SULPHUR STATUS OF THE KUTTANAD SOILS OF KERALA

By

CICY P. MATHEW

THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara, Trichur

1989

DECLARATION

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

Cicy P. Mathew
CICY P. MATHEW

Vellanikkara,
19th December,1989.

Dr.A.I. Jose,
Professor and Head,
Department of Soil Science &
Agricultural Chemistry.

College of Horticulture,
Vellanikkara,
Dated: 19th December,1989.

CERTIFICATE

Certified that this thesis entitled "Sulphur status of the Kuttanad soils of Kerala" is a record of research work done independently by Smt.Cicy P. Mathew 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.Cicy P. Mathew, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled "Sulphur status of the Kuttanad soils of Kerala" may be submitted by Smt.Cicy P. Mathew, in partial fulfillment of the requirement for the degree.

Chairman Dr.A.I. Jose

Members Dr.V.K. Venugopal

Smt. **K..Leela**

Sri.V.K.G. Unnithan

ACKNOWLEDGEMENT

First of all, I bow my head before God Almighty who blessed me with health and confidence and gave his presence throughout the way.

With immense pleasure, I take this opportunity to express my heartfelt gratitude and unforgettable indebtedness to Dr.A.I.Jose, Professor and Head, Department of Soil Science and Agricultural Chemistry and Chairman of my Advisory Committee for his expert guidance, constant encouragement and patience that he has bestowed on me during the course of my research and preparation of this manuscript.

I am extremely grateful to Dr.V.K.Venugopal for the valuable suggestions and sound advice during the course of this research.

I wish to express my profound gratitude to Smt.K. Leela, Sri.Samuel Mathew and Sri.V.K.G. Unnithan for their timely suggestions as the members of the Advisory Committee.

My sincere thanks are also due to all the staff members of the Department of Soil Science and Agricultural Chemistry for their kind co-operation and timely support.

I also wish to record my deep sense of gratitude to Dr.C.T.Abraham, Department of Agronomy for the deep academic interest bestowed on me during the course of my study.

It is with gratitude I remember the unfailing support and constant encouragement of my beloved parents and sisters.

Kind help and co-operation shown by my classmates and friends are sincerely acknowledged. Special thanks are also due to Mrs.K.S.Mini, Miss.D.Prema, Miss.Rosily Mathew, Miss.Rekha Pillai, Miss.S.Ambika and Mr.P.Jayaraj for their help and moral support. It is with heartfelt sorrow I remember my classmate late Mr.B.Sreenivasa Rao.

I wish to acknowledge the ICAR for awarding the Junior Research Fellowship.

Finally, I thank Mr.K.A.Joy for his prompt and neat typing.

CICY P. MATHEW

To my parents and sisters

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Introduction

INTRODUCTION

The importance of sulphur in plant nutrition need not be over emphasized. In plant, sulphur is present in proteins, enzymes and vitamins; and it plays a pivotal role in metabolic processes like respiration, growth and photosynthesis. A sulphur deficiency in soil causes a slackening of protein synthesis in plants and disrupts metabolism, thereby adversely affecting the growth and yield of plants. Even without visible symptoms, sulphur deficiency can reduce crop yields by 10 to 30 per cent (Saalbach, 1973).

The Kuttanad region of Kerala is a unique agricultural area in the world. Practically, the whole area lies 1 to 2.5 m below the sea level and is submerged under water for the major part of the year. It is also 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 the north-east monsoon recedes, sea water again enters the Vembanad lake and the whole area gets saline. Kuttanad area is therefore concurrently faced with serious problems of hydrology, floods and salinity.

Earlier studies have indicated that the soils of Kuttanad region is rich in sulphur. The soils of this region have often been called as acid sulphate, acid saline etc. But as a result of the kayal reclammation programmes, construction and deepening of the spillway at Thottappalli and of late, the commissioning of the Thaneermukkom barrage in 1976, the entire ecosystem of Kuttanad would have undergone considerable changes. The oxidation of organic matter and sulphur containing compounds has been hastened and the intrusion of sea water has been regulated. So the forms and availability of sulphur in the changed soil conditions have to be ascertained.

Kuttanad is the major rice growing tract of the state. Sulphur being an important plant nutrient, the need of its application in Kuttanad soils can be confirmed only after the status and availability of sulphur in this region are evaluated. This study was therefore undertaken with the following objectives in view:

1) To study the forms and availability of sulphur in the karappadam, kayal and kari soils of the Kuttanad region of Kerala; and
2) To predict whether application of sulphur containing fertilizers is necessary in the Kuttanad region of Kerala.

Review of Literature

REVIEW OF LITERATURE

1. General description of the area under study

The name Kuttanad denotes the low-lying area situated between the coastal belt and the uplands in Karthigappally, Mavelikkara, Chengannur, Ambalapuzha, Kuttanad, Thiruvalla, Kottayam, Shertallai and Vaikom taluks. It measures approximately 25 km east-west and 60 km north-south on the west coast of Kerala.

From the very early days, Kuttanad has been acknowledged as the rice bowl of Kerala. According to Pillai (1940), millions of years ago, this land was 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 the present midlands and the coastal region. During these geological upheavals, the entire forest area was submerged far below the ground and thereafter silted upto varying levels.

The geographical area of Kuttanad is 870 sq km in which 290 sq km is garden lands rising 1 or 2 m above mean sea level (Kuriakose, 1974). The remaining area is below the sea level. Of this, an area of 520 sq km was progressively reclaimed by the construction of bunds. The area left unreclaimed is the present Vembanad lake. The Vembanad lake extends upto Cochin and there it is connected to the sea.

Geologically Kuttanad is an alluvial belt, the main formation being delta alluvium. This alluvium is alternating layers of clay and sand of varying sizes and variable percentages of organic matter. These alluvial formations exist in layers varying upto 30 cm depth underlaid by sand stone and mottled clay of tertiary formations.

The rivers Achancoil, Pampa, Manimala and Meenachil discharge their water into the Kuttanad region. These rivers on entering the area flow through a network of channels, leading to the Vembanad lake. During the south west monsoon the entire area will be submerged under flood waters. The flood waters gradually drain through the water courses and Vembanad lake into the sea through the Cochin gut.

The soil characteristics in a water-logged region like Kuttanad is 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 soil reaction and electrical conductivity are the resultant of waterlogging which in turn cause drastic changes in soil environment and influence crop growth (Money and Sukumaran, 1973). Seasonal fluctuation of salinity due to high monsoonal discharge has further modified the chemical and biological characters of the soil. Again human intervention in controlling the water-flow has added a new dimension.

Soils of Kuttanad are known as acid saline or acid sulphate soils. Acid saline soils occurring in Kuttanad proper has been further sub-divided and named according to the morphological conditions, like karappadam, kayal and kari soils. 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 41,000 ha. They are riverborne alluvial soils. The fields lie at about 1-2 m below the sea level. The soils are characterised by high acidity, high salt content and a fair amount of decomposing organic matter (Chattopadhyay and Sidharthan, 1985).

Kayal soils are found in the reclaimed lake bed in Kottayam and Alleppey districts and they occupy an area of about 8,000 ha. The land is situated 2-3 m below the sea level. As they are seriously affected by salinity, crop failures are common in them (Chattopadhyay and Sidharthan, 1985).

Kari soils are peat soils found in large isolated patches in the Alleppey and Kottayam districts, covering an area of about 20,000 ha. They exhibit characteristics of the submerged forest area. Deep black in colour, the soils are characterised by heavy texture, poor aeration, high acidity, high salt content and high organic carbon content. Large amounts of woody matter at various stages of decomposition occur embedded in these soils (Koshy et al., 1977; Chattopadhyay and Sidharthan, 1985). Kari soils are termed as peaty marine mud clay and the soils belong to Histosols (Gopalaswamy and Raychaudhuri, 1969).

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 the location of the soils from which they are collected. Among karappadam, kayal and kari soils the kari soils are more acidic. The pH values for karappadam and kayal soils ranged from 2.6 to 5.8 and 3.0 to 7.3 respectively (Koshy and Brito-Mutunayagam, 1961; Nair and Aiyer, 1968; Sreedevi and Aiyer, 1974; Kabeerathumma and Bidappa, 1975; Aiyer et al., 1975; Venugopal and Koshy, 1978; Amma et al., 1979; Aiyer and Nair, 1979; Nair and Padmaja, 1983; Bhargava and Abrol, 1984; Amma, 1988). Kari soils registered 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; Money, 1961b; Subramoney, 1961; Nair and Aiyer, 1966; Pillai and Subramoney, 1967; Nair and Aiyer, 1968; Koshy, 1971; Sreedevi and Aiyer, 1974; Praseedom and Koshy, 1975; Aiyer et al., 1975; Venugopal and Koshy, 1976a; Ghosh et al., 1976; Aiyer and Nair, 1979; Amma et al., 1979; Kabeerathumma and Patnaik, 1980; Mathews and Jose, 1984; Marykutty and Aiyer, 1987; Amma, 1988). The lowest value of 2.6 was recorded by kari soils from Kallara, Kottayam (Marykutty and Aiyer, 1987).

2.2. Electrical conductivity (EC)

The Kuttanad soils are, in general, saline in nature. The degree of salinity varies from patches to patches. Among the three types of acid saline soils, i.e., karappadam, kayal and kari, the kari soils are more saline. The EC values depend on the location of the soil and the season in which they are collected. Maximum values of EC were generally seen during summer (March-April) while the minimum values were observed during October-November (Kurup and Aiyer, 1973). The EC values recorded by different workers ranged from 0.1 to 43.6 dS/m (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).

2.3. Organic carbon

Acid saline soils are reported to contain fairly high amount of organic carbon.

In karappadam, kayal and kari soils, the organic carbon content ranged from 1.3 to 13.9, 0.4 to 5.5 and 1.8 to 25.0 per cent respectively (Subramoney, 1961; Koshy and Brito-Mutunayagam, 1961; Money, 1961a; 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; Sreedevi *et al.*, 1975; Praseedom and Koshy, 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; Saraswathy, 1989). In the organic matter of kari soils, cellulose and hemicellulose were entirely absent (Koshy, 1970).

2.4. Available phosphorus and potassium

In karappadam soils, the available P (Bray No.1) ranged from traces to 45 ppm as reported by various workers (Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Amma, 1988). The range of available P in kayal soils was 6-51 ppm (Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979) and in kari soils, it ranged from traces to 63 ppm (Alexander and Durairaj, 1968; Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Mathews and Jose, 1984; Amma, 1988).

The content of available K (1N neutral ammonium acetate) in karappadam, kayal and kari soils ranged from 35-72, 37-72 and 37-78 ppm respectively showing that these soils are relatively deficient in available K (Alexander and Durairaj, 1968; Money and Sukumaran, 1973).

2.5. CEC and exchangeable cations (Ca, Mg and Na)

The CEC of Kuttanad soils is comparatively higher as compared to the other acid soils of Kerala due to the larger amount of organic matter contained in these soils. The range of CEC reported were 8-35, 10.4-31.6 and 16.6 to 50.0 me/100 g for karappadam, kayal and kari soils respectively (Pisharody and Brito-Mutunayagam, 1966; Pillai and Subramoney, 1967; Alexander and Durairaj, 1968; Praseedom and Koshy, 1975; Aiyer et al., 1975; Sreedevi et al., 1975; Kabeerathumma and Bidappa, 1975; Venugopal and Koshy, 1976b, Venugopal and Koshy, 1978; Amma et al., 1979; Kabeerathumma and Patnaik, 1980; Bhargava and Abrol, 1984; Amma, 1988; Saraswathi, 1989).

Though the soils of Kuttanad possess high CEC, they have low base saturation. The dominance of Na ion has been observed in saline patches. The low base saturation has been attributed to the reaction of sulphuric acid formed by oxidation and hydrolysis with available bases in the soils. The ranges of exchangeable Ca, Mg and Na in karappadam soils were reported to be 0.9-4.7, 1.3-3.5 and 3.3-15.2 me/100 g respectively (Sreedevi and Aiyer, 1974; Aiyer et al., 1975; Kabeerathumma and Bidappa, 1975; Kabeerathumma and Patnaik, 1980; Amma, 1988). Kabeerathumma and Bidappa (1975) and Kabeerathumma and Patnaik (1978) observed that the content of exchangeable Ca in soils studied by them was 4.49-39.0 me/100 g soil while the content of exchangeable Mg was 1.7 me/100 g. The exchangeable Ca, Mg and Na in kari soils were in the range of 1.0-7.4, 2.5-4.9 and 2.2-19.6 me/100 g soil respectively (Sreedevi and Aiyer, 1974; Aiyer et al., 1975; Venugopal and Koshy, 1976a; Kabeerathumma and Patnaik, 1978; Amma, 1988).

2.6. Particle size analysis

In general, the Kuttanad soils contain larger proportion of clay and silt due to its riverine nature. The kari soils invariably retain large amounts of clay in combination with organic matter. The Kuttanad soils are strongly hydromorphic with aquic characteristics like low chroma and mottled horizons. Reduction of ferric compounds to ferrous compounds as shown by grey colours is common in these soils. Silty clay and clay are the dominant features (Nair et al., 1981). In kari soils, clay content of upto 64.5% has been reported (Marykutty and Aiyer, 1987).

3. Sulphur and plant growth

Sulphur is one of the sixteen nutrient elements which all plants must have for normal growth and development. Sulphur deficiencies in soils have so far been reported from 65 countries including India. Sulphur is best known for its role in the formation of amino-acids (methionine and cystine), synthesis of proteins, chlorophyll, oil in oil seeds and nutritive quality of forages. Sulphur is also associated with the synthesis of vitamins, metabolism of carbohydrates, proteins and oils and formation of flavour imparting compounds in crucifers. Sulphur reduces the HCN content in cassava, promotes nodulation in legumes, produces heavier grains of oil seeds and improves the quality of sugarcane juice. Even without visible symptoms, S deficiency can reduce crop yields by about 10-30 per cent (Saalbach, 1973). An uptake value of 6 kg of S per every tonne of food grain produced has been taken as the average for tropical countries (Kanwar and Mudahar, 1985).

During the past few years, S has been receiving increasing attention worldwide. While reports of S deficiency and crop responses to S application are increasing, the contribution from traditional sources of S is on the decline. Sulphur improved the quality of sugarcane juice (Saroha and Singh, 1979). An increase in the starch content of potatoes due to application of S had been reported (Ramamurthy and Devi, 1981). The content of HCN in cassava was reduced due to the effect of S (Mohankumar and Nair, 1983). Sulphur containing fertilizers were found to improve the oil content of mustard by 8.5 per cent, rai by 7.3 per cent, taramira by 7.6 per cent, soybean by 6.8 per cent, groundnut by 5.1 per cent and sunflower by 3.6 per cent (Tandon, 1986). Sulphur also increased the proportion of S containing amino acids in onion (Balasubramanian et al., 1978), cassava (Mohankumar and Nair, 1983), mustard (Singh and Singh, 1983) and groundnut (Kamala et al., 1986).

Yield response to S application had been reported in crops like groundnut (Patil et al., 1981a; Ankineedu et al., 1983; KAU, 1987), soybean (Jain et al., 1984), rice (Tiwari et al., 1983b), cowpea (Nad and Goswami, 1984) and cassava (Mohankumar and Nair, 1983; KAU, 1984).

4. Forms of sulphur in soils

The main source of S for plants is the soil, where its concentration ranges widely from 0.02 to 0.2 per cent. Sulphur enters the soil from the parent material, mineral fertilizers that contain it as an impurity and precipitation. During soil formation, the mineral forms of S are redistributed and organo-sulphur compounds are synthesised and accumulated. The concentration and distribution of S depend on the genetic characteristics of the soil, nature of the parent material, particle size composition and humus content. Sulphur occurs in two principal forms, organic and mineral. Mineral S is present as sulphate, sulphides and sulphites. In humified soils, it is present chiefly as organic compounds, i.e., esters of sulphuric acid, thiols, disulfides, and sulfones. Plants use the oxidised sulphate form. Thus organo-sulphur compounds are potential sources of the element which become available to the plant after mineralisation (Bramyan and Galstyan, 1986).

4.1. Total sulphur

The total S content in soils is present in varied amounts depending upon its contents in the primary minerals, organic compounds and sulphate ions adsorbed and present in the soil solution. Since India is a sub-continent with a wide variety of tropical climate and soils supporting different agro-ecosystems, the S content among and within soil types as well as regions varies to a great extent (Takkar, 1988).

A twenty nine fold variation existed in total S content of alluvial soils of India, the maximum 851 ppm was found in the fine textured soils of Bihar (Ahmed and Jha, 1969) and the minimum 26 ppm in Ustochrepts from Panjab (Arora and Sekhon, 1977). The mean S content in the soil subgroups identified in Punjab ranged from 59 ppm in sand to loamy sand Ustochrepts and Ustipsamments (Arora and Takkar, 1988) to 213 ppm in sandy loam to loam Ustipsamments and Haplustalfs (Ghai, 1980). Coarse texture and low organic carbon content in the former soil as compared to the latter soil with fine texture and high organic carbon content were the main reasons for such a large variation. The soils of West Bengal were relatively poor in total S (74 ppm) than those from the Uttar Pradesh (143 ppm) despite having fine texture of the former soil (Kanwar and Mohan, 1964; Bhan and Tripathi, 1973). The coastal saline soil from West Bengal contained three times more S (226 ppm) than that in the normal soil (74 ppm) because of the accumulation of sulphate salts from sea water (Mukhopadhyay and Mukhopadhyay, 1980).

The soils of Himachal Pradesh contained lower S contents (189 ppm) as compared to the other hill soils of Himachal Pradesh (276 ppm), West Bengal (221 ppm) and tea and coffee soils of Tamil Nadu (1323 ppm) (Kanwar and Takkar, 1964; Singh et al., 1976; Palaniappan et al., 1978). The finetexture and high organic carbon content in the latter two as compared to the former tea soils were the factors that lead to these variations in the S content of soils. In various soil types of India, the mean content of total S was 213 ppm in red, 329 ppm in alluvial, 350 ppm in lateritic, 456 ppm in hill, 530 ppm in black and 6319 ppm in saline soils (Hegde et al., 1980). The variations in S content within a soil type was 5.3 fold both in hill and lateritic soils, 4.6 in red soils, 3.5 in black and 21 in alluvial soils. The red soils from Andhra Pradesh contained very high amount of sulphur i.e., 1783 ppm (Prasad et al., 1983). Highly weathered lateritic soils as compared to the others contained markedly less S. Total S content of the benchmark soils of Punjab varied from 87-222 ppm (Arora et al., 1988).

Generally, total S content in the tropical soils of India, is lower than the values reported for the temperate zone soils. Since the content of total S in a soil depends primarily on its organic matter and or organic S content, the low S reserve in the tropical Indian soils appears to have resulted largely from their poor organic matter status (Takkar, 1988).

4.1.1. Factors affecting total sulphur

Sulphur in soils is generally present as sulphides, sulphates and organic forms. Sulphides of the plutonic rocks upon weathering get converted into sulphates and depending upon the conditions, either these are adsorbed by soil or precipitated as Ca, Mg and Na salts or are ingressed by plants and soil micro-organisms and form a part of organic combinations with C, N and P or some are reduced to sulphides and elemental S under anaerobic conditions.

Soil organic matter: Total S in most of the soils of India had been shown to be a function of the soil organic matter as they are significantly and positively inter-related (Kanwar and Takkar, 1963; Kanwar and Mohan, 1964; Virmani and Kanwar, 1971). A positive significant correlation between total S and organic carbon had been observed by many workers (Bhan and Tripathi, 1973; Palaniappan _et_ _al_., 1978; Dolui and Nayek, 1981; Singh and Sharma, 1983; Singh _et_ _al_., 1985; Acquaye and Kang, 1987; Arora and Takkar, 1988).

Salt content: Accumulation of S is generally accompanied by the accumulation of sulphates. Very high values of S in saline soils of Canning had resulted from the accumulation of salts of sulphate in these soils (Hegde et al., 1980). The significant positive relation of the total S with sulphate S had been reported by many workers (Bhan and Tripathi, 1973; Aulakh and Dev, 1976; Kumar et al., 1985).

Soil texture: Total S is a function of clay content as shown by Halder and Barthakur (1976), Ruhal and Paliwal (1980b), Dolui and Nayek (1981), Patil et al. (1981b), Singh et al. (1985) and Arora and Takkar (1988). This may be due to the association of organic matter with the clay fraction of the soils.

Soil reaction: Acid soils contained higher S content than the alkaline soils (Kanwar, 1976). As the acidity in the soil of Himachal Pradesh and Tamil Nadu increased, a sharp and successive increase in total S occurred (Singh et al.,1976;Palaniappan et al., 1978). Acid soils are high in free Al and Fe oxides which have high adsorption capacity for sulphates.

Altitude: Twenty fold increase in S content in Tamil Nadu soils and 1.5 fold in Himachal Pradesh soils were noticed as one moved from low to high altitude soil regions. This has resulted largely from the increase in organic matter content of soils because of higher rainfall and lower temperature at high than at low altitudes (Singh et al., 1976; Palaniappan et al., 1978).

Types of vegetation: The sulphur content declined markedly in cultivated soils than forest and virgin soils because of low organic carbon content (Palaniappan et al., 1978).

4.2. Organic sulphur

Most of the S is present as ester sulphates and bonded to carbon as a constituent of amino as well as other acids.

Like total S, the organic S content in the alluvial soils varied widely from 7 ppm in Ustochrepts in Punjab (Arora and Sekhon, 1977) to 109 ppm in the fine textured soils of Bihar (Ahmed and Jha, 1969). The organic S in West Bengal soils constituted as high as 98 per cent of total S whereas in a soil from Bihar it accounted only for 16 per cent of the total (Kanwar and Mohan, 1964; Ahmed and Jha, 1969). The soils of West Bengal had higher amount of organic S as compared to the calcareous soils of Uttar Pradesh. Calcareous nature of Uttar Pradesh soils and high organic matter content of the West Bengal soils were the reasons for the large difference between the two soils. The mean content of organic S was the highest in the red soils of Andhra Pradesh (1783 ppm) followed by 189 ppm in lateritic, 165 ppm in red and reddish brown, 143 ppm in greyish black and 141 ppm in non-lateritic soils of Maharashtra, 98 ppm in the coastal saline soils of West Bengal, 46 ppm in Bundelkhand and the least 34 ppm in the black soils of Gujarat (Reddy and Mehta, 1970; Bhan and Tripathi, 1973; Mukhopadhyay and Mukhopadhyay, 1980; Patil _et al_., 1981b; Prasad _et al_., 1983).

According to Joshi _et al_. (1973) though the red, black and desert soils of Rajasthan had higher organic S (134-153 ppm) yet it accounted for only 39-50 per cent of the total S compared to 89-98 per cent in the hill, terai and alluvial soils of West Bengal with similar range of S content (125-156 ppm). Higher proportion of organic S compared to the inorganic S appears to be the consequence of leaching of inorganic S and its conversion to organic forms by plants in hill and terai soils (Mukhopadhyay and Mukhopadhyay, 1980). Generally, soils high in organic S were also high in total S and organic matter content and vice versa.

4.2.1. Factors affecting organic sulphur

Altitude: Organic S content was markedly higher in the profiles of tea soils located at higher altitude compared with lower altitudes. Similarly acid soils in hills of Himachal Pradesh contained five fold more organic S than the alkaline soils of the alluvial plain of Punjab. This had resulted largely from the increase in organic matter content of soils because of higher rainfall and lower temperature at high than at low altitude (Kanwar and Takkar, 1964).

Soil texture: Fine textured soils of Bihar contained strikingly higher content of organic S (104 ppm) than 70 to 96 ppm in coarse to medium textured soils, even though organic S constituted barely 12 to 20 per cent of the total S. Silt + clay fractions had been

(100 : 1.2) (Joshi, 1984). Further more, intimate relationship of organic S with organic P, as well as with organic C and total N indicates that N, organic S and organic P are important constituents of the soil organic matter and the accumulation of one is accompanied by the simultaneous accumulation of all others (Kanwar and Takkar, 1964).

4.3. Sulphate sulphur

Plants absorb S as SO_4 ions from the growth medium to meet their nutritional requirements. The SO_4-S pool comprises largely of water soluble, adsorbed and easily releasable S from soil organic matter. Since the discovery of widespread deficiency of S in groundnut soils of Ludhiana, Punjab (Kanwar, 1963) and in the tea soils of Kangra, Himachal Pradesh (Kanwar and Takkar, 1964), role of S in crop production in the country has gained momentum and over the years its deficiency has been noticed in many soils and crops.

In hill soils, the 0.15 per cent $CaCl_2$ extractable S in 101 soil samples collected from all over the tea gardens of Himachal Pradesh varied from 0.5 to 25 ppm with a mean value of 7.2 ppm and it formed a small shown to be significantly related with organic S content of the Langarian series of Sangrur, Punjab (Ahmed and Jha, 1969; Aulakh and Dev, 1976). This perhaps partly explains the huge difference between the organic S content in the relatively coarse textured soils (5 ppm) of Gujarat and fine textured soils (170 ppm) of Andhra Pradesh (Reddy and Mehta, 1970; Prasad et al., 1983).

Organic matter: Since S is a constituent of organic matter, its contents in Indian soils have been shown to be governed by the amount and nature of organic matter (Kanwar and Takkar, 1964; Venkateswarlu et al., 1969; Virmani and Kanwar, 1971; Kumar and Singh, 1974; Ruhal and Paliwal, 1980b; Mukhopadhyay and Mukhopadhyay, 1980; Dolui and Nayek, 1981; Singh and Sharma, 1983; Reddy et al., 1985; Arora and Takkar, 1988; Pandey et al., 1989).

Carbon : Organic S ratio: Since S is an integral constituent of the soil organic matter, its enrichment with S generally determines the sulphur supplying capacity of soils. The soils of higher altitude had better S supplying capacity than those at the lower altitude, because of narrow carbon : organic S ratio (100 : 1.4) in the former than the later

(100 : 1.2) (Joshi, 1984). Further more, intimate relationship of organic S with organic P, as well as with organic C and total N indicates that N, organic S and organic P are important constituents of the soil organic matter and the accumulation of one is accompanied by the simultaneous accumulation of all others (Kanwar and Takkar, 1964).

