OCCURRENCE OF FILAMENTOUS ALGAE AND SOIL CHARACTERISTICS IN THE PADDY FIELDS OF KUTTANAD AND KOLE LANDS OF KERALA

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By

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MAY 2015

DECLARATION

I hereby declare that the thesis entitled, **"Occurrence of filamentous algae and soil characteristics in the paddy fields of Kuttanad and Kole lands of Kerala"** is an authentic record of the research work carried out by me under the guidance of Dr. Ammini Joseph, Professor, School of Environmental Studies, Cochin University of Science and Technology in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy under the Faculty of Environmental Studies, Cochin University of Science and Technology and no part of this thesis has been submitted for the award of any degree, diploma, associateship, or any other title or recognition from any University / Institution.

Smitha Sebastian

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Certificate

This is to certify that this thesis entitled, **"Occurrence of filamentous algae and soil characteristics in the paddy fields of Kuttanad and Kole lands of Kerala"** is a bonafide record of research carried out by Ms. Smitha Sebastian under my guidance and supervision in partial fulfillment of the requirements for the degree of Doctor of Philosophy under the Faculty of Environmental Studies, Cochin University of Science and Technology and that no part thereof has been included for the award of any other degree. All the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the Doctoral Committee of the candidate has been incorporated in the thesis.

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Chapter - 1

INTRODUCTION

Algae are simple autotrophic plants that generally lack root, stem, leaves, conducting vessels and complex sex organs. According to Lee, "The algae are thallophytes (plants lacking roots, stems, and leaves) that have chlorophyll *a* as their primary photosynthetic pigment and lack a sterile covering of cells around the reproductive cells" (Lee, 1989). The primitive existence of algae is supported by the Precambrian fossil record which dates back to about 3 billion years ago. According to Guiry (2012) the number of living algae are estimated to range from 30,000 to more than one million species.

The foundation of classification of algae was laid down by Linnaeus and De Jussieu. Fritsch (1935) in his masterpiece on the 'Structure and reproduction of algae', gave a classification of algae into eleven classes based on pigmentation, reserve food, flagellation and also mode of reproduction. The classes are Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillarophyceae, Cryptophyceae, Dinophyceae, Chloromonadinae, Euglenineae, Phaeophyceae, Rhodophyceae and Myxophyceae. Smith (1955) classified algae into seven divisions and each division into several classes. The divisions are Chlorophyta, Euglenophyta, Pyrrhophyta, Chrysophyta, Phaeophyta, Cyanophyta and Rhodophyta. Papenfuss (1955) classified algae into eight divisions such as Chrysophycophyta, Phaeophycophyta, Pyrrhophycophyta, Euglenophycophyta,

Chlorophycophyta, Charophycophyta, Rhodophycophyta and Schizophycophyta. He included blue-green algae along with bacteria.

On the basis of the pigments in the plastid, morphological characters and biochemical differences, Chapman (1962) divided algae into four divisions, which were further subdivided into several classes. The divisions are Euphycophyta, Myxophycophyta, Chrysophycophyta and Pyrophycophyta. Prescott (1969) emphasized the presence or absence of true nucleus in the algal cells for their classification along with other characters like pigmentation, biochemical nature of cell wall and reserve food material, and divided into nine divisions and fourteen classes. The divisions are Chlorophyta, Euglenophyta, Chrysophyta, Pyrrophyta, Phaeophyta, Rhodophyta, Cyanophyta, Cryptophyta and Chloromonadophyta. Round (1973) also recognized the importance of presence or absence of well organised nucleus in algal cells in the classification of algae along with their phylogenetic relationships and other characteristics. He divided algae into two major groups and further divided into several divisions. Group 1 Prokaryota includes only one division Cyanophyta. Group 2 Eukaryota includes the following divisions such as Euglenophyta, Chlorophyta, Chrysophyta, Phaeophyta, Rhodophyta, Cryptophyta and Pyrrophyta. Bold and Wynne (1978) classified algae into nine divisions such as Cyanochloronta, Chlorophycophyta, Charophyta, Euglenophycophyta, Phaeophycophyta, Chrysophycophyta, Pyrrophycophyta, Cryptophycophyta and Rhodophycophyta. Lee (1989) classified algae into four groups and several Phyla. Group 1 Prokaryotic algae includes phylum Cyanophyta and Prochlorophyta. Group 2 Eukaryotic algae with chloroplasts surrounded only by the two membranes of the chloroplast envelope. It includes phylum Glaucophyta, Rhodophyta and Chlorophyta. Group 3 Eukaryotic algae with chloroplasts surrounded by one membrane of chloroplast endoplasmic reticulum. It includes phylum Euglenophyta and Dinophyta. Group 4 Eukaryotic algae with chloroplasts surrounded by two membranes of chloroplast endoplasmic reticulum. It includes phylum Cryptophyta,

Chrysophyta, Prymnesiophyta, Bacillariophyta, Xanthophyta, Eustigmatophyta, Raphidophyta and Phaeophyta. Guiry and Guiry (2011) classified algae into two Empires-Prokaryota and Eukaryota. Empire Prokaryota includes only one kingdom *i.e.,* Bacteria comprising the phylum Cyanobacteria. Empire Eukaryota includes three algal kingdoms such as Chromista, Plantae and Protozoa. Barsanti and Gualtieri (2014) grouped algae in four kingdoms of Bacteria, Plantae, Chromista and Protozoa. The prokaryotic kingdom bacteria includes phylum Cyanobacteria with a single class Cyanophyceae. Kingdom plantae includes four phyla *i.e.,* Glaucophyta, Rhodophyta, Chlorophyta and Charophyta. Kingdom Chromista includes phylum Haplophyta, Cryptophyta, Ochrophyta and Cercozoa. Kingdom Protozoa includes phylum Myzozoa and Euglenozoa.

The habit of different groups of algae varies greatly among them and within the algal divisions. They are classified as unicells and unicell colonial, filamentous, siphonocladous, siphonous, parenchymatous and pseudo-parenchymatous and palmelloid forms. Unicellular algae are either solitary or colonial with or without flagella. They are usually found in the phylum Cyanobacteria, Glaucophyta, Rhodophyta, Chlorophyta, Cryptophyta, Ochrophyta and Haptophyta. Uniseriate row of cells arranged in a definite sequence forms a filamentous habit and are found in phylum Cyanobacteria, Rhodophyta, Chlorophyta, Charophyta, Ochrophyta and Myzozoa. In siphonocladous habit, the algae have multicellular thallai, either branched or unbranched composed of multinucleate cells as in class Ulvophyceae of phylum Chlorophyta. In siphonous habit plant body consists of coenocytic giant tubular cells. They often appear as branched tubes; usually occur in the class Xanthophyceae of phylum Ochrophyta and also in certain members of Chlorophyta. Algae with parenchymatous and pseudo-parenchymatous thalli are macroscopic with tissue of undifferentiated cells dividing in three dimensions. These habits are usually found in phylum Cyanobacteria, Rhodophyta, Chlorophyta, and Ochrophyta. Palmelloid colonies are non-motile

cells that remain embedded in a mucilaginous matrix and the cells are independent of one another and fulfill all functions of an individual. These are present in phylum Chlorophyta and Euglenozoa (Barsanti and Gualtieri, 2014).

Reproduction in algae occurs by three methods: 1. Vegetative reproduction - it may be of several types such as cell division, fragmentation, hormogone formation, hormospores, adventitious thallai, primary or secondary protonema, tubers, starch or amylum stars, bulbils and akinetes. 2. Asexual reproduction – this is achieved through zoospores, aplanospores, hypnospores, autospores, endospores, auxospores, carpospores, neutral spores, paraspores, and microspores. 3. Sexual reproduction – these methods are isogamy (fusion of similar motile gametes), heterogamy (fusion of dissimilar gametes) and aplanogamy or conjugation (fusion of morphologically similar but physiologically dissimilar non-flagellate amoeboid gametes) (Lee, 1999; Barsanti and Gualtieri, 2014).

Algae occur in all earth's environments mainly in the aquatic habitats, and in moist terrestrial environs including soil and soil-free surfaces. The habitats of algae are mainly classified into three categories. They are aerial habitats, aquatic habitats and unusual habitats**.** Aerial algae are those that obtain their water wholly or in large part from moisture in the air. They grow on the terrestrial surfaces such as trees, rock and soil surface. The aerial species belong mostly to the taxonomic groups Chlorophyceae, Cyanophyceae and Xanthophyceae. Aquatic algae are either freshwater inhabiting flowing waters of streams and rivers, lentic habitat of ponds, lakes, pools, ditches and in wetlands or marine as phytoplankton of the estuaries and oceans or as seaweeds in the intertidal and sub tidal environs. Algae of unusual habitats are those growing in extreme environments. They are broadly classified into the following categories- cryophytes or snow algae (found on the mountain peaks covered with snow), thermal algae (occurring in hot springs), halophytic algae (found in the saline water), lithophytes (growing on moist rocks, wet walls and other rocky surfaces), epiphytes (growing on the other aquatic plants or

animals) and symbiotic algae (growing in association with other plants and fungi) (Sambamurty, 2005; James *et al*., 2009).

Algae are ecologically important component of wetlands growing as unicellular or colonial forms suspended in the water column (phytoplankton), on submerged surfaces such as dead wood (epidendron), hard surfaces (epilithon), soft sediments (epipelon), submerged plants (epiphytes) and floating or suspended clumps in the water column beneath the surface layer (metaphyton). They are important in energy and nutrient cycling, stabilizing substrate and serving as habitat of other organisms in the wetlands (Wetzel, 1996; Robinson *et al.,* 2000; Rober *et al.,* 2012).

Paddy fields are artificial wetlands characterized by monoculture, shallow temporary water, plenty of light on the water surface, seasonal dynamics, artificial disturbance (ploughing, flooding, and harvest) and are component of a landscape with adjacent land use (Fernandez-Valiente and Quesada, 2004). The growth of paddy plants as well as the disturbance lead to differentiation of macro environments such as flood water, surface-oxidised soil, reduced soil, paddy plants, plow layer and subsoil. The flood water which is photic and aerobic supports photosynthetic producers such as planktonic, filamentous and macrophytic algae and vascular macrophytes. The oxidised soil layer in 2 to 20 mm thickness is a photic aerobic environment where algae and aerobic bacteria predominate.

The beneficial role of algae in agricultural systems is summarised by Abdel-Raouf *et al.* (2012) as "1. Excretion of organic acids that increase phosphorus availability and phosphorus uptake, 2. Provision of nitrogen by biological nitrogen fixation, 3. Increased soil organic matter, 4. Production and release of bioactive extracellular substances that may influence plant growth and development. These have been reported to be plant growth regulators (PGRs), vitamins, amino acids, polypeptides, antibacterial or antifungal substances that exert phytopathogen biocontrol and polymers, especially

exopolysaccharides, that improve soil structure and exoenzyme activity,5. Crust formation, 6. Stabilization soil aggregation by extracellular polysaccharides of soil aggregate and 7. Concentrate metal ions present in their environment".

The significance of algae in rice fields are directly related with their ability to fix nitrogen and build up of soil fertility, consequently increasing rice growth and yield. Blue-green and green algal populations in the upper top soil are large and diverse, and perform valuable services for the soil ecosystems (Starks *et al.,* 1981). Cyanobacteria are extremely important to fix atmospheric nitrogen in rice fields. They can contribute to the natural fertility of the soils through nitrogen-fixation in their heterocysts (Roger and Ladha,1992). They have been used as biofertilizers and used to inoculate rice fields (Irisarri, 2006) consequently increasing the growth and yield of paddy. Benthic, planktonic and epiphytic cyanobacteria are widespread in rice-fields, and about 50% of the cyanobacterial genera are heterocystous (Whitton, 2000). Prasad and Prasad (2004) recommended some strains of Cyanobacteria as a source of bio-fertilizer for rice productivity in Bagmati and Narayani Zones of Nepal. Cyanobacterial cultures used to pre-soak rice seeds showed enhanced germination, promotion of growth of roots and shoots, and increase in weight and protein content of grains (Jacq and Roger, 1977). Gurung (2004) reported 5.26% increase in soil nitrogen due to blue-green algae inoculation in rice field which ultimately increased the yield of rice. Mishra and Pabbi (2004) also found the yield increased by 12.3-19.5% on blue-green algae inoculation in rice field. Prasad (2005) reported 7.53-21.2% increase in grain yield and 6.57-21.6% increase in straw yield by blue- green algae inoculation. It is also a well known fact that besides contributing to soil nitrogen and improvement in yield of rice, cyanobacteria also produce agronomically significant changes in the physical, chemical and biological properties of soil and soil-water interface of rice fields (Mandal *et al*., 1998; Nayak *et al*., 2004).

