

**A COMPARATIVE STUDY OF THE CHEMICAL COMPOSITION
OF SOILS FROM AQUACULTURE SYSTEMS IN THE COCHIN
ESTUARINE AREA**

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To my parents

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P R E F A C E

In recent years there has been an increasing awareness of the role and benefits of scientific fish farming in coastal waters for augmenting fish production of India, although a traditional practice of aquaculture has been prevailing in these waters for a long time. A comprehensive knowledge of the ecology of the different culture systems forms an integral part of the scientific farming because it directly influences the rate of production. The growth and survival of the organisms used for culture depend largely on the overall productivity of the pond, which in turn, is influenced by the various environmental characteristics of the water and the fertility of the pond soil. In short, the water and soil conditions to a great extent determine the success or failure of the culture operation. Further, the information on the various environmental characteristics of the pond water and soil, availability of essential elements and the rate of organic productivity, would not only help to adopt successful management principles and culture techniques but also to manipulate the ecosystem providing the necessary inputs for obtaining better production. Besides providing an overall picture of the productivity of the ponds, studies on soils furnish information on the inputs to enhance the fertility of soils and also help in selection of suitable sites for construction of farms.

In India it is estimated that between 1.4 to 2.0 million ha. of brackishwater area is potentially available for culture purposes. A considerable extent of this water area is composed of derelict acid sulfate soils which occur on both the coasts, particularly in Orissa, Kerala, Karnataka and Goa. In recent years, considerable attention is being given to bring these derelict acid sulfate soils under productive use of aquaculture. In this context it is essential to develop appropriate techniques for treatment of such soils to obtain as high a production as possible from it.

The nature and composition of soils have several vital roles in the production of fish from ponds. The soils store nutrients and release them into water and plays active role in the mineralization of organic bottom deposits. They are the source of various organic and inorganic compounds which enter the water after biochemical and chemical changes. The bottom soil provides food and shelter for the bottom dwelling organisms and also acts as a bed for the growth of algal flora which forms the food for many species of fish. Also, they form a substrate for bottom fauna that often constitutes an important source of food for the stocked population in the culture system. The bottom soil harbours both useful and harmful matters such as spores, seeds, eggs of aquatic animals, parasites, bacteria and

virusus. Pond soils thus plays several important and dynamic roles in the food chain and production cycle in the pond ecosystems where fish and shell fishes are cultivated.

Although a wealth of information on the water characteristics of various culture systems in the region around Cochin are available, our knowledge on the various types of soil, their fertility and chemical composition is scanty and incomplete. In the context of the importance given to the development of mariculture in our country, studies on soil characteristics of culture fields have assumed a significant position in ecological studies. From the information obtained from these investigations, measures can be taken to overcome deficiencies by adopting methods like liming and fertilization. The rate of fertilizer or lime adopted based on soil tests would avoid wasteful and uneconomical use of them. These studies would also help the entrepreneurs in understanding the various pathways of nutrient cycles which are taking place in space and time so as to decide on the correct doze of application of fertilizers and lime to obtain optimum yield.

In the present work the chemical composition, the total phosphorous contents in the sediments and its grain size distribution from fifty stations located in the periphery of the Cochin Backwaters were collected and analysed in the pre-monsoon

and monsoon periods. The rate of lime required for these sediments were also determined. The information collected revealed interesting fluctuations of the parameters analysed. The data obtained on the fertility, soil composition as well as lime requirement will be highly useful in planning management strategies for intensifying brackishwater aquaculture which envisages significant development in the coming years.

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I N T R O D U C T I O N

It is well known that the overall productivity in the culture system is greatly influenced by the nature of the substratum as well as the prevailing quality of the overlying water. A perusal of literature reveals that relatively more data are available on water quality parameters than on pond soils. Since the physico-chemical composition of the soil plays a significant role in the nutrient distribution and related water quality, detailed information on pond soil characteristics are highly essential and significant in the context of a successful culture practice. The same assumes more importance when techniques of fertilization and liming are envisaged to increase the production.

Investigations on soil and their characteristics have been carried out from early times by many workers. Among them are Mortimer (1941, 1942, 1950); Meehean and Marzulli (1945); Stangenberg (1949); Povoledo (1964) and Danielewski (1965). The early works of Breest (1924); Trong (1930); Schaeperclaus (1933) and Burrows and Cordon (1936) are also important. Schuster (1949); Maciolek (1954); Chou et al. (1961); and Hickling (1962) carried out studies on the inter-relation of soil and water in aquaculture ponds.

Importance of the nature and properties of bottom soils in brackishwater aquaculture has been emphasized by Frey (1947); Watts (1965a, 1965b); Tang and Chen (1967); Golterman (1967) and Matida (1967). Benthic algae which constitute the major fish food organisms in brackishwater ponds, derive their nutrients either directly from the soil or from the soil water interface (Mandal, 1962) and hence the productivity in such ponds largely depends on the nutrient status of pond bottom soils (Pillay et al., 1962). In stagnant fish culture ponds, the nutrients supplied from the pond soil is much more significant when compared to nutrients brought in by the inflowing water (Hickling, 1962).

Mud plays an important role in the generation of organic substances, pH regulation, oxygen balance of water and acts as a reservoir of nutrients. The elements such as P, N, K, Na, Ca, Si and Fe are stored in mud (Golterman, 1967). Of these nitrogen is the most widely studied one. Phosphorous, an equally important element and one of the widely used fertilizer in fish ponds, released by weathering of rocks and by decay of terrigenous organic matter, is transported to various sites of deposition chiefly as complex soluble ions. Compared to all other non-metallic elements the geochemistry of phosphorous in the sedimentary cycle has been more thoroughly studied and much better understood (Naidu and Dora, 1967). The works

carried out by Haynes (1952) on the kinetics of phosphorous exchange in lakes and Hartner (1968) on adsorption of phosphorous by lake sediments are noteworthy. Other workers include Trong (1930); Sommers (1970); Williams (1971); Syers et al. (1973); Hart et al. (1976); Ergeb (1982) and Wolaver et al. (1983).

In India, Rao (1957) made preliminary observations on the total phosphorous content of inshore waters of Malabar coast, off Calicut. The works done by Naidu and Dora (1967); Murty (1968); Banerjea and Gosh (1970) and Ramamurty et al. (1973) in the same field are noteworthy. Murty and Veerayya (1972) studied the total phosphorous in the sediments of the Vembanad Lake, S. India. Ansari and Rajagopal (1974) and Sankaranarayanan and Panampunnayil (1979) also carried out studies on total phosphorous content of sediment in the Cochin Backwaters. Other workers in this field include Rajendran and Venugopalan (1973) and Seeralathan and Seetharamaswamy (1979).

Schaperclaus (1961) quotes in his review about the adsorption characteristics of potassium in mud. He mentions a study of Breest (1924) as the only source of this information. Edwards and Rolley (1965) studied the exchange of potassium between the interstitial waters and water overlying the mud

deposits. Wiklander (1950) highlighted the exchange properties of potassium and Wrobel (1967) has reviewed the exchange of potassium between soil and water and its dependence on the carbon turn-over cycle.

Calcium is generally present in the soil as carbonate. Gupta and Naik (1981) did work on calcium along with other parameters in the Mandovi and Zuari tide dominated river systems. They observed that calcium along with magnesium appeared to take part in some biogeochemical cycles and behave as a semiconservative parameter. Other workers in this field include Banerjea (1967); Saha et al. (1971); Setty and Rao (1972); Marching (1975); Rao (1978) and Mollah et al. (1979).

Regarding the physical properties of pond soils, it is well known that ponds having clayey soils have higher production rate of benthic algae than those with sandy bottoms. The preference for different types of soil varies with the type of fish cultured as exemplified by the brackishwater fish ponds of Phillipines and Java (Frey, 1947). He found that the greatest production of algae on which the milkfish Chanos chanos grew, had predominantly clayey soil, while less production was associated with those having sandy bottom. The clayey and silty soils have more nutrients adsorbed to them than sandy soils which have tendency to leach out the nutrients faster.

Use of fertilizers is considered as the most economical way of increasing production in fish ponds, but fertilizer requirements vary widely with the region and constitution of the soil. Though considerable attempt has been made in India to study the effect of fertilization in fish ponds, much work remains to be done on the rate and doze of fertilization and lime requirement of ponds with respect to the prevailing local conditions.

Lime is frequently applied to fish ponds to improve the water quality and as a response to inorganic fertilization of soft waters and acid muds (Mortimer, 1954; Hickling, 1962; Acre and Boyd, 1974). Till recently no procedure was available for estimating the liming rate. Lime requirement is the amount of liming material needed to neutralize the acidity of bottom muds and increase the total hardness and the total alkalinity to at least 20 mg/l (Boyd, 1974). Therefore, liming is indicated if either the total hardness or the total alkalinity of the pond waters is below 20 mg/l.

The use of lime in pond fish culture has been advocated by fish culturists over a large part of the World. A greater use of lime has been made in Europe, then America and Asia. Hober (1914, 1915); Demoll (1925); Walter and Nolte (1930); Schaeperclaus (1933); Lawson (1937); Krugel and Heinrich

(1939); Neess (1946); Wunder (1949) and Huet (1952) described the favourable effects of liming and stressed its use for increased fish production. More recently, Wrobel (1967); Fijan (1967); Mints and Khairulina (1968) and Boyd (1974) carried out works on liming of ponds and discussed its advantages.

Acid sulfate soil is a major hindrance in the development of brackishwater fish ponds in potential areas of many countries especially in the tropical regions. Actual acid sulfate soils are not common, but far more abundant are potential acid sulfate soils. Such a soil is defined as reduced, water logged, unconsolidated soil material which will become acid sulfate upon draining (Brinkman and Pons, 1973). Studies have been carried out on acid sulfate soils by Watts (1965a, 1965b, 1969); Breeman (1973); Ponnampereuma *et al.* (1973) and Potter (1977). Kawalec (1973) has described the World distribution of acid sulfate soils.

The Vembanad lake, also called Cochin Backwaters is the largest brackishwater ecosystem in the west coast of India. Several investigations have been carried out on the water and sediments of this ecosystem by many workers. Studies relating to the physico-chemical characteristics has been reported by

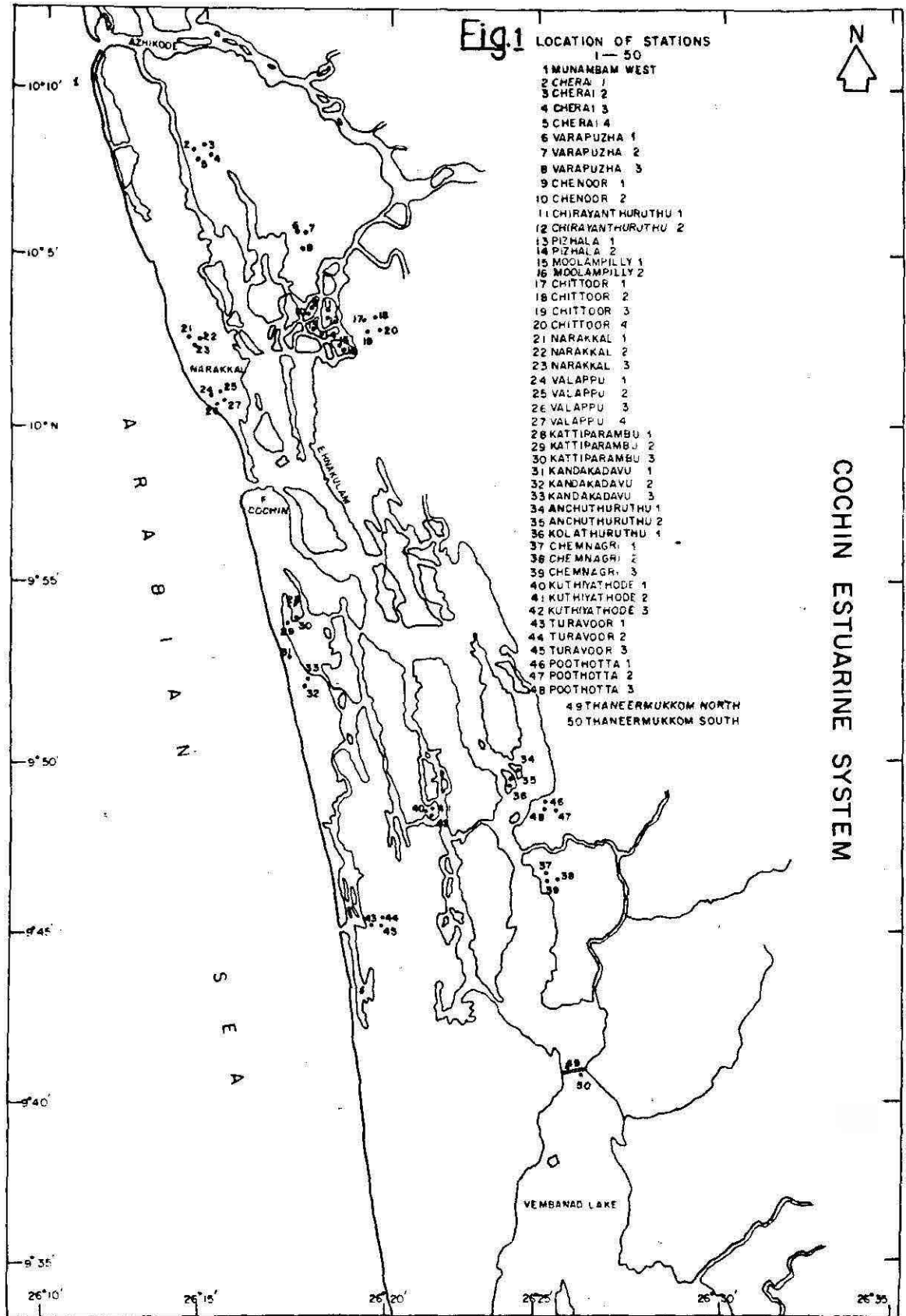
Balakrishnan (1957); George and Kartha (1963); Ramamirtham and Jayaraman (1963); Cherian (1967); Josanto (1967); Sankaranarayanan and Qasim (1969); Manikoth (1975) and Manikoth and Salih (1974). Other workers include Murty and Veerayya (1972); Laxmanan (1982) and Sankaranarayanan and Panampunnayil (1979). Eswaraprasad (1982) investigated the physico-chemical composition of fish pond soils of Vypeen area near Cochin. Besides these works, Josanto (1971) and Pillai (1977) investigated the grain size distribution of soils in this region. However, available information relating to Cochin backwater area are mostly based on the data collected from a single station or from a few stations located near the harbour region. Hence, in this study an attempt has been made to evaluate the chemical composition of pond soils from seasonal as well as perennial fish culture ecosystems of the extensive estuarine area from Munambam to Thaneermukkom (Fig. 1), taking into consideration the potential areas to be developed for brackish-water aquaculture. In this work an attempt has also been made to calculate the lime requirement for pond soils of this area which will be of great practical value since information on these lines are lacking for this region.

MATERIALS AND METHODS

Studies on the chemical properties of soils were carried out from 50 stations in the Cochin Backwater system including Vembanad Lake (Fig. 1). Soil samples from different seasonal and perennial prawn culture fields were collected and analysed for the following parameters: Exchangeable sodium, potassium and calcium, total phosphorous and the lime requirement, based on the estimations of both exchange acidity as well as potential acidity. The sampling was done twice, one each in the premonsoon and monsoon periods.