4.3. Sulphate sulphur

Plants absorb S as SO_4 ions from the growth medium to meet their nutritional requirements. The SO_4-S pool comprises largely of water soluble, adsorbed and easily releasable S from soil organic matter. Since the discovery of widespread deficiency of S in groundnut soils of Ludhiana, Punjab (Kanwar, 1963) and in the tea soils of Kangra, Himachal Pradesh (Kanwar and Takkar, 1964), role of S in crop production in the country has gained momentum and over the years its deficiency has been noticed in many soils and crops.

In hill soils, the 0.15 per cent $CaCl_2$ extractable S in 101 soil samples collected from all over the tea gardens of Himachal Pradesh varied from 0.5 to 25 ppm with a mean value of 7.2 ppm and it formed a small percentage of the total S. A linear relationship existed between this and the water soluble fraction. Nearly 74 per cent of the samples were deficient in S (Kanwar and Takkar, 1964; Takkar, 1987).

Kanwar (1963) had shown extensive deficiency of S in 75 per cent of the 84 soil samples from the groundnut area of Ludhiana, Punjab. Kanwar and Mohan (1964) showed that SO_4-S in the soils of different agro-climatic zones of Punjab varied from 1.4 to 48 ppm and constituted a very small fraction of the total S. By and large, SO_4-S decreased from 10.1 to 3.4 ppm as one moved from alluvial soil groups in arid and semi-arid climatic zones towards hill soils in semihumid and hot, humid to subtropical and prehumid to humid climate (Kanwar and Mohan, 1964).

Ahmed and Jha (1969) had shown a widespread deficiency of S in neutral, acidic and alkaline soils of Bihar. Bharadwaj and Pathak (1969) showed that in the soils of Uttar Pradesh SO_4-S content in the 0-15 cm and 15-30 cm depth varied from 5.7 to 105.6 ppm and 3.1 to 31.5 ppm. Nearly 50 per cent decrease in the 15-30 cm layer has resulted from comparatively high pH and carbonates in the fine textured sub soil. Cheema and Arora (1984) showed that SO_4-S ranged between 0.3 to 56.3 ppm and the extent of S deficiency was 75 per cent in 1983 and 82 per cent in 1984 based on the analysis of 500 surface soil samples from Ludhiana, Punjab. The deficiency was confirmed by the response to S application of wheat grown in some of these fields. In general SO_4-S content for Indian soils ranged from 3.4 to 81 ppm (Sureshlal and Mathur, 1985). The proportion of SO_4-S to total S ranged from 2 per cent in hill soils of Punjab (Kanwar and Mohan, 1964) to 24 per cent (Ghai, 1980). Except with total S, all the forms of S significantly correlated among themselves (Ruhal and Paliwal, 1980a).

4.3.1. Factors affecting sulphate sulphur

Organic matter: Takkar et al. (1984) and Takkar et al. (1985) had shown that soil organic matter regulates markedly the content of SO_4-S in the alluvial soils of Ludhiana and Bhatinda. As the organic carbon increased, the per cent samples deficient in S strikingly decreased. Significant positive relationship between the two had been shown by Bharadwaj and Pathak (1969), Kumar and Singh (1974), Ruhal and Paliwal (1980b) and Arora and Takkar (1988).

Texture: The content of SO_4-S was shown to be a function of the silt plus clay fraction and clay fraction in typic Ustipsamment of Hoshiarpur, Punjab (Aulakh and Dev, 1976; Ghai, 1980; Patil et al., 1981b; Singh and Chhibba, 1987).

Salt content (EC): Ghai (1980) found that EC was significantly and positively correlated with SO_4-S in alluvial soils of Ludhiana (Cheema and Arora, 1984) and in Typic Ustipsamment soils of Bhunga block of Hoshiarpur (Singh and Chhibba, 1987).

Leaching: Because of the anionic nature and high solubility of most of the common salts of sulphate, the leaching losses of SO_4-S were generally large especially in coarse textured soils (Rawat and Sriniwas, 1979; Cheema and Arora, 1984).

Temperature: Bharadwaj and Pathak (1969) showed that temperature increased the SO_4-S content. The duration of heating was more effective in increasing the SO_4-S content than the absolute temperature.

4.4. Nonsulphate sulphur

This is the form of S that remains unextractable after the removal of organic (H_2O_2 extractable) and SO_4-S (0.15 per cent $CaCl_2$) and is mostly made up of insoluble S compounds of Ba, Ca etc. occluded in and absorbed on carbonates of the soils (Evans and Rost, 1945).

By and large, the contents of nonsulphate S in soils of India varied from as low as 1 ppm to as high as 462 ppm and constituted 1 to 75 per cent of the total S. Barring hill and terai soils, by and large, the content of this form is much smaller in the surface soils as compared to that in the subsurface layers and is also considerably higher in the alkaline, calcareous high pH soils of plains of Punjab, Haryana, Rajasthan, saline soils of West Bengal and Rajasthan. Also medium black soils of Rajasthan, terai, lateritic and even alluvial soils of West Bengal contained small amount of nonsulphate S. The presence of $CaCO_3$, alkaline pH and low organic matter content are probably the contributing factors leading to higher amounts of nonsulphate S in alkaline soils. Comparatively small amount of nonsulphate S in acid hill soils which are relatively high in organic matter suggests that the soil forming factors in operation under these conditions continuously break down these forms in the surface layers and leach them down to subsurface horizons, thereby increasing their content in relation to total S in the subsurface horizons. High acidity and rainfall have accelerated these processes over the years in these soils. Depending upon these conditions, either decline or rise in non-sulphate S were noted with depth of soil profile (Kanwar and Takkar, 1964; Kanwar and Mohan, 1964; Ahmed and Jha, 1969; Reddy and Mehta, 1970; Joshi *et al*., 1973; Bhan and Tripathi, 1973; Mukhopadhyay and Mukhopadhyay, 1980; Ghai, 1980; Patil *et al*., 1981b; Sureshlal and Mathur, 1985; Sharma *et al*., 1988).

5. Available sulphur

Since sulphate sulphur is the major source of S supply to plants, it has been estimated by extraction with water, neutral salt solutions, phosphate solutions and buffered acidic solutions. Available S content of Indian soils, in general, is less than 40 ppm (Naik and Das, 1964). //

5.1. Water soluble sulphur

The values of water soluble S ranged from 1.8 to 1161 ppm for soils from different states of India. The minimum value of 1.8 ppm was reported for soils of Madhya Pradesh (Bansal et al., 1979). Water soluble S content of soils of Udaipur, Rajasthan was 15.1 ppm, the range being 9-32 ppm (Rawat and Sriniwas, 1979). The respective values for soils of Himachal Pradesh, Uttar Pradesh, Punjab (benchmark soils) and Tamil Nadu were 17, 15, 22 and 18 ppm (Palaskar and Ghosh, 1982; Tiwari et al., 1983a; Ghai et al., 1984; Balasubramanian and Kothandaraman, 1985). While reviewing the water soluble S content of Indian soils, Sureshlal and Mathur (1985) concluded that the value ranged from 12 to 1161 ppm. Mehta et al. (1988) and Sharma et al. (1988) observed that water soluble S content was less than 35 ppm and it constituted only a small per cent of the total S.

For rice, water soluble SO_4-S was found to be suitable for predicting S availability (Venkateswarlu and Subbiah, 1969).

5.2. Calcium chloride extractable sulphur

The range of SO_4-S extracted by 0.15 per cent $CaCl_2$ was between 2 and 45 ppm. The respective mean values for soils from Madhya Pradesh, Rajasthan, Himachal Pradesh, Uttar Pradesh, bench mark soils of Punjab, Andhra Pradesh and wet temperate zone of Himachal Pradesh were 9, 9, 14, 11, 17, 38 and 13 ppm S (Bansal _et_ _al_., 1979; Rawat and Sriniwas, 1979; Palaskar and Ghosh, 1982; Tiwari _et_ _al_., 1983a; Ghai _et_ _al_., 1984; Reddy _et_ _al_., 1985 and Sharma _et_ _al_., 1988). Calcium chloride (0.15 per cent) was a good extractant for assessing the available S status of soils and it extracted about 10.9 ppm in alluvial soils (Mehta _et_ _al_., 1988).

5.3. Phosphate extractable sulphur

For soils from different states of India, the values of 500 ppm P extractable S ranged from 2 to 1264 ppm. The respective values for different states, Madhya Pradesh, Rajasthan and Uttar Pradesh were 9, 5.4 and 12 ppm S (Bansal _et_ _al_., 1979; Rawat and Sriniwas, 1979; Tiwari _et_ _al_., 1983a). For major soil types of India, the values reported were 27, 50, 26, 39, 80 and 1264 ppm for hill, laterite, red, black, alluvial and saline soils respectively (Hegde et al., 1980). Sharma et al. (1988) observed that the content of phosphate extractable S was below 25 ppm for soils of Himachal Pradesh. For alluvial soils, KH_2PO_4 was found to be a very good extractant (Mehta et al., 1988).

5.4. Morgan's reagent extractable sulphur

Morgan's reagent extractable S ranged from 2 to 1733 ppm for soils from different states of India (Bansal et al., 1979; Hegde et al., 1980; Tiwari et al., 1983a; Ghai et al., 1984; Balasubramanian and Kothandaraman, 1985; Mehta et al., 1988; Arora and Takkar, 1988; Sharma et al., 1988). The corresponding value for soils from Mannuthy, Kerala was 40 ppm (George, 1989).

5.5. Factors affecting available sulphur

Organic matter: Takkar et al. (1984) and Takkar et al. (1985) had shown that soil organic carbon regulates markedly the content of available S in the alluvial soils of Ludhiana and Bhatinda. As the organic carbon increased, the per cent samples deficient in S strikingly decreased.

Texture: The content of S extracted by 0.15 per cent $CaCl_2$ and water in five soil series of Sangrur was shown to be a function of the silt plus clay fraction (Aulakh and Dev, 1976; Ghai, 1980) and clay fraction in typic Ustipsamment of Hoshiarpur, Punjab (Singh and Chhibba, 1987).

pH: An intimate relationship between the pH and water soluble form of S in some soil series of Punjab was shown by Aulakh and Dev (1976) and Ghai (1980). The increase in available S with a decrease in pH had been shown in Tamil Nadu and Himachal Pradesh (Singh _et_ _al_., 1976; Palaniappan _et_ _al_., 1978). The per cent samples deficient in S appreciably increased as the pH of the alluvial soils of Ludhiana and Bhatinda increased beyond 8.5 (Takkar _et_ _al_., 1984; Takkar _et_ _al_., 1985).

Salt content: Ghai (1980) found that EC was significantly and positively correlated with available S extracted by 0.15 per cent $CaCl_2$ and water in some of the bench mark soil series of Punjab.

Flooding: Hegde _et_ _al_. (1980) showed that in all the major soil types of India, available S markedly increased with flooding.

Altitude: Available S content in hill soils of Himachal Pradesh and Tamil Nadu markedly increased with increase in altitude (Palaniappan et al., 1978).

5.6. Critical limits of available sulphur in soils

Since the capacity of different methods to extract available forms of S varies substantially, high and low critical values of available S in a soil type for a crop are expected with different extractants. The critical limits of available S in alluvial soils of Punjab for wheat were 12.5 ppm for heat soluble, 15 ppm for 0.15 per cent $CaCl_2$ and 25 ppm for N NH_4OAc. The critical values in such soils for oats were 11 ppm for 10 per cent NaCl, 20 ppm for ammonium acetate + acetic acid and 22 ppm for 0.5 M $NaHCO_3$ extractable S (Arora and Sekhon, 1977; Arora and Takkar, 1985). The critical values of the same extractant for available S differed for various crops. The critical values of 500 ppm P as $Ca(H_2PO_4)_2$ for available S was 9.3 ppm for alfalfa, 10 ppm for cluster bean, and 14 ppm for maize. Similarly the critical level of ammonium acetate-acetic acid available S in alluvial soils for oats was 20 ppm and rice 11 ppm (Virmani, 1971; Arora and Sekhon, 1977;

Bansal et al., 1979; Tiwari et al., 1983a; Jain et al., 1984). Also the values of 0.15 per cent $CaCl_2$ available S in alluvial soils of Punjab was 9 ppm for mustard, 10 ppm for groundnut, 15 ppm for wheat and 19 ppm for sunflower (Kanwar, 1963; Marok and Dev, 1979; Ghai et al., 1984; Arora and Takkar, 1985). This suggests that there is a need for establishing critical values of available S for a crop and a method in different soils as well as for different crops in a soil. This will provide basis for isolating the S deficient soils from the non deficient in a region for different crops and thus will help in making a sound fertilizer recommendation of S for obtaining optimum crop yields.

6. Sulphur in Kuttanad soils

Acid sulphate soils, confined to the Malabar coast in south western part of India have developed under humid and tropical climate in the alluvium derived mainly from laterite and lateritic soils and occupy lagoons and similar low-lying geomorphic situations. The soils are generlly rich in organic matter. Prolonged submergence from May to December due to heavy discharge from numerous rivers and streams is followed by sea water inundation during the subsequent loan months as a result of tidal cycles.

As early in 1931, Pillai and Subramanyan reported that the kari soils of Travancore contained large amounts of sulphur compounds principally mineral sulphates. They inferred the presence of ferrous and alumium sulphates in the soil and the production of free sulphuric acid by the hydrolysis of the mineral sulphates. Nair and Iyer (1948) reported that wood fossils in the kari soils contained 5-8 per cent S. The soil also contained iron sulphide similar to marcasite which on exposure produced sulphuric acid and ferrous sulphate. They attributed the high acidity of the kari soils to the production of sulphuric acid, possibly by S-oxidising bacteria. Subramoney (1959) proposed a sulphur bacterial cycle as a probable mechanism of toxicity in acid soils of Kerala. The kari soils and the wood fossils associated with them were found to contain different forms of sulphur such as free, organically combined, sulphide and sulphate forms. From the presence of sulphur oxidising and sulphur reducing bacteria in these soils, it is assumed that there exists a sulphur bacterial cycle which involves the conversion of organic forms of S to the sulphuric acid form through the inorganic sulphides and sulphates. The production of H_2S in this manner is considered to be responsible for the extremely acidic nature of the kari soils.

Money(1961a) was of the opinion that the chief sources of toxicity in the area are extreme acidity, solubility of iron and soluble salts especially chlorides and sulphates. All the soils studied were of low pH range. Water soluble sulphates were very high in all the samples. Subramoney (1965) reported that the Kerala soils exhibited the capacity to produce H_2S. Studies on H_2S injury to rice plants revealed that black ferrous sulphide deposits are seen on the roots and base of the stem of paddy which on smearing with dilute HCl evolved H_2S gas. Locking up of earheads and development of black spots on the grain were also noted as a result of H_2S toxicity. Hydrogen sulphide injury is one of the most serious physiological diseases of rice (Nair and Subramoney, 1969). Micromorphological studies of the acid sulphate soils of Kerala indicated that sulphides especially iron pyrites are common in all profiles especially in the Ambalapuzha series of kari soils of Karumadi area (KAU, 1984). Chattopadhyay and Sindharthan (1985) reviewed the studies on kari soils and concluded that free sulphuric acid is formed by the oxidation of sulphur compounds present in the wood fossils found under the soil.

6.1. Forms of sulphur in Kuttanad soils

6.1.1. Total sulphur

Jacob (1966) in his studies on the sulphur status of Kerala soils observed that surface soil samples from Neelamperur which represented karappadam soils contained 6398 ppm S which when compared to the other soil types of Kerala, was very high. Hegde et al. (1980) reported that karappadam soils contained 491 ppm S. Jacob (1966) studied the total S content of kayal soils from R-block and Chitrapuram which contained 4821 and 4873 ppm S respectively. Hegde et al. (1980) observed that total S content was less than the reported values in the kayal soils i.e., 1505 ppm S. Kari soils contained more S than karappadam and kayal soils. Money (1961a) reported a value as high as 19200 ppm, i.e., 1.92 per cent S in kari soils. Jacob (1966) observed that the maximum reserves of sulphur were found in the kari soils of Kerala. Kari soils from Mundar contained 15534 ppm S which was the highest value among different soil types. Leela (1967) also reported a more or less similar high value for the kari soil of Vaikom (9200 ppm). The highest value of total sulphur for kari soils ever reported was 30,000 ppm, i.e., 3.0 per cent (Varghese, 1973). The total S content varied from location to location. Kari soils from Thottappally, North Parur and Kattampalli contained 5600, 7400 and 4950 ppm S respectively (Ghosh et al., 1976). In a study conducted for evaluating S status of different rice soils of India, Kottayam kari and Thottappalli kari were found to contain 8794 ppm S (Hegde et al., 1980).

Total sulphur was found to be significantly and positively correlated with organic carbon content of the soil concerned (Jacob, 1966).

6.1.2. Organic sulphur

Organic sulphur generally constituted the major portion of the total S in most of the soils (Jacob, 1966). In karappadam soils, the contribution of organic S to total S was 64 per cent while it was 95 per cent in kayal soils. The content of organic sulphur reported was 4061 and 4585 ppm respectively in karappadam and kayal soil. In kari soils the content was 13819 ppm which was 90 per cent of the total S. Leela (1967) also obtained a similar result that in kari soils from Vaikom more than 95 per cent of the total S was contributed by organic S. For the kari soil collected from Kattampalli, the contribution was only 46 per cent. Value as high as 24,000 ppm organic S in kari soils was reported which accounted for 80 per cent of the total S (Varghese, 1973). The content of organic sulphur was more in the kari soil from North Parur than kari soils from Kattampalli and Thottapalli. The contribution of organic S to total S also varied among soils collected from different locations (48-64%) (Ghosh et al., 1976).

6.1.3. Sulphate sulphur

Money (1961a) could detect only trace amount of sulphate sulphur in karappadam soils while in kayal soils, the content was 400 ppm. In kari soils, the content was 3667 ppm, which was in agreement with the further studies conducted. Ghosh et al. (1976) observed that soils from North Parur contained more sulphate S than soils from Thottapalli and Kattampalli which was in the range 1500 - 3110 ppm S. Bhargava and Abrol (1984) observed that kayal soils contained more sulphate S than karappadam soils by analysing the saturation extract.

6.1.4. Non-sulphate sulphur

Kari soils were reported to contain fairly good amount of nonsulphate S which may be sulphide, sulphite, polysulfides, thiosulphate and elemental sulphur. Kari soils from North Parur, Thottappalli and Kattampalli were reported to contain 730, 230 and 250 ppm S which constituted 19, 10 and 14 per cent of the total S respectively (Ghosh et al., 1976).

6.2. Available sulphur

6.2.1. Water soluble sulphur

Money (1961a) reported that water soluble sulphates were very high in the kari soils, i.e.,1,4100 ppm. The range was from 1,8200 to 4,3100 ppm (Money, 1961b). Jacob (1966) observed that all the sulphates in soils were not extractable with water and most of the soils retained some sulphates by adsorption. The proportion of water soluble sulphates to total S was high in the karappadam soils (32.5 per cent) while it was only 3 per cent and 8 per cent in the kayal and kari soils respectively. The easily available form of S i.e., water soluble sulphate is low in kayal and kari soils, while more available sulphur is present in the karappadam soils (Jacob, 1966).

6.2.2. Phosphate (500 ppm P) extractable sulphur

Leela (1967) reported that kari soils from Kattampalli and Vaikom contained 325 ppm and 950 ppm S which accounted for 20 and 10 per cent of the total S respectively. In a study on the evaluation of sulphur status of different rice soils of Kerala, it was found that kari soils contained very high amount of phosphate extractable S than kayal and karappadam soils. In karappadam soils, the content was very low i.e., 17 ppm. Kottayam kari and Thottappalli kari contained 1439 and 1135 ppm S which was P extractable and which constituted about 16 and 13 per cent of the total S respectively (Hegde _et_ _al_., 1980).

6.2.3. Morgan's reagent extractable S

Leela (1967) reported that kari soils from Kattampalli and Vaikom contained 200 ppm and 600 ppm S respectively which was less than 10 per cent of the total S. Hegde _et_ _al_. (1980) reported that Morgan's reagent extractable S content was more in kari soil than kayal and karappadam soils, the respective mean values were 1500, 233 and 20 ppm S respectively.

Amma (1988) observed that extractable S content varied from patches to patches. The range was 55-554 ppm and 1106-15,000 ppm S for karappadam and kari soils respectively.

Materials and Methods

MATERIALS AND METHODS

1. Collection and preparation of samples

The material for the present study consisted of 151 surface soil samples representing karapparam, kayal and kari soils. The details of soils collected are given in Table 1.

Surface soils of 0-15 cm depth were collected during summer. The samples were air-dried, gently powdered, passed through a 2 mm seive and stored in properly labelled polythene bags.

2. Analytical procedures

2.1. General properties of soils

The pH of the soil water suspension (1:2.5) was determined using a pH meter. Electrical conductivity of the supernatant liquid of the soil water suspension was read with the help of a conductivity bridge (Jackson, 1958). The hydrometer method (Piper, 1942) was followed for the particle size analysis of the soil.

Organic carbon content was determined by the method of Walkley and Black (1934) as described by Jackson (1958).

Table 1. Location of the soil samples collected

Soil No.	Padasekharam	Village	Taluk	District
1	2	3	4	5
KARAPPADAM SOILS (KP)				
KP1-KP5	Thekumpuram South of Road	Ramankari	Kuttanad	Alleppey
KP6-KP15	Kidangupadam	Veliyanadu	Kuttanad	Alleppey
KP16-KP22	Pongapadam	Nedumudy	Kuttanad	Alleppey
KP23-KP33	Pongabrapadam	Moncombu	Kuttanad	Alleppey
KP34-KP38	Vezhapurampadam	Thakazhy	Kuttanad	Alleppey
KP39-KP42	Changanadipadam	Thalavady	Kuttanad	Alleppey
KP43-KP48	Ashtamompadam	Thalavady	Kuttanad	Alleppey
KAYAL SOIL (KY)				
KY49-KY53	Ettilchira	Pulinkunnu	Kuttanad	Alleppey
KY54-KY59	Vadakkekari Madathanikari	Pulinkunnu	Kuttanad	Alleppey
KY 60	Madathikayal	Pulinkunnu	Kuttanad	Alleppey
KY61-KY71	Othimada and Punnathuram	Kainakary	Kuttanad	Alleppey
KY72-KY73	6-Share Kayal	Kainakary	Kuttanad	Alleppey
KY74-KY78	Seminari Kayal	Kumarakom	Kottayam	Kottayam

Contd.

Table 1. Continued

1	2	3	4	5
KY76-KY82	Methran Kayal	Kumarakom	Kottayam	Kottayam
KY83-KY86	12-Share Kayal	Neelamperur	Kuttanad	Alleppey
KY87-KY90	Maran Kayal	Chennamkari	Kuttanad	Alleppey
KY91-KY95	KL-Appu Kayal	Chennamkari	Kuttanad	Alleppey
KY96-Ky103	Cherukara Kayal	Chennamkari	Kuttanad	Alleppey
KY104-KY108	E-block Kayal (24,000)	Chennamkari	Kuttanad	Alleppey
KY109	R-block Kayal	Kainakary	Kuttanad	Alleppey
KY110	Marthandam Kayal	Kainakary	Kuttanad	Alleppey
<u>KARI SOILS (K)</u>				
K111-K113	Edacheripadam	Nedumudy	Kuttanad	Alleppey
K114-K129	Kavil Thekumpuram-padam	Ambalapuzha	Ambalapuzha	Alleppey
K130-K133	Kunnumma West	Thakazhi	Kuttanad	Alleppey
K134	Pallithodukari	Thuravur	Shertallai	Alleppey
K135	Chengaramkari	Thuravur	Shertallai	Alleppey
K136	Thuravurkari - North	Thuravur	Shertallai	Alleppey
K137	Thuravurkari - South	Thuravur	Shertallai	Alleppey
K138	Thuravurkari - East	Thuravur	Shertallai	Alleppey
K139	Chempakasserikari - East	Vayalar West	Shertallai	Alleppey
K140	Chempakasserikari - West	Vayalar East	Shertallai	Alleppey

Contd.

Table 1. Continued

1	2	3	4	5
K141	Valiyavelichampadam	Vechoor	Vaikom	Kottayam
K142	60-Attethazha	Vechoor	Vaikom	Kottayam
K143	Poovathinkari	Vechoor	Vaikom	Kottayam
K144	Kattukari Kolampurathkari	Vechoor	Vaikom	Kottayam
K145	Puthankari	Vechoor	Vaikom	Kottayam
K146-K148	Appathikari	Purakkad	Ambalapuzha	Alleppey
K149	Malayilthodinu Thekku	Karuvatta	Karthigappally	Alleppey
K150	Ezhavankari	Karuvatta	Karthigappally	Alleppey
K151	Vazhamkari Pulimpikari	Karuvatta	Karthigappally	Alleppey

Available phosphorus was extracted by Bray No.I 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 chlorostannous reduced molybdo-phosphoric blue colour method in HCl system (Jackson, 1958).

Available K was extracted with 1 N neutral ammonium acetate (soil solution ratio 1:5; period of extraction 5 min) and the K content was determined using a flame photometer (Jackson, 1958).

Cation exchange capacity was determined using 1 N neutral ammonium acetate. A known weight of the soil was saturated over night with neutral ammonium acetate to displace the cations. Excess ammonium acetate was washed with alcohol. The soil was distilled with excess NaOH in a macrokjeldahl distillation apparatus. The liberated NH_3 was absorbed in boric acid and titrated against standard HCl using bromocresol green - methyl red mixed indicator and CEC was expressed as me/100 g of soil (Jackson, 1958).

The ammonium acetate leachate obtained at the time of determination of CEC was made use for the determination of exchangeable cations (Piper, 1942). Exchangeable Ca and Mg were determined by the versenate titration method (Hesse, 1971). Exchangeable Na of the leachate was read in a flame photometer and expressed as me/100 g of soil.

2.2. Forms of sulphur

Thirty nine samples representing karappadam, kayal and kari soils were analysed for different forms of sulphur. However, all the surface samples were analysed for available S as extracted by four extractants.

2.2.1. Total sulphur

Sulphur in soil was first oxidised to sulphate following the method of FAO (1988). Weighed out 1 g of 0.15 mm seived soil into a 100 ml conical flask and 5 ml of digestion mixture was added. (The digestion mixture was prepared by dissolving 3 g potassium dichromate in 146 ml of deionised water. It was then added to a mixture of 434 ml 70 per cent perchloric acid of specific gravity 1.65 and 420 ml concentrated nitric acid. Added 10 ml of bromine to each litre of this mixture). The flask was then covered with a funnel and heated on a hot plate. After completion of the oxidation stage (when the dichromate turned to an orange precipitate), allowed the flask to simmer on the hot plate for one hour, It was then cooled and the funnel was washed down with 10 ml of deionised water. About 40 ml water was added so that the final volume was 50 ml. After keeping it overnight, an aliquot was decanted off for the determination of sulphur.