Current knowledge on the ecology of the algae of the flooded paddy fields of the tropics, especially ecosystems such as those associated with

Vembanad- Kole Ramsar site in Kerala, the occurrence of algae with respect to the soil physico-chemical properties and the changing agricultural practices, occurrence of algal bloom and their effect on paddy are fragmentary. Generation of such data is needed to develop sustainable agricultural practices that maintain healthy paddy field ecosystems.

Chapter - 2

ALGAE OF PADDY FIELDS

2.1 Diversity of algae

The diversity and abundance of algae in rice fields have been reported by various authors since 1907 after the accounts of Fritsch. Okuda and Yamaguchi (1956) reported that in Japanese rice soils, common species belonged to the genera *Nostoc, Anabaena,* and *Tolypothrix*. Species of Chlorophyta, Cyanophyta, Chrysophyta and Euglenophyta were observed by Pantastico and Suayan (1974) in the rice fields of Phillipines. El-Nawawy and Hamdi (1975) reported species of *Calothrix, Anabaena, Hapalosiphon, Cylindrospermum, Nostoc, Scytonema, Symploca* and *Nodularia* from Egyptian soils. Cambral and Aboa (1992) conducted a survey of filamentous green algae in Spain, and their distribution and ecology. According to Whitton (2000) cyanobacteria are prevalent in rice-fields of which nearly 50% are heterocystous. Issa *et al.* (2000) have recorded three phyla Chlorophyta, Cyanophyta and Euglenophyta in rice fields in Egypt. Excessive growth of green algae and cyanobacteria occurring in the paddy fields of California was reported by Spencer and Lembi (2007). Siahbalaei *et al.* (2011) reported new records of eight filamentous heterocystous Nostocacean algae for the first time from paddy fields of Iran. Observation of algae in rice fields of Nigeria was reported by Nweze and Ude (2013). They observed a total of eight algal taxa distributed in Bacillariophyta, Chlorophyta, Cyanophyta and Euglenophyta. Lin *et al*. (2013) identified sixty four taxa

belonging to thirty three genera of cyanobacteria, diatoms, green algae and euglenoids from different farm lands including rice fields of Taiwan.

Several reports are found on algae of rice fields of different states of India (Kolte and Goyal, 1986; Anand *et al*., 1995; Sing *et al*., 1997; Sahu *et al*., 1997; Amita Devi *et al*., 1999; Nayak *et al*. 2001; Kaushik and Prasanna, 2002; Nayak and Prasanna, 2007; Digambar Rao *et al*., 2008). Choudhury (2009) studied the periodical occurrence of the members of Chroococcaceae in the rice fields of North Bihar and identified 28 species of cyanobacteria belonging to 9 genera. Gomes *et al.* (2011) reported the abundance of cyanobacteria in various habitats of rice field areas in Goa and recorded a total of sixteen genera and ninety species of heterocystous, non-heterocystous and unicellular blue-green algae. Selvi and Sivakumar (2011) reported cyanobacterial diversity and related physico-chemical parameters in paddy fields of Cuddalore district, Tamilnadu. The results showed that maximum numbers of blue-green algae were non-heterocystous forms, and heterocystous filamentous forms showed limited distribution and diversity. Among the thirty five species identified twenty one species were non-heterocystous belonging to genera *Arthrospira, Gloeocapsa, Gloeothece, Lyngbya, Merismopedia*, *Oscillatoria, Phormidium and Spirulina,* and fourteen species were heterocystous form belonging to genera *Anabaena, Cylnidrospermum, Calothrix* and *Nostoc*. They also reported the presence of thirty heterocystous forms, from this region subsequently (Selvi and Sivakumar, 2012). Dey and Bastia (2012) carried out taxonomical survey of the family Rivulariaceae in the rice fields of North Odisha, and reported that the genus *Calothrix* was the most dominant cyanobacteria with five species, and *Gloeotrichia* was the second dominant genera with four species. Kumar and Sahu (2012) reported diversity of green algae in relation to seasonal variation in paddy fields of Lalgutwa area, Ranchi, Jharkhand. They reported twenty four chlorophycean taxa with wide range of thallus structure. Maheshwari (2013) studied the occurrence of heterocystous cyanobacteria in rice fields of Bundi District of Rajasthan. Totally twelve

species were reported of which *Anabaena* was the dominant genus. Sandhyarani and Kumar (2014) also have reported rich diversity of heterocystous cyanobacteria in the rice fields of Warangal district of Andhra Pradesh. Roy and Keshri (2014) studied the occurrence of nostocales (Cyanophyta) from ponds and adjoining rice field areas of Burdwan, West Bengal and described sixteen species. Jain (2015) studied the diversity of blue-green algae in paddy fields of Madhya Pradesh and reported sixty six blue-green algal species with wide range of thallus structure. They belonged to the orders Chroococcales, Oscillatoriales, Nostocales, and Stigonematales.

The early reports on algae of rice fields in Kerala State are that of Parukutty (1940) and Aiyer (1965). Amma *et al.* (1966) studied the soil algal flora of Kuttanad. Anand and Hopper (1987) studied the algae of rice fields of Kerala and identified thirty taxa of which ten were new records. Jose and Patel (1990) reported *Ecballocystis ramosa* f. minor for the first time from India. Panikkar and Ampili reported species of *Oedogonium* (1992) and *Vaucheria* (1993). Ushadevi and Panikkar reported *Mougeotia* (1993*), Spirogyra* (1994) and *Zygnema* (1994) from different parts of Kerala. Sindhu and Panikkar (1994) studied the occurrence of desmids in the paddy fields of Kerala. Dominic *et al.* (1997) studied the biodiversity of nitrogen fixing cyanobacteria from different agro-climatic regions of Kerala. Panikkar and Sreeja (2005) described the zygospore formation of desmids from Kollam district and studied the genus *Closterium*. John and Francis (2007) have made an extensive investigation on the algal flora of Thodupuzha thaluk, Kerala. Antony *et al*. (2008) identified thirty nine taxa of Chlorophyceae and eighteen taxa of Bacillariophyceae from a canal in Kuttanad. The diversity and seasonal variation of algae in Muriyad wetland was reported by Sanilkumar and Thomas (2006). Tessy and Sreekumar (2007, 2008, 2009, 2010 and 2011) have reported the phytoplankton diversity and their seasonal variation in Thrissur Kol wetlands. They reported several taxa belonging to class Chlorophyceae,

Desmidiaceae, Bacillariophyceae, Chrysophyceae, Euglenophyceae and Cyanophyceae.

The communities of algae in rice fields include those growing on soil surface, in the stagnant floodwaters, and those living in the soil particles directly beneath the soil surface. They are highly susceptible to environmental changes, and exhibit rapid qualitative and quantitative variations along the cultivation cycle. According to Fernandez-Valiente and Quesada (2004) "phytoplankton (mainly chlorophyceans and diatoms) develops early in the cultivation cycle until the tillering phase. From tillering to the initiation of panicle the photosynthetic aquatic biomass reaches its highest values. During this period filamentous green algae and non-N_2-fixing cyanobacteria are dominant, although in some places N_2-fixing cyanobacteria become abundant. Also during this period submerged macrophytes develop dense populations. From panicle initiation to harvest, the total biomass decreases and N_2-fixing cyanobacteria become dominant".

2.2 Ecology of paddy field algae

The occurrence and diversity of algae in the paddy field ecosystem has variously been interpreted as to climatic factors, soil properties and biotic factors (Roger and Reynaud, 1982).

- **Climatic factors**

Among the climatic factors temperature, light and moisture usually do not limit algal growth in the tropical wet paddy fields. Light availability for the soil algae depends upon the season and latitude, plant canopy, location of algae in the photic zone and the turbidity of water. Blue-green algae are generally sensitive to high light intensities. In paddy fields blue-green algae develop later in the cultivation cycle when the plant cover is dense enough to protect them from excessive light (Roger and Reynaud, 1977). The climatic factors as well as the crop decide the availability of light reaching the soil surface. In general

higher light conditions are tolerated by green algae and blue-green algae develop at low light intensity (Roger and Reynaud, 1979). According to Neustupa and Skaloud (2008), availability of light influences the diversity of algae. Temperature is a key variable for the development of algal biomass because it regulates the rate of cellular metabolism, growth and productivity (Munn *et al.,* 1989). Low temperature decreases productivity and favors eukaryotic algae while high temperature favours blue-green algae and increase the algal productivity (Roger and Kulasoorya, 1980).

- **Soil characteristics**

The availability of light, mineral nutrients, moisture and pH are decisive physico-chemical factors in the development of algal community. The soil pH is important as it is related to the solubility of nutrient minerals. In acidic wetland soils, usually pH increases as a result of flooding (Saharwat, 2012) and is reversible on air drying (Kogel Knabner, *et al.,* 2010). The growth of blue-green algae is favored at neutral to alkaline pH (Singh, 1961; Koushik, 1994). Reduced growth was observed in a group of pH tolerant algae when the pH exceeded 9.5 (Pendersen and Hensen 2003). The growth of nitrogen fixing blue-green algae in rice fields is limited by low pH and phosphorus. Application of phosphorus together with lime has showed positive results (Roger and Kulasooriya, 1980). According to Kumar (2002) a positive correlation of nitrates and pH favors the growth of Cyanophyceae. Mansour and Shaaban (2010) reported that pH and electrical conductivity affect the availability of soil nutrients and in turn affect the biodiversity of soil algae. USEPA (2002) reported that Cyanophyta and Chlorophyta exhibit significant positive correlation to rainfall and ammonia. The reason is attributed to increased nutrient supply through runoff and ammonia oxidation to nitrate. Budel and Lange (2003) reported significant positive correlation between very fine sand and cyanobacteria species, whereas silt and clay exhibited a significant positive correlation with green algal species. Fathi and Zaki (2003) reported that the Chlorophyta species showed significant positive correlation

with maximum water holding capacity and capillary water, while there is no correlation with Cyanophyta species. Shathala *et al.* (2009) reported that nitrate is an important environmental variable for the proliferation of Cyanophyceae and Euglenophyceae.

Ray and Thomas (2012) has obtained positive correlation of green algal diversity with phosphorus, calcium and moisture content in the soils of different vegetation types of Western Ghats. Selvi and Sivakumar (2011) concludes that "normal range of various physico-chemical parameters favourably increase the cyanobacterial growth which enhance the growth of paddy.

When the pH and moisture conditions are favourable, the soil nutrient content is decisive in defining the abundance and diversity of the algae. Addition of inorganic fertilizers to soils rich in organic matter leads to visible growth of green algae (Lund, 1947). Blue green algae require Calcium as a macronutrient and cobalt as essential (Aleksandrova, 1956). Organic substrates will support many algae in darkness and stimulate algal growth in the light (Fogg, 1953).

According to Mathew *et al.* (2001) drainage of the paddy fields control salinity, leaching of sodium, calcium and magnesium and it improves the soil quality in Kuttanad. Grybos *et al.* (2009) are of the opinion that low pH favours low oxidation of organic carbon leading to its excessive accumulation, which corresponds to high organic carbon in Kuttanad soil. Ponnamperuma, 1972 concludes that soil characteristics of Kuttanad wetland are rich in organic content because of the high levels of calcium and magnesium.

Ray *et al*. (2014) have observed significant positive correlation between pH and organic carbon and between pH, calcium and magnesium in Kuttanad wetland soils. Dunne *et al*. (2001) have reported that calcium and magnesium are responsible for rise in pH and mobility of phosphorus in soils. However there has been no study to relate the soil characteristics of this wetland paddy ecosystem of Kerala to the diversity of algae.

- **Biotic factors**

Biotic factors that control the growth of algae in paddy fields are pathogens, antagonistic organisms and grazers. Grazers are the most important group that control the algal biomass. The common grazers in paddy fields are cladocerans, copepods, ostracods, mosquito larvae and snails (Roger, 1996). Generally the mucilaginous species are avoided by the grazers. This results in selective feeding affecting the diversity of the soil algae. Grazers to a large extent regulate the population size to the level of suppressing formation of bloom.