Study area

The Vembanad lake, also called Cochin Backwaters is the biggest in the west coast of India, extends between latitudes 9°28' and 10°N and longitudes 76°13' and 76°31'E. Its length is about 113 Km. and width varies from a few hundred meters to about 1.45 Km. It covers an area of approximately 300 sq.km. The backwater as the name implies includes a chain of shallow brackishwater lagoons and swamps covering vast area, extending into the central part of Kerala. The main sources of freshwater in the system are two large rivers - Periyar on the north, Pampa on the south and a small river called Muvattupuzha which flows midway between the two. The backwater has a permanent connection with the Arabian sea about 450 m. wide,



the Cochin Bar Mouth, which forms the main entrance of saline water. There is also a similar entrance in the northern end at Azhikode. The system receives an average rainfall of 3300 mm from the southwest and northeast monsoons, the former being active from early June to September and the latter from October to early December.

Traditional fish culture practices are prevalent in more than 5117 ha. of low lying brackishwater fields adjoining the estuary (Plate I). These fields varying in size from less than 0.5 ha to 10 ha. are confluent with the brackishwater directly or by canals, controlled by sluice gates. The average prawn and fish yield in these fields range from 500 to 1,500 kg/ha. This is a seasonal operation done during the summer months i.e., from November to April, and paddy cultivation carried out during the rest of the year. During the remaining period i.e., during S.W. monsoon, water in these fields becomes almost salt free, a special variety of paddy called 'Pokkali' which is tolerant of salinity upto 8 ppt is grown. The crop lasts only for 90-100 days. Paddy stumps and straw are left to decay after harvest, which forms a good manure to the soil.

In addition to the pokkali fields, there are deeper brackishwater impoundments which are not suitable for growing

paddy. They are used for growing prawns throughout the year. The bottom layer of water in these deep ponds will be saline making it suitable for the growth and survival of prawns during peak monsoon also. These fields ranging in size from 2 ha to 75 ha are called 'Varshakettu' in Malayalam.

In the conventional method, the tidal flow of water coming from the estuary during the high tide is allowed to enter the fields through the sluice gates. Along with the inflowing water the juveniles of prawns and young ones of fishes also enters the fields. However, during the low tide the sluice gates are closed with wooden planks on nylon screens to prevent the prawns and fish from going out. The harvest is closely associated with lunar periodicity because of the advantage of higher drive of water flow. The harvesting is carried out by keeping a conical bag net in the sluice gate.

At Valappu and Narakkal there are a few well designed semi-intensive culture ponds with average depth of 0.5 to 0.1 m of water of size less than one hectare, where aquaculture is practiced by selective stocking and with scientific management (Plate II).



Plate I. A traditional prawn culture field.



Plate II. Semi-intensive culture ponds of the CMFRI at Narakkal.

Soil samples were also collected from the northern and southern aspects of the Thaneermukkom barrage, the salt water barrier constructed across the Vembanad Lake.

Collection of soil samples

The soil samples were collected using a Van Veen grab of area 0.05 m^2 . Bottom soils were taken from the four corners and center of the ponds in each station, and mixed thoroughly in a container before the samples were taken for analysis.

The wet pH of the soil was determined on the same day and then the samples were sun dried over a polythene sheet. The dried samples were transferred into plastic vials, labelled and stored in a desiccator for analysis.

Method

The wet soil pH was determined using an Elico digital pH meter, model L1-120. The sun-dried samples were ground well in a mortar with a pestle to a fine consistency so as to pass through 1 mm mesh sieve.

The dry pH of the sun-dried samples were determined for observing the acidity. 50 g of the soil was weighed into a

250 ml beaker and 50 ml of deionized water was added. The mixture was stirred intermitantly for one hour. Then the pH was determined by a pH meter (Bear, 1964).

The soil samples were analysed for the following parameters:

1. Exchangeable cations viz., sodium, potassium and calcium
2. Total phosphorous
3. Lime requirement

The exchangeable cations were analysed by the ammonium acetate extraction of these cations from the soil into the solution. 2.5 g of the soil was added to 50 ml of 1 N ammonium acetate solution in a Erlenmyer flask and shook well in an electric shaker for half an hour. The solution was then filtered and the filtrate was used to determine the exchangeable cations with the help of an Elico Digital Flame Photometer, Model CL-22D, using the respective filters (Plate III).

In the flame photometer the sample combined with air and gas premixture is sprayed into a high temperature flame. The emitted photon energy is filtered through a narrow band filter and the filtered energy is directed over a photo sensitive device, which is measured over a meter. The meter



Plate III. Elico digital, Flame Photometer, Model CL-22D.

is calibrated with standard solutions and the concentrations of unknown samples are interpreted.

The total phosphorous was determined by the per chloric acid digestion method (FAO Fish. Tech. Paper, 1975). The method is as follows:

Take 0.5 g finely powdered sediment into a 500 ml Kjeldahl flask. Add few drops of water to moisten the sample. Then add 2 ml each of conc. HNO_3 and Conc. HClO_4 . Heat slowly until dry over a pre-heated hot plate. Let the flask cool and then add 1 ml conc. HClO_4 and heat again until dry. Cool the flask and then add 21 ml of diluted H_2SO_4 (1.8 N) solution. Boil slowly for 10 minutes.

After cooling, filter the solution into a 250 ml volumetric flask using Whatman No. 42 filter paper and then dilute to 250 ml.

Pipette out 5 ml of the solution into a 50 ml graduated cylinder and add 25 ml water together with 5 drops of ascorbic acid and 1 ml sulfuric acid - ammonium molybdate solution. After 5 minutes, measure the absorbance at 882 nm in a spectrophotometer.

Estimation of lime requirement

Lime requirement was determined by the method developed by Pillai and Boyd (1985) for pond muds where exchange acidity is involved.

20 g air dried sediment that passes a 0.85 mm sieve is weighed to a 100 ml beaker. 40 ml of para-nitrophenol buffer, made by dissolving 20 g para-nitrophenol, 15 g boric acid, 74 g KCl and 10.5 g KOH in 1000 ml water, is added and the pH is adjusted to 8.00. The contents of the beaker were stirred for 1 hour intermittently using a magnetic stirrer and then the pH was determined to the nearest 0.01 unit using a glass electrode with a pH meter. Each 0.01 unit change in pH represents 0.16 meq. of acidity. The liming rate was calculated as follows:

$$\text{Liming rate (Kg. of CaCO}_3\text{/ha)} = \text{pH change} \times 5600$$

For acid sulfate soils in order to calculate the total lime requirement, since the potential acidity has also to be taken into consideration, the same has been estimated by the method of Boyd (1984). The potential acidity was calculated as follows:

Take 5 g of air dried sediment in a 500 ml long form of beaker and add 20 ml of 30% H_2O_2 . Heat the mixture to

40°C till a noticeable reaction similar to boiling occur. Once the reaction starts, the beaker is to be removed from the heat and the reaction let to continue. Once the reaction stops add 10 ml of 30% H_2O_2 and heat to 40°C. Continue this procedure until no reaction occurs at 40°C. Then add distilled water to a volume of about 100 ml and heat the solution for 30 mts. at 90 to 95°C to remove any excess H_2O_2 .

After the beaker and the contents have cooled, add 5 drops of phenolphthalein and titrate against standard sodium hydroxide. At the end point phenolphthalein produces a faint pink color which persists for at least 30 seconds. The potential acidity is calculated as follows:

$$\text{Meq } H^+ \text{ per 100 g} = \frac{(\text{ml. of NaOH}) (N) (100 \text{ g})}{\text{wt. of the sample in grams.}}$$

$$\text{Lime requirement} = \text{meq} \times 50 \times 2.2 \times 10^6$$

(kg of $CaCO_3$ /ha.)

$$\text{Total lime requirement} = \text{Rate obtained by exchange acidity} \\ + \text{Rate obtained by potential} \\ \text{acidity.}$$

Grain size analysis

Apart from the above chemical analysis, grain size distribution of soil from different regions of sampling were also determined by the sieve and pipette method of Krumbein

and Pettijohn (1938) as quoted by Buchanan and Kain (1971).
The summary of the method is as follows:

Pretreatment

25 g of air dried sediment was weighed into a one litre long form of beaker and 100 ml of 6% H_2O_2 was added. This was allowed to stand overnight and then heated gently over a water bath adding further small quantities of H_2O_2 until there was no reaction. The contents of the beaker was washed down on to a filter paper (Whatman No. 42) in a Buchener funnel under gentle suction. The sediments was then washed from the filter paper into a one litre beaker and 100 ml of sodium hexametaphosphate (6.2 g/l aqueous) was added, then stirred for 10 to 15 mts. using a high speed stirrer. The sediment was left to soak overnight.

Initial splitting of silt clay fraction

The sediment was transferred to the surface of a clean 62μ sieve placed in a flat bottomed white enamel basin. Then 300 to 400 ml distilled water was added to floor the sieve. Wet sieving of the sediment was done by agitating and puddling in the basin of water until most of the fine fraction had passed. The sieve was then lifted and water allowed to drain over the basin. The sieve was then transferred with its

contents to a drying oven at 100°C.

Dry sieving of the sand fraction

The dried sieve with its contents was agitated over a large sheet of glazed white paper and any material which passed through it was transferred to the suspension in the basin. The fraction retained on the sieve was then weighed to get the proportion of sand.

Pipette sample

The contents in the basin was washed down to a one liter cylinder with distilled water. The cylinder was shaken to suspend the sediments evenly throughout the water column. The temperature of the contents in the cylinder was maintained at 20°C by a cold water bath. After exactly 7 minutes 44 seconds a 20 ml. pipette sample was withdrawn from a depth of exactly 10 cm below the surface of suspension and transferred to a pre-weighed china dish and dried in the oven at 100°C. The weight of the contents in the dish gives the weight of silt fraction in the 20 ml sample which can be computed to the weight of silt in one liter of the sample. Then weight of sand and silt fractions were added and deducted from 100 which gave the proportion of clay.

Statistical analysis

All data were subjected to statistical analysis to determine the relationship between different parameters. Correlation coefficients were estimated between different parameters and tested for their significance. These are given in tables. Test of homogeneity of correlations were also carried out between the two seasons of sampling.

RESULTS

(a) Exchangeable cations(i) Sodium

Sodium showed a relatively wide range of all the three exchangeable cations in the samples studied. The pattern of distribution of the cation during the pre-monsoon and monsoon periods is shown in Fig. 2. During the premonsoon period the concentration of sodium ranged from a minimum of 934 ppm in Station No. 50 located in the southern part of the backwaters to a maximum of 12,916 ppm in Station No. 2 in the northern region. The concentration of exchangeable sodium during monsoon ranged from 590 ppm in Station No. 50 to 7,592 ppm in Station No. 33, located in the middle of the backwaters (Table 1). By the onset of monsoon the average value of 7,174.16 during the pre-monsoon declined to 4,240.09 ppm. Significant amount of leaching of the exchangeable cation was observed in all the stations during the monsoon period (Fig. 5). The maximum amount of leaching was observed in Station No. 43 where the rate of water exchange was very high.

(ii) Potassium

Among the cations studied, potassium was found to be the lowest in concentration. The distribution of exchange-

able potassium during the two sampling periods are shown in Fig. 3. During premonsoon, the amount of exchangeable potassium ranged from a low value of 30 ppm in Station No. 49, located in the southern part of the backwaters to 745 ppm in Station No. 27 situated in the north-west part of the backwaters, in Vypeen island. The samples collected during monsoon showed a range of 20 ppm in Station No. 49 to 656 ppm in Station No. 26 at Vypeen island (Table 1). The average value of potassium recorded during the premonsoon period was 344.06 ppm which declined to 246.94 ppm in the monsoon. The seasonal variation of the cation along the stations is shown in Fig. 5, with maximum leaching in Station Nos. 39 and 43 located in the southern part of the backwaters.

(iii) Calcium

The distribution pattern of calcium during the two seasons is represented in Fig. 4. The samples obtained during the premonsoon showed a range of exchangeable calcium from 160 ppm in Station No. 50 to 11,800 ppm in Station No. 16, situated in the north central region of the Cochin backwaters. During the monsoon period it ranged from 60 ppm in Station No. 50 to 7,140 ppm in Station No. 26 at Vypeen island (Table 1). The average value of the exchangeable cation of 5,470.4 ppm during the premonsoon declined to 2,536.08 ppm

by the onset of monsoon. Calcium showed the maximum amount of leaching of all the three exchangeable cations studied (Fig. 6).

(b) Total phosphorous

Total phosphorous showed a definite pattern of distribution, registering higher concentrations in the northern and north central regions of the backwaters located in between Cochin bar mouth and Azhikode while stations in the southern regions it showed relatively low values (Table 2). The pattern of distribution of total phosphorous during the pre-monsoon and monsoon periods over the area sampled is represented in Fig. 7. During the premonsoon period the range of total phosphorous varied from a low value of $71 \mu\text{g/g}$ in Station No. 50 to a high value of $2,643 \mu\text{g/g}$ in Station No. 8 situated in the north central region of the backwaters. The monsoon period showed a range of $65 \mu\text{g/g}$ in Station No. 50 to $2,348 \mu\text{g/g}$ in Station No. 8. The average value recorded during the two periods were $1,118.77 \mu\text{g/g}$ and $871.94 \mu\text{g/g}$ in premonsoon and monsoon seasons respectively. Total phosphorous did not show high fluctuation over the periods. The concentration of phosphorous showed a direct relation with the soil texture in the area registering higher values in those areas with finer fractions of the soil viz., silt and clay (Fig. 7).

(c) pH

The wet and dry pH values of the soil during the pre-monsoon and monsoon periods are shown in Fig. 8. During premonsoon the wet pH of the soil ranged from 6.2 in Station No. 41 located towards the south of the backwaters system to 8.0 at stations 21 and 22 in the north-western part (Narakkal, Vypeen island). During the monsoon period the pH showed a wider range of variation from 6.0 at Station No. 45 in the southern part of the system to 8.4 in Station No. 21 (Table 3). The average values recorded during the premonsoon and monsoon periods were 7.14 and 7.17 respectively.

The dry pH showed lower trend than wet pH in most of the stations with a range of 5 to 7.45 during the premonsoon, with an average value of 6.09. Comparatively, lower pH values were observed in the southern part of the backwater area. During the monsoon, the range of dry soil pH was from 4.65 to 7.70 with an average value of 5.86. The southern part of the backwaters system registered lower pH values during this season (Table 3).

(d) Lime requirement

The amount of lime (calculated as CaCO_3/ha) required for the soils by the exchange acidity (Buffer method)

gave a wide range of values. The estimated amount of lime varied from 0.112 tons/ha at Narakkal (Station No. 23) to 5.6 tons/ha of CaCO_3 at Thuravoor (Station No. 44) located in the south-western part of the study area in premonsoon. During the monsoon, however, the requirement of lime was found to be lower with eleven stations recording nil, and a maximum of 3.528 tons of CaCO_3 /ha being observed in Chennoor (Station No. 9) in the north central region of the ecosystem (Table 4).

The lime requirement based on the potential acidity estimation showed considerable variations in the two periods. In the premonsoon it ranged from 10.63 tons of CaCO_3 /ha in Narakkal (Station No. 22) to 95.73 tons/ha in Station No. 3 in the northern part of the system. During the monsoon in the stations located in the southern parts of the backwaters, the range was from 17.01 tons/ha in Station No. 35 to 89.34 tons/ha in Station No. 42.