Sulphur in the aliquot was determined turbidimetrically according to the method of Chesnin and Yien (1951). To 5 or 10 ml of the aliquot taken in a 25 ml volumetric flask, added 1 g of 30-60 mesh $BaCl_2$ crystals followed by 2 ml of 0.25% gum acacia solution. The solution was made upto the volume. Turbidity readings were taken between 5 and 30 min after the precipitation in a Spectronic-20 spectrophotometer and the sulphate is determined by reference to a standard curve.

2.2.2. Sulphate sulphur

Sulphate sulphur was estimated by the method of Williams and Steinbergs (1959). Soil and 0.15 per cent $CaCl_2$ in the ratio 1:10 were shaken for 30 min. It was filtered and SO_4-S in an aliquot of the extract was determined turbidimetrically according to the method of

Chesnin and Yien (1951). As the extract was coloured, about 1 g of activated charcoal was added to the soil solution mixture before shaking.

2.2.3. Organic sulphur

Total organic sulphur was estimated by the method of Evans and Rost (1945). Depending on the amount of organic matter, 5 to 10 g of the soil was first leached with water, then with 1 per cent hydrochloric acid and finally with distilled water till free of chloride. The soil was transferred to a beaker and oxidised with 30 per cent H_2O_2. When the oxidation was completed, it was filtered through Whatman No.3 filter paper. The residual colour that may appear in the solution was destroyed by addition of a small quantity of bromine water. The filtrate was then made upto 250 ml and sulphate in an aliquot of the extract was determined turbidimetrically according to the method of Chesnin and Yien (1951).

2.2.4. Non-sulphate sulphur

Non-sulphate S which may be sulphide, sulphite, thiosulphate, polysulphides, elemental sulphur etc. were calculated as the difference between total S and the sum of organic S plus sulphate S.

2.3. Available sulphur

Since SO_4-S fraction is the major source of S supply to plants, it was estimated by extracting with

(i) water

(ii) neutral salt solution, 0.15 per cent $CaCl_2$

(iii) phosphate solution, 500 ppm P as KH_2PO_4 and

(iv) acidic solution, Morgan's reagent.

2.3.1. Water soluble sulphur

The method of Freney (1958) was adopted. Fresh wet soil and distilled water in the ratio 1:5 were shaken for 30 min. The suspension was then filtered and SO_4 content was determined turbidimetrically in the extract according to the method of Chesnin and Yien (1951). To obtain clear extract, 1 g of activated charcoal was added to the soil solution mixture before shaking.

2.3.2. Calcium chloride (0.15 per cent) extractable sulphur

The method of Williams and Steinbergs (1959) was adopted. Soil and 0.15 per cent $CaCl_2$ in the ratio 1:10 were shaken for 30 min. The suspension was filtered and

S content in an aliquot of the extract was determined turbidimetrically according to the method of Chesnin and Yien (1951).

2.3.3. Phosphate extractable sulphur

The method of Ensminger (1954) was adopted as 500 ppm P as KH_2PO_4 can extract soluble and adsorbed sulphate from soils. Soil and 500 ppm P solution in the ratio 1: 10 were shaken for 30 min and S content in an aliquot of the extract was determined turbidimetrically according to the method of Chesnin and Yien (1951).

2.3.4. Morgan's reagent extractable sulphur

The method of Chesnin and Yien (1951) was followed. Soil and Morgan's reagent (100 g of sodium acetate and 30 ml 99.5 per cent acetic acid dissolved in 500 ml of water and the volume made upto 1 litre) in the ratio 1:10 were shaken for half an hour and the suspension was filtered and S content in an aliquot of the extract was determined turbidimetrically. In all the cases of available S determination, to overcome the problem of residual colour of soil extract, 1 g activated charcoal was added to the soil solution mixture before shaking.

3. Statistical analysis

Simple correlation and regression were established between the various parameters of soil determined as per the methods of Snedecor and Cochran (1967).

Results and Discussion

RESULTS AND DISCUSSION

The Kuttanad region of Kerala is the low-lying area situated around the Vembanad lake in the districts of Alleppey and Kottayam. Out of the total area of 870 sq km only 290 sq km is garden land at 1 or 2 m above mean sea level while the remaining area is below the mean sea level. A major part of this area includes kayal lands progressively reclaimed by construction of bunds. Geologically, Kuttanad is an alluvial belt. The area situated at relatively high elevation (1-2 m) is the land originally suited for rice cultivation, known as "karappadam". The area reclaimed from the lake which is 1 or 2 m below the MSL, but put under rice by a strenuous system of cultivation is the "kayal" land. The kayal land which is separated from the lake by bunds is brought under cultivation by the continuous pumping of water from the reclaimed land to the lake, a system of cultivation unique to Kuttanad. It is believed that thousands of years ago, the Kuttanad region was dense forest which later got buried under, due to geological upheavals. This hypothesis is supported by the presence of large amount of organic matter and partially burned wooden logs often excavated from the fields of Kuttanad. The patches of land which are very rich in organic matter, possessing extreme acidity are known as "kari" lands (kari means carbon).

The soils of Kuttanad are said to be rich in S, since the soil usually contains good amount of organic matter. Recently, the Kuttanad region of Kerala has undergone considerable ecological changes. The entry of salt water from the sea through the Cochin gut is prevented by the construction of Thaneermukkom barrage in 1976. The construction and deepening of the spill way at Thottappalli in order to drain the stagnant backwater to the sea has also contributed to the changes in the ecosystem of the region. The oxidation of organic matter and S containing compounds would have been hastened under this changed situations. Under the study, 48 karappadam soils, 62 kayal soils and 41 kari soils were examined for the content of available S extracted by different chemical agents. The fractionation of S was carried out in 39 soils selected from the karappadam, kayal and kari soils. The results obtained are presented and discussed.

1. General properties of soils

The data on general properties of soils are presented in Table 2. The coefficients of correlation and regression equations relating to the general chemical properties are given in Table 3.

1.1. Soil reaction (pH)

All the soils were acidic in nature, the pH ranging from 2.7 to 5.6 with a mean value of 3.92. The lowest value of 2.7 was recorded by the kari soils of Kavilthekumpurampadam, Ambalapuzha (K 119, K 120, K 121, K 124). In general, the electrical conductivity of the soil increased with decrease in pH (r = -0.5975**). This is due to the increased electrical conductivity (EC) contributed by hydrogen and aluminium ions, the concentrations of which increase with increase in acidity. Moreover, when the soil become highly acidic, the solubility of many soil constituents increases, resulting in an overall increase in the EC of the soils. The soil pH was also negatively correlated with the total content of organic matter in the soil. This relationship was significant in the case of kari soils (r = -0.4459**) which contained relatively large amount

Table 2. General propoerties of soils

Soil No.	pH	EC(dS/m)	Organic carbon (%)	Available, ppm	
				P	K
KARAPPADAM SOILS					
KP 1	4.4	1.8	2.04	6.5	148
2	4.4	2.1	2.01	7.8	150
3	4.3	1.9	2.02	5.8	150
4	4.5	1.1	1.75	7.1	140
5	4.0	1.8	1.99	7.0	138
6	4.0	0.7	2.81	2.8	174
7	4.0	0.9	3.12	3.0	174
8	3.9	0.5	3.40	3.1	180
9	4.0	0.5	3.30	3.2	175
10	3.9	1.5	3.38	2.1	175
11	3.9	0.9	3.41	2.9	173
12	3.9	0.8	3.66	2.8	170
13	3.9	0.9	2.98	3.1	172
14	3.9	0.9	3.24	2.9	174
15	4.0	1.3	3.35	2.9	169
16	4.0	0.8	1.91	1.9	122
17	4.0	0.6	2.02	1.7	112
18	4.0	0.7	1.71	1.9	130
19	4.0	0.9	1.60	1.9	142
20	4.0	1.0	2.61	2.0	135
21	4.0	1.2	2.12	2.1	143
22	3.9	1.2	2.22	2.0	140
23	3.8	1.0	2.44	4.8	158
24	3.7	1.1	2.70	5.7	162
25	4.2	0.9	2.72	5.1	160
26	4.1	0.8	2.87	5.5	157
27	4.2	0.9	2.14	5.2	162

Contd.

Table 2. Continued

1	2	3	4	5	6
KP 28	4.2	0.6	2.60	4.6	162
29	4.2	0.6	2.72	4.6	140
30	4.1	0.7	2.41	4.7	130
31	4.2	0.7	1.71	4.8	163
32	4.2	0.5	1.63	4.7	160
33	4.2	0.6	1.71	4.6	142
34	4.4	0.4	2.20	7.0	63
35	4.2	0.5	2.70	7.8	62
36	4.8	0.4	2.40	7.3	61
37	4.7	0.4	2.77	7.5	64
38	4.5	0.5	2.65	6.8	59
39	4.7	0.3	2.56	6.0	170
40	4.6	0.4	2.79	6.0	164
41	4.9	0.3	2.56	6.0	162
42	4.8	0.3	2.59	6.0	165
43	4.5	0.9	1.95	9.8	90
44	4.2	0.7	1.65	9.9	87
45	4.9	1.1	2.28	10.3	100
46	4.6	0.8	2.28	9.8	98
47	4.7	0.9	2.28	10.0	99
48	4.8	1.2	1.91	9.5	78
Mean	4.24	0.87	2.44	5.24	137.60
Range	3.7-4.9	0.3-2.1	1.60-3.66	1.7-10.3	59-180
KAYAL SOILS					
KY 49	4.8	0.8	3.01	3.8	140
50	4.6	1.0	4.11	3.9	150
51	4.8	0.8	2.84	3.9	162
52	5.4	0.6	3.03	3.8	159
53	5.4	0.6	3.18	3.5	149
54	5.0	0.6	3.51	6.2	220

Contd.

Table 2. Continued

1	2	3	4	5	6
KY 55	5.0	0.6	3.42	6.5	224
56	3.9	1.4	3.54	6.3	225
57	3.9	1.6	3.01	6.1	230
58	5.1	0.4	4.30	6.1	217
59	5.0	0.4	3.18	6.0	218
60	4.2	0.9	1.23	5.9	217
61	4.8	0.4	1.54	5.1	178
62	4.8	0.7	1.71	5.0	179
63	4.7	0.5	1.88	5.3	177
64	4.7	0.5	1.99	5.3	181
65	3.9	1.6	2.08	4.9	174
66	3.9	1.6	2.25	4.9	175
67	3.9	1.6	2.92	4.8	179
68	3.8	1.6	2.95	4.9	172
69	3.8	1.4	2.93	4.8	180
70	3.8	1.5	2.48	5.0	187
71	3.9	1.5	2.19	4.8	186
72	4.3	0.8	2.47	7.7	86
73	4.3	0.8	2.19	7.6	87
74	4.2	1.4	2.48	7.5	182
75	4.2	1.4	2.33	7.5	174
76	4.2	1.4	1.74	8.5	150
77	3.2	5.3	1.74	2.8	175
78	4.2	1.4	2.00	6.8	180
79	3.6	2.8	2.32	3.0	328
80	3.6	2.8	2.25	3.2	325
81	3.6	2.8	2.08	3.2	300
82	3.6	2.8	2.25	3.2	321
83	3.8	3.2	4.08	5.0	437
84	3.5	3.8	4.19	4.8	438

Contd.

Table 2. Continued

1	2	3	4	5	6
KY 85	3.2	4.2	4.25	4.9	435
86	3.5	3.8	3.96	4.7	425
87	3.8	3.4	3.92	3.9	356
88	3.8	3.4	3.60	3.3	342
89	3.8	3.4	4.02	3.8	355
90	3.8	3.4	3.52	3.9	356
91	3.5	3.9	1.68	5.0	260
92	3.5	3.9	3.29	4.1	262
93	3.5	3.9	3.91	4.5	258
94	3.5	3.9	3.37	6.0	254
95	3.5	3.9	2.70	6.5	250
96	3.8	2.5	2.50	6.0	249
97	4.0	1.7	2.84	5.7	283
98	4.0	1.7	2.84	5.4	286
99	4.0	1.7	2.84	6.7	287
100	3.7	2.4	2.59	6.6	280
101	3.7	2.4	2.39	5.5	235
102	3.7	2.4	1.71	5.6	240
103	3.7	2.4	2.42	5.1	248
104	3.3	3.5	2.99	3.9	213
105	3.3	3.5	3.07	4.0	218
106	3.3	3.5	2.95	3.7	214
107	3.3	3.5	2.81	3.7	216
108	3.8	2.9	3.17	3.6	212
109	5.5	1.4	1.38	3.6	25
110	4.3	0.9	1.84	1.5	150
Mean	3.95	2.11	2.77	4.99	231.79
Range	3.2-5.5	0.4-5.3	1.23-4.30	1.5-8.5	25-438

Contd.

Table 2. Continued

1	2	3	4	5	6
<u>KARI SOILS</u>					
K 111	3.9	0.8	2.33	3.5	110
112	3.9	0.9	4.93	3.0	118
113	3.9	3.4	2.33	3.8	125
114	2.9	5.3	3.42	1.8	11
115	2.7	6.1	3.83	1.9	10
116	2.9	5.3	3.81	1.9	11
117	3.4	3.4	3.33	1.9	10
118	2.9	5.3	3.33	2.5	10
119	2.7	6.1	3.67	3.0	9
120	2.7	6.1	5.13	1.8	8
121	2.7	6.1	5.21	2.5	11
122	3.4	3.4	4.87	5.0	17
123	3.4	3.4	5.04	2.8	12
124	2.7	6.1	5.23	2.9	12
125	2.9	5.3	5.07	1.4	10
126	2.8	3.8	4.73	1.3	14
127	3.1	3.8	4.98	1.8	12
128	3.1	3.8	4.33	1.8	8
129	3.1	3.8	4.16	1.8	8
130	3.8	1.0	2.26	5.5	12
131	3.9	1.0	2.16	5.9	10
132	4.5	1.1	2.14	6.6	12
133	4.5	1.1	2.53	5.5	15
134	3.0	12.5	5.32	2.5	125
135	2.8	13.0	2.79	5.5	12
136	4.7	5.8	3.02	2.0	12
137	4.4	2.0	3.18	2.8	58
138	5.6	4.7	2.89	2.8	50
139	4.0	6.7	2.58	6.1	725
140	5.4	2.5	4.11	6.1	718

Contd.

Table 2. Continued

1	2	3	4	5	6
K 141	2.9	7.0	5.71	3.1	18
142	3.3	3.1	3.12	3.5	19
143	3.0	8.7	6.72	5.2	15
144	3.1	7.1	5.72	5.0	16
145	3.7	1.7	5.72	5.0	19
146	3.6	2.2	4.14	7.0	18
147	3.6	2.2	2.79	7.5	25
148	3.6	2.2	2.94	7.2	19
149	3.6	3.4	5.41	1.8	29
150	3.6	1.8	3.07	1.2	28
151	3.4	2.0	1.83	2.8	43
Mean	3.49	4.19	3.90	3.59	61.59
Range	2.7-5.6	0.8-13.0	1.83-6.72	1.2-7.5	8-725
Grand Mean	3.92	2.28	2.97	4.69	155.64
Range	2.7-5.6	0.3-13.0	1.23-6.72	1.2-10.3	8-725

Table 3. Coefficients of simple linear correlation and regression equations relating to general chemical properties

X	Y	r	Regression equation
1	2	3	4
KARAPADAM SOILS (n = 48)			
Av P	pH	0.7375**	Y = 0.095 X + 3.739
Av K	"	-0.4878**	Y = -0.004 X + 4.828
S_2	"	-0.4219**	Y = -0.002 X + 4.452
S_3	"	-0.3323*	Y = -0.001 X + 4.454
Av P	OC	-0.3232*	Y = -0.071 X + 2.812
Av K	"	0.3699*	Y = 0.006 X + 1.673
S_4	"	0.3204*	Y = 0.002 X + 2.092
Av K	Av P	-0.6041**	Y = -0.042 X + 10.96
S_1	"	-0.3405*	Y = -0.018 X + 6.579
S_2	"	-0.4042**	Y = -0.012 X + 6.856
S_3	"	-0.3469*	Y = -0.009 X + 7.019
S_3	Av K	0.4109**	Y = 0.159 X + 107.0
S_4	"	0.3678*	Y = 0.127 X + 111.1
S_2	S_1	0.6683**	Y = 0.668 X + 24.54
S_3	"	0.2989*	Y = 0.152 X + 46.68
S_3	S_2	0.7021**	Y = 0.606 X + 13.09
S_4	"	0.7002**	Y = 0.550 X + 17.28
S_4	S_3	0.9553**	Y = 1.050 X + 2.605
KAYAL SOILS (n = 62)			
EC	pH	-0.6254**	Y = -0.354 X + 4.702
S_1	"	-0.3374**	Y = -0.003 X + 4.408
S_2	"	-0.3840**	Y = -0.001 X + 4.337
S_3	"	-0.4353**	Y = -0.001 X + 4.399
S_4	"	-0.4224**	Y = -0.001 X + 4.381
OC	EC	0.2794*	Y = 0.448 X + 0.867

Contd.

Table 3. Continued

1	2	3	4
Av P	EC	-0.3420**	Y = -0.307 X + 3.638
Av K	"	0.6202**	Y = 0.009 X + 0.020
S_1	"	0.6688**	Y = 0.010 X + 0.523
S_2	"	0.7784**	Y = 0.005 X + 0.741
S_3	"	0.8360**	Y = 0.003 X + 0.601
S_4	"	0.8363**	Y = 0.003 X + 0.618
Av K	OC	0.5309**	Y = 0.005 X + 1.637
S_1	"	0.3229*	Y = 0.003 X + 2.296
S_3	"	0.3768**	Y = 0.001 X + 2.350
S_4	"	0.3809**	Y = 0.001 X + 2.350
S_2	Av P	-0.2759*	Y = -0.002 X + 5.528
S_3	"	-0.2674*	Y = -0.001 X + 5.525
S_4	"	-0.2831*	Y = -0.001 X + 5.550
S_1	Av K	0.5659**	Y = -0.578 X + 141.1
S_2	"	0.4258**	Y = 0.171 X + 181.2
S_3	"	0.5539**	Y = 0.151 X + 164.3
S_4	"	0.5467**	Y = 0.134 X + 165.9
S_2	S_1	0.7347**	Y = 0.289 X + 71.41
S_3	"	0.7269**	Y = 0.194 X + 70.13
S_4	"	0.7209**	Y = 0.173 X + 71.83
S_3	S_2	0.8325**	Y = 0.564 X + 43.06
S_4	"	0.8573**	Y = 0.522 X + 38.56
S_4	S_3	0.9884**	Y = 0.888 X + 10.31
<u>KARI SOILS</u>	(n = 41)		
EC	pH	-0.4702**	Y = -0.117 X + 3.979
OC	"	-0.4459**	Y = -0.253 X + 4.478
Av P	"	0.3740*	Y = 0.143 X + 2.975
Av K	"	0.4327**	Y = 0.002 X + 3.367
OC	EC	0.4144**	Y = 0.948 X + 0.492

Contd.

Table 3. Continued

1	2	3	4
S_1	EC	0.3800*	Y = 0.015 X + 2.130
S_2	"	0.6111**	Y = 0.004 X + 2.691
S_3	"	0.6506**	Y = 0.004 X + 2.266
S_4	"	0.6348**	Y = 0.003 X + 2.301
S_1	OC	0.5032**	Y = 0.009 X + 2.708
S_2	"	0.4407**	Y = 0.001 X + 3.428
S_3	"	0.5002**	Y = 0.001 X + 3.254
S_4	"	0.4903**	Y = 0.001 X + 3.263
S_2	S_1	0.6836**	Y = 0.107 X + 96.59
S_3	"	0.6095**	Y = 0.089 X + 93.34
S_4	"	0.5939**	Y = 0.080 X + 94.24
S_3	S_2	0.9042**	Y = 0.848 X - 36.68
S_4	"	0.9099**	Y = 0.784 X - 42.37
S_4	S_3	0.9921**	Y = 0.911 X + 0.750
Pooled analysis (n = 151)			
EC	pH	-0.5975**	Y = -0.190 X + 4.350
OC	"	-0.3681**	Y = -0.237 X + 4.621
Av P	"	0.4386**	Y = 0.145 X + 3.238
Av K	"	0.2087**	Y = 0.001 X + 3.736
S_1	"	-0.3164**	Y = -0.003 X + 4.261
S_2	"	-0.3893**	Y = -0.001 X + 4.155
S_3	"	-0.4195**	Y = -0.001 X + 4.224
S_4	"	-0.4202**	Y = -0.001 X + 4.222
OC	EC	0.5503**	Y = 1.114 X - 1.031
Av P	"	-0.3047**	Y = -0.317 X + 3.768
S_1	"	0.4627**	Y = 0.012 X + 0.702
S_2	"	0.6835**	Y = 0.005 X + 0.970
S_3	"	0.7073**	Y = 0.004 X + 0.656
S_4	"	0.6996**	Y = 0.004 X + 0.686
Av P	OC	-0.3475**	Y = -0.179 X + 3.812

Contd.

Table 3. Continued

1	2	3	4
S_1	OC	0.3674**	Y = 0.005 X + 2.354
S_2	"	0.4404**	Y = 0.002 X + 2.556
S_3	"	0.4992**	Y = 0.001 X + 2.407
S_4	"	0.4972**	Y = 0.001 X + 2.414
S_1	Av P	-0.1821*	Y = -0.005 X + 5.285
S_3	"	-0.1627*	Y = -0.001 X + 5.047
S_4	"	-0.1611*	Y = -0.001 X + 5.041
S_1	Av K	0.2425**	Y = 0.370 X + 108.7
S_2	S_1	0.6476**	Y = 0.169 X + 80.57
S_3	"	0.6509**	Y = 0.143 X + 71.18
S_4	"	0.6459**	Y = 0.129 X + 72.01
S_3	S_2	0.8831**	Y = 0.746 X - 15.71
S_4	"	0.8908**	Y = 0.683 X - 16.04
S_4	S_3	0.9912**	Y = 0.900 X + 6.307

** Significant at 1 per cent level of significance
* Significant at 5 per cent level of significance

Av P - Available P
Av K - Available K
OC - Organic carbon
S_1 - Available S extracted by water
S_2 - ,, by $CaCl_2$
S_3 - ,, by KH_2PO_4
S_4 - ,, by Morgan's reagent

of organic matter. The slow anaerobic decomposition of organic matter releases large amount of organic acids causing extreme acidity. The increase in acidity caused a decrease in the availability of soil P as indicated by the significant positive correlation between pH and available P (r = 0.4386**). When the acidity increases, more iron and aluminium become soluble, which could react with soluble phosphates in the soil thereby decreasing the availability of soluble phosphates. The availability of S increased with increase in acidity of the soil indicated by the significant negative correlation between pH and available S extracted by 4 different extractants. This is due to the increased dissolution of the different forms of S, especially organic S at lower values of pH. The mean values of pH for the karappadam, kayal and kari soils observed in this study were 4.24, 3.95 and 3.49 respectively.

1.2. Electrical conductivity

The electrical conductivity of the soil ranged from 0.3 to 13.0 dS/m with a mean value of 2.28 dS/m. The mean specific conductivity of karappadam, kayal and kari soils were 0.87, 2.11 and 4.19 dS/m respectively. As per the USDA norms, a soil is declared to be saline, when the EC of the saturation extract is more than 4 dS/m. In this study, the EC of the 1:2.5 soil water extract is measured, instead of the EC of the saturation extract. The soil testing laboratories of the state consider a soil to be saline when the EC of the 1:2.5 soil water extract is more than 2 dS/m. Taking this criterion, out of the 48 karappadam soils examined, only one was saline. In the case of kayal soils, 28 out of 62 were saline, while in the case of kari soils, 31 soils were saline out of the 41 selected. The EC of the soil water extract was more than 4 dS/m for 17 kari soils. The conductivity is so high that the growth and yield of rice in these soils are affected by salinity (Ponnamperuma, 1981). The salinity of Kuttanad soil is caused by the intrusion of salt through sea water. Though the magnitude of intrusion has been considerably reduced after the construction of the Thaneermukkom barrage, by and large, the soil continues to be saline, hence called acid saline. As already explained, salinity increased with the increasing acidity of the soil. The EC was significantly correlated with the organic carbon content of the soil (r = 0.5503**). As already pointed out, accumulation and anaerobic decomposition of organic matter in kari lands result in high acidity, which in turn cause increased salinity contributed by the hydrogen ion and other soil constituents made soluble at lower values of pH. The EC of the soil registered significant positive correlation with available S extracted by all the 4 extractants (r for S_1, S_2, S_3 and S_4 are 0.4267**, 0.6835**, 0.7073** and 0.6996** respectively). Such a relationship was pronounced even when the karappadam, kayal and kari soils were separately grouped. The influence of salinity on the content of available S is two fold. First, the sulphate content of the sea water causes an increase in the total available S in the soil. Second, the high EC recorded in kari soils, may also be a function of the extreme acidity observed in the soil. At very low pH values, a relatively higher proportion of the total S may become soluble, thereby registering high values for available S.

1.3. Organic carbon

The organic carbon content of the soil varied from 1.23 to 6.72 per cent with a mean value of 2.97

per cent. As per the soil fertility ratings followed by the soil testing laboratories of the state, the average organic carbon content of a loam or clayey soil is taken as 0.5 per cent. Based on this criterion, the soils of Kuttanad are, in general, rich in organic matter. The minimum value of organic carbon observed in the soils selected under this study is 1.23 per cent. The mean values for karappadam, kayal and kari soils were 2,44, 2.77 and 3.90 per cent respectively. The maximum value of organic carbon 6.72 per cent which corresponded to 11.58 per cent organic matter, was found in the kari soil of Vechoor (K143). Based on earlier works, one may expect very high values for organic carbon in kari soils. During 1960's values of organic carbon reported for kari soils from different areas ranged from 2.9 to 25 per cent and during 1970's the values reported ranged from 2.3 to 18.9 per cent (Subramoney 1961; Koshy and Brito-Mutunayagam, 1961; Money, 1961a; Zachariah and Sankarasubramoney, 1961; Nair and Aiyer, 1966; Pisharody and Brito-Mutunayagam, 1966; Pillai and Subramoney, 1967; Nair and Aiyer, 1968; Alexander and Durairaj, 1968; Koshy, 1971; Nair and Money, 1972; Money and Sukumaran, 1973; Sreedevi *et al*., 1975; Praseedom and Koshy, 1975; Aiyer *et al*., 1975; Ghosh et al., 1976; Venugopal and Koshy, 1976b; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Amma et al., 1979). In the present study, the range of organic carbon in kari soils was 1.83 to 6.72 per cent. This shows that there is a progressive decrease in the total content of organic matter in kari soils with advancing period of time. It is presumed that after the construction of the Thaneermukkom barrage, the entry of sea water into the Kuttanad region has been very much regulated hastening the oxidation of organic matter.