- **Agronomic practices**

Agricultural practices such as crop and tillage, fertilization and pesticide application also affect the growth and occurrence of algae in paddy fields. Application of nitrogen fertilisers increase the algal abundance; but decrease the population of nitrogen fixers (Yoshida *et al*., 1973). According to Watanabe *et al*. (1977) NPK fertilizers promote heterotrophic nitrogen fixation while suppressing autotrophic fixation. The nature and quality of fertiliser as well as the mode of application can influence the algal flora affecting total biomass and nitrogen fixing capacity (Roger and Reynaud, 1979).

Paddy fields are susceptible to fertiliser and pesticide runoff which directly affect the surface and ground water quality (Zanella *et al*., 2011; Tirado *et al.*, 2008; Divya and Belagali, 2012; Lamers *et al*.,2011). Pesticide losses of 30 to50% of the applied amount is reported to occur through drainage (Watanabe *et al*., 2007; Sudo *et al.,* 2002). The runoff nutrients lead to eutrophication and excessive algal growth in adjacent channels and nearby streams and lakes. The runoff pesticides contaminate the surface water and biota and disrupt the ecological system. Two major effects of pesticides on rice field algae have been recorded: "a selective toxicity which affects the composition of the algal population, and a growth promoting effect of insecticides due to the decrease of invertebrate populations that graze on algae"

(Roger *et al.,* 1991). The effect of pesticides on individual species has been demonstrated by a number of *in vitro* studies (Mahapatra *et al.,*1992; Das and Adhikary, 1996; Choudhury and Sarma , 2001; Suresh Babu *et al.*, 2001; Kumar *et al.*, 2009; 2012; Giriyappanavar , 2014). Roger *et al*. (1994) conclude that herbicides are most detrimental to phytoplankton than insecticides. Field studies from temperate regions have shown that pesticides decrease phytoplankton abundance (Takamura *et al.,* 1986), reduce phytoplankton diversity (Tomaselli, 1987) and change the population composition due to selective toxicity.

2.3 Allelopathic effects of algae

The allelopathic effects of the algae in paddy field ecosystem are also significant. A variety of algae in soil and water release phycochemicals that are beneficial or inhibitory to the growth of crops or to populations of other species of algae and microorganisms. Yadav and Satsangi (2014) have demonstrated *in vitro* that leachates of blue-green algae has negative to positive allelopathic effect on root length of rice seedlings depending on the species and concentration of the extract.

Gupta and Shukla (1967) studied the algal influence on growth, yield and protein content of rice plants and reported that that pre-soaking rice seeds with blue-green algae extracts enhances germination, promotes the growth of roots and shoots, and increases the weight and protein content of the grain. According to Svircev *et al*. (1997) the growth of plant was enhanced in the presence of cyanobacteria without organic nitrogen fertilizer application. Mishra and Kaushik (1989) observed similar positive indication for presence of auxin like substances in *Nostoc* sp., which may act as root promoting substances. Venkataraman and Neelakantan (1967) concluded that the production of growth substances and vitamins by the algae may be partly responsible for the greater plant growth and yield.

Francis (1878) first time reported the toxicity of cyanobacterial metabolites with regard to their effects on human and environmental health. Some species of cyanobacteria produce toxins which are divided in to three main groups; hepatotoxin, neurotoxin and cyanotoxin (Codd, 2000). According to Sivonen *et al.* (1986) the compounds produced by blue-green algae *Aphanizomenon flos-aquae*, *Nodularia squmigena*, *Microcystis* species and *Oscillatoria* species are toxic, either to other plants or to their own population. Hagmann *et al.* (1996) reported that cyanobacteria *Fischerella muscicola* produces fischerellin, a toxic allelochemical compound and potent photosystem inhibitor and destroys other cyanobacteria and photoautotrophic organisms. According to Weiss *et al.* (2000) cyanotoxins have clear allelopathic effects on aquatic plants, including reductions in growth, chlorophyll contents, and photosynthetic capacity as well as changes in plant pigment composition. According to Gantar *et al*. (2008) the lipophilic extracts containing indole alkaloids from *Fischerella* sp. inhibit photosynthesis of the green alga *Chlamydomonas* sp., causing loss of ultra-structural cell organization. Saqrane and Oudra (2011) reported that Cyanobacteria frequently form blooms in eutrophic water bodies. They produce cyanotoxins that adversely affect the aquatic environment and diverse organisms living there. Allelopathic interactions of this sort have been investigated to develop specific methods to control nuisance algae (Smith and Doan, 1999). Abe *et al.* (1996) reported that, when cyanobacterial blooms occur, the abundance of submerged plants decreases and the diversity of aquatic plant communities are reduced. Suikkanen *et al*. (2005) have suggested that minute allelopathic effects may result in significant planktonic community changes, but have also verified that some documented allelopathic effects in laboratory monocultures were not observed when a natural community was studied. Kannaiyan *et al*. (1992) reported that Cyanobacterial metabolites include a wide range of chemicals, particularly nitrogen rich alkaloids and peptides which have been threats to total environmental health.

2.4 Relevance of the present study

The surface oxidised soil of rice fields are more stable through the cultivation cycle compared to the transient flood water. The algae that flourish on this soil photic layer comprise unicellular planktonic and colonial species as well as filaments. Excessive growth of mat forming filamentous species are reported to entangle the rice seedlings and uproot them when the mats dislodge. Therefore management of the excessive growth of filamentous algae in the paddy field is important. However the knowledge of the ecology of filamentous algae is scarce and fragmentary. Filaments are important in certain aspects:

1. They are excellent adaptive forms enabling better use of resources in confined spaces.
2. They respond positively to phosphorus / nitrogen similar to phytoplankton of lake and hence can serve as bioindicators of soil conditions.
3. They are better biomass accumulators compared to unicellular algae; hence are more amenable to biotechnology applications.

2.5 Objectives of the study

1. To document the diversity of the filamentous algae in the paddy fields of Kuttanad and Kole lands of Kerala.
2. To study the fertility characteristics of soil in relation to the occurrence of algae.
3. To study the probable impact of algal bloom on paddy yield.

Chapter -3
STUDY AREA

3.1 Kuttanad

Kuttanad is part of India's largest Ramsar site - the Vembanad-Kole wetland, located in the fertile low-lying areas of Vembanad Lake, between 9°17'and 9°40'N latitude and between 76°19'and 76°33'E longitude. It is primarily a deltaic formation of Meenachil, Pamba, Manimala, Muvattupuzha, and Achencovil rivers. Much of this region lies 0.6 to 2.2 m below mean sea level; hence saline water ingression occurs during summer months, and remains water-logged almost throughout the year. It is subjected to continued flood during the monsoon. It spreads over Alappuzha, Kottayam, and Pathanamthitta districts, contributing nearly 20% of total rice production of the state, and is called 'Rice Bowl of Kerala' (Narayanan *et al.,* 2011). This is a unique ecologically fragile bio-geographical unit recognized as a Globally Important Agricultural Heritage System (GIAHS) by FAO.

The soils of Kuttanad differ widely in their appearance, productivity, and management requirements. Soil Survey Organization of the Kerala Government grouped soils in Kuttanad into fifteen soil series based on their characteristics. They are Karuvatta series, Pallippad series, Mannar series, Vechoor series, Changanacherry series, Champakulam series, Ramankary series, Edathua series, Purrakad series, Majoor series, Thottappally series,

Ambalapuzha series, Thakazhy series, Muthur series and Kurichy series. The puncha lands (main crop in summer) of Kuttanad are classified under three categories based on elevation, geographical formation and soil characteristics, into Karappadoms, Kayal lands and Kari land (Santhosh and Paulose, 2012).

Morphological and physicochemical properties of the soils of Kuttanad show great degree of variation. They are low to medium in fertility, alluvial with silty clay texture. They are salty and are acidic, enriched by annual silt deposition during the monsoon floods. The acidity is due to the production of sulphuric acid by microbiological oxidation of sulfur compounds present in the soil. High amount of iron, manganese, aluminum and sulphides are also present in the soil (Santhosh and Paulose, 2012). Soils are dark brown to black in colour, sticky, with deposits of lime shells and humus. Organic carbon and cation exchange capacity of the soil are higher compared to other parts of Kerala, but the base saturation is comparatively lower (Thampatti, 1997).

The agricultural practices in Kuttanad are quite unique because much of the land lies below the sea level. The paddy fields situated along the waterways need to be protected by strong and carefully designed bunds. Water is let in and drained out from time to time as per changing requirements of the paddy crop, using waterwheels or electric motors. Soon after the northeast monsoon ends in November, bunds are raised, seeds sown in November- December and the crops are harvested in February- March. The region is divided into six agronomic zones such as Upper Kuttanad, Purakkad, Lower Kuttanad, Kayal lands, Vaikom and North Kuttanad (Indo-Dutch Mission, 1989, Fig.3.1). The sampling locations of this investigation were selected such that it represented all agronomic zones of Kuttanad, and is proportional to the area of each agronomic zone. Thus twenty seven sampling locations were selected. The agronomic zones and sampling locations are given in Table 3.1 and Table 3.2.

Table 3.1 The Agronomic Zones and Number of sampling stations in Kuttanad

Agronomic Zone	Area (ha)	Number of Sampling locations
Upper Kuttanad	10,576	5
Purakkad	4,311	2
Lower Kuttanad	16,280	8
Kayal land	9,464	5
Vaikom	7,748	4
North Kuttanad	6,556	3
Total	54,935	27