The total lime requirement in tons of CaCO_3 /ha, calculated by adding both the exchange acidity and potential acidity varied from 10.79 tons in Narakkal to 96 tons/ha in Cherai during the premonsoon period. During the monsoon sampling the range varied from 12.76 tons/ha in Station No. 50 to 91.22 tons/ha of CaCO_3 at Station No. 20 in the north central region of the backwater system (Table 4).

(e) Grain size analysis

The grain size analysis revealed three main types of soil viz., silty sand, clayey sand and sandy silt in the study area. The soil texture in 30 stations sampled was silty sand with predominance of sand and silt in the soil. 10 stations had sandy silt while the remaining 10 stations consisted of clayey sand. The region-wise distribution of grain size in the backwater system is shown in Table 5. Figures 9 to 9b represent the composition of soil in different regions from where samples were obtained.

(f) Statistical analysis

Correlations (Snedecor and Cochran, 1967) worked out between the various parameters during the premonsoon and monsoon periods are given in Tables 8 and 9 respectively. Sodium and potassium showed highly significant correlations of 0.8504 during premonsoon and 0.6502 during monsoon. Potassium and calcium also showed significant correlations of 0.6377 and 0.7962 during premonsoon and monsoon seasons respectively. Total phosphorous showed highly significant relationships with all the exchangeable cations during both the periods.

Wet pH didn't show any significant correlation with any of the parameters during the premonsoon period. However, during monsoon period significant correlations

of 0.3820 and 0.5050 was observed between calcium and dry pH respectively. Dry pH showed significant relationship with wet pH (0.5050) and an inverse correlation of 0.3080 with lime requirement was noticed during the monsoon period only.

Sodium, potassium, calcium and total phosphorous showed significant relationships of 0.7709, 0.8199, 0.9078 and 0.8960 between their respective distribution patterns in the premonsoon and monsoon periods of sampling (Table 10). Wet pH values didn't show any relation during the two periods while between dry pH and lime requirement a correlation of 0.4836 and 0.3684 was observed during the premonsoon and monsoon periods respectively.

Of the three grain size variables only sand and silt showed highly significant correlations with the exchangeable cations and total phosphorous during the two periods. However, clay showed a significant relationship between total phosphorous during both premonsoon and monsoon periods (0.3635 and 0.4560). Further, during the monsoon sampling clay showed relationship with sodium and potassium. Sand/silt and sand/clay displayed highly significant correlations while no relationship could be established between silt and clay.

Interesting relationship between the different parameters during the two seasons were also observed and are given in Table 10.

'Z' test for determining the homogeneity of correlations of different parameters during the two seasons revealed interesting results. Exchangeable cations and total phosphorous exhibited homogeneity in correlations during the premonsoon and monsoon seasons as well as in their relationship with other parameters. Correlation between wet pH and dry pH wasn't homogeneous. The same was the case with the relationships between dry pH and lime requirement during the two periods. However, wet pH and lime requirement relationship during the two periods of sampling showed homogeneity.

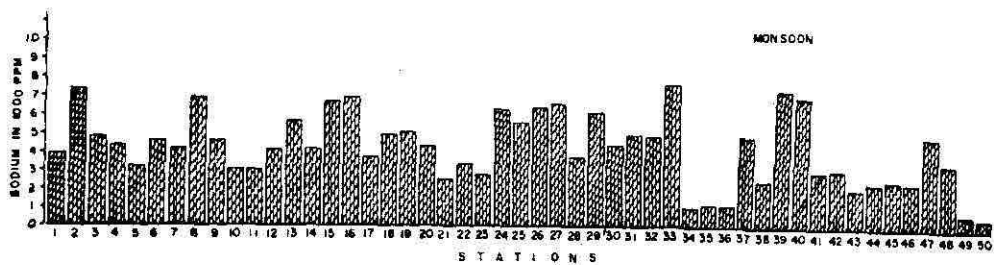
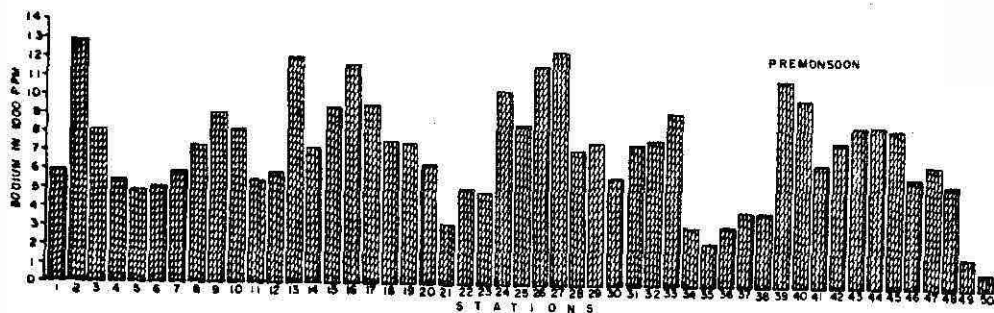


Fig. 2. Variations in the concentration of exchangeable sodium in the soil during the premonsoon and monsoon periods.

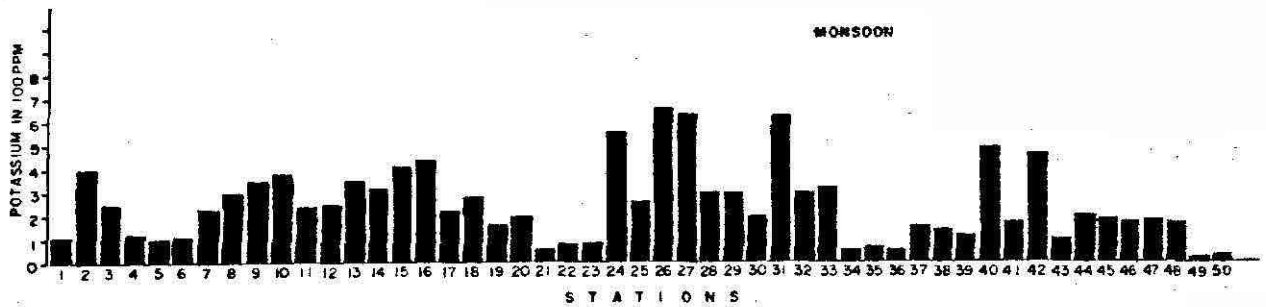
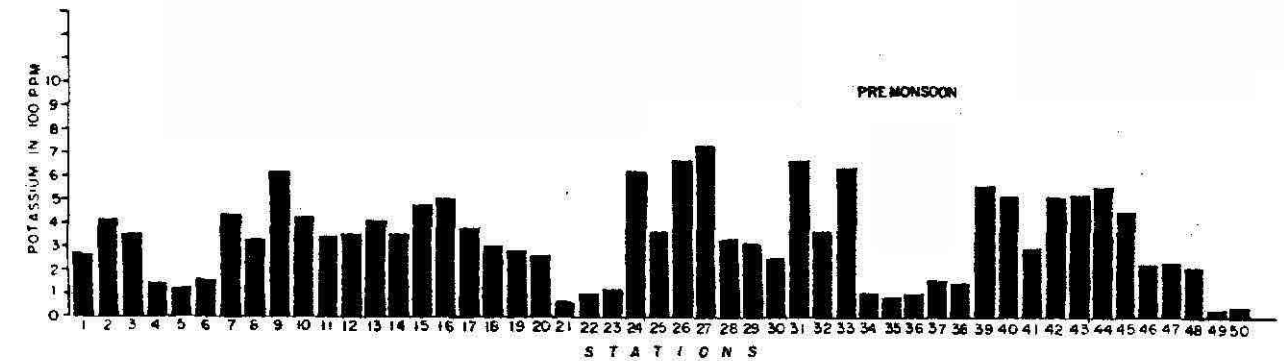


Fig. 3. Variations in the exchangeable potassium content of the soil during the premonsoon and monsoon periods.

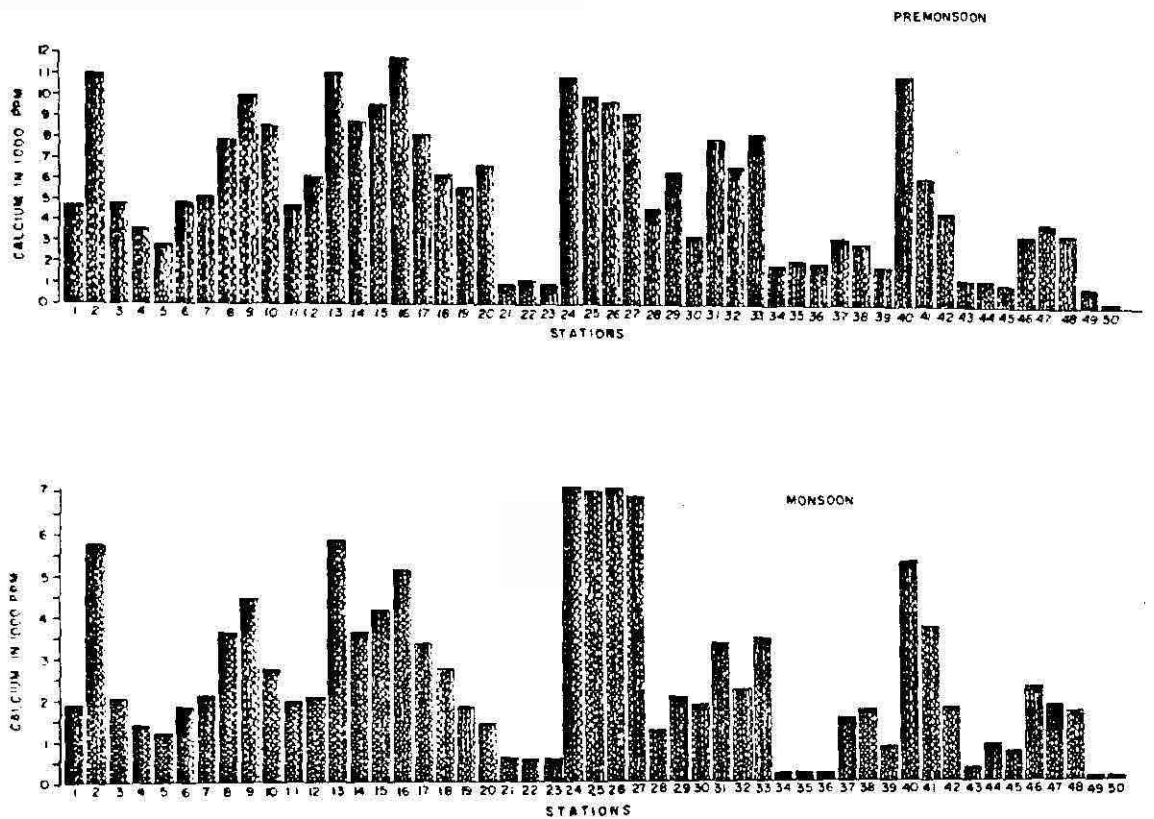


Fig. 4. Variations in the concentration of exchangeable calcium in the soil during the premonsoon and monsoon periods.

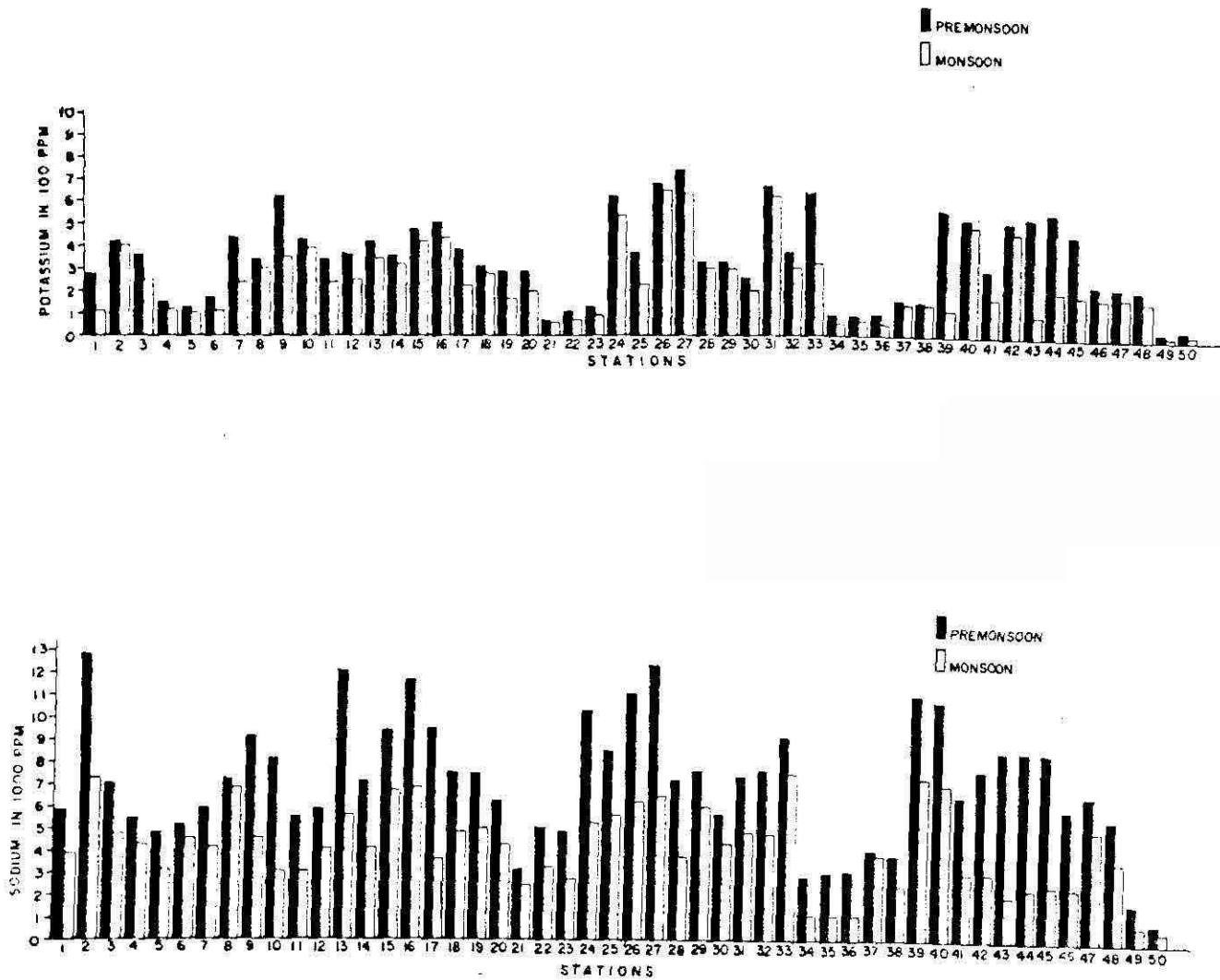


Fig. 5. The comparative distribution of exchangeable potassium and sodium during premonsoon and monsoon periods.

