# Physico-Chemical and Microbiological* studies on the *Kari Soils* of Kerala

V. SUKUMARA PILLAI[1] and N SUBRAMONEY[2]

*Division of Chemistry, Agricultural College and Research Institute, Vellayani*

Received for publication December 5, 1966

Notable among the physical features of Kerala are the backwater areas adjoining the sea. In different parts of these backwater tracts, large areas of peaty or marshy soils, locally known as *Kari,* occur. The name *Kari* is derived from the intense black colour of the soils, *Karl* in Malayalam meaning charcoal. These irregularly shaped and scattered soil formations cover an area of about 30,000 acres in Ambalapuzha, Vaikom and Shertalai Taluks. The origin of these soils is still shrouded in mystery, but it is populary believed that dense forests might have existed in these tracts in bygone ages which, due to geological disturbances, might have been destroyed and got submerged under the sea subsequently. Later the sea might have receded, partly exposing these soils.

The presence of large quantities of undecomposed organic matter, the high acidity despite the occurrence of large proportions of calcareous shells and frequent inundation with sea water are all very unique features of the *Kari* soils. The topography of the area is level and the fields are situated at or below the sea level. The South West and North East Monsoons together bring an annual precipitation of about 275 cm, the temperature varying between 5°—85°F. From February to May the land is submerged under saline water. With the onset of Monsoon in June, the flood waters dilute and push the salt water into the sea.

Based on topography, soil type etc. the area is divided into a number of 'Padasekharams', each about 50-250 hectares in extent. Paddy is the only crop that is cultivated in these fields- With the cessation of monsoon in September, the 'Padasekharams' are bunded around, dewatered and paddy sown broadcast. The crop is harvested by February. Crop failures due to flood and diseases are not infrequent. Due to an acute dearth of cultivable land in this State, farmers are forced to take up

*Condensed from the Thesis submitted by V. Sukumara Pillai in partial fulfilment of the requirements for the award of the M. Sc. (Agri.) Degree of the University of Kerala 1964. Published by kind permission of the University of Kerala, Trivandrum.

**Present** address: 1, V. Sukumara Pillai, Technical Assistant, Directorate of Agriculture, Trivandrum.

2. N. Subramoney, Professor of Chemistry, Agricultural College and Research Institute, Vellayani.

the cultivation of these problem lands. A clear understanding of the physico-chemical properties of these soils is an essential pre-requisite for solving the many management problems encountered in the cultivation of these lands and it was with this object in view that the present work was taken up.

Some work along this line has already been done by other investigators. Pillai (1924) analysed a few soil samples from one of the *Kari* tracts and has furnished some data on their chemical composition, Iyer (1928), working with the soils collected from different *Kari* areas determined their lime requirement, phosphoric acid content and the amount of water soluble salts, based on which he suggested some reclamation procedures. Pillai and Subramoniam (1931) investigated the origin and nature of these peaty soils. Nair (1945) conducted the physico-chemical analysis of surface soils from five representative tracts of *Kari* and investigated the agricultural potential of these soils. Subramoney (1947, 1958) studied the microbiological properties of *Kari* soils and Gopalaswamy (19.58) conducted studies on their fertility status.

**Field study**

For the present study, four representative 'Padasekharams' were selected, which in general features, represent the *Kari* lands of Vaikom Taluk. One profile was taken from each 'Padasekharam'. At the time of collection of the profiles, the fields were under water and hence a special technique was adopted for the collection. Bamboo tubes, about six feet in length, were driven into the soil to the required depth and were withdrawn slowly. The soil columns retained in the tubes were drained. Then the tubes were split open without disturbing the soil columns and the profile characteristics noted. Since there were no distinct horizon differentiation, each profile was divided into three arbitrary horizons, at the following depths, based mainly on textural differences.

| | |
|---|---|
| First horizon | 0-24 cm. |
| Second horizon | 24-75 cm. |
| Third horizon | Below 75 cm. |

The morphological features of the profiles recorded are given below .