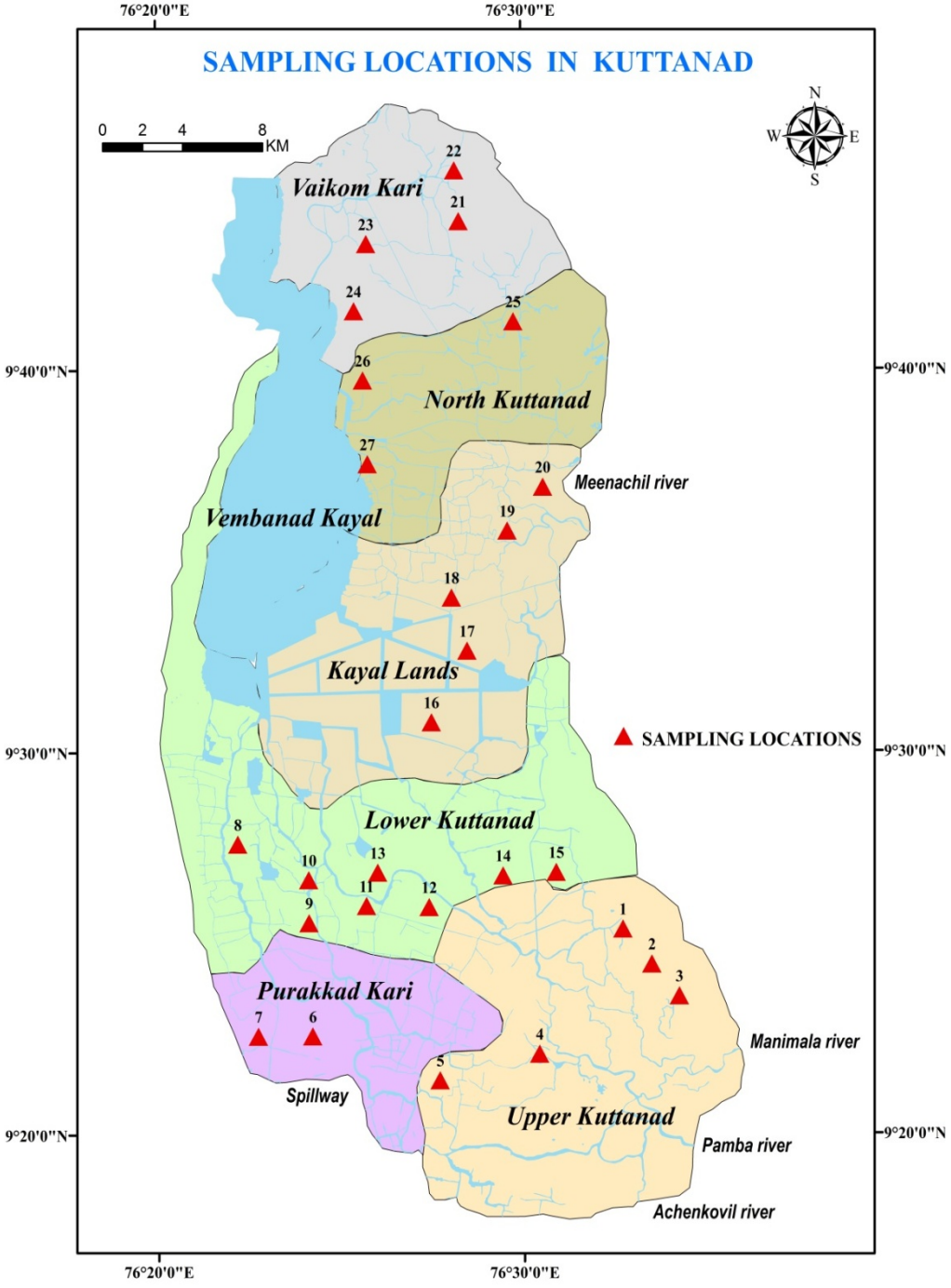


Fig. 3.1 Map of Kuttanad showing agronomic zones and sampling locations

Table 3.2 Sampling locations at Kuttanad

Sl. No.	Agronomic zones of Kuttanad	Sampling locations
1	Upper Kuttanad	Laikad
2		Perumthuruthy
3		Muthoor
4		Thalavadi
5		Edathua
6	Purakkad	Appathykara
7		Karoor
8	Lower Kuttanad	Kainakari
9		Champakulam
10		Nedumudi
11		Mancompu
12		Ramankary
13		Pulinkunnu
14		Veliyanad
15		Kidangara
16	Kayal Lands	Thuruthy
17		Valady
18		Neelamperoor
19		Chingavanam
20		Pallom
21	Vaikom	Ayamkudi
22		Ezhumanthuruthu
23		Koovam
24		Vechoor
25	North Kuttanad	Neendoor
26		Kallara
27		Kumarakom

3.2 Kole Lands

The Kole lands are one of the largest, most threatened and highly productive wetlands in Kerala. It is one of the rice granaries of Kerala and a part of the unique Vembanad-Kole wetland ecosystem comprising of 1,51,250 ha included as a Ramsar site in 2002. Kole lands extend from the northern bank of Chalakudy River in the south to the southern bank of Bharatapuzha River in the north (Sujan and Sivaperuman, 2008). They are low lying tracts 0.5 to 1 m below mean sea level located between $10^0$20' and $10^0$40'N latitude and between $75^0$58' and $76^0$11'E longitude**.** The fields are geographically distributed in Mukundapuram, Chavakkad and Thrissur taluks of Thrissur district and Ponnani Taluk of Malappuram district. The Karuvannur river divides the Thrissur Kole into North and South Koles. The fields are flooded during the south west monsoon. The cyclical nutrient recharging of the wetland during the flood season render the area as one of the most fertile soils of Kerala (Jayan and Sathyanathan, 2010).

Geologically, Kole soils are rich alluvium deposits brought along by Kechery and Karuvannur rivers; a major portion of it remains submerged under water for about six months in a year (Jeena, 2011). It is a basin with a saucer shape flanked by laterite hills in the western and eastern margins and contains black carbonaceous clay. Kole land soil has been classified into clay, sandy loam, sandy clay loam and clay loam based on the textural analysis. The total nutrient content of the soil throughout the Kole land is 0.14-0.57% Nitrogen, 0.2-0.24% Phosphorus pentoxide and 0.09-0.60% of Potassium oxide. Calcium Oxide levels also are very high (Jayan and Sathyanathan, 2010).

The regions of Kole originally under cultivation has reduced considerably due to reclamation and urban development. Therefore sampling locations of this investigation in Kole lands were randomly selected from regions of active paddy cultivation. These locations were at Muriyad, Palakkal, Nedupuzha and Puzhakkal (Fig. 3.2).

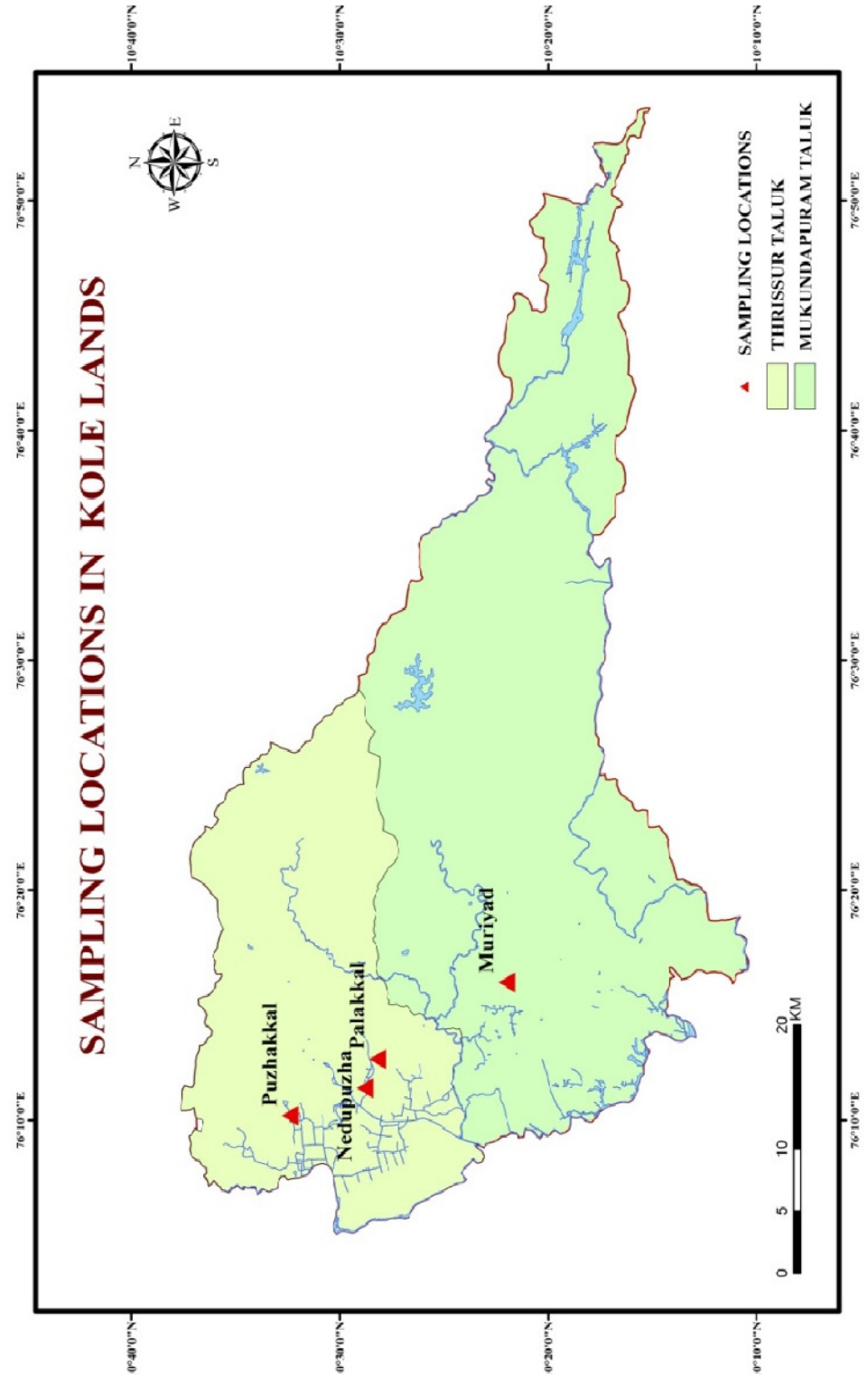


Fig.3.2 Map of Kole lands of Thrissur showing sampling locations

Chapter - 4
METHODS OF OBSERVATION AND ANALYSIS

4.1 Algal sampling

The samples for the study were collected from the paddy fields of Kuttanad during the cropping period of December 2010 to February 2011 and from November 2011 to February 2012. Algae were collected once in a month from all locations by taking soil surface layer (0-2cm) using a clean scoop. Twenty soil samples were collected randomly from different places at each location and combined together for observing the algae. The algae were also scrapped off any soil, and debris, forgein materials and submerged vegetation, as well as filtered out from stagnant water. The samples were placed in clean polythene bags, and carried to the laboratory where they were processed immediately or after short term storage in dark at 4^0C.

Samples for the study at Kole lands were also collected during October 2011 to January 2012. The soil samples for observation of algae were collected by the same procedure followed in Kuttanad.

4.2 Soil Sampling

Soil samples for analysis of soil properties were collected from all the sampling locations of Kuttanad from December 2010 to February 2011 and Kole lands from October 2011 to January 2012, simultaneous with algal sample collection. Soil samples were collected from the top 15cm layer for physico-chemical and chemical analysis. Ten samples were collected randomly from

different places at each location and pooled together. The debris, leaves, plant roots and course materials were removed from the sample. They were placed in polythene bags and transported to the laboratory within two to three hours.

The samples were dried in a well spread thin layer at ambient temperature of the laboratory (28-32^{0}C) for seven to ten days. Sub samples of air dry materials were dried at 105^{0}C in oven to constant weight and the % moisture content was computed from the weight loss. It was ensured that the residual moisture of air dry soil was <5%. The air dried samples were then gently powdered in a wooden mortar and sieved through 2mm steel sieve, and stored in polythene bags in a desiccator. These samples were used for all chemical analysis.

4.3 Analysis of filamentous algae

Laboratory observation of the samples was initiated within twenty four hour of collection. Samples were transferred to petriplates; remnants of vegetation, soil invertebrates and pebbles, if any were removed. The algae present in this were observed following two methods: direct observation and enrichment method.

4.3.1 Direct observation

Soil samples of 2g was mixed thoroughly with distilled water in a beaker. This suspension was filtered through a linen cloth. The filtrate was observed under microscope. The algae scrapped off from surfaces were suspended in distilled water and subsamples directly observed under microscope.

4.3.2 Enrichment method

The soil samples of 2g were taken in petriplates of diameter 100 mm and spread evenly (Fig.4.1). They were enriched with BG 11 medium and Ward and Parrish medium so as to wet the soil. Cover glasses were placed

randomly on the soil surface. The petriplates were covered with their lids and placed by the window side to receive natural light. After 12 days algal growth was observed on the underside of cover glass. The cover glasses were taken out and algae were viewed under light microscope and microphotographs were taken using digital camera. Micrometric measurements of the filamentous algae were taken using ocular micrometer.

Fig. 4.1. Enrichment method of observation of algae

4.3.3 Identification and classification of algae

Identification and classification of algae was carried out based on morpho-taxonomic description with the help of monographs, taxonomic keys, standard publications and websites. The taxonamic keys referred were Desikachary (1959), Randhawa (1959), Prescott (1962), Gonzalves (1981), Anand and Hopper (1987), Anand (1989), Krishnamurthy (2000) and Mahendra Perumal and Anand (2008). The online source used was www.algaebase.org (Guiry and Guiry, 2014). Blue-green algae were classified as per Desikachary (1959) and green algae according to www.algaebase.org (Guiry and Guiry, 2014).

4.4 Quantitative analysis of soil algae

4.4.1 Frequency distribution of algal species

The distribution of filamentous algae across the sampling sites was studied by computing their frequency of occurrence. Frequency was calculated following the relation.

$$\text{Frequency (\%)} = \frac{\text{No. of samples of occurrence}}{\text{Total no. of samples}} \times 100$$

The frequencies were plotted graphically for each agronomic zone of Kuttanad and the four locations of Kole lands. The constancy of occurrence of each species spatially was computed in terms of the presence or absence data in various sampling locations and assigned to constancy classes.

The similarity of occurrence of species in different agronomic zones of Kuttanad and that of Kole lands was calculated using Sorensen index of similarity.

$$\text{Coefficient of Sorensen } S_s = \frac{2a}{2a+b+c}$$

where

a = Number of species in sample A and sample B (joint occurrence)

b = Number of species in sample B but not in sample A

c = Number of species in sample A but not in sample B

The overall similarity among the six agronomic zones of Kuttanad and among the four regions of Kole was elucidated through cluster analysis. The dissimilarity computed as 1- S_s was taken as the distance in y-axis for plotting the dendrogrm using the software Kyplot.