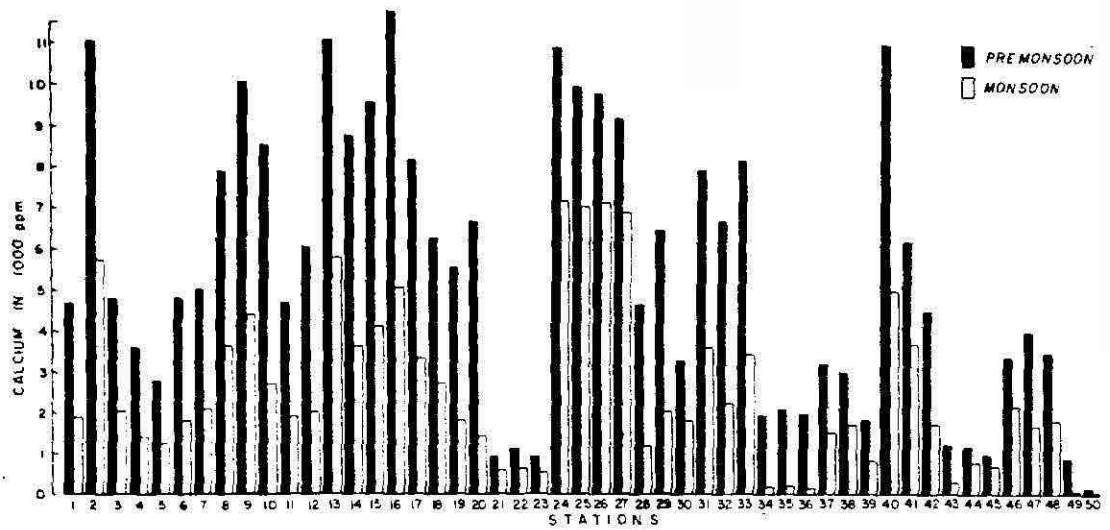


Fig. 6. The comparative distribution of exchangeable calcium during the premonsoon and monsoon periods.

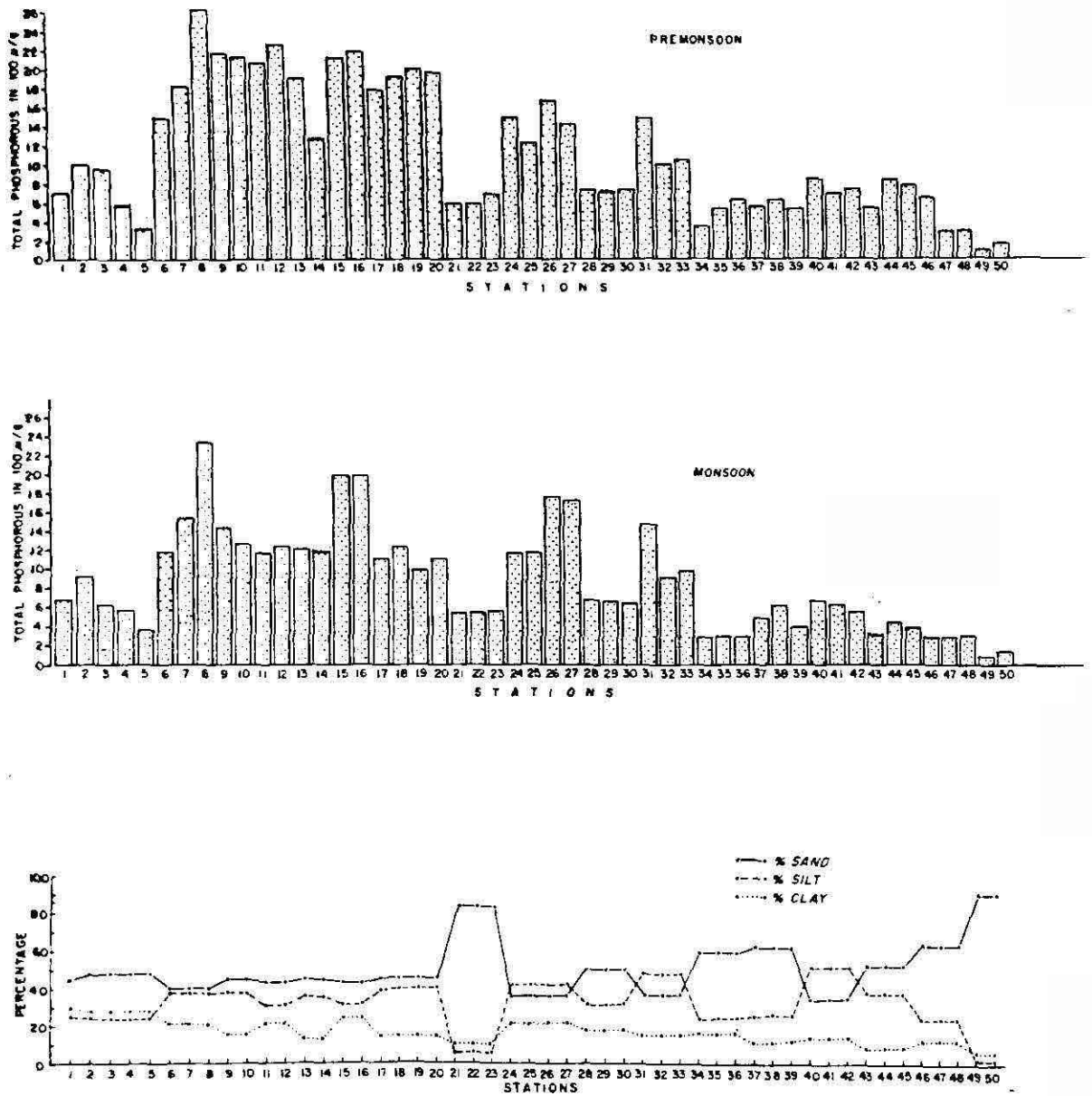


Fig. 7. Variations in the concentration of total phosphorous during the premonsoon and monsoon periods and its relation with the grain size distribution of soil.

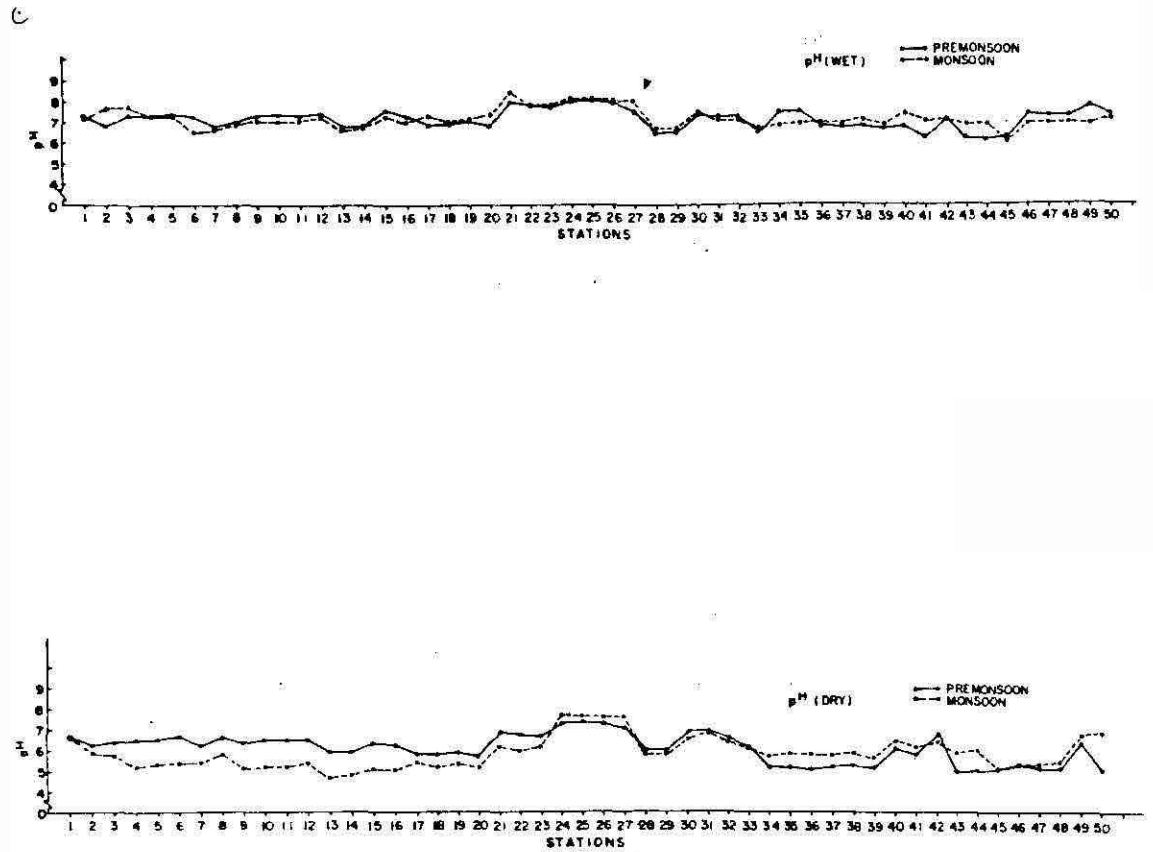


Fig. 8. Seasonal variation in the wet and dry pH of the soil.

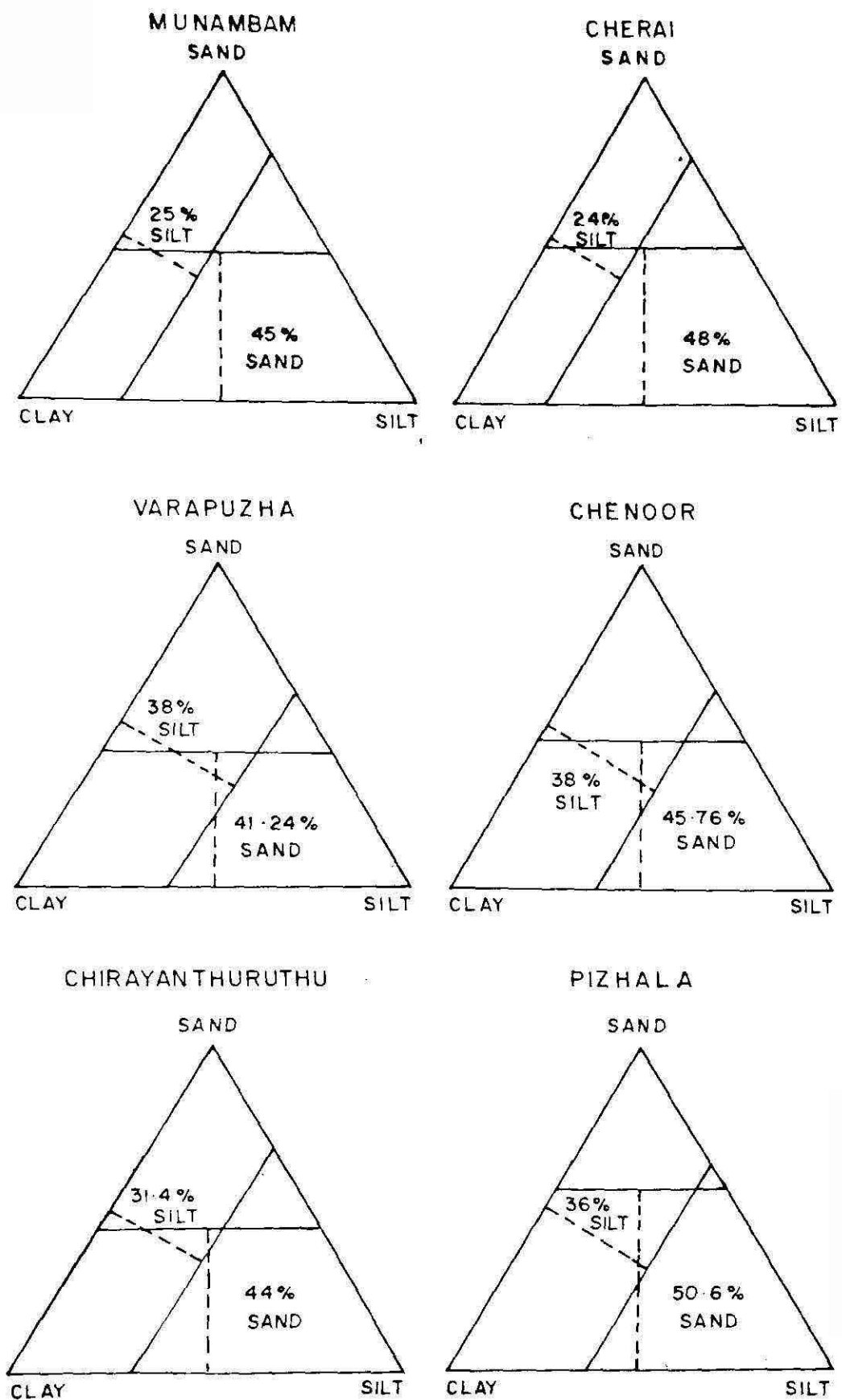


Fig. 9. Average soil composition in the different stations of sampling.

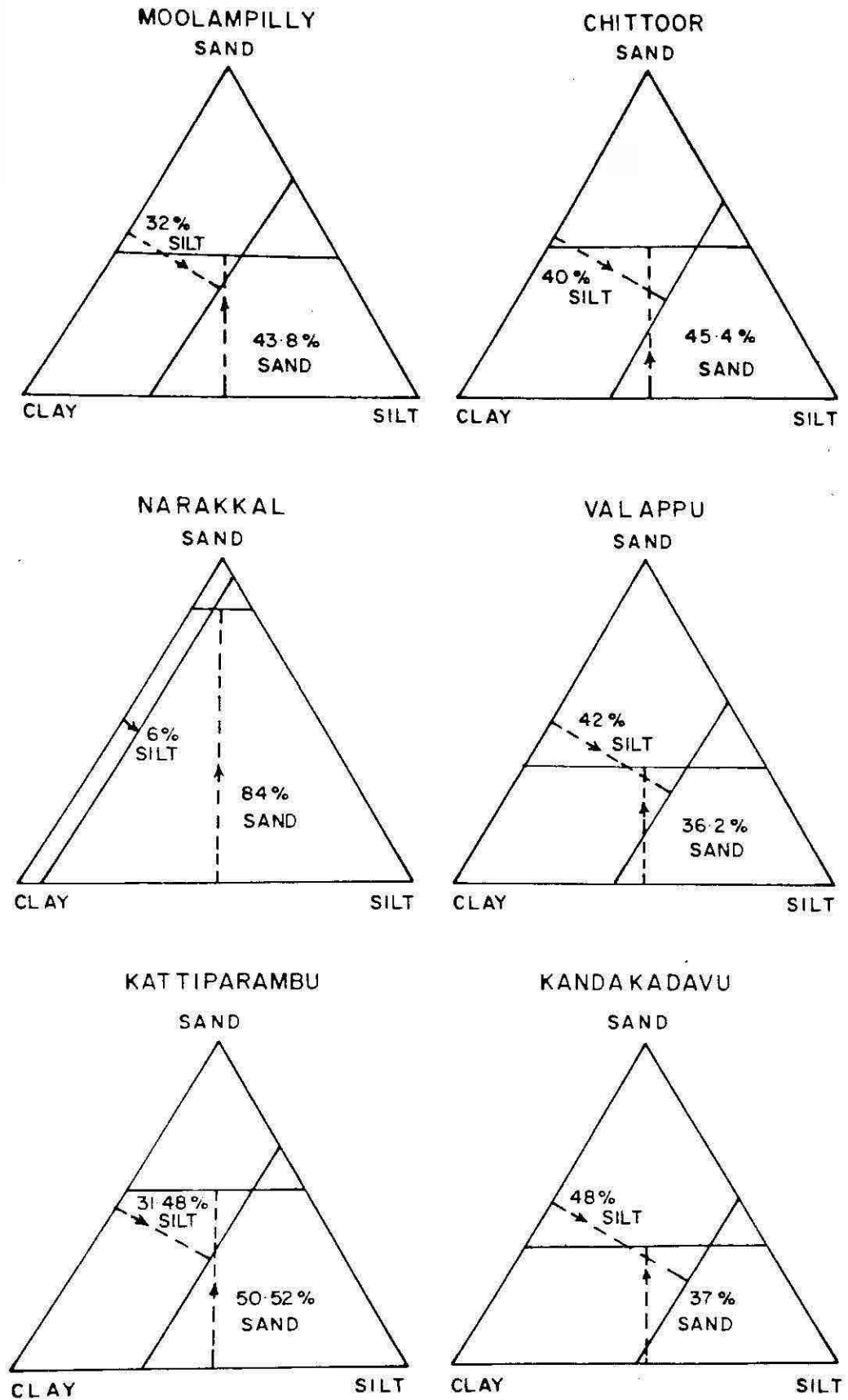


Fig. 9a. Average soil composition in the different stations of sampling.