Profile I

| | |
|---|---|
| Location | Koithuruthu Padasekharam, Vechoor village, Vaikom Taluk. |
| Topography | Flat and level. |
| Vegetation | Originally marsh and aquatic grasses, now under rice. |
| Special features | Water logged for mo st part of the year. |

| Sample No. | Depth in cm. | Description |
|---|---|---|
| 1 | 0-24 | Black, 7.5 YR, 2/0; clay loam; soft, sticky and plastic when wet., poorly drained; undecomposed plant residues and roots abundant horizon differentiation difficult. |
| | 24-75 | Very dark grey, 7.5 YR. 3/0; sandy clay loam; not very sticky or plastic when wet; poorly drained; undecomposed plant residues and few roots ; horizon differentiation difficult; carbonates present. |

| Sample No. | Depth in cm. | Description |
|---|---|---|
| 3 | Below 75 | Dark grey, 7.5 YR, 4/0; clay ; very sticky and plastic when wet., poorly drained ; undecomposed plant residues and roots spare, carbonates present. |

Profile II.

| | | |
|---|---|---|
| Location | | Oorikari Padasekharam. Thalayazham Village, Vaikom Taluk. |
| Topography | | Flat and level. |
| Vegetation | | Aquatic weeds, marsh grasses and cultivated rice. |
| Special features | | Waterlogged for most part of the year. |
| Sample No. | Depth in cm. | |
| 4 | 0-24 | Black, 5 YR. 2/1 ; clay loam ; sticky and plastic when wet; poorly drained ; undecomposed plant residues and roots abundant, horizon differentiation difficult. |
| 5 | 24-75 | Very dark grey, 5 YR, 3/1 ; clay loam ; not so sticky and plastic when wet poorly drained ; undecomposed plant residues and roots absent. |
| | Below 75 | Dark grey, 5 YR. 4/1 ; clay ; very sticky and plastic when wet; very poorly drained ; plant roots and undecomposed organic matter absent ; carbonates present. |

Profile III.

| | | |
|---|---|---|
| Location | | Elurkalam Padasekharam, Vechoor Village, Vaikom Taluk. |
| Topography | | Flat and level. |
| Vegetation | | Originally aquatic and marsh grasses, now reclaimed for rice cultivation. |
| Special features | | Waterlogged for most part of the year. |
| Sample No. | Depth in cm. | |
| 7 | 0-24 | Black, 2.5 YR, 2/0; clay ; sticky and plastic when wet, poorly drained; plant roots and undecomposed plant residues abundant; horizon differentiation difficult. |
| | 24-75 | Very dark grey, 2.5 YR, 3/0 clay loam ; not very sticky and plastic when wet undecomposed organic residues and plant roots few ; poorly drained: horizon differentiation difficult. |
| | Below 75 | Dark grey, 2.5 YR. 4/0 ; clay; highly sticky and plastic when wet. drainage very poor; undecomposed plant residues and plant roots absent differentiation from other horizons difficult, carbonates present. |

Profile IV

| | | |
|---|---|---|
| Location | | Kochukottakari Padasekharam, Kallara Village, Vaikom Taluk. |
| Topography | | Flat and level. |
| Vegetation | | Aquatic grass, marsh weeds and cultivated rice. |
| Special features | | Waterlogged for most part of the year. |
| Sample No | Depths in cm | |
| 10 | 0-24 | Reddish black, 10R 2 I , sandy clay loam ; somewhat sticky and plastic when wet; drainage very poor; undecomposed organic residues and plant roots plenty ; horizon differentiation difficult. |
| 11 | 24-75 | Dark, reddish grey, 10 R. 3/1, sandy *clay* loam; not very sticky or plastic when wet; ill drained undecomposed plant residues and roots very few, horizon differentiation difficult. |
| 12 | Below 75 | Dark reddish grey, 10 R. 4/1 clay loam; very sticky and plastic when wet ; plant roots absent; very poorly drained, horizon differentiation difficult, carbonates present. |

**Experimental**

Representative soil samples were collected from the different horizons of the profiles for laboratory studies. The samples were air dried and passed through a 2 mm sieve. Mechanical analysis was carried out by the international pipette method. Single value constants were determined by Keen-Raczkowsky box experiments. Organic carbon was estimated by Walkley and Black's method (1934) and organic matter calculated from this figure. Total nitrogen was determined by the Kjeldahl method as described by Wright (1939). The HCl extract was prepared and analysed for the various constituents by standard procedures as outlined by Piper (1950) and Jackson (1960). Available phosphorus was extracted with Bray's reagent and available potassium with Morgan's reagent and estimated using a Klett-Summerson colorimeter. Carbonates were estimated by titration with standard HCl Conductivity and water soluble ions were determined in a 1:5 soil water extract. The cation exchange capacity was determined by the neutral normal ammonium acetale method The pH of wet and air dry samples was determined in 1:2.5 soil-water suspension with a Beckman pH meter.