4.4.2 Estimation of soil chlorophyll *a*

The biomass of soil algae was estimated in terms of Chlorophyll *a.* Soil samples were collected from the top 1 cm layer for estimation of Chlorophyll *a.,* and analysed immediately after reaching the laboratory. One gram wet soil samples were suspended in 90% acetone and kept overnight in dark at 4^0C.

These samples were thawed to room temperature centrifuged and made up to 10ml with 90% acetone (Tsujimura *et al*., 2000). The absorbencies of the supernatant were read at 664nm, 665nm and 750nm in a uv-visible spectrophotometer, before and after acidification (Lorenzen, 1967). The concentrations of Chlorophyll *a* per liter of the extract was computed.

$$\text{Chlorophyll } a \text{ µg /L} = \frac{26.7(664\text{ b}-665\text{ a}) \times V_1}{V_2 \times L}$$

V_1	=	Volume of extract, mL
V_2	=	Volume of sample, L
L	=	Path length of cuvette, cm
664 b and 665 a	=	Optical densities of 90% acetone extract before and after acidification respectively.

The value 26.7 is the absorbance correction and equals A x K

Where,

A	=	Absorbance coefficient for chlorophyll *a* at 664 nm=11.0 and
K	=	Ratio expressing correction for acidification.

The amount of the pigment was expressed as Chlorophyll *a* in µg g^{-1} dry weight of the soil. The dry weight was determined by oven drying of duplicate samples at 105^0C to a constant weight. The soil chlorophyll *a* was converted to algal biomass by multiplying with the factor 67 (APHA, 1998) to assess the contribution of soil algae to soil organic matter.

4.5 Analysis of soil properties

The physico-chemical and chemical parameters analysed were texture, pH, electrical conductivity, organic carbon, available phosphorus, available potassium, total inorganic nitrogen, available calcium and magnesium. The moisture content of the air dry sample was determined shortly before all the analysis and the moisture correction factor determined for the computation of analytical results (Jackson, 1973).

4.5.1 Texture

Soil texture was determined by hydrometer method (Jackson, 1973). The percentages of sand, silt and clay were calculated. Soil texture was read from the soil texture triangle using the particle analysis data.

4.5.2 pH

Soil pH was measured using a soil water extract in the ratio 1:25. 20 g portion of the air dried soil was weighed into a 100 mL beaker; added 50 mL of distilled water and stirred for 30 minutes. The pH of the filtrate was determined using pH meter with a glass electrode (Jackson, 1973).

4.5.3 Electrical Conductivity

Electrical conductivity was measured using a soil water suspension in the ratio 1:2.5. 20 g of the air dried soil was weighed into a 100 mL beaker; added 50 mL of distilled water and stirred for 30 minutes. Conductivity of the suspension was measured in a calibrated Digital Conductivity Meter (Jackson, 1973).

4.5.4 Organic Carbon

Organic carbon was determined using Walkley – Black (1934) procedure. The method involves the estimation of residual potassium dichromate against titration with ferrous sulphate following combustion of the soil in a mixture of potassium dichromate and sulphuric acid. The carbon content of the soil was obtained by

$$\% C = M \times (V_1 - V_2/s) \times 0.39 \times mcf$$

Where

M	=	molarity of ferrous sulphate solution (from the blank titration)
V_1	=	ferrous sulphate solution required for blank ml
V_2	=	ferrous sulphate solution required for sample ml
s	=	weight of air dry sample in gram
0.39	=	$3 \times 10^{-3} \times 100$ % x 1.3 (3 = equivalent weight of carbon)
mcf	=	moisture correction factor

4.5.5 Available Phosphorus

Weighed 2g of air dried and 2 mm sieved soil and placed in a 50 ml extraction beaker. Added 20ml of Bray 1 extracting reagent and shaken for 5 minutes on a shaker at 200 oscillations per minute. The suspension was filtered through a Whatman No.2 filter paper. Available Phosphorus in the filtrate was determined by Ascorbic acid method. Ammonium molybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form phosphomolybdic acid, which is reduced to intensely colored molybdenum blue by ascorbic acid. The absorbance was measured at 880 nm in a uv-visible spectrophotometer (Bray and Kurtz, 1945).

4.5.6 Available Potassium

Weighed 2g of air dried and 2 mm sieved soil and placed in a 50 ml extraction beaker. Added 20 ml of ammonium acetate extracting solution. It was shaken for 5 minutes on a shaker at 200 oscillations per minute, and filtered through a Whatman No.2 filter paper. Potassium was determined by Flame emission photometry. The extracts were aspirated and the emission intensity was measured at 766.5 nm. The potassium concentration was read from calibration curve (Stanford and English, 1949).

4.5.7 Total Inorganic Nitrogen

Two grams of air dried and 2 mm sieved soil, were placed in a 50 ml extraction beaker. 25 ml of 2M potassium chloride extracting solution was added and shaken for 5 minutes on a shaker at 200 oscillations per minute. The suspension was filtered. Total Inorganic Nitrogen of the filterate was estimated as the sum of nitrate, and ammonium. The nitrate in the extract was first reduced to nitrite by hydrazine sulphate. Nitrite was determined by colorimetric method. The ammonium content of the extract was determined by Phenate method. The reaction is based on the formation of blue compound indophenol, by the reduction of ammonia, hypochlorite and phenol catalyzed by sodium nitroprusside. The absorbance of the blue colour was measured in uv-

visible spectrophotometer at 640 nm and the amount of ammonium was computed (Jackson, 1973).

4.5.8 Available Calcium and Magnesium

Weighed 2g of air dried and 2 mm sieved soil, and placed in a 50 ml extraction beaker. Added 20 ml of ammonium acetate extracting solution and shaken for 5 minutes on a shaker at 200 oscillations per minute. The suspension was filtered through a Whatman No.2 filter paper. The soluble Calcium in the extract was determined by EDTA titrimetric method using muroxide indicator after adjusting the pH to eleven with 1N NaOH. At this pH, magnesium is precipitated as Mg $(OH)_2$ and only calcium react with EDTA. Magnesium was determined by calculation method (Jackson, 1973).

4.5.9 Correlation of soil physico-chemical and biological properties

The data on the soil parameters as analysed above were subject to Pearson correlation analysis (using Excel software) to establish the type of association among the soil properties. The biological properties of the soil in terms of the algal biomass measured as chlorophyll *a* and observed species richness of filamentous algae in each agronomic zone of Kuttanad and sampling locations of Kole lands were similarly correlated with each soil parameter. The correlation coefficients were considered significant at $p<0.05$ level using t-test.

4.5.10 Nutrient index

The fertility status of the soils of Kuttanad and Kole lands were determined in terms of nutrient index. The index is based on the range of organic carbon, available phosphorus, available potassium, available calcium and available magnesium. The samples were individually categorized as low, medium and high (Table 4.1 and 4.1.a).

Table 4.1 Rating chart for soil test values (DAC, 2011)

Soil Fertility Level	Organic Carbon (%)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)
Low	Below 0.5	Below 22	Below 123
Medium	0.5 – 0.75	22 – 54	123 – 293
High	Above 0.75	Above 54	Above 296

Table 4.1a Rating chart for soil test values for Available Calcium and Magnesium

Status	Available Calcium (mg/kg)*	Available Magnesium (mg/kg)*
Low	<150	<50
Medium	150-300	50-100
High	>300	>100

*The formula for converting kg/ha to mg/kg is $\frac{\text{Value in (kg/ha)}}{2}$

The nutrient index was computed based on the above chart and the soils were categorised into three nutrient classes (Table 4.2) based on the following formula (Parker, 1951):

Nutrient index

$$= \frac{(1 \text{ X no. of samples in low category}) + (2 \text{ X no. of samples in medium category}) + (3 \text{ X no. of samples in high category})}{\text{Total number of samples}}$$

Table 4.2 Nutrient index with range and remarks
(Ramamoorthy and Bajaj, 1969)

Nutrient index	Range	Remarks (OC, P, K, Ca, Mg)
I	Below 1.70	Low
II	1.71 – 2.33	Medium
III	Above 2.33	High

Chapter - 5
RESULTS AND DISCUSSION

5.1 Diversity of filamentous algae

The pattern of cultivation in Kuttanad is related to the rainfall and salt water intrusion from the adjoining Vembanad estuary. Paddy is cultivated either once, twice or thrice in a year depending upon the location of the paddy fields. The sampling locations of this study were those paddy fields cultivated once a year *i.e.,* the puncha crop in summer.

The first phase of sampling of soil algae in this study at Kuttanad was during December 2010 to February 2011. The sampling began in the month of December when the crop was at the seedling stage and continued till harvest in February 2011. Presence of algae in the soil and flooded water was not visibly observed in the initial stages of crop. Occasional green to yellow discoloration of the soil was observed as the paddy plants grew up which could be related to algal growth. The second phase of sampling in Kuttanad was from November 2011 to February 2012. The sampling started as the field was prepared for sowing and continued till the harvest. During this phase, algal growth was observed as green and blue-green patches on the soil surface. Progressing towards harvest, blooms of algae were observed in the waterlogged areas in the field, and in canals running along the sides of paddy fields. They appeared as surface mats on soil within the waterlogged areas in the fields and as surface scum and benthic mats in the adjacent canals (Fig.5.1). By the end of the sampling period, in February 2012, the soil was dry and algal blooms in the canals disappeared.

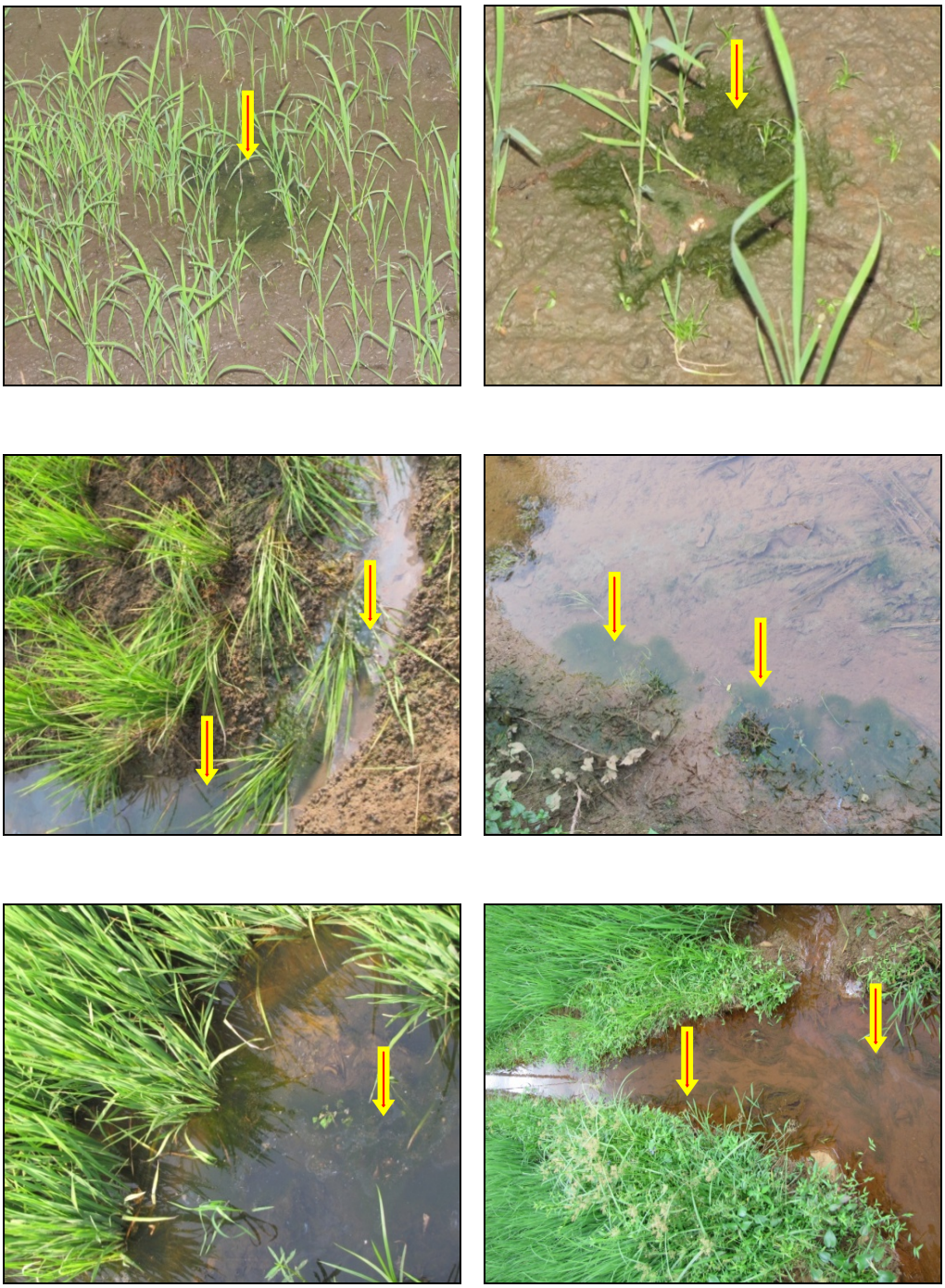


Fig.5.1 Algal bloom observed in Kuttanad and Kole fields during 2011-2012 punja crop season

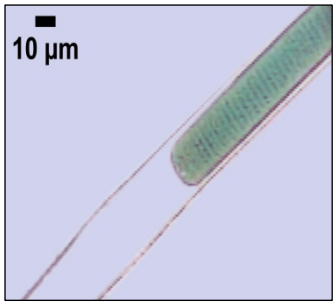
Algae of the Kole lands were studied from October 2011 to January 2012. When the sampling began, the fields were prepared to sow seeds or in some fields sowing had been completed. As the sampling proceeded to November and December green algal blooms were observed in the adjacent canals. At the end of sampling period in January 2012 the canals and the soils in the fields were dry and the blooms disappeared.