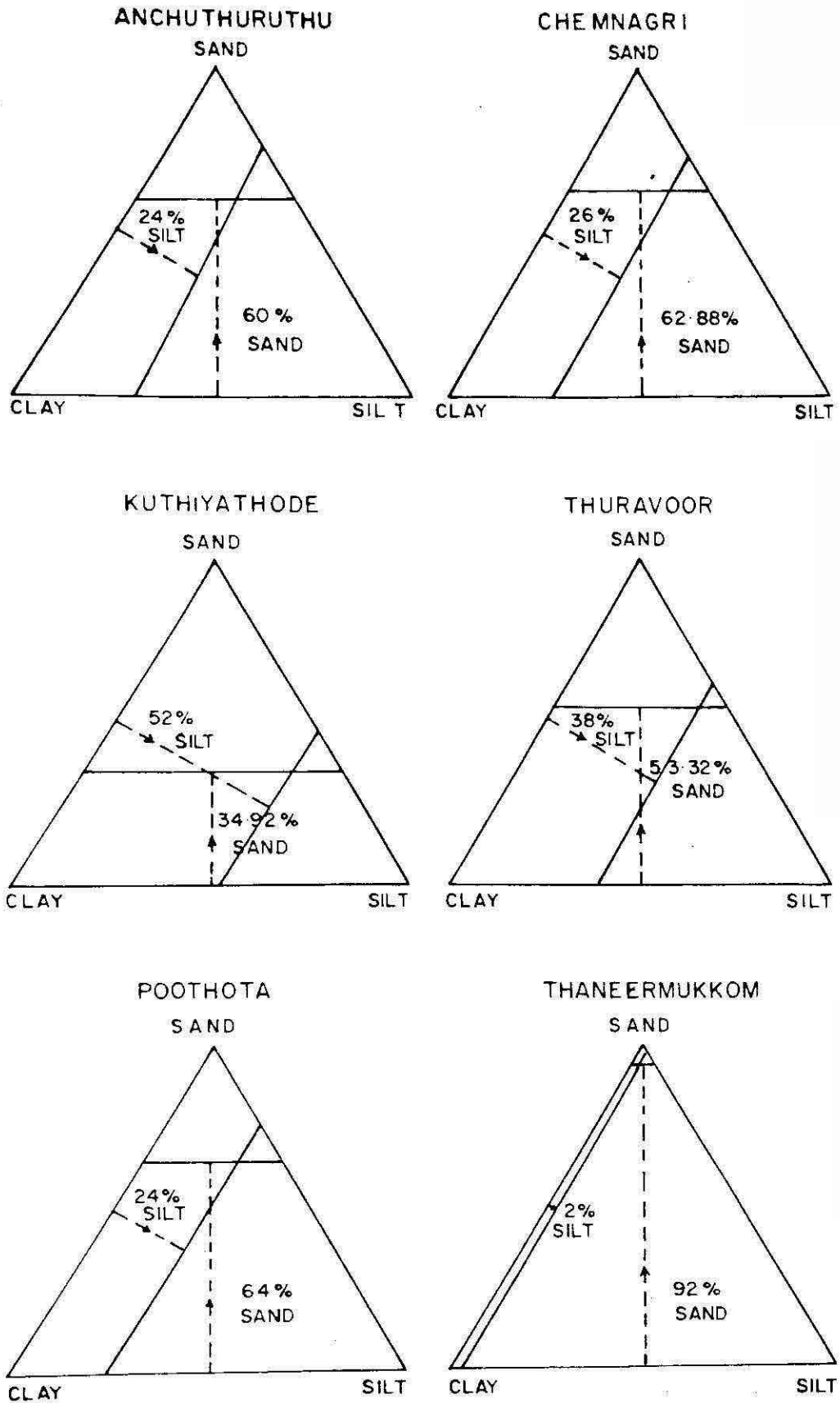


Fig. 9b. Average soil composition in the different stations of sampling.

Table 1. Variations in the concentrations of the exchangeable cations; sodium, potassium and calcium during the premonsoon and monsoon periods

Sta- tion No.	Sodium		Potassium		Calcium	
	Premonsoon	Monsoon	Premonsoon	Monsoon	Premonsoon	Monsoon
1	5,972	3,973	272	110	4,700	1,900
2	12,916	7,368	412	400	11,005	5,780
3	8,083	4,815	359	250	4,800	2,010
4	5,486	4,342	149	120	3,600	1,400
5	4,861	3,170	123	101	2,800	1,260
6	5,199	4,605	163	110	4,800	1,840
7	6,000	4,184	439	238	5,030	2,140
8	7,333	6,973	334	300	7,900	3,680
9	9,199	4,632	623	350	10,015	4,480
10	8,200	3,080	430	380	8,600	2,780
11	5,533	3,010	343	240	4,700	1,980
12	5,933	4,100	357	250	6,100	2,020
13	12,133	5,657	417	350	11,000	5,840
14	7,200	4,185	356	320	8,800	3,660
15	9,468	6,789	480	418	9,600	4,120
16	11,733	6,900	510	440	11,800	5,140
17	9,533	3,697	386	226	8,200	3,340
18	7,600	4,960	312	278	6,300	2,740
19	7,533	5,020	289	156	5,600	1,840
20	6,334	4,342	280	198	6,700	1,440
21	3,264	2,500	66	55	990	600
22	5,139	3,329	101	72	1,250	660
23	4,931	2,763	127	84	950	580
24	10,416	6,315	628	536	10,900	7,120
25	8,680	5,672	378	230	9,950	7,080

Table 1. Continued..

Station No.	Sodium		Potassium		Calcium	
	Premonsoon	Monsoon	Premonsoon	Monsoon	Premonsoon	Monsoon
26	11,736	6,381	685	656	9,800	7,140
27	12,500	6,578	745	640	9,200	6,900
28	7,291	3,789	334	306	4,600	1,240
29	7,638	6,100	329	300	6,400	2,020
30	5,763	4,355	254	200	3,300	1,820
31	7,534	4,987	676	630	8,000	3,360
32	7,734	4,815	371	300	6,700	2,200
33	9,266	7,592	645	322	8,200	3,480
34	2,900	1,092	96	52	1,900	160
35	2,934	1,118	87	66	2,100	200
36	3,134	1,157	100	54	2,000	180
37	4,067	4,973	160	150	3,200	1,540
38	3,999	2,500	153	145	3,000	1,760
39	11,195	7,434	570	116	1,840	860
40	10,866	7,100	526	496	11,000	5,300
41	6,599	3,010	298	170	6,200	3,720
42	7,866	3,118	517	470	4,500	1,790
43	8,666	2,010	535	100	1,250	340
44	8,675	2,421	565	204	1,240	880
45	8,600	2,578	465	188	1,040	700
46	5,999	2,500	233	176	3,400	2,240
47	6,667	5,010	235	184	4,000	1,720
48	5,667	3,697	220	172	3,500	1,680
49	1,799	829	30	20	900	80
50	934	590	40	24	160	60

Table 2 . Distribution of total phosphorous in the premonsoon and monsoon periods

Sta- tion No.	Total phosphorous in $\mu\text{g/g}$		Sta- tion No.	Total phosphorous in $\mu\text{g/g}$	
	Premonsoon	Monsoon		Premonsoon	Monsoon
1	682	671	26	1,691	1,794
2	1,090	906	27	1,418	1,754
3	950	619	28	736	695
4	579	560	29	693	671
5	375	360	30	743	643
6	1,481	1,180	31	1,500	1,497
7	1,831	1,532	32	1,010	910
8	2,643	2,348	33	1,025	985
9	2,188	1,434	34	341	291
10	2,153	1,271	35	545	293
11	2,080	1,174	36	611	286
12	2,296	1,239	37	546	486
13	1,937	1,213	38	615	610
14	1,363	1,173	39	515	392
15	2,154	2,000	40	852	671
16	2,200	2,017	41	695	652
17	1,800	1,108	42	750	582
18	1,948	1,239	43	545	358
19	2,010	1,000	44	818	456
20	1,980	1,115	45	789	392
21	586	522	46	358	293
22	593	523	47	287	280
23	693	560	48	295	292
24	1,500	1,174	49	71	65
25	1,227	1,181	50	150	130

Table 3. Seasonal variation in the wet pH and dry pH of the soil at different stations

Station No.	Premonsoon		Monsoon	
	Wet pH	Dry pH	Wet pH	Dry pH
1	7.30	6.65	7.18	6.65
2	6.80	6.25	7.68	5.86
3	7.30	6.45	7.70	5.74
4	7.35	6.50	7.25	5.20
5	7.40	6.52	7.37	5.35
6	7.30	6.70	6.50	5.30
7	6.80	6.20	6.60	5.40
8	7.00	6.60	6.90	5.80
9	7.30	6.42	7.10	5.10
10	7.40	6.50	7.00	5.20
11	7.30	6.45	7.10	5.20
12	7.40	6.50	7.20	5.40
13	6.75	5.88	6.60	4.65
14	6.80	5.89	6.70	4.70
15	7.60	6.30	7.40	5.05
16	7.30	6.20	7.00	5.00
17	6.90	5.80	7.38	5.40
18	6.90	5.80	7.00	5.20
19	7.00	5.90	7.11	5.30
20	6.80	5.75	7.34	5.10
21	8.00	6.87	8.41	6.20
22	7.80	6.75	7.76	6.00
23	7.70	6.70	7.79	6.10
24	7.95	7.30	8.06	7.70
25	8.00	7.40	8.16	7.65

Table 3. Continued...

Station No.	Premonsoon		Monsoon	
	Wet pH	Dry pH	Wet pH	Dry pH
26	7.90	7.30	8.00	7.60
27	7.50	7.10	7.99	7.60
28	6.50	6.00	6.70	5.80
29	6.50	6.00	6.60	5.70
30	7.35	6.85	7.40	6.50
31	7.25	6.55	7.30	6.90
32	7.30	6.60	7.10	6.40
33	6.50	6.20	6.70	6.10
34	7.50	5.20	6.86	5.70
35	7.50	5.20	6.98	5.85
36	6.80	5.10	6.96	5.80
37	6.70	5.20	6.98	5.75
38	6.80	5.30	7.20	5.85
39	6.70	5.15	6.85	5.60
40	6.80	6.10	7.42	6.47
41	6.20	5.80	7.10	6.20
42	7.20	6.80	7.28	6.35
43	6.20	5.00	6.90	5.90
44	6.20	5.00	6.98	6.00
45	6.30	5.10	6.00	5.25
46	7.40	5.30	6.98	5.30
47	7.30	5.10	7.00	5.35
48	7.30	5.10	7.01	5.40
49	7.80	6.40	6.88	6.80
50	7.40	5.10	7.16	6.90

Table 4. Total lime requirement based on exchange and potential acidity

Sta- tion No.	Premonsoon			Monsoon		
	Exchange acidity	Potential acidity	Total* tons/ha	Exchange acidity	Potential acidity	Total* tons/ha
1	0.448	54.24	54.73	1.120	31.02	32.14
2	1.512	very high	very high	0.784	55.30	56.08
3	0.896	95.73	96.62	0.560	29.77	30.33
4	0.280	74.45	74.73	0.056	34.03	34.08
5	0.224	53.18	53.40	0.056	33.18	33.23
6	1.400	52.12	53.52	2.016	44.67	46.68
7	5.040	57.43	62.47	1.904	51.05	52.95
8	3.752	55.31	59.06	2.072	55.30	57.37
9	1.344	77.64	78.98	3.528	72.32	75.85
10	1.008	75.51	76.52	3.360	68.06	71.42
11	1.456	75.51	76.96	0.840	29.77	30.61
12	0.784	76.58	77.36	0.560	31.54	32.10
13	1.568	76.58	78.15	2.128	76.69	78.82
14	1.400	75.51	76.91	2.016	77.78	79.79
15	0.560	73.40	73.96	1.400	55.30	56.70
16	0.728	74.50	75.23	1.232	51.05	52.28
17	3.024	44.67	47.69	1.288	85.06	86.34
18	2.800	52.12	54.92	1.680	87.25	88.93
19	3.248	51.05	54.29	1.568	88.11	89.67
20	3.192	55.31	58.50	1.904	89.32	91.22
21	0.168	12.76	12.93	**	18.29	18.29
22	0.168	10.63	10.79	**	17.43	17.43
23	0.112	11.70	11.81	**	17.86	17.86
24	0.784	65.94	66.72	**	46.79	46.79
25	0.616	63.82	64.43	**	44.67	44.67

Table 4. Continued ..

Sta- tion No.	Premonsoon			Monsoon		
	Exchange acidity	Potential acidity	Total* tons/ha	Exchange acidity	Potential acidity	Total* tons/ha
26	0.840	64.68	65.52	**	47.65	47.65
27	1.008	63.82	64.83	0.056	51.05	51.10
28	1.400	74.45	75.85	0.672	42.54	43.21
29	1.232	75.58	77.81	0.504	44.67	45.17
30	1.120	74.45	75.57	0.560	38.28	38.84
31	0.840	85.09	85.93	0.504	63.82	64.32
32	0.728	84.03	84.76	0.448	64.94	65.42
33	1.680	82.96	84.64	0.560	59.56	60.12
34	2.856	21.27	24.12	**	19.14	19.14
35	2.800	29.78	32.58	**	17.01	17.01
36	2.912	26.59	29.50	**	21.27	21.27
37	3.308	42.54	45.85	0.840	42.54	43.38
38	3.640	44.67	48.31	1.624	43.06	44.68
39	2.968	43.60	46.57	0.224	34.03	34.25
40	3.304	69.10	72.40	0.840	80.83	81.67
41	3.920	63.82	67.74	2.016	85.09	87.10
42	3.192	59.45	62.64	1.400	89.34	90.74
43	5.040	85.09	90.13	1.120	61.68	62.72
44	5.600	86.15	91.75	0.840	59.56	60.40
45	5.488	80.23	85.72	0.560	65.03	65.59
46	3.864	42.54	46.40	0.840	59.56	60.40
47	3.920	52.12	56.04	1.120	61.62	62.74
48	2.576	42.54	45.11	1.008	64.03	65.03
49	3.304	10.63	13.93	**	12.76	12.76
50	3.752	12.76	16.51	**	14.88	14.88

* The lime requirement is calculated by considering the weight of soil of 15 cm depth per hectare.