The total microbial count was determined by plating the loil in 1:10,000 dilution in Thornton's standardised medium. Ammonifying power was estimated by using Remy's medium. Jensen's medium was used for determining the nitrogen fixing power of the soils. Isolation of the organism was done in Ashby's mannitol phosphate agar medium.

Results and Discussion

The results of the present study indicate that the *Kari* soils of Kerala are unique in their physico-chemical and microbiological properties and that they differ considerably from other soil types found in this State.

1. *Mechanical composition*

The mechanical composition and some single value constants of the soils are given in Table I. Though the organic nature of *Kari* soils is revealed by the high values for carbon and loss on ignition, the level of organic matter in the soil is not in sufficient proportions to designate them as peaty soils, as typical peaty soils ought to contain more than 20 per cent of organic matter (Lawton, 1955). The observed single value constants too suggest their intermediary position between a true peat and a typical mineral soil. The high values for loss on ignition in the lower layers may be partly due to the carbonates present in them. The soils are clays or clay loams and there is an irregular distribution of the various soil separates in the profiles which indicates the predominant role played by transportation and sedimentation process in the formation of these soils. It will be reasonable to assume that the lime shells found in abundance in these areas might have given rise to the large amounts of carbonates in the lower layers of these soils.

*2. Soil acidity and carbon: nitrogen relationships*

The data on pH and carbon: nitrogen relationships of the *Kari* soils are given in Table II. The soils have a pH as low as 2.7 in the upper layers while the pH of the lower layers is near about 7.0. It is probable that the high organic matter content in the upper layers makes them acidic, (Nair, 1945) while the carbonates present in the lower layers are responsible for the neutral reaction in these horizons. Another interesting phenomenon about the pH of these soils is that the waterlogged soils which are almost neutral in reaction becomes extremely acidic on air drying. This may be due to the presence of elements like sulphur capable of changing their degree of oxidation and reduction with a consequent fall or rise in pH (Russell, 1962). The high sulphur content of the soils under investigation supports this view.

The carbon and nitrogen contents of the soils are rather high and decrease with depth. The high content of these elements is accompanied by a wide ratio between them. This may be due to the probable losses of nitrogen from these soils through ammonification and denitrification, both processes being favoured by the reducing, waterlogged conditions existing in them. The same reducing conditions which favour the losses of nitrogen, also conserve the carbon of the soil by preventing the oxidation of organic matter.

*3. Chemical composition and fertility status*

The chemical composition and fertility status of the soils are presented in Table III. The high sesquioxide content indicates that the inorganic component of the soils is of lateritic origin. The high contents of nitrogen, phosphorus and potassium in these soils suggest that they are inherently fertile. The high levels of these elements may be attributed to the organic matter content, heavy dressings of phosphatic fertilisers and the presence of potassium containing minerals respectively.

The soils are also rich in secondary elements such as calcium, magnesium and sulphur. Though the soils are rich in total plant nutrients, their availability is extremely low, probably due to the unfavourable conditions prevailing in the soil. Foremost among those conditions are the acidity and the wide C/N ratio. Unavailability of phosphorus and potassium may be due to chemical and mineralogical fixation of these elements in the soils. The conductivity and soluble salt estimations suggest that the soils contain salts in toxic concentrations so as to impair their productivity. The cation exchange capacity of the surface soils is comparatively low in spite of their high organic matter content. On the other hand, the cation exchange capacity of the lower horizons tends to be higher, which might be attributed to their higher clay content. Obviously the organic matter in the upper layers is in a unhumified form and hence makes very little contribution towards this property.

Separation and analysis of the clay fraction of the soils revealed high silica : sesquioxide (above 2.0) and silica alumina (3.5-6.0) ratios and high cation exchange capacity (44-50 me./100 g) This suggests that there is a good proportion of montmorillonitic clays associated with some illtitic materials (as suggested by the high proportions of potassium) in these soils.