As already pointed out, an increase in the organic matter content of the soil increased the acidity and EC. At low pH, microbial activity is greatly reduced resulting in very slow oxidation of organic matter (Alexander, 1961). It was observed that in karappadam soils, organic carbon was negatively correlated with available P (r = -0.3232*). This can be attributed to the increase in acidity associated with the higher content of organic matter and role of soil acidity in the fixation of soil P (Mathews and Jose, 1984). Organic carbon was significantly and positively correlated with available S irrespective of the extractants used. This is quite expected since on an average 62.0 per cent of the total S in the soil was in organic form.

1.4. Available phosphorus

The available P, extracted by Bray No.I extractant ranged from 1.2 to 10.3 ppm with a mean value of 4.69 ppm. In general, the content of available P in Kuttanad soils is low which is mainly attributed to the high rate of P fixation taking place in the acid saline soils. The mean values for available P in karappadam, kayal and kari soils were 5.24, 4.99 and 3.59 ppm, respectively. The kari soils are highly deficient in available P, even though they have good amount of organic matter. The relationships of available P with pH, EC and organic carbon have already been described. Acidity and accumulation of organic matter always result in decreased availability of P in soil due to enhanced P fixation. A significant negative correlation was observed between available P and available S in the soil. This is due to the fact that high organic matter was associated with high acidity which caused decreased P availability whereas more S was brought to solution with increasing acidity. This relationship was observed irrespective of the extractant used for the estimation of available S.

1.5. Available potassium

The available K content of the soil, as extracted by 1<u>N</u> neutral ammonium acetate, showed very high variation between the samples. The values ranged from 8 to 725 ppm with a mean value of 155.6 ppm. As compared to karappadam and kayal soils, the kari soils contained only very low amount of available K, the mean values for karappadam, kayal and kari soils being 137.6, 231.8 and 61.5 ppm respectively. The low content of available K in kari soil has been reported by Alexander and Durairaj (1968), Money and Sukumaran (1973) and Ghosh <u>et al</u>. (1976). The relationships of available K with other soil chemical properties like pH, EC, organic matter, available P and available S were not consistent. It was positively correlated with available S in karappadam and kayal soils but failed to establish significant correlation with the available S content of kari soils. Similarly, available K was found to be significantly and positively correlated with organic carbon content of karappadam and kayal soils but not in kari soils.

2. Available sulphur

Plants absorb sulphur as sulphate ions from the soil to meet their nutrient requirements. The sulphate

S pool comprises largely of water soluble S, sulphate S adsorbed by the soil and sulphur that can be easily released from the soil organic matter. The plant available S has been extracted by a variety of chemical agents and the estimates are mainly a function of the ability of the chemical agent to extract different forms of S in the soil. The extractants usually employed include water, neutral salt solutions, phosphate solutions and weak acid solutions. Accordingly, in the present study, available S has been estimated by four extractants viz., (1) water (2) 0.15 per cent $CaCl_2$ (3) 500 ppm P as KH_2PO_4 and (4) Morgan's extractant (sodium acetate plus acetic acid buffered to pH 4.0). Available S extracted by these extractants are presented in Table 4 and the correlation and regression of available S with other chemical properties of the soil are presented in Table 3.

2.1. Available S extracted by water

The content of available S in the soil ranged from 25 to 395 ppm, the mean value being 126.6 ppm. As reported by the earlier workers (Money, 1961a; Jacob, 1966) the Kuttanad soils contain relatively higher

Table 4. Available sulphur extracted by different extractants, ppm

Soil No.	Water	0.15% $CaCl_2$	500 ppm P as KH_2PO_4	Morgan's reagent
1	2	3	4	5
KARAPPADAM SOILS				
KP 1	86	180	220	217
2	62	162	250	250
3	63	168	215	217
4	70	115	250	242
5	86	127	167	162
6	66	79	100	115
7	81	101	147	135
8	86	191	375	375
9	115	100	160	245
10	76	422	557	700
11	132	200	245	250
12	120	138	250	287
13	36	135	187	200
14	34	128	232	200
15	30	120	275	260
16	145	165	190	180
17	67	175	190	175
18	42	115	162	137
19	82	103	177	175
20	320	450	225	222
21	170	262	245	250
22	57	68	165	182
23	45	65	80	112
24	40	262	237	262
25	88	108	212	210
26	126	146	200	205

Contd.

Table 4. Continued

1	2	3	4	5
KP 27	95	125	330	335
28	45	75	145	160
29	88	128	312	240
30	91	218	418	437
31	73	93	180	195
32	107	127	217	237
33	70	90	117	137
34	76	96	115	147
35	25	37	135	147
36	41	61	172	167
37	45	65	100	115
38	32	52	50	97
39	63	83	165	175
40	42	142	217	215
41	33	37	67	117
42	55	75	165	167
43	57	105	160	195
44	83	103	110	160
45	125	170	312	375
46	35	55	68	72
47	32	52	67	69
48	34	53	69	72
Mean	76.50	131.85	195.92	208.25
Range	25-320	37-450	50-557	69-700
<u>KAYAL SOILS</u>				
Ky 49	107	198	202	167
50	128	92	165	200
51	145	165	217	275
52	45	65	115	155

Contd.

Table 4. Continued

1	2	3	4	5
KY 53	113	133	160	210
54	57	77	110	147
55	225	325	475	500
56	105	187	407	425
57	100	140	217	236
58	100	180	222	250
59	57	157	210	250
60	87	107	137	167
61	121	141	152	195
62	71	81	85	135
63	95	105	115	167
64	67	80	115	147
65	75	275	535	590
66	132	350	406	375
67	88	105	187	225
68	76	116	181	197
69	70	123	181	187
70	87	115	260	250
71	90	170	181	230
72	120	142	290	300
73	72	122	220	222
74	145	245	450	468
75	287	387	245	215
76	107	237	150	192
77	165	1175	1000	1250
78	207	375	575	612
79	142	198	250	250
80	351	535	675	687
81	320	680	825	800
82	232	342	550	612

Contd.

Table 4. Continued

1	2	3	4	5
KY 83	225	650	1050	1250
84	297	382	1200	1250
85	300	350	487	590
86	207	482	657	702
87	263	550	950	1140
88	307	582	825	1000
89	300	515	775	832
90	170	370	537	537
91	220	420	737	800
92	188	650	1140	1250
93	180	380	1140	1250
94	270	470	867	897
95	245	687	942	1025
96	122	150	250	275
97	95	167	182	197
98	68	128	202	195
99	120	300	375	425
100	132	179	245	250
101	125	250	305	310
102	95	192	350	375
103	57	115	395	400
104	220	382	675	700
105	337	650	625	915
106	245	400	800	825
107	145	249	650	680
108	200	475	722	737
109	95	150	225	250
110	105	100	145	150
Mean	156.8	295.2	447.1	481.7
Range	45-351	65-1175	85-1140	150-1250

Contd.

Table 4. Continued

1	2	3	4	5
KARI SOILS				
K 111	70	188	295	315
112	75	198	500	485
113	67	180	375	485
114	70	195	375	485
115	59	135	210	255
116	188	215	240	270
117	57	126	185	240
118	42	86	70	100
119	107	286	406	445
120	100	255	425	485
121	100	503	525	550
122	151	237	400	462
123	220	385	535	570
124	290	450	535	570
125	266	650	1000	1150
126	80	150	125	185
127	182	420	468	468
128	145	415	543	575
129	120	300	343	405
130	57	175	275	290
131	95	250	245	250
132	80	112	125	187
133	138	280	306	400
134	113	651	1900	1950
135	175	1625	1300	1400
136	170	205	375	380
137	113	200	230	240
138	245	420	440	440
139	175	425	475	485

Contd.

Table 4. Continued

1	2	3	4	5
K 140	73	134	320	320
141	170	536	575	600
142	157	197	275	310
143	395	2400	2450	2500
144	245	1925	2000	2400
145	195	315	475	495
146	188	226	255	255
147	145	375	320	400
148	116	195	245	230
149	120	266	335	365
150	71	116	200	210
151	107	235	710	730
Mean	139.8	405.78	521.60	571.63
Range	42-395	86-2400	70-2450	100-2500
Grand Mean	126.66	207.07	387.47	419.19
Range	25-395	37-2400	50-2450	69-2500

amount of water soluble S. The ranges of water soluble S for the karappadam, kayal and kari soils were 25-320, 45-351 and 42-395 ppm, respectively. On an average, nearly 6.3 per cent of the total S was in water soluble form. The maximum content of water soluble S was observed in kari soils. The kari soil from Vechoor (K 143) recorded 395 ppm water soluble S while the total content of S in this soil was 9900 ppm. Comparing to the values reported for other Indian soils, the soils of Kuttanad retain large amount of water soluble S. The mean values of water soluble S in the soils of Madhya Pradesh, Rajasthan, Himachal Pradesh, Uttar Pradesh, Punjab and Tamil Nadu were 1.8, 15.1, 17, 15, 22 and 18 ppm respectively (Bansal et al., 1979; Rawat and Sriniwas, 1979; Palaskar and Ghosh, 1982; Tiwari et al., 1983a; Ghai et al., 1984; Balasubramanian and Kothandaraman, 1985). In the case of kayal soils, the values of water soluble S were found to be significantly and negatively correlated with pH (r = -0.3374**). This is due to the fact that increased acidity was associated with higher content of organic matter and high salinity; both inturn, caused an increase in the total as well as the sulphate S content of the soils.

The EC of the soil was positively correlated with water soluble S in all soils except karappadam soils, the respective r values for kayal and kari soils being 0.6688** and 0.3800*. This may be due to the presence of water soluble sulphates contained in the soil at higher level of salinity. Water soluble S was also found correlated with the organic carbon content of the soil. The coefficients of correlation of water soluble S with organic carbon for kayal, kari and all soils taken together were 0.3229*, 0.5032** and 0.3674** respectively. As pointed out, the major form of S in the soils under study was organic S and therefore the water soluble S released due to the mineralisation of soil organic matter decisively contributes towards the water soluble sulphate pool of the soil. The significant positive correlation between water soluble S and available K in kayal soils may be due to the indirect influence of soil organic matter, since there was a positive correlation between organic carbon and available K in the soil (r = 0.5309**). The water soluble S was found to be correlated with the available S extracted by $CaCl_2$ in all soils and with available S extracted by phosphate in kayal and kari soils. The relationship among available S extracted by different extractants is well anticipated since the composition of the available sulphate pool does not vary much with differences in the extractants employed.

2.2. Available sulphur extracted by 0.15 per cent calcium chloride

The available S as extracted by $CaCl_2$ widely ranged from 37 - 2400 ppm, the mean value being 207 ppm. The ranges of values for karappadam, kayal and kari soils were 37 - 450, 65 - 1175 and 86 - 2400 ppm respectively. The highest value was recorded by the kari soil of Vechoor (K 143). As compared to the range of values reported for other Indian soils, the Kuttanad soils are very rich in available S extracted by $CaCl_2$. The values of $CaCl_2$ extractable S for the soils of Madhya Pradesh, Rajasthan, Himachal Pradesh, Uttar Pradesh, Punjab and Himachal Pradesh were 9, 9, 14, 11, 17 and 13 ppm, respectively (Bansal et al., 1979; Rawat and Sriniwas, 1979; Palaskar and Ghosh, 1982; Tiwari et al., 1983a; Ghai et al., 1984; Sharma et al., 1988). The high content of available S in the Kuttanad soil has also been observed by earlier workers (Ghosh et al., 1976). The $CaCl_2$ extractable S increased with the total

S content of the soil. It contributed to 17.4 per cent of the total S in the soils under study. Since the $CaCl_2$ extractable S represents the sulphate form of S, the values for $CaCl_2$ extractable S was almost double (1.6 times) than the values of water soluble S.

The content of available S extracted by $CaCl_2$ increased with the increasing acidity of the soil as shown by the significant negative correlation with pH, the r values being -0.4219**, -0.3840** and -0.3893** for karappadam, kayal and all soils taken together, respectively. This relationship is the indirect influence of the significant correlations between pH and organic carbon and between pH and EC already described. Accumulation of organic matter has been associated with a decrease in pH and increase in EC and the higher content of $CaCl_2$ extractable S is the outcome of higher content of organic matter and salinity observed in the soil. This is further supported by the significant positive correlation of $CaCl_2$ extractable S with EC (r values being 0.7784**, 0.6111** and 0.6835** for kayal, kari and all soils taken together, respectively).

Sulphur extracted by $CaCl_2$ was significantly correlated with the available S extracted by other agents, irrespective of the group of the soil. Thus the coefficients of correlation with water soluble S for karappadam, kayal and kari soils were 0.6683**, 0.7347** and 0.6836** respectively. The corresponding values with phosphate extractable S were 0.7021**, 0.8325** and 0.9042** while those with Morgan's extractable S were 0.7002**, 0.8573** and 0.9099** respectively for karappadam, kayal and kari soils.

2.3. Available S extracted by 500 ppm phosphorus solution

The content of available S extracted by 500 ppm P solution as KH_2PO_4 ranged from 50 - 2450 ppm with a mean value of 387.5 ppm. The mean values of phosphate extractable S in karappadam, kayal and kari soils were 195.9, 447.1 and 521.6 ppm respectively. In general, the content of phosphate extractable S was 21.9 per cent of the total S content of the soil. It was approximately three times that of the water soluble S and 1.9 times of the $CaCl_2$ extractable S. The relatively higher values for the S extracted by the phosphate solution may be attributed to the relatively higher efficiency of phosphate to exchange the sulphate ions from the soil colloids. Spencer and Freney (1960) and Williams and Steinbergs (1964) also observed that generally phosphate solution extract more SO_4-S from soil than can be extracted with water or $CaCl_2$ solution because phosphate ion displaces the adsorbed sulphate more efficiently than by chloride. As in the case of water soluble and $CaCl_2$ extractable S, the available S extracted by 500 ppm P solution was significantly correlated with the content of organic carbon in kayal (r = 0.3768**), kari (r = 0.5002**) and all soils taken together (r = 0.4992**). The influence of soil organic matter on the content of available S in soil has already been explained. Since the major source of S in soil is the organic matter, the available S is expected to increase with the increase in content of soil organic matter. The pH of the soil decreased with increase in content of organic matter as a result of which available S extracted by phosphate solution established a significant and negative correlation with pH (r = -0.4196**). Available S extracted by phosphate was significantly correlated with the EC of the soil.

This may be either due to the higher content of sulphate sulphur in the soluble salts contained in the soil or due to the indirect effect of increasing acidity observed with increasing salinity of the soil. A significant negative correlation (r = -0.1627*) was seen between available P and S extracted by the phosphate solution. It may be recalled that at lower values of pH, the availability of P decreased continuously whereas S availability increased thereby registering a negative correlation between available P and S. The sulphur extracted by phosphate solution showed significant positive correlation with the available K content of the karappadam (r = 0.4109**) and kayal (r = 0.5539**) soils. It is pointed out that the content of total organic carbon was significantly correlated with available K in karappadam (r = 0.3699*) and kayal soils (r = 0.5309**). Probably, this may be the reason for the relationship between available K and available S in these two types of soils. The decisive role of organic matter on the pool of available S in soil has already been stressed. As expected, available S extracted by the phosphate solution established significant positive correlation with water soluble S, S extracted by $CaCl_2$, and S extracted by Morgan's reagent, irrespective of the soil type. This is mainly because, the main source of available S in soil is the sulphate S which is extracted by all the four extractants tried, though slight variations exist in their ability to extract this form of S. Even if a small proportion of the other forms of S is accounted by the available S, their contribution is not significant enough to shift the pattern of relationship between available S and sulphate sulphur.

2.4. Available S extracted by Morgan's reagent

The available S extracted by Morgan's reagent ranged from 69 - 2500 ppm, with a mean value of 419.2 ppm. The highest amount of available S was found in the kari soil of Vechoor (K 143). As in the case of available S extracted by other reagents, S extracted by Morgan's reagent was high in kari soils in proportion to the high content of total S in these soils. The mean values of Morgan's extractable S in karappadam, kayal and kari soils were 208.3, 481.7 and 571.6 ppm respectively. The magnitude of available S extracted by Morgan's reagent was almost similar to that extracted by the phosphate solution showing that the ability of

Morgan's reagent to extract available S from the acid soils used in this study is almost equivalent to that of the 500 ppm KH_2PO_4. Similar observations were also made by Hegde *et al*. (1980). As a result, the relationships between S extracted by Morgan's reagent and the other soil properties like pH, EC, organic carbon, available P and available K were similar to those between phosphate extractable S and the above soil properties.

The foregoing observations clearly showed that the soils of Kuttanad are very rich in available S in the increasing order of karappadam, kayal and kari soils. While the critical values of available S suggested for various soils are restricted to a range of 10 - 25 ppm depending on the extractant employed and the type of test crop used, the content of available S in most of the soils studied confined to a range of 100 to 500 ppm. In general, nearly 6.3 per cent of the total S remains in water soluble form and approximately one-fifth of the total S exists in the available form extracted by $CaCl_2$, phosphate or Morgan's reagent. Thus, considerable amount of available S still persists in the soils of Kuttanad and the addition of S containing fertilizers may not be necessary in these soils for many years to come.

3. Fractionation of sulphur

To study the pattern of distribution of different forms of S in Kuttanad soils, fractionation of S was carried out in 39 selected soils. They consisted 10 karappadam soils, 18 kayal soils and 11 kari soils. The general chemical properties of these soils and the content of available S as extracted by different agents have already been discussed. Additional soil properties associated with transformation of S in soils were studied in these 39 soils so as to gain better understanding on the distribution of different forms of S in them in relation to the properties of the soil. The additional soil properties thus examined were soil texture, CEC and exchangeable plus water soluble cations. The data on the additional soil properties are given in Table 5.

3.1. Soil texture

Out of the 39 soils examined, 38 were loam and only one soil was clay. The most dominant subgroups under loam were sandy loams and sandy clay loams. All the 10 karappadam soils were sandy clay loam in nature. On an average, the soils contained 62.13 per cent sand,

Table 5. General properties of soils selected for sulphur fractionation

Soil No.	Particle size analysis (%)			Textural class	CEC (me/100 g)	Exchangeable + water soluble cations, me/100 g		
	Sand	Silt	Clay			Ca	Mg	Na
1	2	3	4	5	6	7	8	9
KARAPPADAM SOILS								
KP 2	58.8	18.3	22.9	Sandy clay loam	14.5	3.3	3.4	2.6
9	57.5	15.0	27.5	Sandy clay loam	25.0	2.5	1.2	0.4
10	71.2	12.4	16.4	Sandy clay loam	24.5	4.5	4.2	1.0
17	65.8	17.1	17.1	Sandy clay loam	21.7	3.0	4.7	0.8
21	54.5	20.7	24.8	Sandy clay loam	20.8	6.7	1.6	0.9
24	50.6	26.4	23.0	Sandy clay loam	13.4	2.8	1.0	0.8
28	62.9	8.4	28.7	Sandy clay loam	13.3	2.1	2.7	0.8
35	50.0	22.5	27.5	Sandy clay loam	20.3	2.9	1.2	1.0
41	57.5	17.5	25.0	Sandy clay loam	21.8	2.5	2.5	0.5
45	58.1	12.6	29.3	Sandy clay loam	19.3	3.2	3.2	1.5
Mean	58.69	17.09	24.22		19.46	3.35	2.57	1.03
Range	50.0-71.2	8.4-26.4	16.4-29.3		13.3-25.0	2.1-6.7	1.0-4.7	0.4-2.6
KAYAL SOILS								
KY 50	79.3	8.3	12.4	Sandy loam	29.6	4.3	2.5	1.1
56	65.8	17.1	17.1	Sandy loam	20.0	3.7	6.2	2.7
64	71.0	20.7	8.3	Sandy loam	26.4	4.8	4.3	0.3

Contd.

Table 5. Continued

1	2	3	4	5	6	7	8	9
KY 66	50.1	31.6	18.3	Sandy loam	20.8	4.4	6.1	7.1
70	58.9	25.9	15.2	Sandy loam	29.6	2.2	5.0	1.0
76	74.0	9.5	16.5	Sandy loam	14.8	3.0	3.3	1.5
77	70.0	4.0	26.0	Sandy loam	14.0	9.1	6.2	0.2
80	57.8	24.5	17.7	Sandy loam	17.6	5.6	2.8	2.9
83	69.0	17.0	14.0	Sandy loam	63.6	8.3	5.4	4.3
87	71.0	10.5	18.5	Sandy loam	62.9	7.2	5.1	4.2
92	72.5	10.0	17.5	Sandy loam	34.9	4.0	8.6	8.1
95	73.0	9.0	18.0	Sandy loam	35.7	2.2	2.5	4.1
99	63.5	14.0	22.5	Sandy clay loam	29.0	4.2	4.6	1.7
101	55.6	16.4	28.0	Sandy clay loam	34.5	4.5	5.7	5.4
105	50.6	16.4	33.0	Clay loam	35.0	4.8	8.2	6.3
108	62.9	8.4	28.7	Sandy clay loam	31.8	8.5	1.2	32.6
109	78.0	9.0	13.0	Sandy loam	10.8	2.0	5.4	2.9
110	75.0	9.0	16.0	Sandy loam	16.4	3.1	6.9	3.8
Mean	66.55	14.52	18.93		27.08	4.77	5.00	5.01
Range	50.1-79.3	4.0-31.6	8.3-33.0		10.8-63.6	2.0-9.1	1.2-8.6	0.2-32.6
<u>KARI SOILS</u>								
K 113	60.1	31.6	8.3	Sandy loam	40.5	4.4	1.2	1.1
122	49.8	41.8	8.4	Sandy loam	39.0	3.1	5.6	1.3
124	56.9	25.9	17.2	Silt loam	44.5	2.5	5.6	1.3

Contd.

Table 5. Continued

1	2	3	4	5	6	7	8	9
K 125	80.0	7.5	12.5	Sandy loam	39.8	4.6	5.6	2.0
130	53.0	16.5	30.5	Clay loam	38.8	5.6	2.2	0.5
132	63.5	14.0	22.5	Sandy clay loam	37.5	6.1	2.3	0.3
135	75.0	8.5	16.5	Sandy loam	45.4	18.5	2.6	4.3
139	62.0	27.5	8.5	Sandy loam	32.3	12.1	4.2	4.2
143	31.8	15.6	52.5	Clay	78.8	16.1	5.8	8.9
147	24.5	57.8	17.7	Silty loam	10.0	4.0	1.8	1.5
151	62.0	29.5	8.5	Silty loam	58.4	2.1	3.6	0.8
Mean	56.23	25.1	18.46		42.27	7.19	3.68	2.38
Range	24.5-80.0	7.5-57.8	8.3-52.5		10.0-78.8	2.1-18.5	1.2-5.8	0.3-8.9
Grand Mean	62.13	17.99	19.88		29.41	5.09	4.01	3.25
Range	24.5-80.0	4.0-57.8	8.3-52.5		10-78.8	2.0-18.5	1.0-8.6	0.2-32.6

17.99 per cent silt and 19.88 per cent clay. The clay soil from Vechoor (K 143) contained 52.5 per cent clay, the maximum value recorded in the study.

The clay fraction of the soil was found to be negatively correlated with pH and sand (r = -0.4771** and r = -0.3515*). Clay was positively correlated with total S, organic S, sulphate S, nonsulphate S and available S. Since the sulphate ions are adsorbed by the soil colloids, the content of the sulphate S increased with increasing content of clay fractions thus establishing a positive correlation. Since the sulphate S is the major constituent of available S and partly that of total S, the relationship between SO_4-S and clay content, in turn, give rises to the positive correlations of clay with available S and total S. In general, soils dominating in clay fraction tend to retain relatively higher content of organic matter and this can be attributed to the positive significant linear relationship between clay and organic S (r = 0.4600**).

3.2. Cation exchange capacity

The cation exchange capacity of the Kuttanad soil varied from 10.0 - 78.8 me/100 g soil with a mean value of 29.41. The wide variation observed in the CEC of the soil is due to the variation in the content of organic matter and clay in these soils. In general, kari soil possessed very high CEC. The mean values of CEC for karappadam, kayal and kari soils were 19.46, 27.08 and 42.27 me/100 g soil respectively. The highest CEC of 78.8 me/100 g soil was recorded by the kari soil from Vechoor (K 143). This soil contained 6.72 per cent organic carbon, the highest value recorded in this study. In general, the soils of Kerala are poor in CEC, since the predominant clay mineral in them is the 1:1 type kaolinite. However, the relatively high CEC of the Kuttanad soil projects the role of soil organic matter in considerably increasing the CEC of the soil. Marykutty and Aiyer (1987) also observed that kari soils from Kallara, Kottayam had high CEC, i.e., 43.6 me/100 g soil. The role of organic matter in increasing the CEC of soil was reflected in the significant positive linear relationship between CEC and organic carbon (r = 0.6022**). Since the pH of the soil decreased with increasing content of organic matter, a negative linear relationship was observed between pH and CEC of the soils (r =-0.3930*). Also the positive correlation between CEC and EC ($r = 0.5247^{**}$) appears to be a reflection of the relationship between soil acidity and CEC, since EC of the soil increased with increasing acidity. The contents of sulphate S, available S extracted by all the four extractants, organic S and total S were significantly correlated with CEC (r values are 0.5834**, 0.5140** (S_1), 0.5834** (S_2), 0.7011** (S_3), 0.6826** (S_4), 0.5055** and 0.6407** respectively). As already mentioned, sulphate S is the major constituent of the available S and therefore, the ability of the soil colloids to retain S in the form of sulphate ions increased with the increasing content of soil colloids as indicated by the positive significant correlation between CEC and SO_4-S. Also, the CEC was positively correlated with total S, probably as an indirect effect of the relationship of total S with organic matter, organic S and SO_4-S.