** The stations showed no lime requirement by the exchange acidity method.

Table 5. The structural composition of the soil
at different stations

Sta- tion No.	Percentage composition			Soil texture
	Sand	Silt	Clay	
1	45.00	25.00	30.00	Clayey sand
2	48.00	24.00	28.00	Clayey sand
3	48.20	23.80	28.30	Clayey sand
4	48.40	23.60	27.70	Clayey sand
5	47.40	24.60	28.00	Clayey sand
6	41.24	38.00	20.76	Silty sand
7	42.00	38.30	21.00	Silty sand
8	40.48	37.70	20.52	Silty sand
9	45.76	38.00	16.24	Silty sand
10	45.76	38.00	16.24	Silty sand
11	44.20	31.20	21.80	Silty sand
12	43.80	31.60	21.40	Silty sand
13	50.60	36.80	13.50	Silty sand
14	50.60	35.20	13.30	Silty sand
15	43.90	32.10	24.40	Silty sand
16	43.70	31.90	24.00	Silty sand
17	45.40	40.00	14.60	Silty sand
18	45.30	40.30	14.70	Silty sand
19	45.60	40.10	14.50	Silty sand
20	45.30	39.60	14.60	Silty sand
21	84.00	06.00	10.00	Clayey sand
22	83.60	06.30	09.10	Clayey sand
23	84.40	07.70	10.90	Clayey sand
24	36.20	42.00	21.70	Sandy silt
25	36.30	42.30	21.50	Sandy silt

Table 5. Continued ..

Station No.	Percentage composition			Soil texture
	Sand	Silt	Clay	
26	36.10	42.50	21.60	Sandy silt
27	36.20	41.20	22.00	Sandy silt
28	50.52	31.48	18.00	Silty sand
29	50.50	31.42	17.30	Silty sand
30	50.54	31.54	18.70	Silty sand
31	37.10	48.70	14.20	Sandy silt
32	37.00	48.00	15.00	Sandy silt
33	36.90	47.30	15.80	Sandy silt
34	61.00	24.90	15.80	Silty sand
35	60.00	24.00	16.00	Silty sand
36	59.00	23.10	16.20	Silty sand
37	62.88	26.20	11.00	Silty sand
38	62.83	26.00	11.20	Silty sand
39	62.93	25.80	10.80	Silty sand
40	34.92	52.00	13.08	Sandy silt
41	34.90	52.20	13.00	Sandy silt
42	34.94	51.80	13.16	Sandy silt
43	53.32	38.20	08.67	Silty sand
44	53.30	38.00	08.69	Silty sand
45	53.28	37.80	08.68	Silty sand
46	64.00	24.10	11.30	Silty sand
47	63.80	24.00	12.70	Silty sand
48	64.20	23.90	12.00	Silty sand
49	91.00	02.30	05.00	Clayey sand
50	93.00	01.70	07.00	Clayey sand

Table 6. The Range, Mean and Standard deviations of different parameters during premonsoon

Parameter	Range	Mean	Standard deviation
Sodium (ppm)	934-12,916	71,746.16	± 2,821.08
Potassium (ppm)	30-745	344.06	± 188.55
Calcium (ppm)	160-11,800	5,470.40	± 3,375.62
Total phosphorous ($\mu\text{g/g}$)	71-2,643	1,118.77	± 688.03
Wet pH	6.2-8.0	7.14	± 0.48
Dry pH	5.0-7.5	6.09	± 0.69
Lime requirement Total (Tons/ha)	10.79-96.0	61.23	± 24.63

Table 7. The Range, Mean and Standard deviations of different parameters during monsoon

Parameter	Range	Mean	Standard deviation
Sodium (ppm)	590-7,592	4,240.09	\pm 1,865.37
Potassium (ppm)	20-656	246.94	\pm 162.44
Calcium (ppm)	60-7,140	2,536.08	\pm 2,003.60
Total phosphorous ($\mu\text{g/g}$)	65-2,348	871.94	\pm 537.29
Wet pH	6.0-8.4	7.17	\pm 0.46
Dry pH	4.7-7.7	5.86	\pm 0.76
Total lime require- ment (Tons/ha)	12.76-91.22	51.60	\pm 22.90

Table 8. Correlation coefficients between the different soil parameters during premonsoon period

	Sodium	Potassium	Calcium	Total phosphorous	Wet pH	Dry pH	Lime requirement	Sand	Silt	Clay
Sodium	1									
Potassium	0.8504*	1								
Calcium	0.7439*	0.6377*	1							
Total phosphorous	0.4752*	0.4777*	0.6819*	1						
Wet pH	-0.1957	-0.2150	0.0507	0.0267	1					
Dry pH	--	--	--	--	0.1045	1				
Lime requirement	--	--	--	--	-0.1050	0.1201	1			
Sand	-0.6082*	-0.6385*	-0.7068*	-0.5572*	--	--	--	1		
Silt	-0.5740*	-0.6956*	-0.6141*	0.7629*	--	--	--	-0.9092*	1	
Clay	-0.0315	-0.2367	0.0119	0.3635*	--	--	--	-0.5915*	0.1944	1

* Significant at 1% level

Table 9. Correlation coefficients between the different soil parameters during monsoon period

	Sodium	Potassium	Calcium	Total phosphorous	Wet pH	Dry pH	Lime requirement	Sand	Silt	Clay
Sodium	1									
Potassium	0.6502*	1								
Calcium	0.6957*	0.7962*	1							
Total phosphorous	0.6262*	0.7236*	0.6286*	1						
Wet pH	0.1749	0.2507	0.3820*	0.2475	1					
Dry pH	--	--	--	--	0.5050*	1				
Lime requirement	--	--	--	--	-0.1872	-0.3080	1			
Sand	-0.5586*	-0.6659*	-0.6208*	-0.6037*	--	--	--	1		
Silt	0.4262*	0.6396*	0.5373*	0.5797*	--	--	--	-0.9092*	1	
Clay	-0.7999*	0.3169	0.0601	0.4560*	--	--	--	-0.5915*	0.1944	1

* Significant at 1% level

Table 10. Correlation coefficients between the different parameters during premonsoon and monsoon periods

	<u>Premonsoon</u>									
	Sodium	Potassium	Calcium	Total Phosphorus	Wet pH	Dry pH	Lime requirement	Sand	Silt	Clay
<u>Monsoon</u>										
Sodium	0.7709*	0.6198*	0.7468*	0.4810*	-0.0350	--	--	-0.5586*	0.4262*	-0.7999*
Potassium	0.7497*	0.8199*	0.7989*	0.5335*	0.5772*	--	--	-0.6651*	0.6396*	0.3169
Calcium	0.7591*	0.6478*	0.9078*	0.5229*	0.1696*	--	--	-0.6208*	0.5373*	0.0601
Total phosphorous	0.5494*	0.5959*	0.7616*	0.8960*	0.0333	--	--	-0.6037*	0.5797*	0.4560*
Wet pH	0.1347	0.0704	0.1936	-0.0146	0.1960	0.6094*	-0.1465	--	--	--
Dry pH	--	--	--	--	-0.0162	0.4836*	-0.1549	--	--	--
Lime requirement	--	--	--	--	0.1923	-0.1839	0.3684*	--	--	--
Sand	-0.6082*	-0.6385*	-0.7068*	-0.5572*	--	--	--	--	--	--
Silt	0.5740	0.6956*	-0.6140*	0.7629*	--	--	--	--	--	--
Clay	-0.315	0.2367	0.0119	0.3657*	--	--	--	--	--	--

* Significant at 1% level

DISCUSSION

There have been several studies on the water characteristics of the Cochin Backwaters and the adjoining fields. However, those relating to the physico-chemical characteristics of the soil are limited. With the increasing importance of brackishwater aquaculture in the suitable areas of the Cochin Backwaters to augment fish production, studies on the nature of soils and its characteristics have assumed greater importance. This is particularly so as the soil not only form a base for the culture of organisms but also play an important role in the production of the culture system.

The soil fertility depends to a certain extent on the exchangeable cations present, nature of the soil, its structure, and the magnitude of its exchange capacity. Among the exchangeable cations studied sodium was the highest cation encountered in the soil followed by calcium and potassium. Dean (1960) gave the range of these exchangeable cations in humid soils of temperate regions in shallow waters as 1,000 to 60,000 ppm for sodium, 2,000 to 40,000 for calcium and 1,000 to 60,000 for potassium. The values of exchangeable sodium recorded in the present study were found well within this range. However, in a few stations, values lower than the range given were also recorded. This might be accounted to the predominance

of sand in the soil (84 to 92%) and higher influence of freshwater in those stations.

Mollah et al. (1979) observed potassium contents of brackishwater pond soils in Bangladesh. He obtained maximum values up to 640 ppm, which was almost in accordance to that obtained in the present study. Banerjea (1967) recorded very low potassium contents in freshwater ponds. Milkfish ponds in Taiwan were classified into three categories or types by Tang and Chen (1967) on the basis of available potassium into low (less than 350 ppm), medium (350 to 500 ppm) and high (more than 500 ppm). In the present work, almost half the number of stations were found to belong to the low potassium category (less than 350 ppm), and ten stations to that of high potassium type. However, the distribution of potassium in this study area did not follow any specific pattern of variation. The soils containing higher proportion of sand had low potassium content, although the values were relatively lower as compared to the potassium ranges given by Dean (1960) for humid soils of the temperate regions.

Banerjea (1967) classified the soils with a calcium range of less than 1,000 ppm as low, 1,000 to 2,000 ppm as medium, 2,000 to 3,000 ppm as high and above 3,000 ppm as very high, while working on freshwater fish pond soils in different

States of India. In the present investigation, majority of the stations registered very high calcium values (above 3,000 ppm) during both the periods of sampling. In the freshwater pond soils, Banerjea (1967) recorded the maximum value of calcium at 3,870 ppm, while in the present study it was 11,005 ppm during premonsoon which declined to 7,140 ppm by the onset of monsoon. The algal pasture soils of Taiwan were classified by Tang and Chen (1967) based on their calcium content as low calcium (upto 700 ppm), medium calcium (700 to 1,200 ppm) and high calcium (more than 1,200 ppm). Majority of the stations in the Cochin Backwaters studied at present registered calcium values well in the high calcium range of Tang and Chen (1967), although some stations in the southern regime recorded lower calcium values. Further, the exchangeable calcium values of the ecosystem was also found to be in the range given by Dean (1967) for majority of the stations (2,000 to 40,000 ppm). Mollah et al. (1979) observed lower calcium values (upto 700 ppm) in their investigations on brackishwater pond soils of Bangladesh. Saha et al. (1971) observed the calcium content of a freshwater perennial pond in Orissa and recorded a maximum of 3,600 ppm of the cation. Most of the stations in the southern region of the backwaters during the premonsoon and majority of the stations during the monsoon period showed calcium content around this value or even lower.

Eswaraprasad (1982) carried out investigations on the exchangeable cations in the sediments of some brackishwater prawn culture fields near Cochin. He recorded a wide variation in the exchangeable cations viz., sodium, calcium and potassium in the sediments. He also reported wide monthly variation in the concentration of the cations from January to June. The maximum value of sodium reported by him was 21,502.78 ppm during the early part of the year which declined to 10,692.36 ppm by the onset of monsoon. Potassium ranged from 350.63 ppm to 1,002.48 ppm. Lower potassium values were recorded during monsoon. Concentration of calcium varied from 6,739.19 ppm to 11,997.78 ppm. In the present study the values obtained for exchangeable cations fell well within the range reported by him (Eswaraprasad, 1982) in the more estuarine areas while lower values were observed in freshwater dominated zones. The concentrations of the cations showed a decreasing trend towards the southern part of the backwaters where freshwater ingress was more. Besides, the tidal influence was also relatively less in this region as it was away from the bar mouth. However, relatively low values of sodium obtained in this study might be due to a few heavy premonsoon showers preceding the sampling.

Tang and Chen (1967) reported that during the rainy season the exchangeable cations may be washed out as they are

soluble in water. All the cations showed appreciable amount of leaching, with calcium registering the highest. Eswaraprasad (1982) reported that exchangeable sodium and calcium had direct relationship with the salinity of the overlying water, while potassium and salinity were not found to be significantly correlated. The sharp decline in the sodium and calcium content in the soils during the monsoon period in the present findings might be due to their direct relationship with salinity as opined by Eswaraprasad (1982). He also reported a steep decline in the salinity of the brackishwater ponds due to the heavy rains during the monsoon period.

Statistical analysis revealed significant correlations between the exchangeable cations and grain size distribution. Sand fraction of the soil showed highly significant inverse relationships during both the sampling periods. This indicated that a high content of sand lowers or brings down the concentration of the cations. The cations also showed significant correlations with the silt fraction, displaying higher concentrations when the proportion of silt was greater in the soil. Clay didn't have significant correlations with any of the cations during premonsoon. Direct relationship was also seen between the different cations, as higher concentration of one cation was indicative of greater concentration of the other or vice versa (Tables 8 & 9).

The amount of the exchangeable cations present in the soil, their retention and leaching depended upon the grain size distribution as well as the rate of water exchange in the ponds. Ponds with higher rate of water exchange, by way of direct link to the main water systems or to canals had lower concentration of the cations in the soil. The amount of leaching in such ponds were also considerable. In those ponds, with minimum exchange of water, higher concentration of the cations were observed. Also the leaching of the cations over the season was not high in these pond soils. Thus both the rate of water exchange as well as soil texture play significant roles in the concentration of the cation in the soil.

The importance of soil phosphorous in determining the productivity of fish ponds is well recognised. Its apparent success as a fertilizer has attracted considerable interest in its studies. Phosphorous is generally recognised as the key nutrient in the fertility of fish ponds. This nutrient frequently limits plant production and ultimately influences fish production. Conversely, too much phosphorous is sometimes responsible for excessive blooms in ponds.

The dynamics of phosphorous in fish ponds have been discussed by Boyd (1971). According to him the in situ supply of phosphorous in newly constructed ponds is the vegetation and

the newly inundated soil. Other possible sources of inputs of phosphorous are inflow of water, from the atmosphere by precipitation, plants bordering the pond, animals in the waterbody and fertilization. The possible ways of loss of phosphorous are by outflow of water, animal activity, fish harvest and permanent loss to the sediment. Phosphorous in sediments may be present in either organic or inorganic forms, the sum of these being the total phosphorous. It is the inorganic forms that are generally regarded as being more readily available to the life forms.

Several studies have been carried out on the distribution of total phosphorous in the Cochin Backwaters. Murty and Veerayya (1972) investigated the distribution of total phosphorous of the sediments in the Vembanad lake. Their analysis revealed that the phosphorous content varies from $37 \mu\text{g/g}$ to $1,679 \mu\text{g/g}$, with an average value of $416 \mu\text{g/g}$. They recorded that the amount of phosphorous showed a decreasing trend from the estuarine region to the freshwater zone. Sankaranarayanan and Panampunnayil (1979) also studied the total phosphorous in the Cochin Backwaters. Their findings showed that the total phosphorous ranged from $900 \mu\text{g/g}$ to $2,400 \mu\text{g/g}$. They observed a lower value during the monsoon months. Qasim and Sankaranarayanan (1972) reported that total phosphorous in the detritus of Cochin Backwaters ranged from $1300 \mu\text{g/g}$ to

1900 $\mu\text{g/g}$.