4. *Microbiological properties*

A low microbial count which increases with depth and the predominance of fungi over bacteria are characteristic of the microbial population in these soils. The data on the microbiological properties of the soils and the nitrogen fixing capacity of the organism isolated are given in Table IV. The low microbial population in the soils which increases with depth seems to be a consequence of the higher acidity in the upper layers, which decreases with depth in the profile. The generally poor microbial inhabitation of these soils can be attributed to the anaerobic conditions, the high concentrations of soluble salts and the wide C/N ratio. The ammonifying capacity of the soils which is more in the upper layers should be attributed to the predominance of fungi in these layers, as fungi are known to be the chief ammonifiers, especially in acid soils (Muntz *et al* 1893). The low ammonification in the lower layers may be the result of the calcium carbonate present in them which is unfavourable for the growth and functioning of ammonifiers. The comparatively high nitrogen fixing capacity of the soils in the lower layers may be due to the presence of lime and a neutral pH.

The similarity in the growth and morphological characters and the nitrogen fixing capacity of the organisms isolated from the different horizons suggest that they are all of the same species. The environmental conditions under which these bacteria occur indicate that the organisms do not belong to the *Azotobacter* species. The work of Starkey and De (1939) Barooah and Sen (1959) and others suggest that these organisms belong to the genus *Beijerinckia*, But some typical characteristics of *Beijerinckia*, such as gum formation are not observed for these organisms, while the acid tolerance shown by them is typical of the *Beijerinckia* species. Further work is required for the elucidation of the nature of these organisms and for classifying them

TABLE I

Mechanical Composition and single value constants of ***Kari*** soils of Kerala

| Sample No. | Depth (cm) | Moisture % | Loss on ignition % | Textural separates: Coarse sand % | Fine sand % | Silt % | Clay % | Texture | Apparent density | Maximum water holding capacity % | Pore space % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Profile I. Koithuruthu** | | | | | | |
| 1 | 0-24 | 8.55 | 17.41 | 1.93 | 21.24 | 22.47 | 36.09 | Clay loam | 1.11 | 46.90 | 55.50 |
| 2 | 24-75 | 9.95 | 15.50 | 7.69 | 33.17 | 18.70 | 26.47 | Sandy clay loam | 0.94 | 65.40 | 63.90 |
| 3 | Below 75 | 7.05 | 14.56 | 0.89 | 2.19 | 38.61 | 45.18 | Clay | 1.14 | 56.30 | 60.70 |
| | | | | | **Profile II. Oorikari** | | | | | | |
| 4 | 0-24 | 10.89 | 10.71 | 1.34 | 17.87 | 31.30 | 37.45 | Clay loam | 1.18 | 52.30 | 60.30 |
| 5 | 24-75 | 9.45 | 7.90 | 3.67 | 26.08 | 23.71 | 37.90 | Clay loam | 1.18 | 52.00 | 61.90 |
| 6 | Below 75 | 5.20 | 5.35 | 0.94 | 3.08 | 39.43 | 43.50 | Clay | 1.32 | 53.90 | 60.00 |
| | | | | | **Profile III. Elurkalam** | | | | | | |
| 7 | 0-24 | 8.23 | 12.27 | 1.39 | 9.39 | 34.12 | 44.20 | Clay | 1.16 | 47.20 | 53.10 |
| 8 | 24-75 | 10.85 | 10.40 | 2.09 | 14.48 | 33.65 | 38.87 | Clay loam | 0.98 | 70.10 | 60.10 |
| 9 | Below 75 | 4.95 | 10.17 | 1.78 | 3.94 | 39.00 | 47.38 | Clay | 1.18 | 54.10 | 55.30 |
| | | | | | **Profile IV. Kochukottakari** | | | | | | |
| 10 | 0-24 | 10.65 | 12.06 | 4.98 | 27.11 | 21.54 | 34.21 | Sandy clay loam | 1.10 | 47.10 | 56.20 |
| 11 | 24-75 | 11.33 | 7.72 | 12.17 | 29.44 | 19.70 | 30.33 | Sandy clay loam | 1.09 | 55.50 | 58.60 |
| 11 | Below 75 | 6.16 | 9.90 | 1.88 | 17.56 | 33.76 | 40.45 | Clay loam | 1.20 | 59.70 | 62.10 |