3. Exchangeable plus water soluble cations

In general, the soils showed high variation in the content of exchangeable plus water soluble Ca and Mg. The highest amount of Ca was found in the kari soil from Thuravur (K 135) which also recorded the highest value for EC. The Ca and Mg contents were significantly and positively correlated with water oluble and available S content of the soil. In Kuttanad, periodic ingress of brackish water takes place during summer, resulting in the accumulation of sulphate containing soluble salts. This may be the reason for the significant positive relationship of exchangeable plus water soluble Ca and Mg with water soluble and available forms of S. In general, Ca content ranged from 2.0 to 18.5 me/100 g soil with a mean value of 5.09 me/100 g. The mean value for water soluble plus exchangeable Mg was 4.01 me/100 g soil.

The values of exchangeable plus water soluble Na ranged from 0.2 to 32.6 me/100 g soil. The content of Na showed positive significant linear relationship with EC (0.7295**), water soluble S (0.7448**), available S, SO_4-S (r = 0.9244**), organic S (0.6976*), total S (r = 0.9034**) and clay (r = 0.6248*) content of the kari soil. The intrusion of sea water would have caused the accumulation of sulphates along with soluble and exchangeable Na resulting in above positive correlations. The increase in EC and acidity observed with the accumulation of organic matter could explain the positive relationships between organic S and exchangeable plus water soluble Na content in the soil.

4. Forms of sulphur

The data on the forms of S in soil are presented in Table 6 and the data on the proportion of the forms of S expressed as percentage of total S are presented in Table 7. Table 8 shows the coefficients of correlation and linear regression equations of the different forms of S in soil.

4.1. Total sulphur

The soil derives its S from the primary minerals, organic compounds and sulphate ions present in exchangeable and water soluble form. In humid tropics, S mainly occurs in organic form.

The study revealed that the soils of Kuttanad, which are acid saline in nature, contained large amount of S. The values ranged from 600-9900 ppm with a mean value of 2324.1 ppm. Among the three soil types, the content of total S was maximum in kari soils with a mean value of 4020 ppm, while the corresponding values

Table 6. Forms of sulphur in soil, ppm

Soil No.	Sulphate S	Organic S	Nonsulphate S	Total S
1	2	3	4	5
KARAPPADAM SOILS				
KP 2	162	397	341	900
9	100	895	230	1225
10	422	910	318	1650
17	175	330	95	600
21	262	537	426	1225
24	262	576	137	975
28	75	225	350	650
35	37	595	48	680
41	37	585	238	860
45	170	812	518	1500
Mean	170.2	586.2	270.1	1026.5
Range	37-422	225-910	48-518	600-1650
KAYAL SOILS				
KY 50	92	700	83	875
56	187	825	238	1250
64	80	655	115	850
66	350	507	123	980
70	115	877	118	1110
76	237	715	243	1195
77	1175	4460	220	5855
80	535	1317	148	2000
83	650	1277	193	2120
87	550	1150	550	2250
92	650	1150	200	2000
95	687	1580	713	2980
99	300	810	270	1380
101	250	1402	848	2500
105	650	2762	148	3560

Contd.

553

Table 6, Continued

1	2	3	4	5
KY 108	475	2365	910	3750
109	150	420	180	750
110	100	475	175	750
Mean	401.8	1302.6	304.1	2008.6
Range	80-1175	420-4460	83-910	750-5855
<u>KARI SOILS</u>				
K 113	180	507	438	1125
122	237	1487	1476	3200
124	450	4613	687	5750
125	650	2085	1635	4370
130	175	1010	565	1750
132	112	800	213	1125
135	1625	4322	803	6750
139	425	4475	600	5500
143	2400	4367	3133	9900
147	375	1470	405	2250
151	235	1777	488	2500
Mean	624.0	2446.0	949.4	4020.0
Range	112-2400	507-4613	213-3133	1125-9900
Grand Mean	405.10	1441.6	477.4	2324.1
Range	37-2400	225-4613	48-3133	600-9900

Table 7. Forms of sulphur expressed as percentage of total S

Soil No.	SO_4-S	Organic S	Nonsulphate
1	2	3	4
KARAPPADAM SOILS			
KP 2	18.0	44.1	37.8
9	8.2	73.0	18.8
10	25.6	55.1	19.3
17	29.2	55.0	15.8
21	21.4	43.8	34.8
24	26.9	39.0	14.0
28	11.6	34.6	53.8
35	5.5	87.5	7.0
41	4.3	68.0	27.7
45	11.4	54.1	34.5
Mean	16.57	57.11	26.33
Range	4.3-29.2	34.6-87.5	7.0-53.8
KAYAL SOILS			
KY 50	10.5	80.0	9.5
56	15.0	66.0	19.0
64	9.4	77.1	13.5
64	35.7	51.7	12.6
70	10.4	79.0	10.6
76	19.9	59.8	20.3
77	20.1	76.4	3.5
80	26.8	65.8	7.4
83	30.7	60.2	9.1
87	24.5	51.1	24.4
92	32.5	57.5	10.0
95	23.1	53.0	23.9
99	21.8	58.7	19.5
101	10.0	56.1	33.9
105	18.3	77.6	4.1
108	12.7	63.1	24.2

Contd.

Table 7. Continued

1	2	3	4
KY 109	20.0	56.0	24.0
110	13.4	63.3	23.3
Mean	20.00	64.86	15.15
Range	9.4-35.7	51.1-80.0	3.5-33.9
<u>KARI SOILS</u>			
K 113	16.0	45.1	38.9
122	7.4	46.5	46.1
124	7.8	80.2	12.0
125	14.9	47.7	37.4
130	10.0	57.7	32.3
132	10.0	71.1	18.9
135	24.1	64.0	11.9
139	7.7	81.4	10.9
143	24.2	44.2	31.6
147	16.6	65.4	18.0
151	9.4	71.1	19.5
Mean	15.50	60.86	23.60
Range	7.4-24.2	44.2-81.4	10.9-46.1
Grand Mean	17.4	62.1	20.5
Range	4.3-35.7	34.6-87.5	3.5-53.8

Table 8. Coefficients of simple linear correlation and regression equations relating to the forms of S

X	Y	r	Regression equation
1	2	3	4
KARAPPADAM SOILS (n = 10)			
Av P	pH	0.6676*	Y = 0.094 X + 3.737
Ex Na	EC	0.8234**	Y = 0.733 X + 0.195
S_3	"	0.6552*	Y = 0.003 X + 0.327
Org S	OC	0.6693*	Y = 0.001 X + 1.746
SO_4-S	Clay	-0.6660*	Y = -0.025 X + 28.48
S_2	"	-0.6660*	Y = -0.025 X + 28.48
Org S	CEC	0.6520*	Y = 0.012 X + 12.34
S_1	Ex Ca	0.7007*	Y = 0.020 X + 1.828
Non SO_4-S	S_1	0.6503*	Y = 0.204 X + 20.58
S_3	S_2	0.9012**	Y = 0.803 X - 14.26
S_4	"	0.8451**	Y = 0.601 X + 9.177
Total S	"	0.6628*	Y = 0.220 X - 55.30
S_4	S_3	0.9751**	Y = 0.778 X + 21.21
SO_4-S	"	0.9012**	Y = 1.012 X + 57.59
Total S	"	0.7686**	Y = 0.286 X - 63.79
SO_4-S	S_4	0.8451**	Y = 1.189 X + 65.71
Total S	"	0.8380**	Y = 0.391 X - 133.1
S_3	SO_4-S	0.9012**	Y = 0.803 X - 14.26
S_4	"	0.8451**	Y = 0.601 X + 9.177
Total S	"	0.6628*	Y = 0.220 X - 55.30
Total S	Org S	0.8278**	Y = 0.531 X + 41.44
KAYAL SOILS (n = 18)			
EC	pH	-0.7466**	Y = -0.318 X + 4.704
Av K	"	-0.5739*	Y = -0.003 X + 4.721
Sand	"	0.5161*	Y = 0.032 X + 1.816
Clay	"	-0.6323**	Y = -0.059 X + 5.033
S_1	"	-0.5860*	Y = -0.004 X + 4.599
S_2	"	-0.7201**	Y = -0.001 X + 4.499
S_3	"	-0.6691**	Y = -0.001 X + 4.511
S_4	"	-0.6691**	Y = -0.001 X + 4.486

Contd.

Table 8. Continued

1	2	3	4
SO_4-S	pH	-0.7201**	Y = -0.001 X + 4.499
Org S	"	-0.6430**	Y = -0.0003X + 4.412
Total S	"	-0.6901**	Y = -0.0003X + 4.522
Clay	EC	0.5865*	Y = 0.128 X + 0.013
Ex Ca	"	0.5528*	Y = 0.330 X + 0.796
S_1	"	0.6525**	Y = 0.010 X + 0.676
S_2	"	0.9640**	Y = 0.004 X + 0.645
S_3	"	0.9053**	Y = 0.003 X + 0.589
S_4	"	0.9237**	Y = 0.003 X + 0.634
SO_4-S	"	0.9640**	Y = 0.004 X + 0.645
Org S	"	0.8036**	Y = 0.001 X + 1.017
Total S	"	0.8742**	Y = 0.001 X + 0.670
Av K	OC	0.5688*	Y = 0.005 X + 1.428
CEC	"	0.6583**	Y = 0.057 X + 1.074
CEC	Av K	0.6983**	Y = 6.417 X + 48.35
Ex Ca	"	0.5042*	Y = 21.20 X + 120.9
S_1	"	0.5805*	Y = 0.628 X + 115.9
S_3	"	0.6382**	Y = 0.165 X + 133.6
Silt	Sand	-0.6521**	Y = -0.809 X + 78.92
Clay	"	-0.5028*	Y = -0.754 X + 80.42
Ex Na	Clay	0.4934*	Y 1 0.405 X + 16.34
S_1	"	0.5169*	Y = 0.036 X + 12.24
S_2	"	0.5772*	Y = 0.012 X + 13.65
SO_4-S	"	0.5772*	Y = 0.012 X + 13.65
Org S	"	0.7294**	Y = 0.004 X + 12.75
S_3	CEC	0.5006*	Y = 0.012 X + 19.62
S_4	"	0.6232**	Y = 0.005 X + 19.87
S_2	Ex Ca	0.6232**	Y = 0.005 X + 2.903
S_3	"	0.5721*	Y = 0.004 X + 2.886
S_4	"	0.5982**	Y = 0.003 X + 2.888

Contd.

Table 8. Continued

1	2	3	4
SO_4-S	Ex Ca	0.6232**	$Y = 0.005\ X + 2.903$
Org S	"	0.6400**	$Y = 0.001\ X + 2.965$
Total S	"	0.6595**	$Y = 0.001\ X + 2.623$
Non SO_4-S	Ex Na	0.6098**	$Y = 0.017\ X - 0.133$
S_2	S_1	0.6252**	$Y = 0.181\ X + 96.28$
S_3	"	0.6596**	$Y = 0.158\ X + 84.61$
S_4	"	0.6792**	$Y = 0.136\ X + 86.00$
SO_4-S	"	0.6252**	$Y = 0.181\ X + 96.28$
Total S	"	0.4937*	$Y = 0.031\ X + 106.6$
S_3	S_2	0.8735**	$Y = 0.719\ X + 15.87$
S_4	"	0.9030**	$Y = 0.625\ X + 20.77$
Org S	"	0.8308 **	$Y = 0.241\ X + 87.46$
Total S	"	0.8730**	$Y = 0.190\ X + 20.65$
S_4	S_3	0.9851**	$Y = 0.828\ X + 31.73$
SO_4-S	"	0.8735**	$Y = 1.061\ X + 110.3$
Org S	S_3	0.5589*	$Y = 0.197\ X + 279.7$
Total S	S_3	0.6603**	$Y = 0.174\ X + 186.4$
SO_4-S	S_4	0.9030**	$Y = 1.305\ X + 186.4$
Org S	"	0.6222**	$Y = 0.261\ X + 85.44$
Total S	"	0.7031**	$Y = 0.221\ X + 269.6$
Org S	SO_4-S	0.8308**	$Y = 0.241\ X + 87.46$
Total S	"	0.8730**	$Y = 0.190\ X + 20.65$
Total S	Org S	0.9757**	$Y = 0.730\ X - 163.9$
KARI SOILS (n = 11)			
EC	pH	-0.6434*	$Y = -0.094\ X + 3.877$
OC	"	-0.6540*	$Y = -0.226\ X + 4.249$
S_1	"	-0.7088*	$Y = -0.004\ X + 4.121$
S_3	"	-0.6021*	$Y = -0.001\ X + 3.828$
S_4	"	-0.6137*	$Y = -0.001\ X + 3.864$
Total S	"	-0.6637*	$Y = -0.0001X + 4.008$
Ex Ca	EC	0.8242**	$Y = 0.566\ X + 0.433$
Ex Na	"	0.7295*	$Y = 1.120\ X + 1.832$
S_1	"	0.6395*	$Y = 0.024\ X + 0.378$

Contd.

Table 8. Continued

1	2	3	4
S_2	EC	0.7945**	$Y = 0.004\,X + 1.826$
S_3	"	0.6793*	$Y = 0.004\,X + 1.614$
S_4	"	0.6830*	$Y = 0.004\,X + 1.378$
SO_4-S	"	0.7945**	$Y = 0.004\,X + 1.826$
Org S	"	0.8518**	$Y = 0.002\,X - 0.457$
Total S	"	0.8614**	$Y = 0.001\,X - 0.430$
Ex Mg	OC	0.8364**	$Y = 0.785\,X + 38.61$
S_1	"	0.8978**	$Y = 0.014\,X + 1.072$
S_3	"	0.6503*	$Y = 0.002\,X + 2.346$
S_4	"	0.6559*	$Y = 0.002\,X + 2.247$
Non SO_4-S	"	0.7725**	$Y = 0.002\,X + 2.209$
Total S	"	0.7078*	$Y = 0.0004\,X + 1.804$
Silt	Sand	-0.6619*	$Y = -0.715\,X + 74.26$
Ex Na	Clay	0.6249*	$Y = 3.217\,X + 10.74$
S_2	"	0.6771*	$Y = 0.012\,X + 10.76$
S_3	"	0.6522*	$Y = 0.013\,X + 9.108$
S_4	"	0.6325*	$Y = 0.012\,X + 8.706$
SO_4-S	"	0.6771*	$Y = 0.012\,X + 10.76$
Non SO_4-S	"	0.7284*	$Y = 0.011\,X + 8.637$
S_2	CEC	0.6374*	$Y = 0.015\,X + 33.08$
S_3	"	0.7633**	$Y = 0.019\,X + 28.37$
S_4	"	0.7438**	$Y = 0.018\,X + 27.70$
SO_4-S	"	0.6374*	$Y = 0.015\,X + 33.08$
Non SO_4-S	"	0.6968*	$Y = 0.014\,X + 30.34$
Ex Na	Ex Ca	0.8202**	$Y = 1.836\,X + 2.818$
S_2	"	0.8186**	$Y = 0.006\,X + 3.176$
S_4	"	0.6754*	$Y = 0.006\,X + 2.690$
Org S	"	0.6303*	$Y = 0.002\,X + 1.846$
Total S	"	0.7233*	$Y = 0.002\,X + 1.158$
S_1	Ex Mg	0.7867**	$Y = 0.013\,X + 1.406$
Total S	"	0.6372*	$Y = 0.0001\,X + 2.045$
S_1	Ex Na	0.7446**	$Y = 0.018\,X - 0.744$

Contd.

Table 8. Continued

1	2	3	4
S_2	Ex Na	0.9244**	Y = 0.003 X + 0.356
S_3	"	0.9010**	Y = 0.003 X - 0.111
S_4	"	0.8892**	Y = 0.003 X - 0.265
Org S	"	0.6976*	Y = 0.001 X - 0.261
Non SO_4-S	"	0.8415**	Y = 0.003 X + 0.192
Total S	"	0.9034**	Y = 0.001 X - 0.985
S_2	S_1	0.7426**	Y = 0.108 X + 106.2
S_3	"	0.7875**	Y = 0.124 X + 83.42
S_4	"	0.7866**	Y = 0.123 X + 76.70
Org S	"	0.8392**	Y = 0.105 X + 83.19
Total S	"	0.8854**	Y = 0.034 X + 37.11
S_4	S_2	0.9572**	Y = 1.030 X -187.3
Org S	"	0.6485*	Y = 0.286 X - 75.66
Non SO_4-S	"	0.8451**	Y = 0.730 X + 2.307
Total S	"	0.8911**	Y = 0.235 X - 321.5
S_4	S_3	0.9979**	Y = 0.987 X - 53.24
Non SO_4-S	"	0.9271**	Y = 0.736 X + 92.55
Total S	"	0.8690**	Y = 0.211 X - 123.4
Non SO_4-S	S_4	0.9270**	Y = 0.744 X + 149.1
Total S	"	0.8567**	Y = 0.210 X - 57.12
Org S	SO_4-S	0.6485*	Y = 0.286 X - 75.66
Total S	"	0.8911**	Y = 0.235 X - 321.5
Total S	Non SO_4-S	0.7919**	Y = 0.242 X - 114.9
POOLED ANALYSIS (n = 39)			
EC	pH	-0.6681**	Y = -0.153 X + 4.278
OC	"	-0.4946**	Y = -0.258 X + 4.617
Clay	"	-0.4771**	Y = -0.123 X + 4.503
CEC	"	-0.3930*	Y = -0.022 X + 4.282
Ex Ca	"	-0.5402**	Y = -0.023 X + 4.543
S_1	"	-0.4011*	Y = -0.065 X + 4.446
S_2	"	-0.6235**	Y = -0.001 X + 4.206

Contd.

Table 8. Continued

1	2	3	4
S_2	pH	-0.6390**	$Y = -0.001 X + 4.208$
S_4	"	-0.6490**	$Y = -0.001 X + 4.320$
SO_4-S	"	-0.6235**	$Y = -0.001 X + 4.206$
Org S	"	-0.6713**	$Y = -0.0003 X + 4.321$
Non SO_4-S	"	-0.4633**	$Y = -0.001 X + 4.109$
Total S	"	-0.6985**	$Y = -0.0002 X + 4.349$
OC	EC	0.4372**	$Y = 0.997 X - 0.241$
CEC	EC	0.5247**	$Y = 0.096 X - 0.208$
Ex Ca	"	0.8066**	$Y = 0.572 X - 0.302$
S_1	"	0.6176**	$Y = 0.017 X - 0.068$
S_2	"	0.8412**	$Y = 0.005 X + 0.684$
S_3	"	0.7600**	$Y = 0.004 X + 0.434$
S_4	"	0.7530**	$Y = 0.004 X + 0.362$
Org S	"	0.8563**	$Y = 0.002 X + 0.147$
Non SO_4-S	"	0.5830**	$Y = 0.003 X + 1.343$
Total S	"	0.8867**	$Y = 0.001 X - 0.009$
CEC	OC	0.6022**	$Y = 0.048 X + 1.440$
S_1	"	0.5621**	$Y = 0.007 X + 1.844$
S_2	"	0.4821**	$Y = 0.001 X + 2.374$
S_3	"	0.5422**	$Y = 0.001 X + 2.178$
S_4	"	0.5375**	$Y = 0.001 X + 2.155$
Org S	"	0.4298**	$Y = 0.0003 X + 2.316$
Non SO_4-S	"	0.6642**	$Y = 0.001 X + 2.226$
Total S	"	0.5790**	$Y = 0.0003X + 2.111$
Sand	Clay	-0.3515*	$Y = -0.204 X + 32.15$
S_2	"	0.4364**	$Y = 0.008 X + 16.58$
S_3	"	0.3469*	$Y = 0.006 X + 16.60$
S_4	"	0.3354*	$Y = 0.006 X + 16.57$
Org S	"	0.4600**	$Y = 0.007 X + 16.58$
Total S	"	0.3187*	$Y = 0.001 X + 16.78$
Silt	CEC	0.4148**	$Y = 0.566 X + 19.23$

Contd.

Table 8. Continued

1	2	3	4
Ex Ca	CEC	0.4925**	Y = 1.913 X + 19.67
S_1	"	0.5140**	Y = 0.079 X + 17.83
S_2	"	0.5834**	Y = 0.018 X + 22.09
S_3	"	0.7011**	Y = 0.022 X + 18.42
S_4	"	0.6826**	Y = 0.019 X + 18.25
SO_4-S	"	0.5834**	Y = 0.018 X + 22.10
Org S	"	0.5055**	Y = 0.006 X + 21.45
Non SO_4-S	"	0.6841**	Y = 0.018 X + 21.28
Total S	"	0.6407**	Y = 0.004 X + 19.09
Ex Na	Ex Ca	0.3178*	Y = 0.217 X + 4.384
S_1	"	0.4479**	Y = 0.018 X + 2.491
S_2	"	0.8027**	Y = 0.006 X + 2.499
S_3	"	0.6898**	Y = 0.005 X + 2.306
S_4	"	0.6754**	Y = 0.005 X + 2.247
SO_4-S	"	0.8027**	Y = 0.006 X + 2.499
Org S	"	0.6847**	Y = 0.002 X + 2.314
Non SO_4-S	"	0.5500**	Y = 0.004 X + 3.407
Total S	"	0.7524**	Y = 0.001 X + 1.968
S_1	Ex Mg	0.3833*	Y = 0.008 X + 2.778
S_3	"	0.3386*	Y = 0.001 X + 3.251
Ex Na	S_1	0.3366*	Y = 5.804 X + 127.6
S_2	"	0.6771**	Y = 0.136 X + 91.28
S_3	"	0.7348**	Y = 0.147 X + 71.59
S_4	"	0.7456**	Y = 0.138 X + 67.24
SO_4-S	"	0.6771**	Y = 0.136 X + 91.28
Org S	S_1	0.6174**	Y = 0.044 X + 83.25
Non SO_4-S	"	0.5526**	Y = 0.094 X + 103.8
Total S	"	0.6899**	Y = 0.031 X + 74.18
S_3	S_2	0.9395**	Y = 0.929 X - 69.29
S_4	"	0.9277**	Y = 0.856 X - 84.95
Org S	"	0.7319**	Y = 0.258 X + 32.62
Non SO_4-S	"	0.7330**	Y = 0.623 X + 123.6

Contd.

Table 8. Continued

1	2	3	4
Total S	S_2	0.8771**	$Y = 0.197X - 51.73$
Ex Na	S_3	0.3387*	$Y = 29.281X + 415.6$
S_4	"	0.9909**	$Y = 0.922X - 17.04$
Org S	"	0.6476**	$Y = 0.231X + 178.5$
Non SO_4-S	"	0.7533**	$Y = 0.646X + 219.0$
Total S	"	0.8164**	$Y = 0.184X + 82.06$
Ex Mg	S_4	0.3627*	$Y = 89.43X + 214.2$
Org S	"	0.6532**	$Y = 0.250X + 212.2$
Non SO_4-S	"	0.7077**	$Y = 0.652X + 277.8$
Total S	"	0.8062**	$Y = 0.196X + 117.4$
Org S	SO_4-S	0.7319**	$Y = 0.258X + 32.62$
Non SO_4-S	"	0.7330**	$Y = 0.623X + 123.6$
Total S	"	0.8771**	$Y = 0.197X - 51.73$
Non SO_4-S	Org S	0.5307**	$Y = 1.278X + 864.1$
Total S	"	0.9391**	$Y = 0.596X + 56.06$
Total S	Non SO_4-S	0.7653**	$Y = 0.202X - 17.05$

** Significant at 1 per cent level of significance
* Significant at 5 per cent level of significance

Av P - Available P
Av K - Available K

Ex Ca - Exchangeable plus water soluble Ca
Ex Mg - ,, Mg
Ex Na - ,, Na

Oc - Organic carbon
Org S - Organic sulphur

S_1 - Available S extracted by water
S_2 - ,, by $CaCl_2$
S_3 - ,, by KH_2PO_4
S_4 - ,, by Morgan's reagent

for karappadam and kayal soils were 1026.5 and 2008.6 ppm, respectively. The highest amount of total S was recorded by the kari soil of Vechoor (K 143). It should be pointed out that this soil, which contained the highest amount of total S also recorded the highest values for organic carbon, CEC and clay. Comparing with the content of total S reported for other Indian soils (Hegde <u>et al</u>., 1980) the acid saline soils of Kuttanad can be considered to be very rich in total S. This is in conformity with the observations made by Jacob (1966), Leela (1967), Varghese (1973), Ghosh <u>et al</u>. (1976) and Hegde <u>et al</u>. (1980) who also reported high accumulation of S in the Kuttanad soils of Kerala.