In the present investigation, the total phosphorous values ranged from 71 $\mu\text{g/g}$ to 2,643 $\mu\text{g/g}$ during the premonsoon and 65 $\mu\text{g/g}$ to 2,348 $\mu\text{g/g}$ in monsoon. These values agree with those reported by Sankaranarayanan and Panampunnayil (1979) and Murty and Veerayya (1972) with some marginal variations. The maximum value of total phosphorous reported by Murty and Veerayya (1972) were low when compared to that recorded in the present study. The variability might be explained to the textural nature of the sediments and also that their (Murty & Veerayya) sampling stations were located in the open waters of the Vembanad lake. Also, they did not include the northern sector of the backwater in their study. In the present study most of the samples were from shallow ponds adjoining the backwater system. Both Murty and Veerayya (1972) and Sankaranarayanan and Panampunnayil (1979) observed a decline in the phosphorous values from the estuarine to the freshwater zone and this agrees with the present findings. Sankaranarayanan and Panampunnayil (1979) recorded lower phosphorous values during the monsoon, and increased values in the following months. Lower values were also observed during monsoon in the present work; a decline in the average value of total phosphorous from 1,118.78 $\mu\text{g/g}$ during premonsoon to 871 $\mu\text{g/g}$ during monsoon was observed. The lower values recorded during the monsoon

period might be due to the leaching of phosphorous both from interstitial and adsorbed forms from mud to the overlying water. Freshwater dominates the system during this period and during high-tide saline waters enter the estuary in the form of a tongue beneath the overlying freshwater and intense circulation during the period might be helping the release of phosphates from the mud to the overlying water.

Seeralathan and Seetharamaswamy (1979) investigated the total phosphorous distribution in the modern deltaic sediments of Cauvery River and reported that the marine zone had higher concentrations of phosphorous and the river channel the least. Hart et al. (1976) analysed the total phosphorous of sediments in Lake Mulwala, Australia, which is a fresh water lake. They observed a range of total phosphorous from 350 to 1,188 $\mu\text{g/g}$. Similar values were recorded in the present work in the fresh-water zones of the Cochin Backwaters.

Total phosphorous showed highly significant correlation with silt and clay and an inverse relationship with sand contents of the soil. Soils containing higher proportions of the finer fractions of the soil registered high phosphorous values while those containing more sand contained comparatively lower concentrations of phosphorous. Murty and Veerayya (1972) also observed that the fine grained sediments viz., silty clays

and clayey silts had higher concentrations of phosphorous than those in the sands and silty sands.

In the present study, the total phosphorous showed a definite pattern of distribution with the northern and north central regions of the Cochin Backwaters recording higher concentration of phosphorous, while the middle and southern zones showed relatively lower values. Gopinathan et al. (1982) reported that the north central regions of the Cochin Backwaters were the most productive areas in the system. The high production in this zone could be explained by the fact that the area has two openings to the sea at a short distance enabling greater water circulation and nutrient exchange. The river Periyar deposits a large amount of silt and clay in this region and this also attributes to the high nutrient content and higher fertility in the zone.

pH of the soil is dependant on various factors. If mud layers are not well aerated, oxygen supply falls short, decomposition of organic matter becomes slow and its by products are reduced or partially oxidized compounds such as H_2S , CH_4 and short chain fatty acids. These make the soils acidic leading to decreased rate of bacterial action, ultimately to less productivity. pH of soil influences inorganic transportation of soluble phosphate and control the adsorption and

release of ions of essential nutrients at soil water interface.

Banerjea (1967) grouped freshwater pond soils into five categories according to their pH (i) less than 5.5 (ii) 5.5 to 6.5 (iii) 6.5 to 7.5 (iv) 7.5 to 8.5 and (v) greater than 8.5. He also observed that most of the ponds with pH less than 5.5 were unproductive. Ponds with pH near neutral were highly productive. No production was met with in high alkaline condition (pH greater than 8.5). According to him, the optimal soil reaction was found in the pH range of 6.5 to 7.5, though they might not be considered very rigorously with respect to production. In the present study, wet pH values ranged from 6.2 to 8.0 in the premonsoon while during monsoon the range was from 6.0 to 8.4. The areas thus could be categorized as belonging to the productive area as classified by Banerjea (1967).

The dry pH of the soil showed an acidic trend during both the periods, with lower values being recorded during monsoon. Pillai et al. (1983) recording low pH (3.0 to 7.0) in the Vembanad Lake reported on the effect of pH variation noted in the waters and subsequent mortality of the fauna especially the clams, Villorita sp. They explained that the low pH values were due to the leaching out of acid waters from

the paddy fields and adjacent canals with the onset of monsoon after a severe summer season. In the present investigation, low pH values were obtained in majority of the stations in the southern regions, and this might be related to the same phenomenon as explained by Pillai et al. (1983). The dry pH during the monsoon period was not very low in the same area because flushing of the area by rainwater might have removed a substantial amount of acidity from the soil.

The dry pH during premonsoon showed significant relationship with wet pH during monsoon. During monsoon lower wet pH values were recorded due to the release of acidity by the rainwater. When distilled water is added to the sun dried premonsoon soil samples, the acidity is released which lowers the pH which is similar to the wet pH values during monsoon where rainwater releases the acidity, if present, in the dry soil.

The application of lime to improve the fertility as well as production is already being practiced by the traditional farmers and aquaculturists in this region. However, the dosage applied is not based on any scientific data or estimation. Recently, due to the increasing awareness of the benefits of liming, scientifically estimated dosages have been recommended by many workers. A dosage of 1 to 2 tons/ha of

quicklime for acidic soils and 1.8 to 2.2 tons/ha of the same for stagnant water pond soils have been recommended by Yap *et al.* (1979). Tripathi (1983) has advocated the use for 200 to 800 kg/ha of quicklime for combating acidity and improving the bottom soil in the freshwater regime.

Usually the estimation of lime requirement for fish ponds are based on the exchange acidity of the soils. However, in some tropical areas like The Phillipines, India etc., the soil in the brackishwater regions are prevalent with acid sulfate. In such type of soils in order to correctly estimate lime requirement, the potential acidity of the soil is also to be analysed in addition to the estimation by exchange acidity. The total lime requirement is calculated by adding both values together. In some of the culture fields in the present study, the soil is reported to be having the acid sulfate problem.

Barnhisel (1975) calculated the lime requirement for acid sulfate soils of brackishwater pond soils in Phillipines as ranging from 0.1 to 11.3 tons of CaCO_3 /ha for soils of pH 7.8 and 3.2 respectively on the basis of exchange acidity. In the present work, the estimated lime requirement by this method varied from 0.112 to 5.6 tons/ha during premonsoon when pH ranged from 6.2 to 8.0 and from zero to 3.52 tons of

CaCO_3/ha , in monsoon when the pH was 8 and 6 respectively.

Lime requirement calculated by potential acidity method gave high values during both the seasons. It ranged from 10.63 to 95.73 tons/ha in premonsoon and from 17.01 to 89.34 tons/ha in monsoon. The pH was well within the normal range in all the stations (6.0 to 8.4). Barnhisel (1975) calculated lime requirement by the potential acidity method upto 56 tons/ha in ponds with pH 7 and 47 tons of CaCO_3/ha in those with pH 7.8. The average values of lime needed, calculated during the present investigation by the same method were similar to the values obtained by Barnhisel (1975). He reported the paradox between the pH and potential acidity and observed that samples from submerged or recently drained areas had high pH values but their potential acidity was high and often these high pH values were misleading. This might explain the high potential acidity observed in the samples with normal pH during the present studies.

Potter (1977) opined that acid sulfate soils require relatively larger quantity of lime application, between 20 to 100 tons/ha due to their low pH values. As the pH in most of the stations recorded in the present study was above 6.0, and the estimated lime requirement as indicated above was 10 to 95 tons/ha and this agrees with the estimate of Potter (1977).

Statistical analysis showed no significant correlation between pH and lime requirement. This might be due to the collection of submerged mud samples during both the seasons. However, during monsoon season dry pH and lime requirement showed some correlation. This might be due to flooding and leaching of the soil acidity during the heavy rains.

The data presented here are from results of limited experiments carried out in the laboratory and estimated by considering the values obtained by exchange and potential acidity together (Table 4), the quantity obtained appears to be high. Hence it is suggested that field trials may be carried out to confirm the rates of lime application recommended for this region.

From the present investigation it was observed that ponds with soil predominantly composed of the finer fragments of silt and clay were nutrient rich and hence ranks high in fertility. In soils with higher proportion of sand, these nutrients were found to leach out particularly during the heavy rains and correspondingly reducing the soil fertility which in turn affects the productivity of the area. The seasonal and perennial fields located in the north central part of the Cochin Backwaters, between the Cochin bar mouth and Azhikode, had higher contents of the exchangeable cations and phosphorous in their

soils. The soil in this region also had predominance of silt and clay, further this region was supplied with regular tidal waters from the two bar mouths. These features contributed to the relatively higher production rates of this area. This observation confirms the earlier findings of Gopinathan et al. (1982).

Since the present investigations were time bound as well as of a short term nature, it was not possible to cover all the aspects of soil studies. Some of the parameters like nitrogen and trace metals in the soil could not be estimated due to shortage of time. However, the information obtained and the data collected revealed the basic nature of the soil characteristics and also the soil fertility of a large area in Cochin Backwaters. The required information for the calculation of lime requirement, which will help considerably to augment the overall production in the ecosystem is also made available. The information presented will be of immense use in future for the Government agencies as well as for the individual farmers who will be interested in taking up brackishwater aquaculture in the region.

SUMMARY

1. This study deals with a comparative account of the soil properties from the aquacultural systems located in the periphery of the Cochin Backwaters.
2. Soil samples were collected from seasonal and perennial culture systems located in the backwater area covering a distance of about 75 km. north-south, during premonsoon and monsoon periods.
3. Soil samples were sun-dried and analysed for exchangeable sodium, potassium and calcium; total phosphorous. The grain size distribution were also estimated. Wet pH was determined on the same day of sampling and dry pH recorded prior to analysis. Lime requirement based on exchange acidity as well as potential acidity were estimated and finally the total lime requirement was calculated.
4. The exchangeable cations showed wide variation in space and time. The cations registered lower values during the monsoon period. The variation in the concentration of exchangeable cations have been explained due to the soil texture and the rate of water exchange in the culture systems.
5. Total phosphorous also showed wide variation in concentration with a definite pattern of distribution, with the

northern and north central regions recording higher values.

6. Both wet and dry pH showed an acidic trend in the monsoon than in the premonsoon. This is attributed to the release of acidity possibly due to the flushing by rainwater.
7. Grain size analysis revealed three textural classes. Clayey sand, silty sand and sandy silt. Significant correlations were obtained between the grain size and the concentration of exchangeable cation as well as total phosphorous.
8. Lime requirement calculated from potential acidity showed high values although the pH values were moderate. This is explained due to the reason that samples collected from areas submerged under water showed high pH values though their potential acidity was high.
9. It was found that the northern and north central regions of the backwaters ranked higher in fertility. This is explained due to the predominance of the fine grained fractions of the sediment in the soil. The intense circulation of water by tidal action, brought through the two bar mouths situated at a short distance and the deposition of silt, clay and nutrients by the River

Periyar, adds to the fertility of this area.

10. The fertility status of this system is comparable to those studied in other parts of India as well as in the south east Asian Countries, where aquaculture operations are in vogue.

R E F E R E N C E S

- *ACRE, R.G. AND C.E. BOYD. 1975. Effects of agricultural limestone on the water chemistry, phytoplankton productivity and fish production in soft water ponds. Trans. Amer. Fish. Soc., 104: 308-312.
- ANSARI, Z.A. AND M.D. RAJAGOPAL. 1974. Distribution of mud phosphates in the Cochin Backwaters. Mahasagar. Bull. Nat. Inst. Oceanogr., 7(3 and 4): 151-156.
- BALAKRISHNAN, A. 1957. Variation of salinity and temperature in the Ernakulam Channel. Bull. Cent. Res. Inst., 2: 7-9.
- BANERJEA, S.M. 1967. Some observations on water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian J. Fish., 14(1 and 2): 115-142.
- BANERJEA, S.M. AND S.R. GOSH. 1970. Studies on the correlation between soil reaction and different forms of bond phosphorous in pond soils. J. Inld. Fish. Soc. India, 2: 113-120.
- BEAR, FIRMAN. 1964. Chemistry of the soil. Oxford and IBH Publishing Company, New Delhi.
- *BOWLING, M.L. 1962. The effects of lime treatment on benthos production in Georgia farm ponds. Proc. Annual. Conf. S.E. Association Game and Fish Comm., 16: 418-424.
- BOYD, CLAUDE, E. 1971. Phosphorous dynamics in Ponds. Proc. of 25th Annual Conf. S.E. Association Game and Fish Comm., 16: 418-426.
- BOYD, CLAUDE, E. 1974. Lime requirement of Alabama fish ponds. AL Agr. Exp. Sta., Auburn Univ., A.L. Bull., 459: 1-20.
- BOYD, CLAUDE, E. 1976. Lime requirement and application in fish ponds, In: T.V.R. Pillay and W.A. Dill (Ed.) Advances in Aquaculture Fishing News (Books) Ltd., Farsham, England, 120-122.
- BOYD, CLAUDE, E. 1982. Water Quality in warm water fish ponds. Auburn University, Alabama, USA.

- BARNHISEL, I. RICHARD. 1975. Preliminary and Final Reports, Acid Problem at the Brackishwater Aquaculture Center, Leganes Iloilo, Phillipines.
- BREEMAN, N. VAN. 1973. Soil Forming Process in Acid Sulfate Soils. Proc. of Inter. Sym. on Acid Sulfate Soils, 1: 66-161.
- *BREEST, F. 1924. Uber die Beziehungen Zwischen Teichwasser, Teichschlamm and Teichuntergrund, Arch. Hydrobiol., p. 422.
- BRINKMAN, R. AND L.J. PONS. 1973. Recognition and Prediction of Acid Sulfate soil conditions. Proc. of Inter. Sym. on Acid Sulfate soils., 1: 169-203.
- *BURROWS, W. AND T.V. CORDON. 1936. The influence of the decomposition of organic matter on the oxidation reduction potentials of the soils. Soil. Sci., 42: 1-10.
- CHERIYAN, P.V. 1967. Hydrobiological studies in and around Cochin Harbour, Bull. Dept. Mar. Bio. and Oceanogr. Uni. Kerala, 3: 9-17.
- *CHOU et al., 1961. Freshwater fish culture in China, Peking Science Publishing House, p. 612.
- *DANIELEWSKI, S. 1965. Mineralisation of bottom sediments during winter draining of fish ponds. Roc. Zn. Nank. Rol(B)., 2: 341-359.
- DEAN, A. JOHN. 1960. Flame Photometry. McGraw-Hill series in Advanced Chemistry.
- *DEMOLL, R. 1925. 'Teichdungung' (Pond Manuring). Handb. d. Binnenfischerei. Mitteleuropos., 4: 53-160.
- *EDWARDS, R.W. AND H.L.J. ROLLEY. 1965. Oxygen consumption of river muds. J. Ecol., 53(1): 1-19.
- ERGEB. 1982. Phosphorous release from lake sediments. Limnol. Oceanogr., 18: 5-59.
- ESWARAPRASAD, P. 1982. Studies on soils of some brackishwater prawn culture fields around Cochin. Unpublished M.Sc. Dissertation submitted to the Cochin University.
- FAO. 1975. Manual of methods in aquatic environmental research. Part I - Methods for detection, measurement and monitoring of water pollution. FAO. Fish. Tech. Paper., 137: 206-208.