5.1.1 Filamentous algae of paddy fields of Kuttanad

The flora of filamentous algae collected from paddy fields of Kuttanad belonged to blue-green and green algae. Altogether 32 species of blue-green algae and 5 species of green algae were collected during the two cropping seasons combined. Four different morphotypes of *Spirogyra* were distinguished based on the filament width, number chloroplast and type of end wall. These were named as *Spirogyra* type 1, type 2, type 3, and type 4. The taxonomic description of the species along with their orginal microphotographs are given below.

1. *Lyngbya bergi* Smith, G.M.

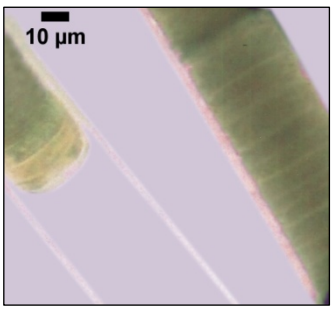
Filaments straight, 16-18 µm broad, sheath firm, trichome not constricted at the cross walls, cells 15-20 µm broad, ends rounded, not attenuated, not capitate; cells shorter than broad.



Division - Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 296, Pl. 50, Fig.7, 8)

2. *Lyngbya magnifica* Gardner

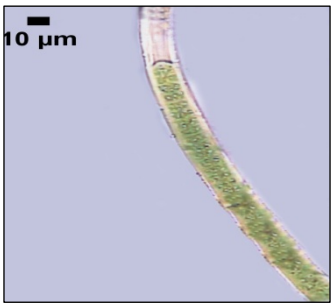
Filaments long, straight 30-36 µm broad, sheath 1.5-2 µm thick, trichome 28-32 µm broad, not attenuated at the ends, not constricted at cross-walls, cells 3-4 µm long, end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 320)

3. *Lyngbya hieronymusii* Lemm

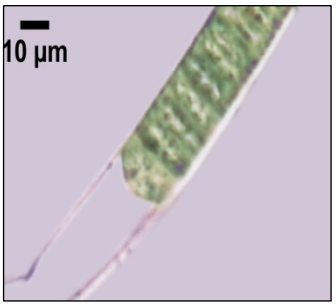
Filaments straight or slightly bent, 12-13 µm broad; sheath firm, colourless; cells 10-12 µm broad, 2-3 µm long, not constricted at the cross-walls, granulated, with gas- vacuoles, not attenuated; end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 297, Pl. 48, Fig.4)

4. *Lyngbya major* Menegh ex Gomont

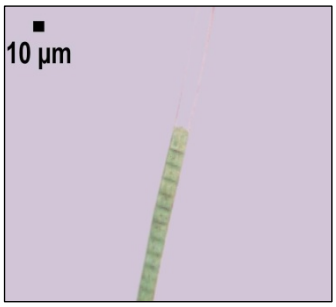
Filaments long, straight, cells17-20 µm broad, 2-3 µm long, granulated at the septa, not constricted at the cross-walls, sheath thick, end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 320, Pl. 52, Fig.11)

5. *Lyngbya shackletonic* W.et G.S.West

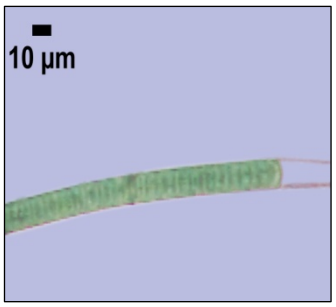
Filaments straight, 12-12.5 µm broad; sheath firm, colourless; trichome not constricted at the cross walls; not attenuated at the ends; cells 2-3 µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .296, Pl. 53, Fig.13)

6. *Lyngbya martensiana* Menegh ex Gomont

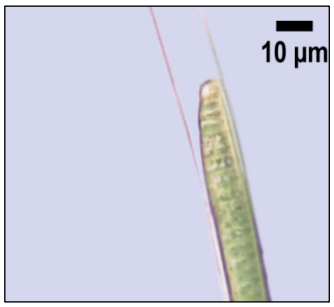
Trichome 8-11 µm broad, not constricted at the cross-walls; sheath, colourless; apices not attenuated; cells 1-2 µm long; end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p.318, Pl. 52, Fig.6)

7. *Lyngbya semiplena* (G.Ag.) J. Ag.ex Gomont

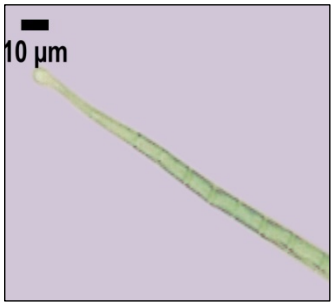
Trichome yellowish green, not constricted at the cross-walls, 8-10 µm broad; sheath thick, colourless; at the ends slightly attenuated, capitate, 2-3 µm long cells, end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-NostocalesFamily- Oscillatoriaceae
(Desikachary 1959, p. 315, Pl. 49, Fig. 8, Pl. 52, Fig.7)

8. *Oscillatoria splendida* Grev. ex Gomont

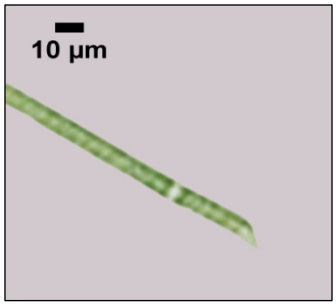
Trichome straight, not constricted at the cross-walls, at the ends gradually attenuated, cells 2-5 µm broad, 3-7 µm long, end cells capitate, nearly rounded, without calyptra.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .234, Pl. 37, Figs.7, 8 & Pl. 38, Fig.10 & Pl. 40, Fig.11)

9. *Oscillatoria acuminata* Gomont

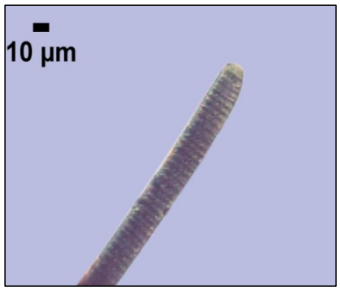
Trichome more or less straight, not constricted at the cross-walls, 4-6 µm broad, at the ends briefly tapering, sharply pointed, cells longer than broad, 6-8 µm long, end cell mucronate, without calyptra.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p 240, Pl. 38, Fig.7 & Pl. 40, Fig.13)

10. *Oscillatoria princeps* Vaucher ex Gomont

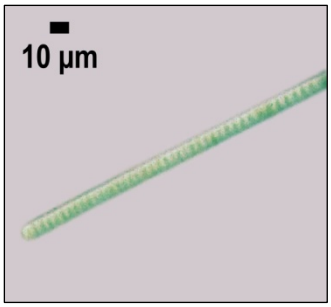
Trichome14-18 µm broad, straight, not constricted at the cross-walls; cells 3-4 µm long, apices slightly attenuated; end-cells rounded, slightly capitate, without thickened membrane.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p210, Pl.37, Figs.1,10,11, 13, 14)

11. ***Oscillatoria subbrevis*** Schmidle.

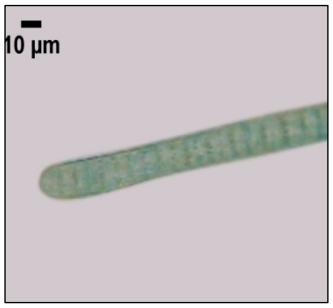
Trichome 4-6 µm broad, straight, not attenuated at the apices, cells 0.5-1 µm long, end-cells rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 207, Pl. 37 Fig.2 and Pl.40 Fig. 1)

12. ***Oscillatoria tenuis*** Ag. ex Gomont

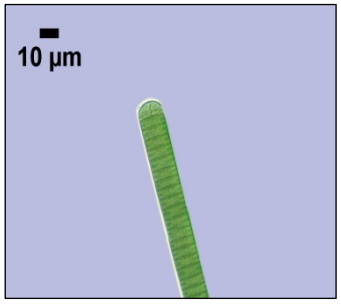
Trichome straight, slightly constricted at the cross-walls; not attenuated at the apices; cells 10-14 µm broad, 2-3 µm long, at the septa mostly granulated, end cell more or less hemispherical.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
Desikachary 1959, p.222, Pl. 42, Fig.15)

13. ***Oscillatoria limosa*** Ag. ex Gomont

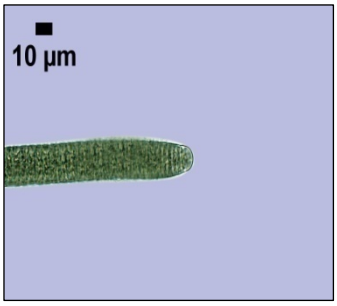
Trichome more or less straight; not constricted at the cross-walls, 10-12 µm broad, cells 2-4 µm long, cross walls frequently granulated; end cell flatly rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .206, Pl. 42, Fig.11)

14. *Oscillatoria sancta* (kutz) Gomont

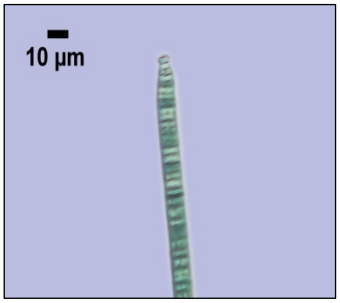
Thallus dark blue-green, trichome straight, slightly constricted at the cross walls, ends briefly attenuated, cells 14-17 µm broad, cells 2-3 µm long, cross walls frequently granulated, end cell hemispherical, capitate.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .203, Pl. 42, Fig.10)

15. *Oscillatoria vizagapatensis* Rao, C.B.