The content of total S in soil established positive correlations with organic carbon (r = 0.5790**), EC (r = 0.8867**), CEC (r = 0.6407**) and clay (r = 0.3187*). Fig. 1 shows the relationship between total S and EC. Total S was negatively correlated with pH (r = -0.6985**). This relationship has been shown in Fig. 2. The significant positive relationships of total S with available S extracted by different extractants i.e., water, $CaCl_2$, KH_2PO_4 and Morgan's reagent are given in Fig. 3, 4, 5 and 6 respectively. The

Fig. 1 Relationship between total S and EC

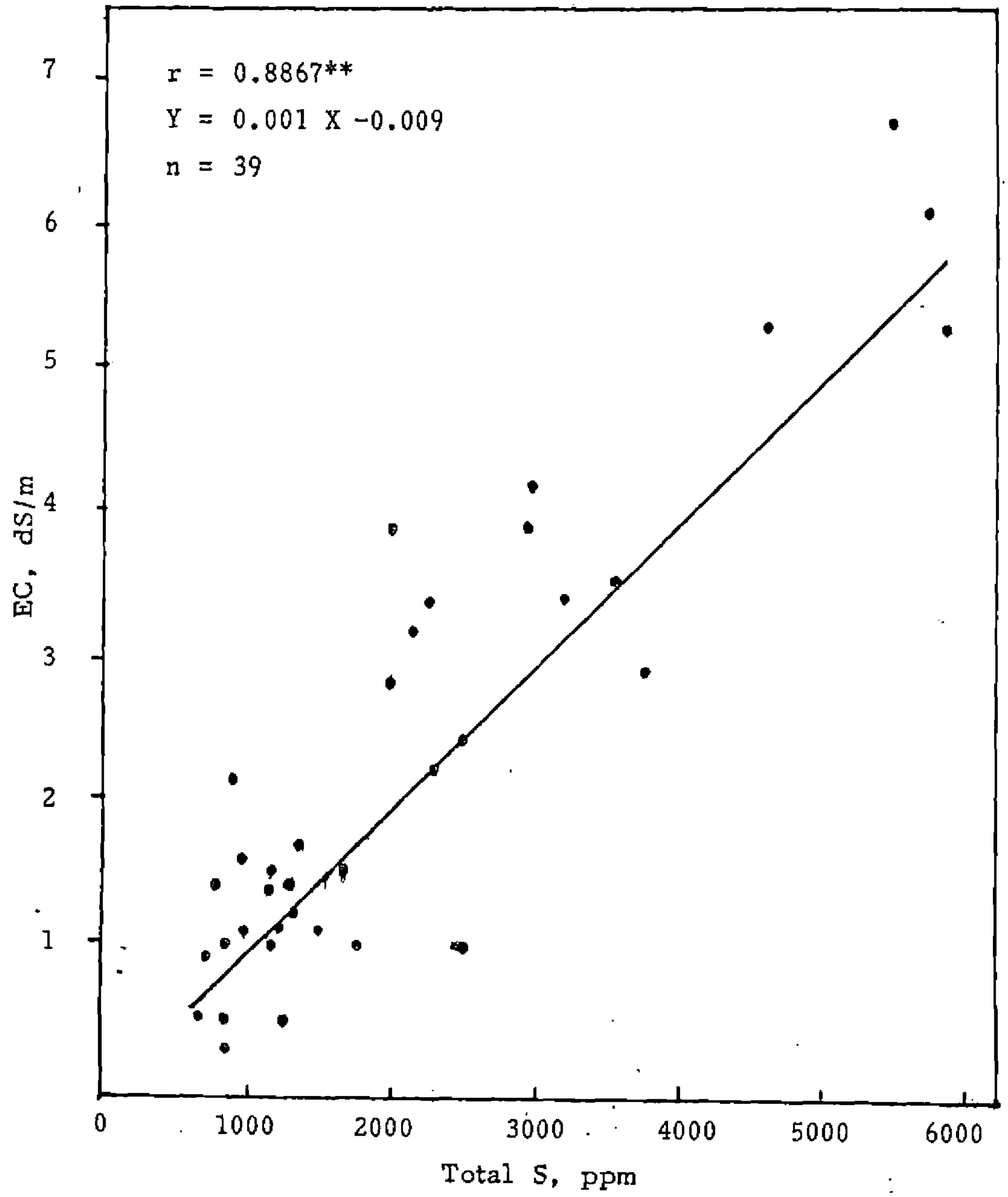


Fig. 2 Relationship between total S and pH

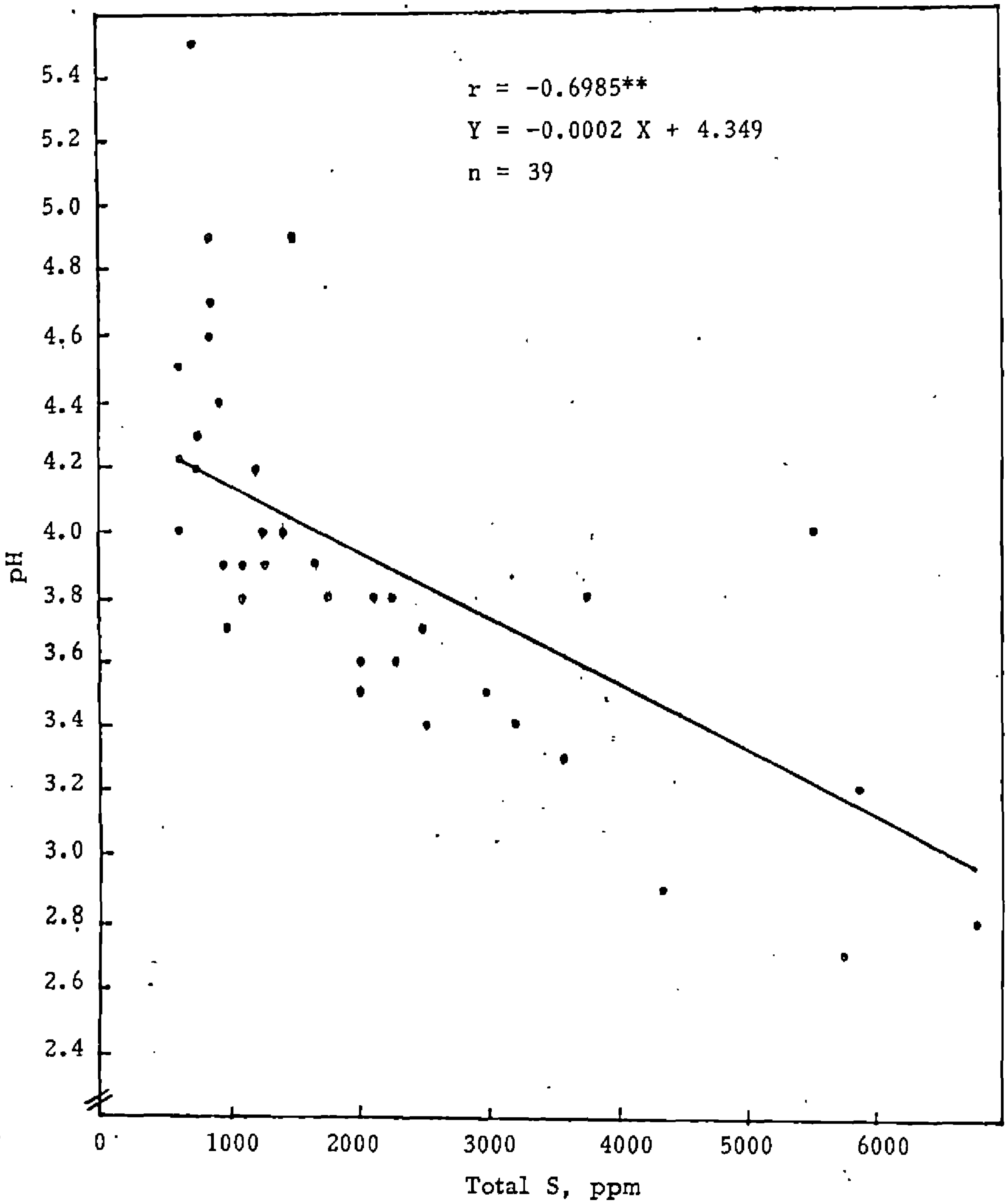


Fig. 3 Relationship between total S and water soluble S

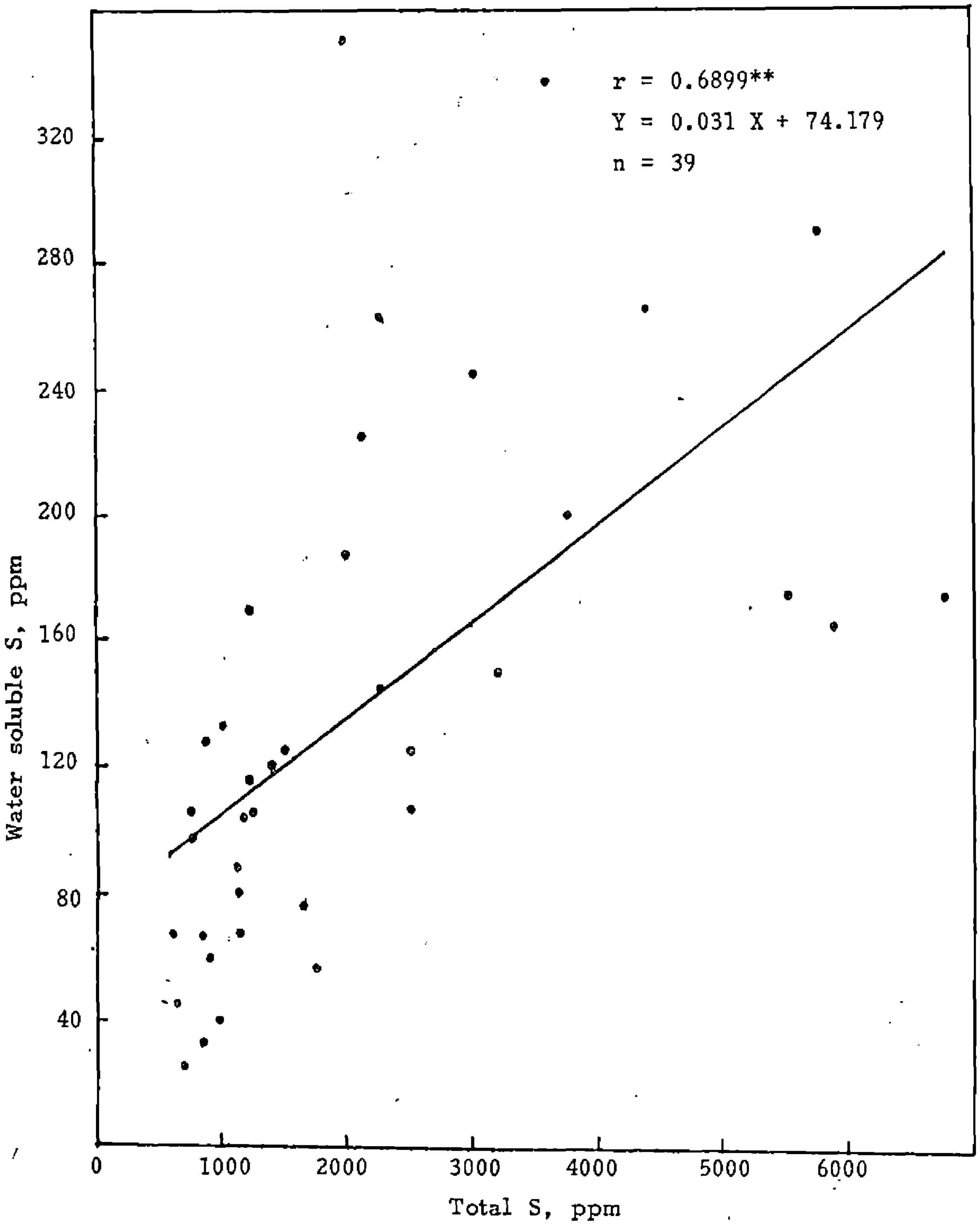


Fig. 4 Relationship between total S and SO_4-S

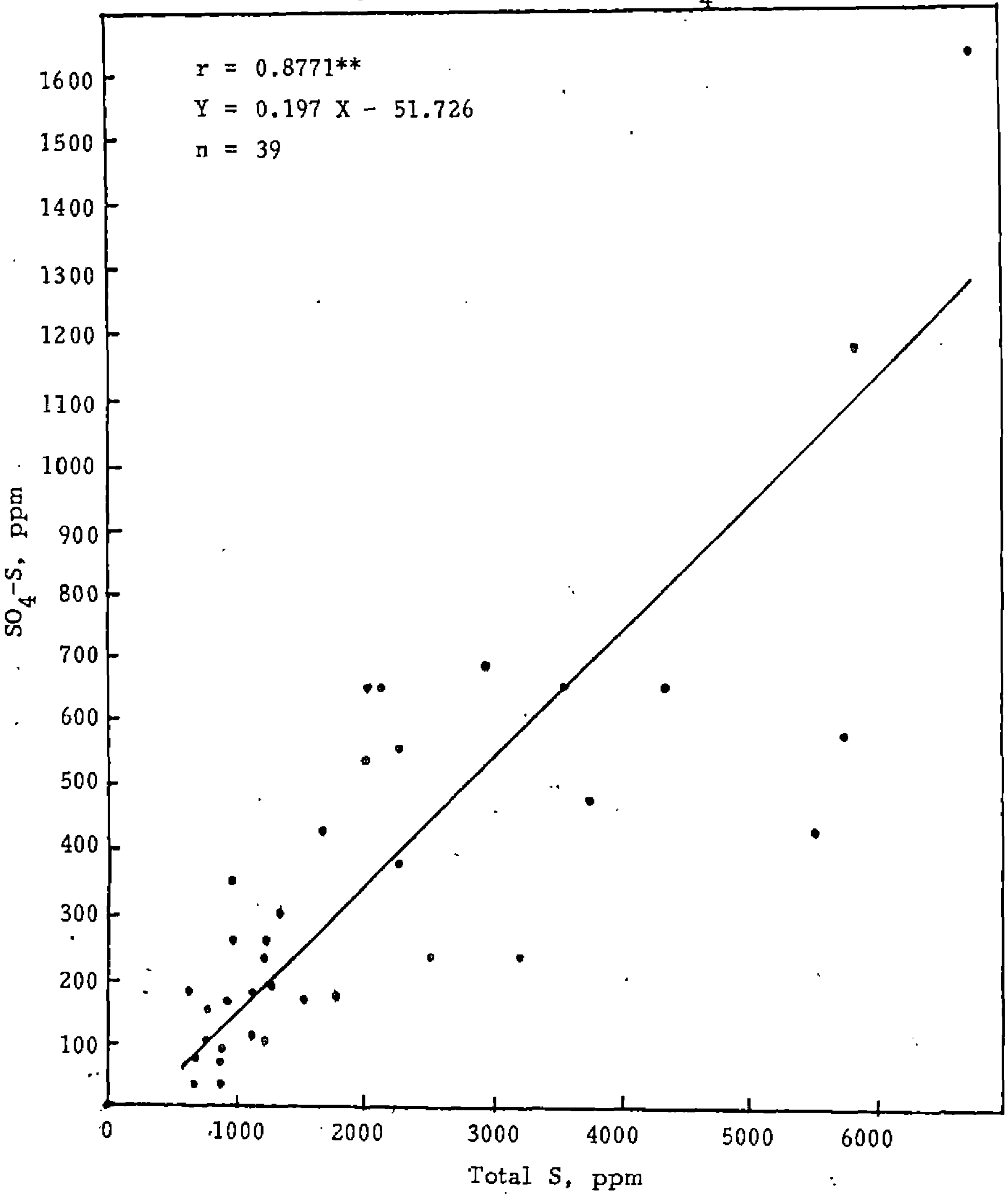


Fig. 5 Relationship between total S and phosphate extractable S

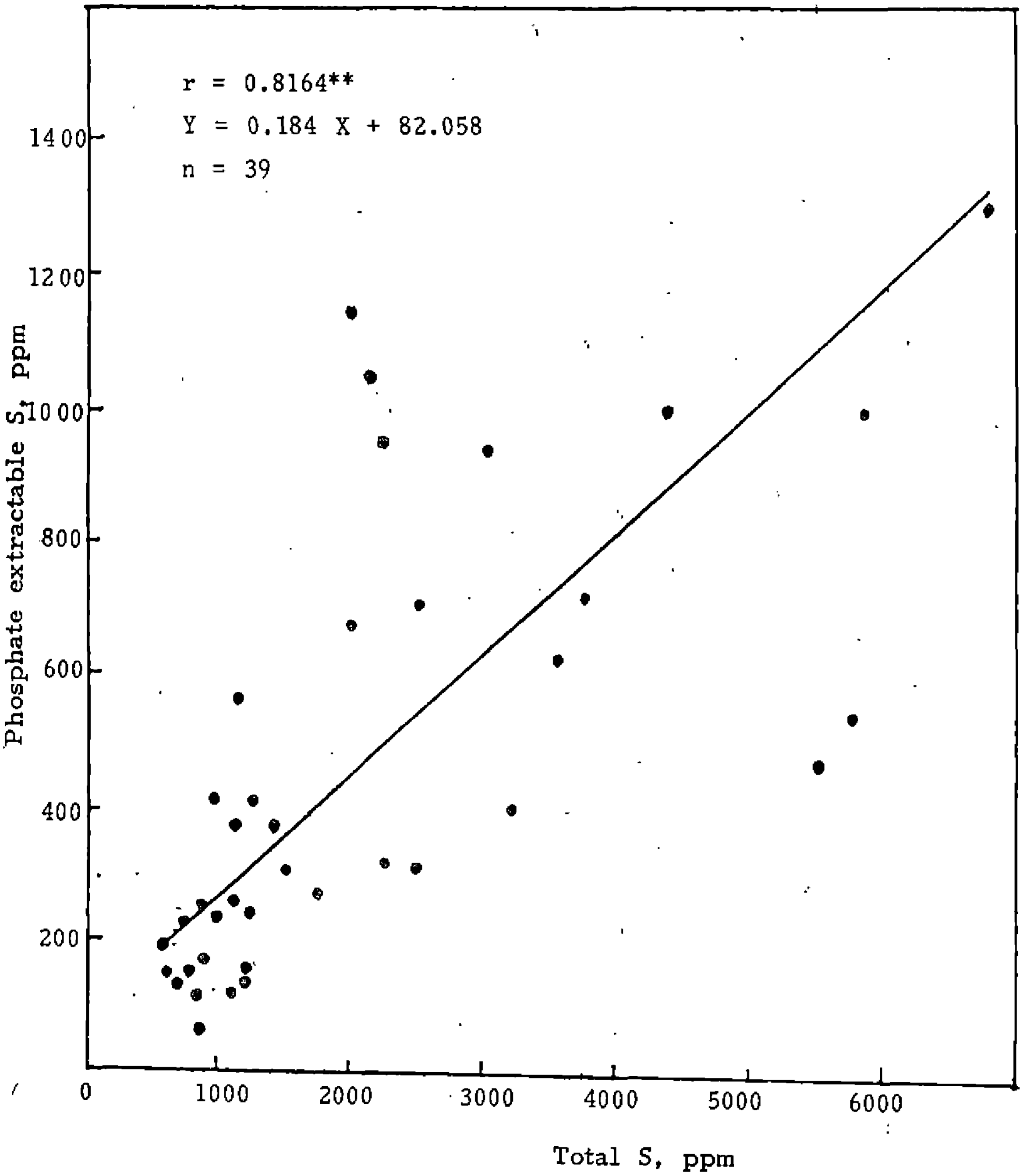
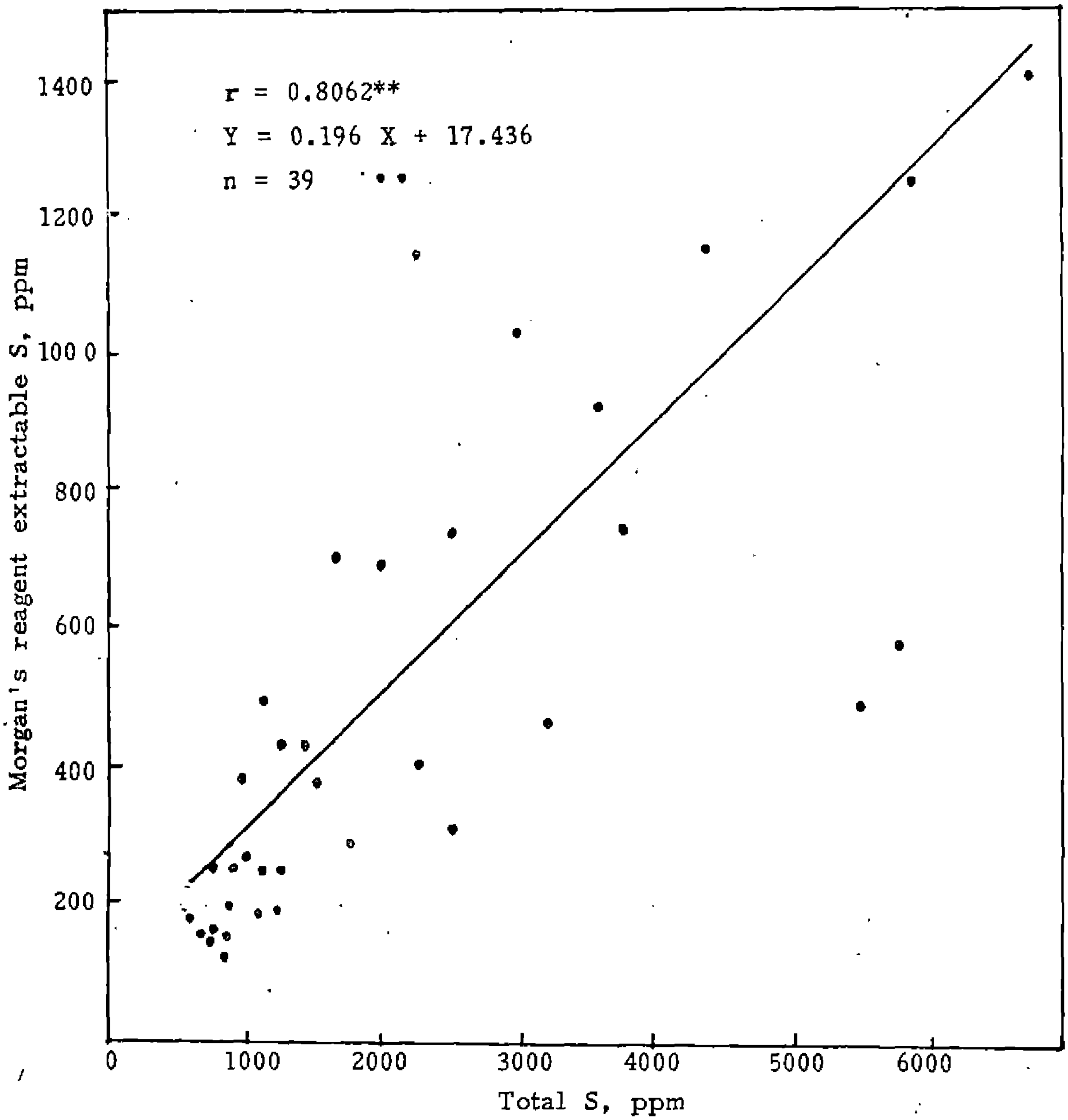


Fig. 6 Relationship between total S and Morgan's reagent extractable S



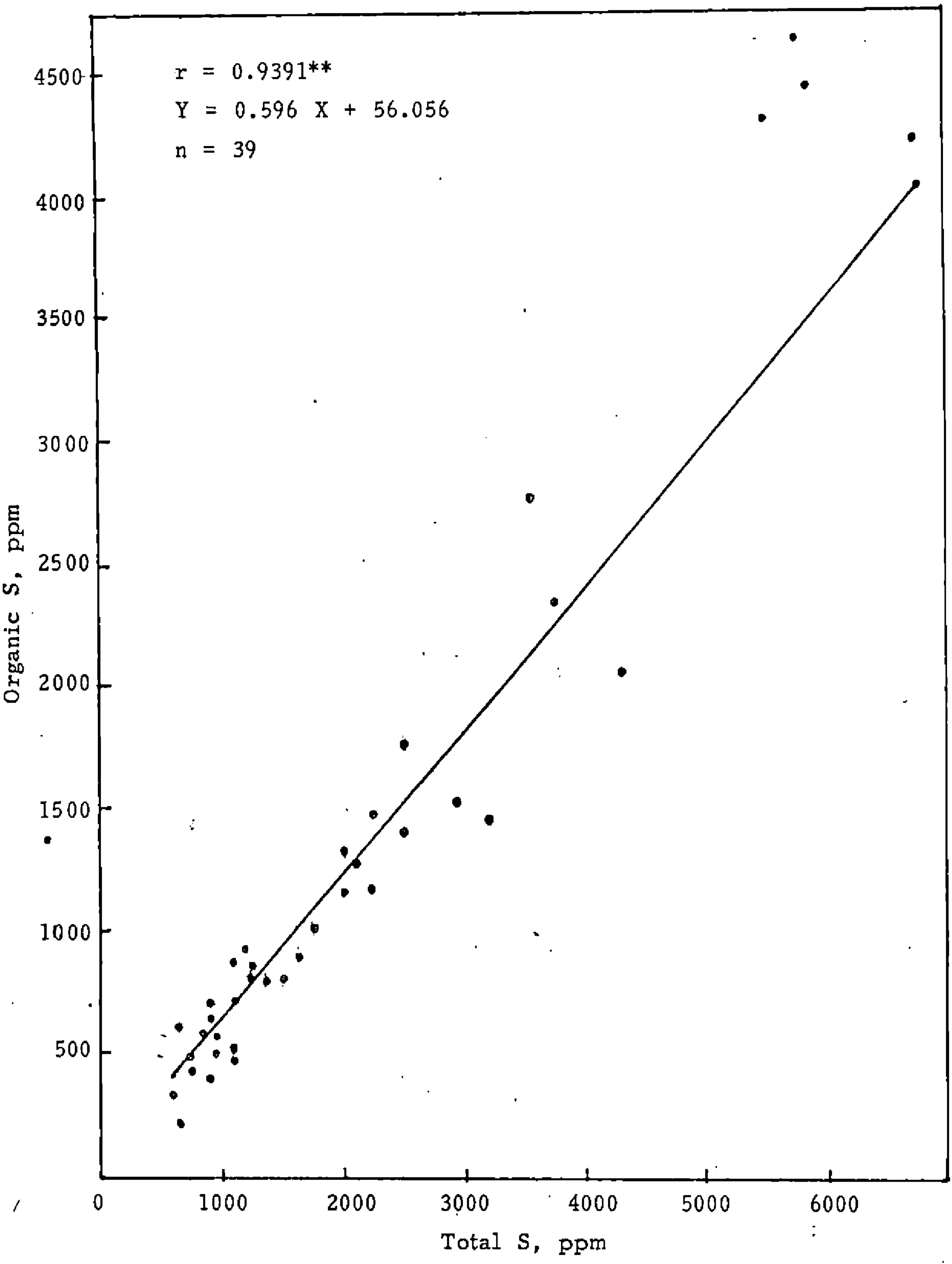
relationship between total S and organic S was positive and highly significant, the r value being 0.9391**. Fig. 7 shows the relationship between total S and organic S. Accumulation of organic matter with consequent decrease in pH, increase in EC and CEC explains the relationship of total S with pH, EC, organic carbon and CEC. The significant positive relationships of total S with available S extracted by different extractants and the forms of S are expected since the available S and forms of S contributed to the total content of S in soils.

The relatively high content of total S in the Kuttanad soils of Kerala rules out the possible need of S containing fertilizers in this region of the state which is a major rice growing tract. It is possible that the crops may have to confront with the complexities resulting out of the accumulation of reduced S compounds under highly anaerobic conditions and the formation of H_2SO_4 when the soil is oxidised, rather than a dificiency of this nutrient element.