- *FIJAN, N. 1967. Problem in carp pond fertilization. FAO fish Rep., 3(44): 114-123.
- *FREY, D.G. 1947. The Pond Fisheries of Phillipines. J. Mar. Res., 6: 247-258.
- GEORGE, M.J. AND K.N.K. KARTHA. 1963. Surface salinity of Cochin Harbour with respect to tide. J. Mar. Biol. Ass. India, 5.
- GEORGE, K.C. 1974. Some aspects of prawn culture in the seasonal and perennial fields of Vypeen Island. Ind. J. Fish., 21(1): 1-19.
- GOOCH, BRUWELL, C. 1967. Appraised of N. American fish culture fertilization studies. FAO. Fish. Rep., 40(1): 13-27.
- GOLTERMAN, H.L. 1967. Influence of soil on the chemistry of water in relation to productivity. FAO. Fish. Rep., 44(3): 27-42.
- GOPINATHAN, C.P., P.V. RAMACHANDRAN NAIR, V. KUNJUKRISHNA PILLAI, P. PARAMESWARAN PILLAI, M. VIJAYAKUMARAN AND V.K. BALACHANDRAN. 1982. Environmental characteristics of the seasonal and perennial prawn culture fields in the estuarine system of Cochin. Proc. Sym. Coastal. Aquaculture, 1: 369-382.
- GUPTA SEN, R. AND SUGANDHINI NAIK. 1981. Studies on the Calcium, Magnesium and Sulfate in the Mandovi and Zuari River systems (Goa). Ind. J. of Mar. Sci., 10(1): 24-34.
- HART, B.T., R.J. MCGREGOR AND W.S. PERRIMAN. 1976. Nutrient status of the sediments in Lake Mulwala. I. Total phosphorous, Aust. J. Mar. Fresh. Res., 27: 129-135.
- HARTNER, R.D. 1968. Adsorption of phosphorous by lake sediments. Soil. Sci. Soc. Am. Proc., 32: 514-518.
- *HAYNES, F.R. 1952. On the kinetics of phosphorous exchange in lakes. J. Ecol., 40: pp. 202.
- *HICKLING, C.F. 1962. Fish cultures, Faber and Faber, London, pp. 225.
- *HOBER, 1914 and 1915. "Teichdungsersucke" (Pond manuring experiments) Ost. Fisch. Ztg., Nos. 11 and 12.

- *HUET, M. 1952. Treatise on Fish Culture. Bruxelles, Editions la Vic Rustique, Avenue Georgis Henri., 299-369.
- JOS ANTO, V. 1967. The bottom salinity characteristics and the factors that influence the salt water penetration in Vembanad lake. Bull. Dept. Mar. Biol. and Oceanogr. Kerala Uni.
- JOS ANTO, V. 1971. On the grain size distribution of the Cochin Backwater Sediments. Bull. Dept. Mar. Biol. Uni. Cochin, 5: 109-172.
- *KAVELEC, A. 1973. World distribution of acid sulfate soils. Proc. of Int. Sym. on Acid. Sulfate soils, 1: 292-295.
- *KRUGELL, C. AND H. HEINRICH. 1939. Fertilization of ponds. Superphosphate, 12: 101-106.
- KRUMBEIN, W.C. AND C.T. PETTIJOHN. 1938. Manual of sedimentary Petrography. Appleton century - crofts, New York.
- *LAWSON, E.B. 1937. Fertilisation of fish ponds in Czechoslovakia. The Programme Fish Culturist., 1-131(32): 18-23.
- LAXMANAN, P.T. 1982. Distribution and seasonal variation of temperature and salinity in Cochin Backwaters. Ind. J. Mar. Sci., 11: 170-172.
- *MARCHING, V. 1975. 'Forshungsergebnisse'. Meteor., 11: pp.104.
- *MACIOLEK, A. 1954. Artificial fertilization of lakes and ponds. Spec. Sci. Rep. U.S. Fish. Wildl. Ser. Fish., (113): p. 41.
- MANDAL, L.N. 1962. Effect of salinity on the transformation of Nitrogen in brackishwater fish farm soil. J. Ind. Soc. Soil. Sci., 10(4): 255-262.
- MANIKOTH SREEDHARAN, 1975. A preliminary study of the distribution of calcium in Cochin Backwaters. J. Mar. Biol. Assn. India., 17(3): 706-710.
- MANIKOTH SREEDHARAN AND MOHAMMED SALIH. 1974. Distribution characteristics of nutrients in the estuarine complex of Cochin. Ind. J. Mar. Sci., 3: 125-130.

- MANIVASAKAM, N. 1985. Physico-chemical examination of water, sewage and industrial effluents. Pragati Prakashan, Meerut, India.
- MATIDA YOSHIHIRO, 1967. The role of soil in fresh pond productivity in Asia and the Far East. FAO. Fish. Rep., 44(3): 54-63.
- MEEHEAN, O.L. AND F. MARZULLI. 1945. The relationship between production of fish and carbon and nitrogen contents of fertilized ponds. Trans. Amer. Fish. Soc., 69: 257-262.
- MINTS, A.G. AND E.N. KHAIRULINA. 1968. Intensive forms of rearing fish in ponds in peat hags. FAO. Fish. Rep., 5(44): 233-234.
- MOLLAH, O.L., A.K.M. AMINUL HAQUE, M. EAQUB, M. IDRIS AND M.Y. CHAUDHURY. 1979. Interaction between pond bottom soil and water qualities. Ind. of Fish., 26: 1-2.
- *MORTIMER, C.H. 1941. The exchange of dissolved substances between mud and water in lakes. J. Ecol., 29: 280-329.
- *MORTIMER, C.H. 1942. The exchange of dissolved substances between mud and water in lakes. J. Ecol., 30: 147-201.
- *MORTIMER, C.H. 1949. Seasonal changes in the chemical composition near the mud surface in two English lake districts. Verh. Int. Ver. Limnol., 10: 353-356.
- *MORTIMER, C.H. 1950. Underwater soils: A review of lake sediments. J. Soil. Sci., 1: 63-73.
- *MORTIMER, C.H. 1954. Fertilizers in fish ponds. Her Majesty's stationary office. London, Fish Publ., 5: 155 p.
- MURTY, P.S.N. AND M. VEERAYYA. 1972. Studies on the sediments of Vembanad Lake, Kerala State. I. Distribution of total phosphorous. Indian J. Mar. Sci., 1(2): 106-115.
- NAIDU, A.S. AND X.L. DORA. 1967. Geochemical behaviour of phosphorous in the non-detrital sedimentary cycle - A Review. Bull. Dept. Mar. Biol. and Oceanogr. Uni. of Kerala, 3: 33-40.

- *NEESS, J.C. 1946. Development and status of pond fertilization in Central Europe. Trans. Amer. Fish. Soc., 76: 355-358.
- PILLAY, T.V.R., M.R. VIJAYARAGHAVAN AND S.C. THAKURTA. 1962. An ecological study of benthic flora in brackishwater bheries. Proc. Nat. Inst. Sci. India., (B), 28(5): 416-431.
- PILLAI GOPALAKRISHNA, N. 1977. Distribution and seasonal abundance of macrobenthos of the Cochin Backwaters. Indian J. of Mar. Sci., 6(1): 1-5.
- PILLAI, V.K., A.G. PONNIAH, D. VINCENT AND I. DAVID RAJ. 1983. Acidity in Vembanad Lake causes fish mortality. Mar. Fish. Infor. Serv. T&E Ser., 53: 8-15.
- PILLAI, V.K. AND C.E. BOYD. 1984. A simple method for calculating liming rates for fish ponds. Manuscript submitted to Aquaculture.
- PIPER, C.S. 1947. Soil and plant analysis, the University of Adelaide, Adelaide.
- POMEROY, L.R., E.E. SMITH AND C.M. GRANT. 1965. The exchange of phosphate between estuarine water and sediments. Limnol. Oceanogr., 10(2): 167-172.
- PONNAMPERUMA, F.N., T. AHANANADAMA AND GORA BEYE. 1973. Amelioration of three acid sulfate soils for lowland rice. Proc. of Inter. Sym. on Acid Sulfate Soils., 2: 384-391.
- POTTER THOMAS. 1977. The problem to fish culture associated with acid sulfate soils and methods for their improvement. Joint FAO-UNDP/SCSP and SEAFDEC regional Workshop on Aquaculture Engineering.
- *POVOLEDO, D. 1964. Some comparative physical and chemical studies on soil and lacustrine organic matter. Mem. Inst. Ital. Hydrobiol., 17: 21-32.
- QASIM, S.Z. AND V.N. SANKARANARAYANAN. 1972. Organic detritus of a tropical estuary. Mar. Biol., 15(3): 193-199.
- RAJENDRAN, A. AND V.K. VENUGOPALAN. 1973. Distribution of dissolved particulate and mud phosphorous in Vellar Estuary. Indian J. of Mar. Sci., 2: 13-18.

- RAMAMIRTHAM, C.P. AND R. JAYARAMAN. 1963. Some aspects of the hydrographical conditions of the backwaters around Willingdon Island (Cochin). J. Mar. Biol. Assn. India, 5(2): 170-177.
- RAMAMURTY, M.P., P.V. SESA RAO AND M. POORNCHANDRA RAO. 1973. Geochemistry of phosphorous in the bottom sediments of the eastern parts of Bay of Bengal. J. Mar. Biol. Assn. India., 15(2): 685-689.
- RAO, S.V.S. 1957. Preliminary observation on total phosphorous content of inshore waters of the Malabar coast off Calicut. Proc. Indian Acad. Sci., 45(B): 77-85.
- RAO, MADHUSUDANA. 1978. Distribution of CaCO_3 , Ca^{++} and Mg^{++} in the sediments of Northern half of Western continental shelf of India. Indian J. Mar. Sci., 7(3): 151-154.
- SAHA, G.N., K.L. SEHGAL, EVAMITRA AND A.C. NANDY. 1971. Studies on the seasonal and diurnal variations in physico-chemical and biological conditions of a perennial freshwater pond. J. Inland. Fish. Soc. India., 3: 79-102.
- SANKARANARAYANAN, V.N. AND S.Z. QASIM. 1969. Nutrients of the Cochin Backwaters in relation to environmental characteristics. Mar. Biol., 2(3): 236-247.
- SANKARANARAYANAN, V.N. AND V. PANAMPUNNAYIL. 1979. Studies on organic carbon, nitrogen and phosphorous in sediments of the Cochin Backwaters. Indian J. Mar. Sci., 8: 27-30.
- *SCHAEPERCLAUS, W. 1933. Text book of pond culture. U.S. Dept. of Interior Fish and Wildlife Service, Fishery Leaflet, 311: 162-166.
- *SCHAEPERCLAUS, W. AND F. HUND. 1933. Text book of pond culture. Rearing and keeping of carp., Trout and allied fishes, Fish. Leafl. Wash., 331: 260 p.
- *SCHAEPERCLAUS, W. 1961. Teichurirtschaft. Berlin pary. 582 p.
- SCHUSTER, W.H. 1949. Fish culture in brackishwater ponds of Java. Spec. Pub. Indo. Pacific. Fish Coun., 1: 143 p.
- SEERALATHAN, P. AND A. SEETHARAMASWAMY. 1979. Phosphorous distribution in modern deltaic sediments of the Cauvery river. Indian J. of Mar. Sci., 8(3): 130-138.

- SETTY, M.G.A.P. AND C.H. MADHUSUDANA RAO. 1972. XXIV.
Int. Geol. Cong. Sec., 8(1972): 182 p.
- SNEDECOR, G.W. AND W.G. COCHRAN. 1967. Statistical method,
Oxford and IBH Publishing Company.
- SOMMERS, L.E. 1970. Determination of total organic phosphorous
in lake sediments. Limnol. Oceanogr., 15: 301-303.
- *STANGENBERG, M. 1949. Nitrogen and carbon in the bottom
deposits and in the soil under Carp ponds. Verh.
Int. Var. Limnol., 10: 422-427.
- SWERDRUP, H.W., JOHNSON AND FLEMING. 1942. Oceans - Their
Physics, Chemistry and General Biology. Asia
Publishing House, Bombay, 167-180.
- SYERS, J.K. AND R.F. HARRIS. 1973. Phosphate chemistry in
Lake sediments. J. Environ. Qual., 2: 1-14.
- TANG, Y.A. AND S.H. CHEN. 1967. A survey of the algal
pasture soils of milkfish ponds of Taiwan. FAO.
Fish. Rep., 44(3): 198-209.
- *TRIPATHI, S.D. 1983. Techniques of composite fish culture.
Lecture delivered for the short-term training
course on Aquaculture Engineering (Fish Pond
Construction), I.L.T. Kharagpur.
- *TRONG, E. 1930. The determination of readily available
phosphorous of soils. J. Amer. Soc. Agron.,
23: 874-882.
- VENUGOPALAN, V.K. AND A. RAJENDRAN. 1975. Dissolved and
particulate nitrogen in Vellar Estuary. Bull. Dept.
Mar. Sci., Uni. Cochin, 7(4): 885-897.
- VIJAYARAGHAVAN, SUMITRA. 1973. A comparative account of the
soil-water relationship in three tropical ponds.
Indian J. of Fish., 20(2): 617-623.
- *WALTER, E. AND O. NOTLE. 1930. "Dungsuersuche in
Fischteichen 1926-29" (Manuring experiments in fish
ponds, 1926-29). Mitt. dents. Landwges., 45: 74-77.
- Water Quality Management in Aquaculture. 1985. CMFRI Spl.
Pbln., 22.

- *WATTS, J.C.D. 1965a. Liming of the local acid sulfate soils. Invest. Rep. Trop. Fish. Cult. Res. Inst., 1: 4.
- *WATTS, J.C.D. 1965b. The chemical analysis of muds from pond system of the Tropical Fish Culture Research Institute. Invest. Rep. Trop. Fish. Cult. Res. Inst., 3: 9.
- *WATTS, J.C.D. 1969. Phosphate retention in acid sulfate pond muds from Malacca Area. Malaysian Agri. J., 46(4): 477-484.
- *WIKLANDER, L. 1960. Fixation of potassium by clay saturated in different cations. Soil. Sci., 69: 261-280.
- *WILLIAMS, J.D. 1971. Levels of inorganic and total phosphorous as related to other sediment parameters. Envr. Sci. Technology, 5: 113-120.
- WOLAVER, THOMAS, G., ZEIMAN, C. JOSEPH, WETZEL RICHARD AND KEN. 1983. Tidal exchange of nitrogen and phosphorous between a mesohaline vegetated marsh and the surrounding estuary in the lower chesapeake Bay. Estuarine Coast. and Shelf Sci., 16: 321-332.
- WOLNY PAWEL. 1967. Fertilization of warm water fish ponds in Europe. FAO. Fish. Rep., 44(1): 64-81.
- WROBEL STAISLAW. 1967. The role of soils in fish production in ponds. FAO. Fish. Rep., 44(3): 153-163.
- *WUNDER, W. 1949. "Fortschrittliche Karpfenteichurirts chaft" (Progressive pond culture of Carp). E. Schweitzerbart sche Verlagsbuchhandlung., Erwin Nagele, Stuttgart, pp. 386.
- *YAP, W.G., F.D. APUD AND J.H. PRIMAVERA. 1979. Manual of Prawn farming. Aquaculture Extension Manual No. 5. Aquaculture Department SEAFDEC., Phillipines.
- ZICKER, E.L. AND K.C. BERGER. 1956. Phosphorous release from Bog Lake muds. Limnol. Oceanogr., 1(4): 296-303.

 * Not consulted in original.