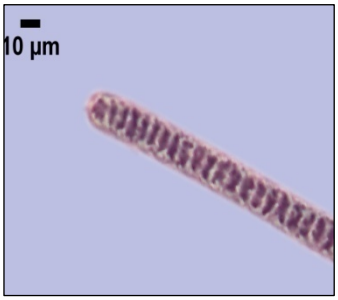
Trichome straight, uniformly broad except at the extream apex, 8-9 µm broad; without constrictions at the cross walls, cells 2-1 µm long, and end cell broadly rounded forming a cap.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p 205, Pl. 39, Fig.16, 18)

16. *Oscillatoria perornata* skuja

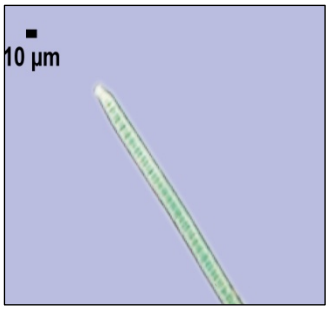
Trichomes14-15 µm broad; well constricted at the cross- walls, cell 3-5 µm long, end cells hemispherical, calyptra absent.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 205, Pl. 41, Fig.8, 9, 14)

17. *Oscillatoria proboscidea* Gomont

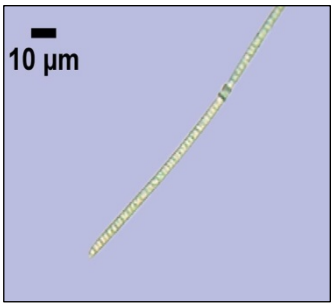
Trichome more or less straight, not constricted at the cross-walls, bent at the end, slightly attenuated, 9-12 µm broad, cells 1-2 µm long, end cells flatly rounded, capitate.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 211, Pl. 38, Fig.9)

18. *Oscillatoria laete-virens* (crouan) Gomont

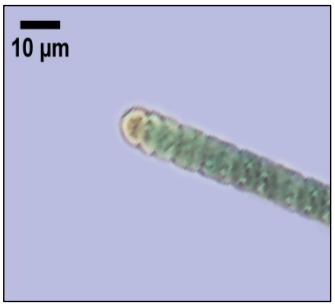
Thallus thin, trichome yellowish green, straight, slightly constricted at the cross-walls, 2-3 µm broad, apices attenuated, cells 2-3 µm long, end cells not capitate, more or less conical.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 213, Pl. 39, Fig.2, 3)

19. *Oscillatoria formosa* Bory ex Gomont

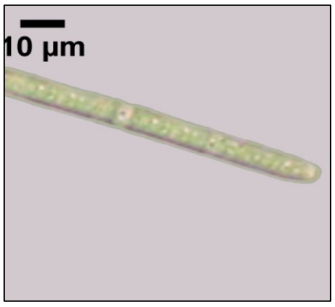
Trichome straight, slightly constricted at the cross-walls,7-8 µm broad, attenuated at the ends; ,cells 3-4 µm long, end cell obtuse, not capitate.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 232, Pl. 40, Fig.15)

20. *Oscillatoria rubescens* Dc ex Gomont

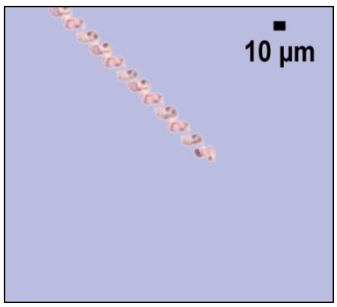
Trichome straight, at the ends gradually attenuated, 6-7 µm broad, not constricted at the cross-walls, cells 2 µm long, and end cell capitate.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 235, Pl. 42, Fig.12)

21. *Spirulina princeps* W. et G.S. West

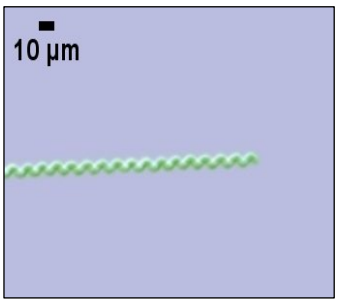
Trichome 4-5 µm broad; regularly spirally coiled, spirals 10-12 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .197, Pl. 36, Fig. 7)

22. *Spirulina gigantea* Schmidle

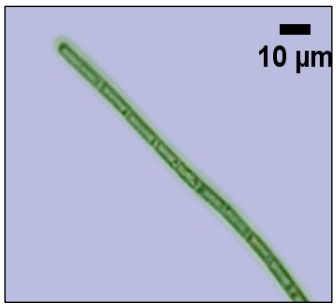
Trichome 3-4 µm broad; regularly spirally coiled, at the end conical attenuated, spirals 10-12 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 197, Pl. 36, Fig. 12, 14, 17)

23. *Phormidium tenue* (Menegh.) Gomont

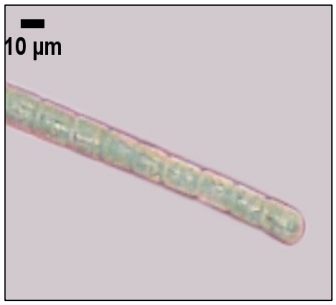
Thallus thin, membranous, trichome straight, slightly constricted at the cross walls, 2-3 µm broad; sheath thin; cells 4-5 µm long, cells up to three times longer than broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p.259, Pl. 43, Figs. 13-15 & Pl.44, Figs.7-9)

24. *Phormidium retzii* (Ag.) Gomont

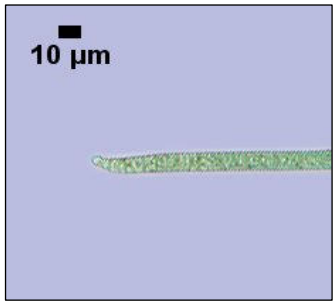
Filaments more or less straight, mostly constricted at the cross walls, not attenuated at the ends, not capitate, 11-13 µm broad, sheath thin, cells 6-9 µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 268, Pl. 44, Figs. 13&15)

25. *Phormidium uncinatum* (Ag.) Gomont

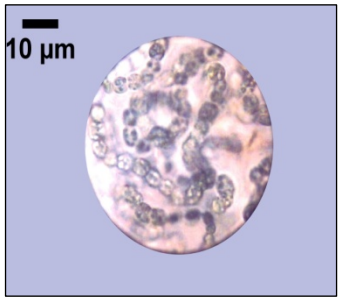
Filaments straight or slightly bent, not constricted at the cross walls, 6-9 µm broad, ends briefly attenuated, capitate, end cell with a round or depressed conical calyptra.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .276, Pl. 43, Figs. 1, 2 &Pl.45 Figs.9, 10)

26. ***Nostoc linckia*** (Roth) Bornet ex Born. et Flah.

Thallus gelatinous, yellowish brown to blue green, trichome 3-4 µm broad, cells barrel-shaped, 3-4 µm long, heterocysts almost spherical, 5-6 µm broad; spores in long chains, more or less spherical 6-7 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p.377, Pl. 67, Fig.1)

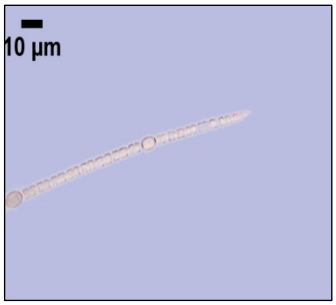
27. ***Nostoc commune*** Vaucher ex Born. et Flah.

Thallus globose, sheath yellowish, distinct at the periphery, trichome 5-6 µm broad; cells barrel-shaped, 4-5 µm long, heterocysts almost spherical, 6-7 µm broad.

Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p. 387, Pl. 68, Fig. 3)

28. ***Anabaena naviculoides*** Fritsch

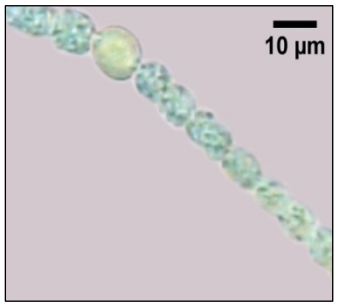
Trichome thin, gelatinous, apices acuminate; cells more or less barrel-shaped, 3-4 µm broad; heterocysts intercalary, 5-6 µm broad , broader than the vegetative cells, apices acuminate, apical cell conical.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p. 410, Pl. 72, Fig. 2)

29. ***Anabaena sphaerica*** Bornet et Flahault

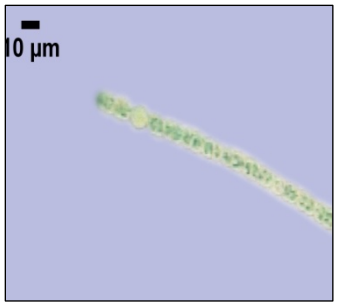
Thallus blue-green, trichomes straight, 6-9 µm broad; cells spherical to short barrel-shaped; heterocysts subspherical, 8-10 µm broad, 9-11µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p .393, Pl. 71, Fig. 10)

30. ***Anabaena ballyganglii*** Banerji

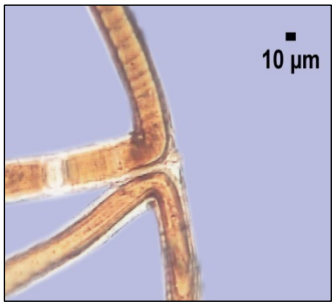
Trichome circinate; cells compressed, spherical, 7-9 µm broad, 5-6 µm long, contents granular, heterocysts somewhat spherical, 8-9 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p.409, Pl. 77, Fig.4)

31. ***Scytonema cincinnatum*** Thuret ex Born. et Flah.

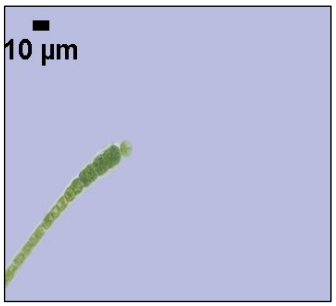
Filaments 30-35 µm broad, false branches mostly germinate; sheath firm, brownish; trichomes 15-18 µm broad, slightly constricted at the cross walls; heterocysts single, quadrate.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family –Scytonemataceae
(Desikachary 1959, p 453, Pl. 93, Fig.1)

32. *Cladothrix contarenii* (Zanard.) Bornetet Flah.

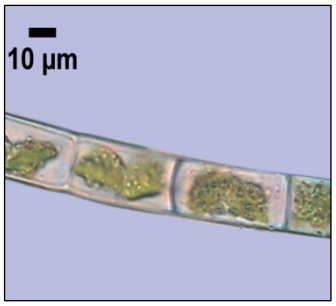
Filaments long, swollen at the base, 7-10µm broad; sheath colourless, heterocyst basal.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family –Rivulariaceae
(Desikachary 1959, p 524, Pl. 111, Figs. 2, 5, 8)

33. *Sirogonium* Kutzing

Unbranched uniseriate filaments; up to several times as long, lacks outer mucilage layer and non slimy to touch; cells cylindrical, 15-18µm broad, 42-45µm long, chloroplast ribbon like, straight, with pyrenoids; sexual reproduction by scalariform conjugation.



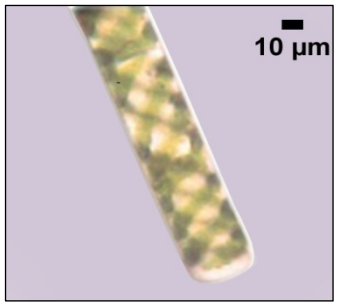
Phylum-Charophyta
Class-Zygnematophyceae
Order-Zygnemales
Family-Zygnemataceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

34. *Spirogyra* Link

Thalli comprised of unbranched uniseriate filaments, slimy to touch; cells cylindrical, 10 to 200 µm in diameter, most 20 to 60 µm, up to several times as long; end walls plane; chloroplasts from 1-15 per cell; plastids ribbon like, coiled, pressed against cell wall within parietal layer of cytoplasm, Sexual reproduction by conjugation.

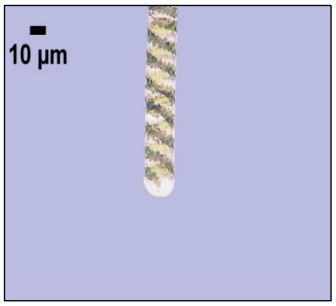
Phylum-Charophyta
Class-Conjugatophyceae
Order-Zygnemales
Family-Zygnemataceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

34.1. *Spirogyra* type 1



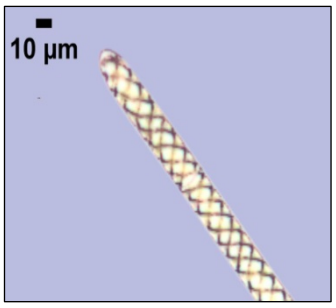
Unbranched uniseriate filaments; slimy to touch; cells cylindrical, 28-31 µm broad, 142-145 µm long, chloroplasts two, six to seven turns per cell, ribbon like, coiled, end wall plane.

34.2. *Spirogyra* type 2



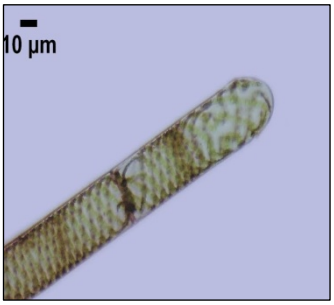
Unbranched uniseriate filaments; slimy to touch, cells cylindrical,16-18 µm broad, 95-100 µm long; chloroplasts one, five to six turns per cell, ribbon like, coiled, end wall plane.