TABLE II

pH and Carbon : Nitrogen relationship *of Kari* soils

| Sample No | Depth (cm.) | pH Fresh Soil | pH Air dry soil | % | Carbonates as $CaCO_3$ % | Organic carbon % | Nitrogen Total % | Nitrogen Available % | C/N ratio |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Profile I. Koithuruthu | | | | | |
| 1 | 0-24 | 6.8 | 3.7 | 17.01 | | 10.01 | 0.618 | 0.026 | 16.19 |
| 2 | 24-75 | 1 I | 6.7 | 14.19 | 2.12 | 8.35 | 0.401 | 0.018 | 20 82 |
| 3 | Below 75 | 7.1 | 7.1 | 12.58 | 6.73 | 7.40 | 0.291 | 0.008 | 25.43 |
| | | | | Profile II Oorikkari | | | | | |
| 4 | 0-24 | 6.5 | 3.6 | 9.95 | | 8.85 | 0.217 | 0.014 | 26.90 |
| 5 | 24-75 | 6.8 | 5.6 | 7.77 | | 4.57 | 0.183 | 0 007 | 24.98 |
| 6 | Below 75 | 7.9 | 7.2 | 2.75 | 6.89 | 1.62 | 0.126 | 0.005 | 16.39 |
| | | | | Profile III Elurkalam | | | | | |
| 7 | 0-24 | 6.1 | 3.4 | 11.59 | | 6.82 | 0.218 | 0.021 | 31.29 |
| 8 | 24-75 | 6.2 | 2.6 | 9.94 | | 5.85 | 0.210 | 0.011 | 27.85 |
| 9 | Below 75 | 7.3 | 6.7 | 8.89 | 5.94 | 5.23 | 0.140 | 0.006 | 37.36 |
| | | | | Profile IV. **Kochukottakari** | | | | | |
| 10 | 0-24 | 6.3 | 4.1 | 11.54 | | 6.73 | 0.178 | 0.059 | 37.87 |
| 11 | 24-75 | 6.5 | 3.7 | 8.41 | | 4.95 | 0.152 | 0.024 | 32.56 |
| 12 | Below 75 | 6.8 | 6.8 | 7.66 | 5.56 | 4.85 | 0.144 | 0.007 | 31.32 |

## TABLE III

### Chemical characteristics of *Kari* soils

| Sample No. | Depth in cm. | $Fe_2O_3$ $Al_2$ % | $P_2O_5$ Total % | $P_2O_5$ Avail % | $K_2O$ Total % | $K_2O$ Avail % | CaO % | MgO % | Sulphur $SO_4$ % | T.S.S. % | Conductivity mm-/cm. | C.E.C m.e/100g. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Profile X. Koitburuthu | | | | | | | |
| 1 | 0-24 | 16.15 | 0.185 | 0.0009 | 0.233 | 0.0060 | 0.63 | 0.314 | 1.852 | 1.51 | 4.5 | 19.2 |
| 2 | 24-75 | 15.85 | 0.148 | 0.0013 | 0.192 | 0.0086 | 1.33 | 0.607 | 2.674 | 2.60 | 6.0 | 18.4 |
| 3 | Below 75 | 22.68 | 0.258 | 0.0021 | 0.349 | 0.0137 | 3.41 | 0.432 | 4.320 | 1.56 | 5.0 | 22.3 |
| | | | | | Profile II Oorikkari | | | | | | | |
| 4 | 0-24 | 19.25 | 0.149 | 0.0007 | 0.251 | 0.0077 | 0.52 | 0.411 | 1.440 | 1.29 | 3.X | 17.0 |
| 5 | 24-75 | 21.78 | 0.227 | 0.0008 | 0.368 | 0.0068 | 1.05 | 0.661 | 2.880 | 1.20 | 4.0 | 15.6 |
| 6 | Below 75 | 15.75 | 0.187 | 0.0011 | 0.405 | 0.0187 | 3.73 | 0.534 | 3.497 | 0.93 | 2.8 | 23.0 |
| | | | | | Profile III. **Elurkalam** | | | | | | | |
| 7 | 0-24 | 19.53 | 0.139 | 0.0007 | 1.213 | 0.0053 | 0.61 | 0.322 | 1.661 | 0.51 | 3.0 | 25.8 |
| 8 | 24-75 | 20.00 | 0.138 | 0.0007 | 0.323 | 0.0081 | 0 53 | 0.406 | 2.934 | 1.98 | 50 | 21.2 |
| 9 | Below 75 | 21.50 | 0.353 | 0.0012 | 0.337 | 0.0141 | 2.50 | 0.398 | 3.701 | 0.84 | 4.0 | 20.9 |
| | | | | | Profile IV **Kochukottakari** | | | | | | | |
| 10 | 0-24 | 21.88 | 0.136 | 0.0008 | 0.233 | 0.0064 | 2.55 | 0.216 | 1.214 | 0.55 | 2.7 | 16 6 |
| 11 | 24-75 | 21.78 | 0.205 | 0.0007 | 0.322 | 0.0089 | 0.63 | 0.362 | 2.376 | 0.98 | 4.0 | 14.4 |
| | Below 75 | 25.53 | 0.270 | 0.0019 | 0.400 | 0.0138 | 1.87 | 0.543 | 3.185 | 0.85 | 3.6 | 17.1 |