4.2. Organic S

On an average, the soils contained 1441.6 ppm of organic S. Soils exhibited considerable variation

Fig. 7 Relationship between total S and organic S



in the content of organic S in them, the range of variation being 225 to 4613 ppm. The highest amount of organic S was seen in kari soils, the mean value being 2446.6 ppm. The kari soil of Ambalapuzha (K 124) recorded the maximum content of organic S (4613 ppm). The high content of organic S in the acid saline soils of Kuttanad had already been reported by different workers (Jacob, 1966; Leela, 1967; Varghese, 1973; Ghosh et al., 1976). When the relative contribution of organic S to the total S content of the soil was expressed as percentage, it was seen that on an average, organic S accounted for 62 per cent of the total S, the range being 34.6 to 87.5 per cent. Kanwar and Takkar (1964) reported that tea soils of Himachal Pradesh had 45 ppm organic S which constituted 72 per cent of the total S. In hill and alluvial soils of West Bengal, organic S contributed 89-98 per cent of the total S (Mukhopadhyay and Mokhopadhyay, 1980). The high contribution of organic S to total S is often attributed to the loss of inorganic S consequent to leaching in humid tropical soils. The acid saline soils of Kuttanad is subjected to periodic inundation by salt water or brackish water and hence, the relatively low percentage of organic S to the total S may be presumably due to the accumulation of inorganic forms of S from sea water.

The organic S was positively correlated with EC ($r = 0.8563^{**}$), organic carbon (0.4298^{**}), CEC ($r = 0.5055^{**}$) and clay content ($r = 0.4600^{**}$) of the soil and negatively correlated with the soil pH ($r = -0.6713^{**}$). Fig. 8 shows the relationship between organic S and EC and Fig. 9 shows the negative relationship between organic S and pH. The positive significant relationship between organic S and organic carbon showed the influence of organic matter in contributing towards the organic S content of the soil. Organic S was also positively correlated with available S extracted by different extractants and other forms of S. This reveals that the organic S plays a decisive role in the total available S pool of the soil.

An examination of carbon : organic S ratio of the soil revealed that, on an average, the soils gave a value of 19.83. The variation between the soil types was very pronounced, the ratio for the karappadam, kayal and kari soils being 43.86, 20.11 and 14.36 respectively.

Fig. 8 Relationship between organic S and EC

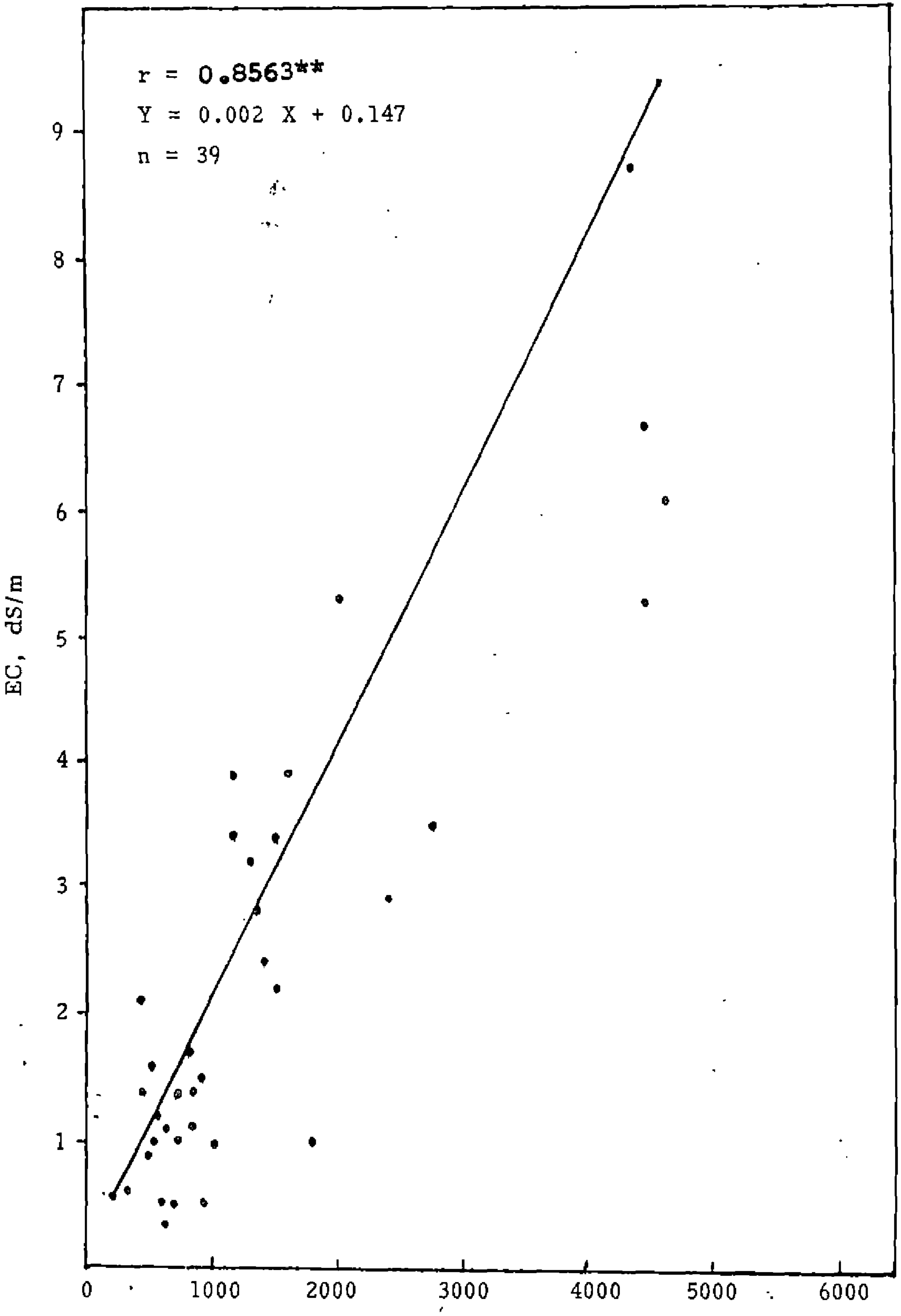
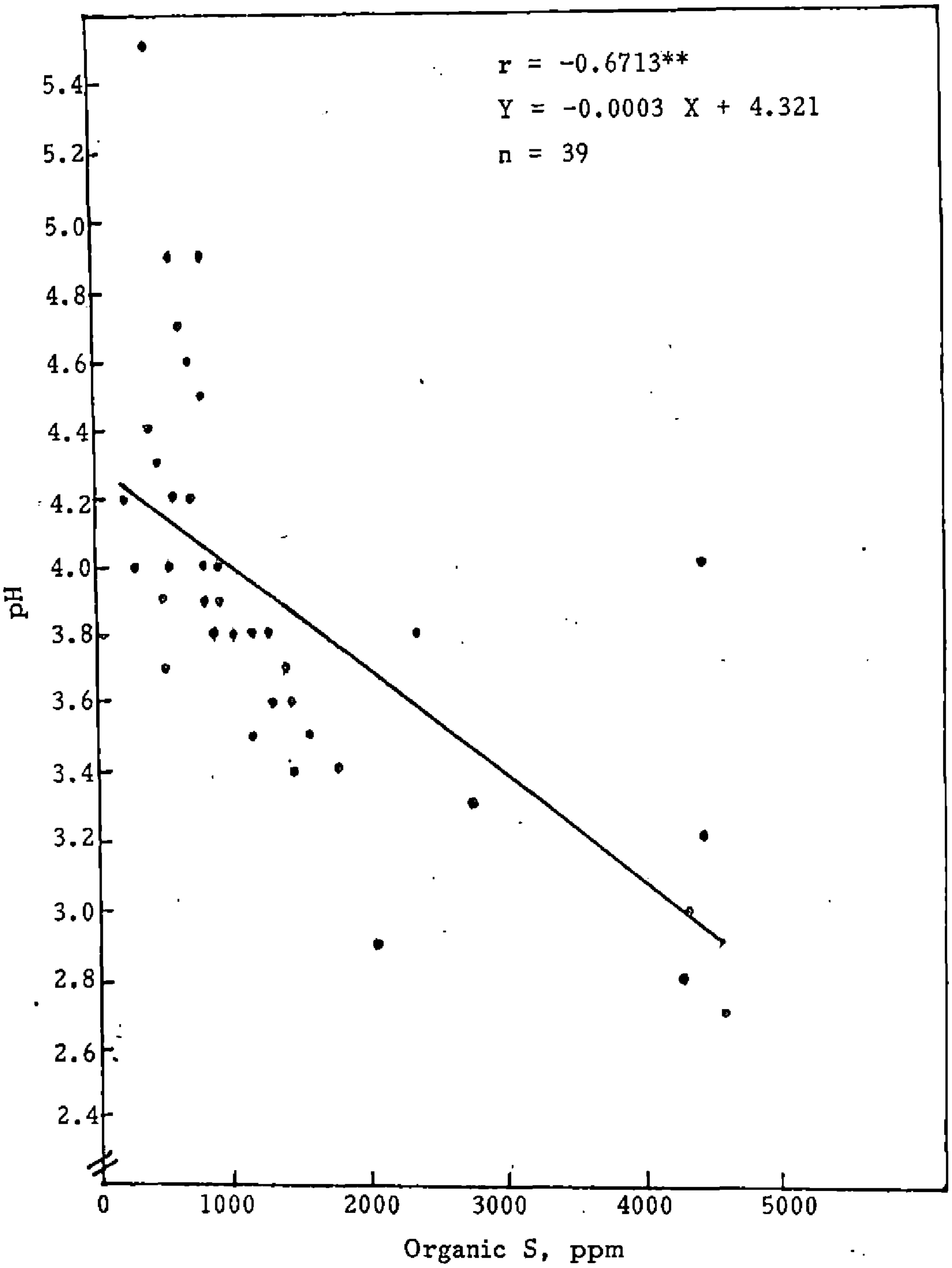


Fig. 9 Relationship between organic S and pH



Though the Kuttanad soils in general, can be considered as submerged soils, the degree of submergence is comparatively low in the karappadam soils, compared to prolonged submergence existed in kayal and kari lands. Under highly anaerobic conditions, mineralisation of S containing compounds in the soil organic matter is curtailed due to the nonavailability of electron acceptors in the respiratory chain of the microorganisms. This causes preferential retention of S containing compounds in soil organic matter thereby reducing the C : S ratio considerably. This would explain the relatively wider C : S ratio observed in karappadam soils and very narrow C : S ratio observed in kayal and kari soils.

4.3. Sulphate sulphur

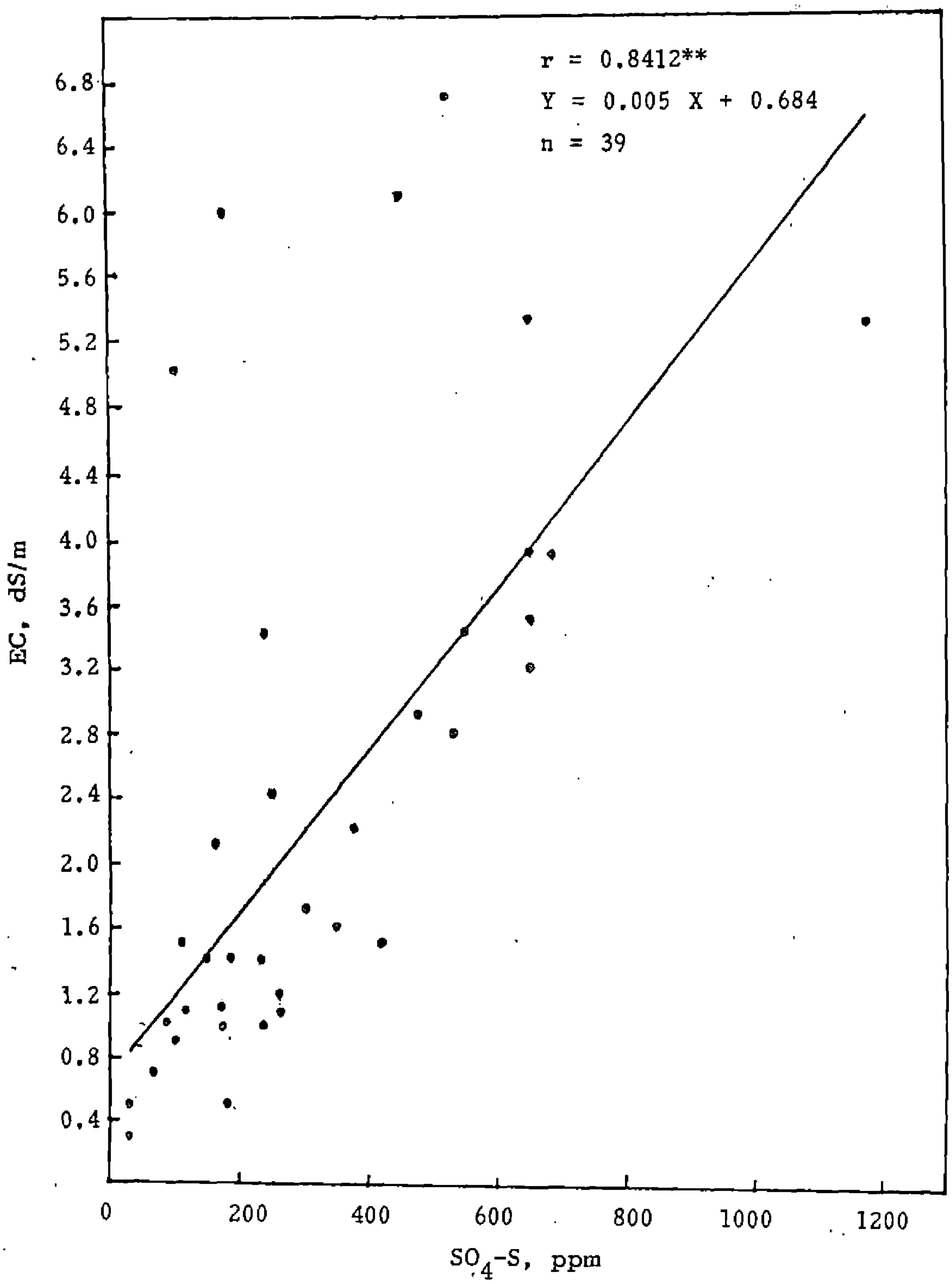
The content of SO_4-S showed very high variation ranging from 37 to 2400 ppm with a mean value of 405.1 ppm when all the soils were considered. As in the case of organic S, the SO_4-S also was high in kari soils. The mean values for the karappadam, kayal and kari soils being 170.2, 401.8 and 624.0 ppm respectively. The SO_4-S accounted for 17.4 per cent of the total S in the soil. The high content of SO_4-S in kari soil may be either due to the high content of total S or the relatively high content of organic matter which gradually released SO_4-S on mineralisation. Moreover, most of the kari soils are saline in nature as a result of which the soil may contain inorganic sulphate under the influence of sea water. The reported mean values of SO_4-S for the soils from Madhya Pradesh, Rajasthan, Himachal Pradesh, Uttar Pradesh, Punjab, Andhra Pradesh and wet temperate zone, Himachal Pradesh were 9, 9, 14, 11, 17, 38 and 13 ppm S, respectively (Bansal et al., 1979; Rawat and Sriniwas, 1979; Palaskar and Ghosh, 1982; Tiwari et al., 1983a; Ghai et al., 1984; Reddy et al., 1985; Sharma et al., 1988). In comparison with the above soils, the content of SO_4-S in Kuttanad soil is relatively high obviously due to the acid saline nature of the soil with the accumulation of organic matter under anaerobic conditions. The Kuttanad soil is, therefore, quite appropriately called as "acid sulphate soils".

The sulphate extracted by $CaCl_2$ solution includes the water soluble SO_4-S and adsorbed sulphates. The water soluble S in soil has been separately estimated.

Since the water soluble S is almost entirely contributed by the SO_4-S the difference between SO_4-S and water soluble S will approximately represent the adsorbed SO_4-S in the soil. It was seen that the water soluble S, on an average, accounted for 36.2 per cent of the total SO_4-S. Such a large proportion of water soluble sulphate is due to the acid saline nature of the soil.

Plants absorb S mainly in the form of sulphate ions and therefore, the content of SO_4-S in the soil is of prime importance as far as the availability of this plant nutrient is concerned. It also constitutes major part of the available S extracted by various chemical agents. Since SO_4 ions are adsorbed by the clay and organic colloids, the content of SO_4-S was relatively high in soil containing high amounts of clay and organic matter. As the acidity was found associated with increasing salinity and higher content of organic matter, the SO_4 level of the soil increased with increase in acidity. As a result, SO_4-S established positive correlations with EC ($r = 0.8412^{**}$), organic carbon ($r = 0.4821^{**}$), clay ($r = 0.4364^{**}$) and CEC ($r = 0.5834^{**}$). Fig. 10 shows the relationship between SO_4-S and EC.

Fig. 10 Relationship between SO_4-S and EC

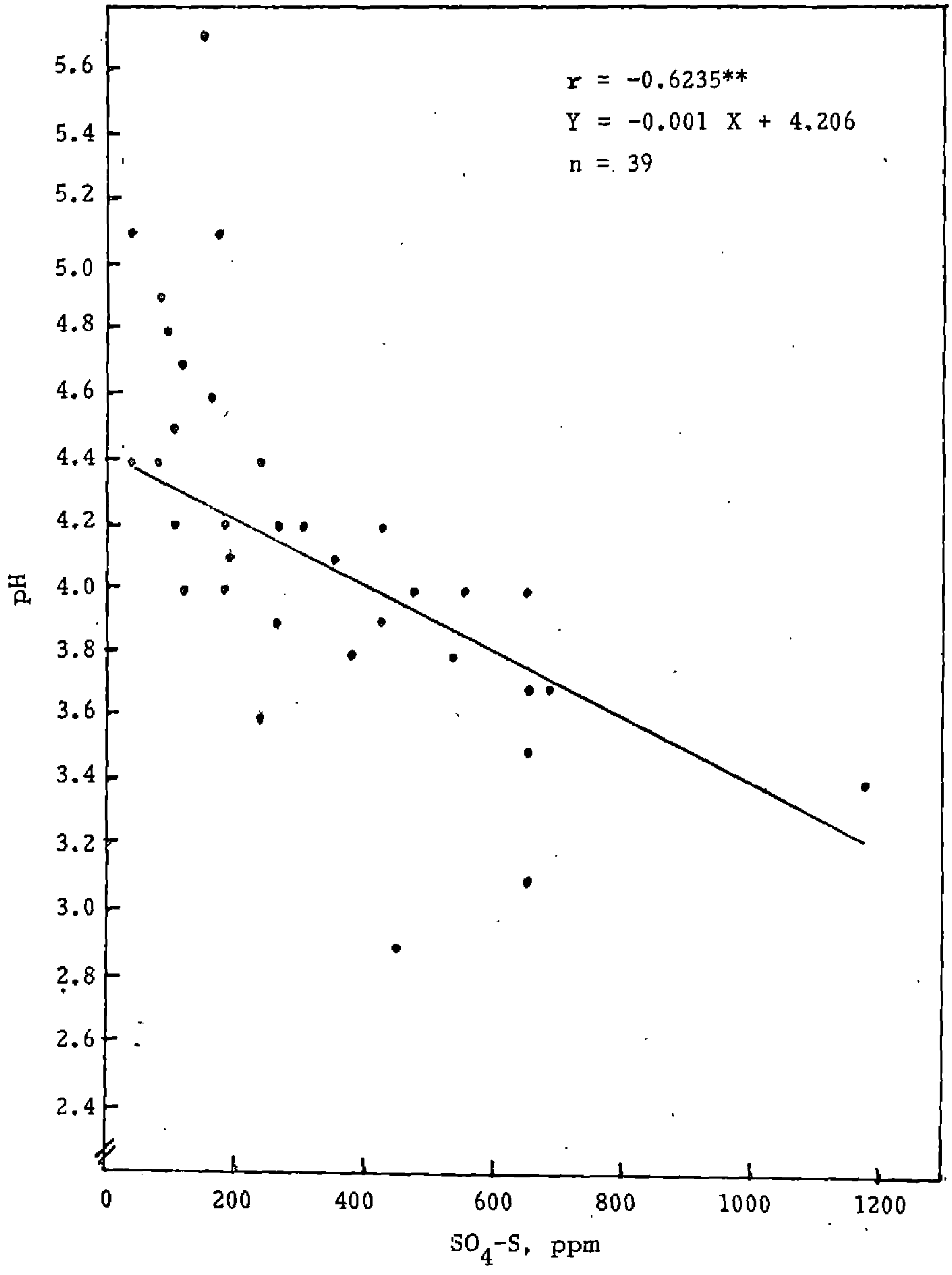


The negative relationship between pH and SO_4-S is shown in Fig. 11. Sulphate S established significant positive correlation with available S extracted by water ($r = 0.6771^{**}$), phosphate solution ($r = 0.9395^{**}$) and Morgan's reagent ($r = 0.9277^{**}$). It was also correlated with other forms of S.

4.4. Non-sulphate sulphur

The non-sulphate S refers to the form of S that may remain unextractable after the removal of organic S (H_2O_2 extractable) and sulphate S ($CaCl_2$ extractable). It is mainly made up of insoluble S compounds of Ba, Ca etc. occluded in and adsorbed on carbonates of the soils (Evans and Rost, 1945). Ghosh et al. (1976) observed that a minor part of the inorganic S in soil may remain as sulphide, sulphite, thiosulphate, elemental S etc. However, no attempt has been made in this study to find out the composition of non-sulphate S contained in the soil. Data presented in Table 6 revealed that the content of non-sulphate S varied from 48 to 3133 ppm with a mean value of 477.4 ppm. The mean values for karappadam, kayal and kari soils were 270.1, 304.1 and 949.4 ppm, respectively. Kari soils registered

Fig. 11 Relationship between SO_4-S and pH



relatively higher values for non-sulphate S probably because of the high content of total S in these soils. The content of non-sulphate S, on an average, accounted for 20.5 per cent of the total S in the soil. Kanwar and Takkar (1964) reported a value of 45 ppm nonsulphate S which accounted for 24 per cent of the total S in the hill soils of Himachal Pradesh.

Since the Kuttanad soils remain under submergence for major part of the year, it is likely that a good portion of the S remains as highly reduced sulphides, especially iron sulphide. Nair and Iyer (1948) reported that Kuttanad soil contained iron sulphide similar to marcasite which on exposure produced sulphuric acid and ferrous sulphate. It is quite possible that the oxidation of sulphides on drying, may not be complete and the sulphides that persist in air dry soil will be accounted under the nonsulphate S in the fractionation procedure. This would explain the relatively higher proportion of nonsulphate S observed in the soils under study. As in the case of other forms of S, nonsulphate S established significant positive correlation with organic carbon (0.6642**), CEC (r = 0.6841**), EC (0.5830**) and negative correlation with pH (r = -0.4633**). It was also positively correlated with available S extracted by different methods and other forms of S. Such relationships have already been described in the case of total and available S. The nonsulphate S increased with the total and other forms of S and hence, the above correlations are only the reflection of the inter-relationships among nonsulphate S, total S and different forms of S in the soil.

The foregoing discussions revealed that the acid saline soils of Kuttanad contained large amount of water soluble, available and total S. Their content has not been considerably reduced due to the soil and environmental changes that took place in the region during the last one or two decades. Recently it has been opined whether the application of S fertilizers may become essential due to the enhanced rate of oxidation of S contained in the soils of Kuttanad subsequent to the construction of Thaneermukkom bund and the ecological changes associated with it. The present study tends to suggest that the soils of Kuttanad still enjoy a good supply of available S form its native reserve of total S and addition of sulphur sources may not be a necessity in the near future.

Summary

SUMMARY

An investigation was carried out to study the forms and availability of S in the acid saline soils of Kuttanad and to understand whether the application of S containing fertilizers is necessary in this region which is the major rice growing tract of the state. Surface soil samples (0-15 cm) were collected during summer. They consisted of 48 karappadam soils, 62 kayal soils and 41 kari soils. The available S in these soils was determined by employing four different extractants, i.e., water, $CaCl_2$ solution, KH_2PO_4 solution and Morgan's reagent. The fractionation of S was carried out in 39 soils selected from the karappadam, kayal and kari soils. The fractions estimated were total S, organic S, sulphate S and nonsulphate S.

All the soils were acidic in nature, the pH ranging from 2.7 to 5.6. The kari soils were extremely acidic with a mean pH value of 3.49. The electrical conductivity of the soils ranged from 0.3 to 13.0 dS/m. Most of the kari soils were saline in nature. The electrical conductivity of the soil increased with decrease in pH ($r = -0.5975^{**}$).

The organic carbon content of the soil varied from 1.23 to 6.72 per cent, with a mean value of 2.97 per cent. Kari soils retained relatively high amounts of organic matter with a mean value of 6.71 per cent. Increase in organic carbon content of the soil increased EC and soil acidity. In general, the Kuttanad soils were low in available P, values ranging from 1.2 to 10.3 ppm. Available P was positively correlated with pH and negatively correlated with EC and organic carbon. On an average, the content of available K in soil was low, the values ranging from 8 to 725 ppm. It was positively correlated with the organic carbon content in karappadam and kayal soils but not in kari soils.

In general, soils of Kuttanad contained large amount of water soluble S, the mean value being 126.6 ppm. Nearly 6.3 per cent of the total S was in water soluble form. Maximum content of water soluble S was found in kari soils. Water soluble S was negatively correlated with pH and positively correlated with EC and organic carbon. It was also significantly correlated with available S extracted by other agents.

Available S extracted by $CaCl_2$ ranged from 37 - 2400 ppm, the highest values being recorded by kari soils. The content of $CaCl_2$ extractable S decreased with increasing pH and increased with increasing EC and organic carbon. It was also significantly correlated with available S extracted by other extractants.

The values of available S extracted by 500 ppm P as KH_2PO_4 ranged from 50 - 2450 ppm with a mean value of 387.5 ppm. As in the case of $CaCl_2$ extractable S, phosphate extractable S was negatively correlated with pH and positively with EC, organic carbon and available S extracted by other agents.

The values of available S extracted by Morgan's reagent ranged from 69 - 2500 ppm. The mean values for karappadam, kayal and kari soils were 208.3, 481.7 and 571.6 ppm respectively. The magnitude of available S extracted by Morgan's reagent was almost similar to that extracted by the phosphate solution. Available S extracted by Morgan's reagent established significant negative correlation with pH and positive correlations with EC, organic carbon, available K and available S extracted by other agents.

Most of the soils selected for S fractionation study were loam and the CEC ranged from 10.0 - 78.8 me/100g soil. In general, kari soil possessed relatively high CEC. The CEC increased with the increasing content of clay and organic carbon.