requires further investigation. The high C.E.C. of the soils and clay fraction and the high silica: sesquioxide ratios of the clay separates suggest the presence of 2:1 lattice type of minerals. There is considerable difference in pH between fresh and air dried soils and the upper and lower layers of the profiles. The soils have a wide C/N ratio and are rich in major and secondary plant nutrients, the availability of which is surprisingly low. The soils have a low microbial count which increases with depth in the profile. The ammonifying power of the soils is more in the top layers, whereas the nitrogen fixing power is more in the lower layers. The nitrogen fixing organism isolated resembles both *Azotobacter* and *Beijerinckia* in its characters. Further work is required to elucidate its nature and for its identification.

**Acknowledgements**

The authors wish to express their indebtedness to Dr. C. K. N. Nair, Principal and Additional Director of Agriculture (Research), Agricultural College and Research Institute, Vellayani, for providing necessary facilities for carrying out the work. The first author is deeply grateful to Dr. M. M. Koshy, Additional Professor of chemistry and Dr. R. S. Aiyer, Junior Professor, for their valuable suggestions in the course of the work.

## References

1. Barooab, P. P. and Sen, A. (1959) Studies on Beijerinckia from some acid soils of India. *Indian Jour. of Agric. Sci*: 29:4.
2. Gopalaswamy, V. (1958) Studies on the fertility status of some peaty, marshy and swampy soils. *M.Sc, Thesis, Indian Agric. Res. Inst.* (Unpublished)
3. Iyer, Narayana K. R. (1928) *Dept. Agri. Trav. Bull.* **123, 126, 130**.
4. Jackson, M. L. (1960) -*Soil Chemical Analysis';* Prentice Hall, Inc. N. J. U. S. A.
5. Lawton, Kirk (1955) Chemical composition of soils *'Chemistry of Soils'* Edited by F. E. Bear, Reinhold Publishing Corpn. pp. 73-74.
6. Muntz, A. and Coudon, H. (1893) *Compt Rend. Acad. Sci.* 84: 301-303.
7. Nair, C K. N. (1945) Studies on *Kari* Soils of Travancore. *M.Sc. Thesis, University of Travancore.* (unpublished)
8. Pillay, K. P. 0942) *Dept. Agri. Trav. Bull. 9.*
9. Pillay, T. R N. and Subramoniam, V. (1930) *Journ. Ind. Inst. Sci.* 13. A 1.
10. Pillay, T. R. N. and Subramoniam, V. (1931) The origin and nature of peaty soils of Travancore. *Journ. Ind. Inst Sci.* 14. A. 99.
11. Pillay, T. K. V. (1940) *Travancore State Manual'* Vol. I. p. 88. Vol. II. p. 285.
12 Piper, C. S. (1950) '*Soil and Plant Analysis'* The University of Adelaide, Adelaide.
13. Russel, F W. (1962) '*Soil Conditions and Plant Growth*'. Longmans Green and Co , London.
14 Starkey, R. L. and De, P. K. (1938) A new species of *Azotobacter. Soil Science,* 47: 329-343
15. Subramoney, N. (1947) Fertility investigations on the acid peats of Travancore *Bull. Central Res. Inst. Univ. of Trav.* II - 1
16 Subramoney, N. (1958) Chemical and and microbiological studies on the acid peats of Kerala. *Ph. D. Thesis, University of Travancore.* (Unpublished)