The study revealed that soils of Kuttanad contained large amount of total S, values ranging from 600 - 9900 ppm with a mean of 2324.1 ppm. The highest amount of total S was observed in kari soils. Content of total S established significant negative correlation with pH and positive correlation with organic carbon, EC, CEC, clay, available S extracted by different agents and other forms of S in soil.

On an average, soils contained 1441.6 ppm of organic S. The highest amount of organic S (4613 ppm) was recorded in kari soils. In general, organic S accounted for 62 per cent of total S. This fraction of S was negatively correlated with pH and positively with EC, organic carbon, CEC, clay, available S extracted by different agents and other forms of S.

The carbon : organic S ratio of the soil recorded a mean value of 19.38. The variation between the soil types was very pronounced, the ratio for the kari, kayal and karappadam soils being 14.36, 20.11 and 43.86 respectively.

The content of SO_4-S showed very high variation ranging from 37 to 2400 ppm. The maximum content was observed in kari soil. In general, SO_4-S accounted for 17.4 per cent of the total S. On an average, 36.2 per cent of the total sulphate S was extracted by water as available S. Sulphate S registered significant negative correlations with pH and positive correlations with EC, organic carbon, clay, CEC, available S extracted by different agents and other forms of S.

The content of non-sulphate S varied from 48 to 3133 ppm, maximum values being registered by kari soils. Nonsulphate S accounted for 20.5 per cent of the total S. As in the case of other forms of S, it established significant negative correlation with pH and positive correlations with EC, CEC, organic carbon, available sulphur and other forms of S.

The study revealed that the contents of total and available S in the acid saline soils of Kuttanad are so high that these soils are not likely to run deficient in S in the near future.

References

REFERENCES

Acquaye, D.K. and Kang, B.T. 1987. Sulphur status and forms in some surface soils of Ghana. Soil Sci. 144:43-51.

Ahmed, S. and Jha, K.K. 1969. Sulphur status of Bihar soils. J. Indian Soc. Soil Sci. 17:197-202.

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(1):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(1): 15-19.

Alexander, M. 1961. Soil Microbiology. Wiley Eastern Ltd. New Delhi, p.3-15.

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(1):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(1):44-49.

Ankineedu, G., Rao, J.V. and Reddy, B.N. 1983. Advances in fertiliser management for rainfed oil seeds. Fert. News. 28(9):76-90.

Arora, B.R., Ghai, V.K. and Hundal, H.S. 1988. Distribution of S in benchmark soils of Punjab. J. Indian Soc. Soil Sci. 36:367.

Arora, B.R. and Sekhon, G.S. 1977. Evaluation of soil tests for the estimation of available S. J. agric. Sci. Camb. 88:203-206.

Arora, C.I. and Takkar, P.N. 1985. Paper presented at the 50th convention of Indian Society of Soil Science held at Gujarat Agric. Univ., Anand. Quoted by Takkar, P.N. 1988. TSI-FAI Symposium on S in Indian Agriculture. The sulphur Institute, USA and the Fertiliser Association of India, New Delhi.

Arora, C.I. and Takkar, P.N. 1988. Influence of soil characteristics on the forms and availability of sulphur in some Entisols and Inceptisols. J. Indian Soc. Soil Sci. 36:496-499.

Aulakh, M.S. and Dev, G. 1976. Profile distribution of sulphur in some soil series of Sangrur district, Punjab. J. Indian Soc. Soil Sci. 24:308-313.

Balasubramanian, A.S. and Kothandaraman, G.V. 1985. Different forms of sulphur in major soil series of Coimbatore district. Proc. National Seminar on Sulphur in Agriculture. Tamil Nadu Agricultural University and FACT, Udyogamandal. p.95-99.

Balasubramanian, A.S., Kothandaraman, G.V. and Krishnamoorthy, K.K. 1978. Effect of S application on the yield and quality of onion. Agric. Res. J. Kerala. 17(1):138-140.

Bansal, K.N., Sharma, D.N. and Singh, D. 1979. Evaluation of some soil test methods for measuring available sulphur in alluvial soils of Madhya Pradesh. J. Indian Soc. Soil Sci. 27:308-313.

Bhan, C. and Tripathi, B.R. 1973. The forms and contents of sulphur in some soils of Uttar Pradesh. J. Indian Soc. Soil Sci. 21:499-504.

Bharadwaj, S.P. and Pathak, A.N. 1969. Fractionation of sulphur in soils of Uttar Pradesh and its relation to phosphorus. J. Indian Soc. Soil Sci. 17:285-289.

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.

Bramyan, S.A.A. and Galstyan, A.S.H. 1986. Regulation of activity of sulphur metabolic enzymes in soil. Soviet Soil Sci. 18(6):28-37.

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

Cheema, H.S. and Arora, C.I. 1984. Sulphur status of soils, tube well waters and plants in some areas of Ludhiana under groundnut-wheat cropping system. Fert. News. **29**(3):28-31.

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

Dolui, A.K. and Nayek, A.K. 1981. Distribution of different forms of S in some red and lateritic soil profiles of West Bengal. Indian Agric. **25**: 185-189.

Ensminger, L.E. 1954. Some factors affecting the adsorption of sulphate by Alabama soils. Proc. Soil Sci. Soc. Am. **18**:259-264.

Evans, C.A. and Rost, C.O. 1945. Total organic sulphur and humus sulphur in Minnesota soils. Soil Sci. **59**:125-127.

FAO, 1988. Sulphur News letter No.11. Fertiliser and Plant nutrition Service, Land and Water development Division, FAO, Rome.

Freney, J.R. 1958. Determination of water soluble sulphates in soils. Soil Sci. **86**:241-244.

George, S. 1989. Response of Rice to Applied Sulphur. M.Sc.(Ag.) thesis. Kerala Agricultural University, Vellanikkara, Trichur.

Ghai, V.K. 1980. Characterisation of Bench Mark Soils of Punjab for Sulphur Supply. M.Sc.(Ag.) thesis. Punjab Agricultural University, Ludhiana.

Ghai, V.K., Arora, B.R., Vig, A.C. and Dev, G. 1984. Evaluation of soil tests for available S in bench mark soils of Punjab. J. Indian Soc. Soil Sci. 32:768-770.

Ghosh, S.K., Das, D.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.

Gopalaswamy, V. and Raychaudhuri, S.P. 1969. Studies on the physical properties of some peaty soils of Kerala. Indian J. agric. Chemistry. 2(1):1-5.

Halder, B.R. and Barthakur, H.P. 1976. Sulphide production in some typical rice soils of Assam. J. Indian Soc. Soil Sci. 24:387-395.

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 Test Book of Soil Chemical Analysis. John Murray, London. pp.520.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi. pp.474.

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

Jain, C.L., Sahu, M.P. and Somani, L.L. 1984. Secondary nutrient research in Rajasthan, Proc. FAI(NRC) Seminar. p.147-174.

Joshi, D.C. 1984. Relationship of C, N, P and S in major soils of Rajasthan and in their humus fractions. J. Indian Soc. Soil Sci. 32:35-38.

Joshi, D.C., Choudhari, J.S. and Jain, S.V. 1973. Distribution of sulphur fractions in relation to forms of phosphorus in soils of Rajasthan. J. Indian Soc. Soil Sci. 21:289-294.

Kabeerathumma, S. and Bidappa, C.C. 1975. Influence of liming on the exchangeable potassium of two acid sulphate soils of Kerala. Agric. Res. J. Kerala. 13(1):67-69.

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(2):181-187.

Kabeerathumma, S. and Patnaik, S. 1980. Studies on the change of lime potential of acid sulphate soils of Kerala on submergence. Agric. Res. J. Kerala. 17(1):44-49.

Kamala, T.R., Sathasivam, R.N. and Natarajaratnam, S.R. 1986. Effect of S fertilisation on nutrient content, dry matter production and yield of groundnut. Madras agric. J. 13:151-154.

Kanwar, J.S. 1963. Investigations on S in soils I. Sulphur deficiency in groundnut soils of Samrala (Ludhiana). Indian J. agric. Sci. 33:196-198.

Kanwar, J.S. 1976. Soil Fertility - Theory and Practice. Indian Council of Agricultural Research, New Delhi. p.202-228.

Kanwar, J.S. and Mohan, S. 1964. Sulphur in soils - Distribution and forms of sulphur in Punjab soils. Bull. nat. Inst. Sci. India. 26:31-34.

Kanwar, J.S. and Mudahar, M.S. 1985. Fertiliser S and food production. Research and policy implications for tropical countries. Fert. News. 30(11):37-54.

Kanwar, J.S. and Takkar, P.N. 1963. Sulphur, P and N deficiency in tea soils of Punjab. Indian J. agric. Sci. 33:291-294.

Kanwar, J.S. and Takkar, P.N. 1964. Distribution of sulphur forms in tea soils of Punjab. J. Res. Punjab agric. Univ. 1:11-15.

KAU, 1984. Research Report 1982-83. Kerala Agricultural University, Vellanikkara, Trichur. p.243-244, 371-396.

KAU, 1987. Research Report 1984-85. Kerala Agricultural University, Vellanikkara, Trichur. p.271.

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(2):94-95.

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

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

Kumar, B.V.P., Rao, P.V.N., Rao, A.S. and Rao, I.V.S. 1985. Sulphur fractions of Krishna western delta alluvium in relation to blackgram production. *Andhra agric. J.* **32**(3):157-159.

Kumar, V. and Singh, M. 1974. Organic and available S status of Nainital terai soils. *J. Indian Soc. Soil Sci.* **22**:198-200.

Kuriakose, T.N. 1974. *Report on Kuttanad Development Project*. Government of Kerala. Stock No.56472 of the Kerala Legislative Library, Trivandrum.

Kurup, T.K.B. and Aiyer, R.S. 1973. Seasonal variations in soil reaction and soluble salt content of Kuttanad rice soils. *Agric. Res. J. Kerala*. **11**(1): 57-60.

Leela, K. 1967. *Forms, Availability and Distribution of S in Representative Soil Profiles of Kerala State*. M.Sc.(Ag.) thesis. University of Madras.

Marok, A.S. and Dev. G. 1979. Response of sunflower to S application and evaluation of the S status of soils. *J. nuclear Agric. Biol.* **8**(3):100-102.

Marykutty, K.C. and Aiyer, R.S. 1987. Effect of liming and washing on soil characters. *Agric. Res. J. Kerala*. **25**(1):27-35.

Mathews, R.P. and Jose, A.I. 1984. Effect of submergence of inorganic P fractions and available P in two acid rice soils of Kerala. Agric. Res. J. Kerala. 22(2):107-112.

Mehta, V.S., Singh, V. and Singh, R.B. 1988. Evaluation of soil test methods for available sulphur in alluvial soils. J. Indian Soc. Soil Sci. 36: 743-746.

Mohankumar, B. and Nair, P.G. 1983. Effect of S containing fertilisers on the yield and quality of cassava in acid laterite soils. Paper presented at the VIth symposium of the International Society for Tropical Root Crops, Lima, Peru.

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

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

Money, N.S. and Sukumaran, K.M. 1973. Chemical, Microbiological 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.

Mukhopadhyay, P. and Mukhopadhyay, A.K. 1980. Status and distribution of different forms of S in some typical soil profiles of West Bengal. J. Indian Soc. Soil Sci. 28:454-459.

Nad, B.K. and Goswami, N.N. 1984. Calcium, magnesium and sulphur requirements of greengram, cowpea and mustard in sequence. *Indian J. agric. Sci.* **54**:569-572.

Naik, M.S. and Das, N.B. 1964. Available S status of Indian soils by *Aspergillus niger* method. *J. Indian Soc. Soil Sci.* **12**:151-155.

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

Nair, J.Y. and Subramoney, N. 1969. Studies on H_2S injury to rice plants. *Agric. Res. J. Kerala.* **7**(1):21-24.

Nair, K.M. and Padmaja, P. 1983. Phosphorus fixing capacity of major rice soils of Kerala. *Agric. Res. J. Kerala.* **21**(1):63-65.

Nair, P.G. and Money, N.S. 1972. Studies on some chemical and mechanical properties of salt affected rice soils of Kerala. *Agric. Res. J. Kerala.* **10**(1): 51-53.

Nair, P.S. and Aiyer, R.S. 1966. Studies on the factors governing the available P status of the acid rice soils of Kerala State. 1. Evaluation of different methods for determination of available P in relation to soil chemical characteristics. *Agric. Res. J. Kerala.* **6**(1):20-26.

Nair, P.K. and Aiyer, R.S. 1968. Status of available silica in rice soils of Kerala State. 1. Evaluation of different methods for determination of available silica in soil. *Agric. Res. J. Kerala.* **10**(1):51-53.

Nair, V.B., Prabhakaran, L. and Varghese, G. 1981. Kuttanad - Perspectives and Potentialities. Soils Bulletin 2, Soil Survey Branch, Department of Agriculture, Trivandrum, Kerala.

√ Palaniappan, R., Krishnamoorthy, K.K. and Ramanathan, G. 1978. Sulphur status of soils and the influence of environmental factors on its availability. Mysore J. agric Sci. 12:244-248.

Palaskar, M.S. and Ghosh, A.B. 1982. An appraisal of some soil test procedures for available sulphur in alluvial soils. J. Indian Soc. Soil Sci. 30:194-199.

Pandey, D.K., Tiwari, K.N. and Tiwari, R.C. 1989. Different forms of S in alluvial soils. J. Indian Soc. Soil Sci. 37:161-163.

Patil, J.D., Shinde, P.H., More, D.A. and Zende, G.K. 1981a. Effect of application of B, S, and farm yard manure on the yield and quality of groundnut. J. Maharashtra agric. Univ. 6(1):17.

√ Patil, J.D., Tanawade, S.K. and Zende, G.K. 1981b. Relationship between different forms of S and the soil attributes like organic carbon, pH, clay and percent free lime content of Maharashtra soils. J. Maharashtra agric. Univ. 6(10):1-13.

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

Pillai, T.R. and Subramanyan, V. 1931. The origin and nature of the peaty soils of Travancore. J. Indian Inst. Sci. 14(1):99-117.

Pillai, V.S. and Subramoney, N. 1967. Physioo-chemical and microbiological studies on the kari soils of Kerala. Agric. Res. J. Kerala. 5(1&2):54-64.

Piper, C.S. 1942. Soil and Plant Analysis. Reprint for Asia 1966. Hans Publishers, Bombay. pp.368.

Pisharody, P.N. and Brito-Mutunayagam, A.P.A. 1966. Manganese status of rice soils of Kerala. Agric. Res. J. Kerala. 4(2):39-46.

Ponnamperuma, F.N. 1981. Some Aspects of the Physical Chemistry of Paddy Soils. Proc. Symposium in paddy soils. Institute of Soil Science, Academica sinica, Science Press, Beiging. p.59-95.

Prasad, B.R., Rao, A.S. and Rao, I.V.S. 1983. Sulphur status of some intensively cultivated grape garden soils. J. Indian Soc. Soil Sci. 31:608-610.

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

Ramamurthy, N. and Devi, L.S. 1981. Gypsum - A good source of S for potato. Curr. Res. 10:80-81.

Rawat, U.S. and Sriniwas. 1979. Sulphur in soils of Udaipur. Fert. News. 24(10):37-40.

Reddy, A.T., Rao, A.S. and Rao, I.V.S. 1985. Forms and distribution of sulphur in soils of Anthra Pradesh. J. Indian Soc. Soil Sci. 33:416-418.

Reddy, C.S. and Mehta, B.V. 1970. Fractionation of S in some soils of Gujarat to evolve a suitable method for assessing available S status. Indian J. agric. Sci. 40(1):5-12.

Ruhal, D.S. and Paliwal, K.V. 1980a. Inter-relationships between sulphur forms in Rajasthan soils. J. Indian Soc. Soil Sci. 28:392-393.

Ruhal, D.S. and Paliwal, K.V. 1980b. Soil properties affecting the availability of sulphur in soils of Rajasthan. J. Indian Soc. Soil Sci. 28: 529-531.

Saalbach, E. 1973. The effect of S, Mg and Na on yield and quality of agricultural crops. Pontificiae Academiae Scientiarum Scripta varia, The Vetican 38:541-548.

Saraswathi, P. 1989. Urease Activity in Rice Soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agricultural University, Vellanikkara, Trichur.

Saroha, M.S. and Singh, H.G. 1979. Effect of prevention of iron chlorosis on the quality of sugarcane grown in Vertisols. Pl. Soil. 52:467-473.

Sharma, B.R., Kanwar, B.S. and Kanwar, B.B. 1988. Forms of sulphur and available S extracted by some extractants in soils of north-western Himalaya. J. Indian Soc. Soil Sci. 36:500-509.

Singh, B.P. and Singh, H.G. 1983. Inter-relationship between soil and foliar applied S on oil per cent in seed and oil yield of mustard. Crop Physiol. 1:69-76.

Singh, D. and Chhibba, I.M. 1987. Sulphur indexing of soils and crops in a sandy tract of Hoshiarpur, Punjab. International Symposium on Managing sandy soils, CAZRI, Jodhpur.

Singh, R., Goraya, D.S. and Brar, S.P.S. 1976. Distribution of different forms of S in some soils of Himachal Pradesh. J. Res. Punjab agric. Univ. 13:255-260.

Singh, S.P.M., Singh, K. and Chahal, R.S. 1985. Vertical distribution of S in soils of Haryana. Proc. National Seminar on Sulphur in Agriculture. Tamil Nadu Agricultural University and the Fertilisers and Chemicals Travancore Ltd., Cochin. p.171.

Singh, V. and Sharma, R.L. 1983. Forms of S in citrus growing soils of Agra region in Andhra Pradesh. J. Indian Soc. Soil Sci. 31:482-485.

Snedecor, G.W. and Cochran, W.G. 1967. Statistical Methods 6th ed. Oxford and IBH Pub. Co. Calcutta, pp.593.

Spencer, K. and Freney, J.R. 1960. A comparison of several procedures for estimating the S status of soils. Aust. J. agric. Res. 11:948-959.

Sreedevi, S. and Aiyer, R.S. 1974. Potassium status of the 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(1):58.

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

Subramoney, N. 1961. Oxygen uptake by the acid infertile soils (kari) of Kerala. J. Indian Soc. Soil Sci. 9:77-82.

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

Sureshlal and Mathur, B.S. 1985. Sulphur status of Indian soils and its role in agriculture. Proc. National Symp. on Sulphur in Agriculture. Tamil Nadu Agric. Univ. and FACT, Udyogamandal. pp.188.

Takkar, P.N. 1987. Economics of sulphur fertilizer use in India. Proc. Symp. on Fertilizer Sulphur Requirements and Sources in Developing Countries of Asia and the Pacific. FADINAP/FAO/The Sulphur Institute and ACIAR, Bankok, p.123-137.

Takkar, P.N. 1988. Sulphur status of Indian soils. TSI-FAI Symposium on Sulphur on Indian Agriculture. The sulphur Institute Washington, USA and FAI, New Delhi.

Takkar, P.N., Bansal, R.L. and Nayyar, V.K. 1984. Annual Progress Report. All India Co-ordinated Scheme on Micronutrients in Soils and Plants, Punjab Agricultural University, Ludhiana.

Takkar, P.N., Bansal, R.L. and Nayyar, V.K. 1985. Annual Progress Report. All India Co-ordinated Scheme on Micronutrients in Soils and Plants. Punjab Agricultural University, Ludhiana.

Tandon, H.L.S. 1986. Sulphur Research and Agricultural Production in India. 2nd ed. Fertilizer Development and Consultation Organisation, C110, New Delhi. pp.76.

Tiwari, K.N., Nigam, V. and Pathak, A.N. 1983a. Evaluation of some soil test methods for diagnosing S deficiency in alluvial soils of U.P. J. Indian Soc. Soil Sci. 31:245-249.

Tiwari, K.N., Nigam, V. and Pathak, A.N. 1983b. Effect of S fertilisation on yield response and sulphur and nitrogen composition of rice grown in soils of Kanpur district. Indian J. agric. Sci. 53: 812-819.

Varghese, V.P. 1973. Morphological and Physico-chemical Properties of the Acid Peat Soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agricultural University, Vellanikkara, Trichur.

Venkateswarlu, J. and Subbiah, B.V. 1969. A comparison of several procedures for estimating the S status of rice soils. J. Indian Soc. Soil Sci. 17:155.

Venkateswarlu, J., Subbiah, B.V. and Tamhane, R.V. 1969. Vertical distribution of forms of sulphur in selected rice soils of India. Indian J. agric. Sci. 39:426-431.

Venugopal, V.K. and Koshy, M.M. 1976a. Exchangeable cations of some important soil profiles of Kerala. Agric. Res. J. Kerala. 14(1):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**(1):58-63.

Venugopal, V.K. and Koshy, M.M. 1978. CEC and chemical composition of clay fraction of some important soil groups of Kerala. *Agric. Res. J. Kerala*. **16**(2):233-234.

Virmani, S.M. 1971. Comparative efficiency of different methods of evaluating available sulphur in soils. *Indian J. agric. Sci.* **41**(2):119-125.

Virmani, S.M. and Kanwar, J.S. 1971. Distribution of forms of Sulphur in six soil profiles of north-east India. *J. Indian Soc. Soil Sci.* **19**:73-77.

Walkey, A. and Black, I.A. 1934. An examination of Degt fare off method for determining soil organic matter and proposed modification on the chromic acid titration method. *Soil Sci.* **37**:29-34.

Williams, C.H. and Steinbergs, H. 1959. Soil sulphur fractions as chemical indices of available Sulphur in some Australian soils. *Aust. J. agric. Res.* **10**:340-352.

Williams, C.H. and Steinbergs, A. 1964. The evaluation of plant available sulphur in soils-II. The availability of adsorbed and insoluble sulphates. *Pl. Soil* **21**:50-62.

Zachariah, P.K. and Sankarasubramoney, H. 1961. Relationship between the available nitrogen content and organic carbon as determined by Walkey and Black's method for the typical soils of Kerala. *Agric. Res. J. Kerala*. **1**(1&2):106-108.

SULPHUR STATUS OF THE KUTTANAD SOILS OF KERALA

By

CICY P. MATHEW

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara, Trichur

1989

ABSTRACT

An investigation was carried out to study the forms and availability of S in the acid saline soils of Kuttanad and to understand whether the application of S containing fertilizers is necessary in this region which is a major rice growing tract of the state. Surface soil samples (0-15 cm depth) were collected during summer. They consisted of 48 karappadam soils, 62 kayal soils and 41 kari soils. The available S in these soils was determined by four different extractants, i.e., water, $CaCl_2$ solution, KH_2PO_4 solution and Morgan's reagent. The physico-chemical properties like pH, EC, organic carbon, available P and available K were also determined in these soils. The fractionation of S was carried out in 39 soils selected from the karappadam, kayal and kari soils. These soils were also analysed for pH, EC, organic carbon, available P, available K, CEC, exchangeable cations and soil texture. The sulphur fractions estimated were total S, organic S, sulphate S and nonsulphate S.

All the soils were acidic in nature with a mean pH value of 3.92. The kari soils were extremely acidic, the lowest pH value recorded being 2.7. The EC of the

soils ranged from 0.3 to 13.0 dS/m. Most of the kari soils were saline in nature. The electrical conductivity was negatively correlated with pH. The organic carbon content of the soil varied from 1.23 to 6.72 per cent with a mean value of 2.97 per cent. Kari soils retained relatively high amounts of organic carbon, the maximum value recorded being 6.72 per cent which corresponded to 11.58 per cent organic matter. Increase in organic carbon content of the soil increased the EC and decreased the pH. In general, the Kuttanad soils were low in available P, values ranging from 1.2 to 10.3 ppm. Available P was positively correlated with pH and negatively correlated with EC and organic carbon. In general, the content of available K in soil was low, the values ranging from 8 to 725 ppm. It was positively correlated with the organic carbon content of Karappadam and kayal soils.

In general, soils of Kuttanad contained large amount of water soluble S, the mean value being 126.6 ppm. The value ranged from 25 - 395 ppm. On an average, nearly 6.3 per cent of the total S was in water soluble form. Maximum content of water soluble S was found in kari soils. Water soluble S was negatively correlated with pH and positively correlated with EC and organic carbon. Available S extracted by $CaCl_2$ and KH_2PO_4 ranged from 37 - 2400 ppm and 50 - 2450 ppm respectively. The calcium chloride extractable S and phosphate extractable S were negatively correlated with pH and positively with EC and organic carbon. The mean values of available S extracted by Morgan's reagent for karappadam, kayal and kari soils were 208.3, 481.7 and 571.6 ppm respectively with an overall mean of 419.2 ppm. The magnitude of available S extracted by Morgan's reagent was almost similar to that extracted by the phosphate solution. Available S extracted by Morgan's reagent established significant negative correlation with pH and positive correlation with EC, organic carbon, and available K. Values of available S extracted by the four extractants were significantly and positively correlated among themselves, the r values ranging from 0.6459** to 0.9912**.

Most of the soils selected for S fractionation study were loam and the CEC ranged from 10.0 to 78.8 me/100 g soil. In general, kari soil possessed relatively high CEC. The CEC increased with the increasing content of clay and organic carbon. The study revealed that soils of Kuttanad contained large amount of total S, values ranging from 600 - 9900 ppm with a mean value of 2324.1 ppm. The highest amount of total S was observed in kari soil. On an average, soils contained 1441.6 ppm of organic S, the mean values for karappadam, kayal and kari soils being 586.2, 1302.6 and 2446.0 ppm respectively. Organic S accounted for 62 per cent of the total S. The carbon : organic S ratio of the soil recorded a mean value of 19.83. The variation between the soil types was very pronounced, the ratio for karappadam, kayal and kari soils being 43.86, 20.11 and 14.36 respectively. The content of SO_4-S showed very high variation ranging from 37 to 2400 ppm. The maximum content was observed in kari soil. In general, SO_4-S accounted for 17.4 per cent of the total S. On an average, 36.2 per cent of the total sulphate S was extracted by water as available S. Total S, organic S and sulphate S registered significant negative correlations with pH and positive correlations with EC, CEC, clay and organic carbon. The content of nonsulphate S varied from 48 to 3133 ppm, maximum values being registered by kari soils. It accounted for 20.5 per cent of the total S. It established significant negative correlations with pH and positive correlations with EC, CEC and organic carbon. Total S, organic S, sulphate S and nonsulphate S were found to be highly significantly and positively correlated among themselves (r = 0.5309** to 0.9391**) and with available S extracted by different extractants (r = 0.5526** to 0.9395**).

In general, the soils of Kuttanad are rich in available S as well as total S and the addition of S containing fertilizers may not be necessary in the near future.