34.3. *Spirogyra* type 3



Unbranched uniseriate filaments; slimy to touch, cells cylindrical, 15-18 µm broad, 170-185 µm long; chloroplasts two, eight to ten turns per cell, ribbon like, coiled, end wall plane.

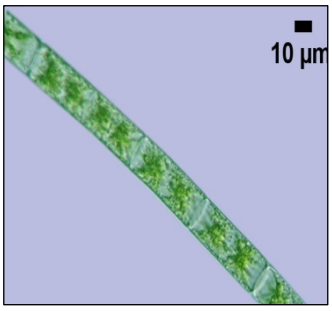
34.4. *Spirogyra* type 4



Unbranched uniseriate filaments, slimy to touch; cells cylindrical,25-28 µm broad, 130-140 µm long; chloroplasts two, eighteen to twenty turns per cell, ribbon like, coiled, end wall plane.

35. *Zygnema* C. Agardh

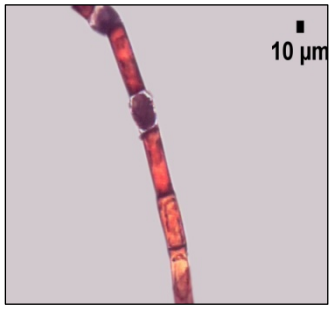
Thalli comprised of unbranched uniseriate filaments, cells cylindrical, 15-17 µm broad, 42-45 µm long, and chloroplast two per cell, stellate.



Phylum-Charophyta
Class-Conjugatophyceae
Order-Zygnemales
Family-Zygnemataceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

36. *Oedogonium brevicingulatum* Jao

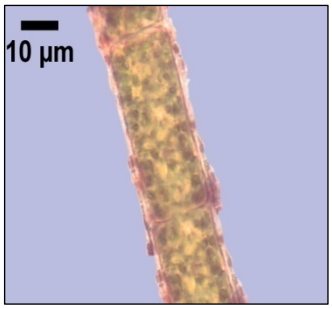
Cells cylindrical, 95-120 µm long, 22-24 µm broad; oogonium single, obovoid to globose, 70-75 µm long, oospore globose.



Phylum-Chlorophyta
Class-Chlorophyceae
Order-Oedogoniales
Family-Oedogoniaceae
(Gonzalves, 1981, p. 159, fig.22)

37. *Rizoclonium* Kutzing

Unbranched uniseriate filaments; Cells cylindrical, 14-16 µm broad, 45-48 µm long, Chloroplast parietal with pyrenoids, often packed with starch.



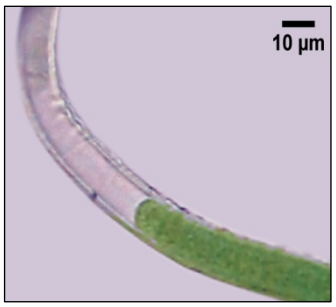
Phylum-Chlorophyta
Class-Ulvophyceae
Order-Cladophorales
Family-Cladophoraceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

5.1.2 Filamentous algae of paddy fields of Kole

Filamentous algae collected from the paddy fields of Kole belonged to blue-green and green algae. There were 28 species of blue-green algae. Green algae were *Mougeotia* species and five filament types of *Spirogyra.* Among these fifteen species of blue-green and two filament types of *Spirogyra* were same as those observed in Kuttanad. These species are *Lyngbya bergi*, *Lyngbya hieronymusii*, *Lyngbya major, Oscillatoria splendida*, *Oscillatoria accuminata*, *Oscillatoria princeps*, *Oscillatoria subbrevis*, *Oscillatoria perornata*, *Oscillatoria laete-virens*, *Oscillatoria limnosa, Oscillatoria proboscidea*, *Phormidium tenue*, *Phormidium retzii*, *Nostoc commune, Anabaena naviculoides, Spirogyra* type1, *Spirogyra* type 3. The taxonomic descriptions of the other species are given below.

1. ***Lyngbya dendrobia*** Bruhl et Biswas

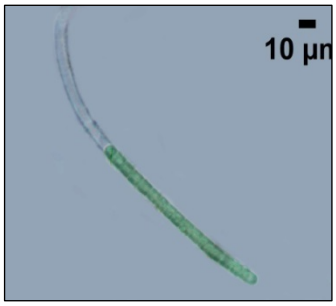
Trichome 11-13 µm broad, sheath 2-2.5 µm thick, colourless, trichome 8-10 µm broad, not constricted at the cross-walls, cells 2-3 µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 302, Pl. 50, Figs3, 10 & Pl. 55, Figs.2-4)

2. ***Lyngbya palmarum*** (Martens) Bruhl et Biswas

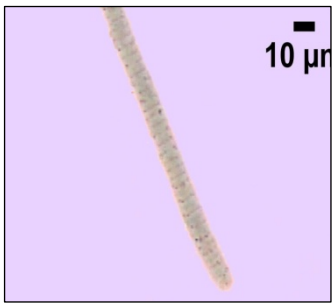
Trchome 5-7 µm broad, not constricted at the cross-walls; apices rounded, cells 3-4 µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 301, Pl. 55, Fig.6)

3. *Oscillatoria raoi* De Toni, J.

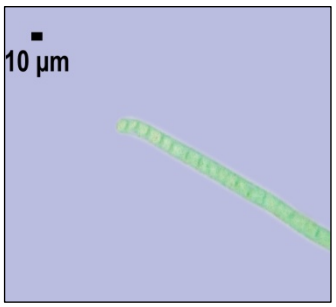
Trichome straight, uniform thickness, without constrictions at the joints, 6-9 µm broad, granules closely arranged on either side of the septa, cells 2-3 µm long, end cells rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 223, Pl. 42, Figs.16-19)

4. ***Oscillatoria chalybea*** (Mertens) Gomont

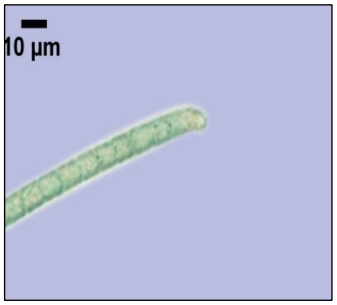
Trichome more or less straight, 8-11 µm broad; bent at the end, slightly attenuated; slightly constricted at the cross walls; cells 3-5 µm long, end cells obtuse.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p. 218, Pl. 38, Fig.3)

5. *Oscillatoria boryana* Bory ex Gomont

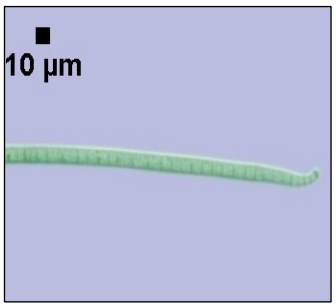
Trichome straight, slightly constricted at the cross-walls, 4-7 µm broad; cells 4-7 µm long; end cell rounded.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .218, Pl. 38, Fig.12)

6. *Oscillatoria amoena* (kutz) Gomont

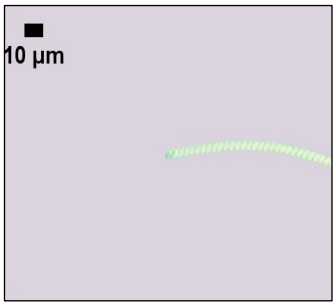
Trichome straight, ends gradually attenuated, 5-8 µm broad; cells 2-3 µm long; end cells capitate, broadly conical with calyptra.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p .230, Pl. 40, Fig.12)

7. *Spirulina subsalsa* Oerst. ex Gomont

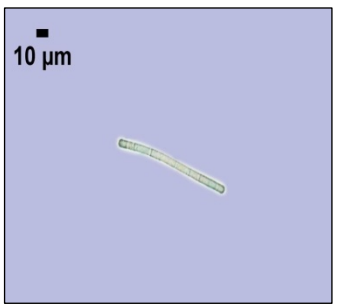
Trichome 1-2 µm broad, blue-green colour, spirally coiled, spirals very close to each other, 3-4 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p.193, Pl. 36, Fig 3, 9)

8. *Phormidium inundatum* Kutzing ex Gomont

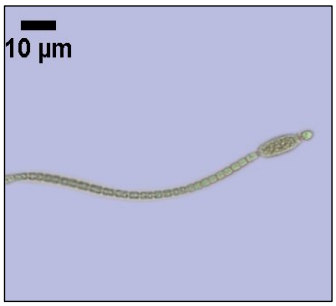
Trichome blue-green, straight, not constricted at the cross walls; sheath thin; cells 3-4 µm broad, 4-7 µm long, nearly quadrate, granulated at the septa.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Oscillatoriaceae
(Desikachary 1959, p.271 and MahendraPerumal and Anand, 2008, P.7, Fig. 2)

9. *Cylindrospermum indicum* Rao, C.B.,orth. Mut. De Toni

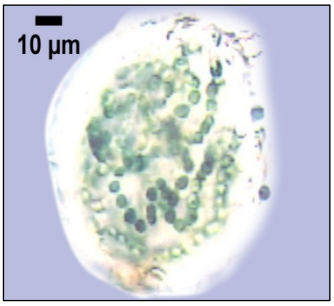
Trichome single with deep constrictions at the joints, 2-4 µm broad, cells almost quadrate, or more or less barrel-shaped, 3-4 µm long, heterocysts spherical, one at each end of the trichome, 2-3 µm broad, spores ellipsoidal, 7-8 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p .369, Pl. 64, Figs. 4&11)

10. *Nostoc punctiforme* (Kuttz.) Hariot

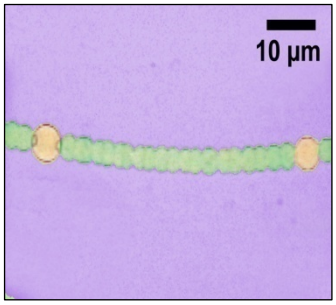
Thallus sub-globose; sheath mucous; trichome 3-4 µm broad, cells barell-shaped; heterocyst 5-6 µm broad, 6-7 µm long.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p .374, Pl. 69, Fig. 1)

11. *Anabaena circinalis* Rabenhorst ex Born.et Flah.Var. crassa Ghose

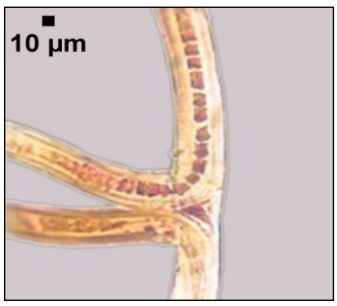
Trichome single, loosely coiled, cells nearly spherical, but generally shorter than broad, 5-6 µm broad; heterocysts globose, 7-8 µm broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family- Nostocaceae
(Desikachary 1959, p .414, Pl. 77, Fig. 5)

12. ***Scytonema myochrous*** (Dillw) Ag.ex Born. et Flah.

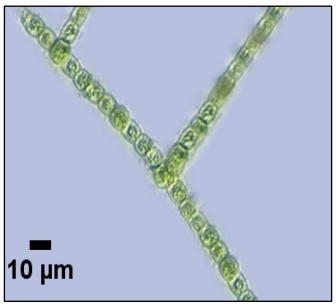
Thallus brownish black, 35-40 µm broad, sheath yellowish brown, trichome 8-12 µ broad, heterocysts longer than broad.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family –cytonemataceae
(Desikachary 1959, p. 487, Pl. 90, Fig. 3& Pl.99, Fig.2)

13. ***Hapalosiphon welwitschii*** W. et G.S.West

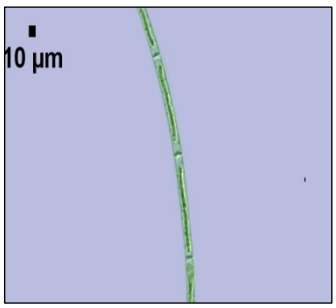
Filaments 5-8 µm broad, sheath very close, colourless; cells sub spherical or elongate, as long as broad; lateral branches short, 4-6 µm broad, slightly attenuated at the ends.



Division –Cyanophyta
Class- Cyanophyceae
Order-Nostocales
Family –Hapalosiphonaceae
(Desikachary 1959, p. 588, Pl. 137, Fig. 5)

14. ***Mougeotia*** C.Agardh

Unbranched uniseriate filaments; cells cylindrical, 8-10 µm broad, 110-115 µm long, chloroplast axil, uncoiled, one per cell, plate like.

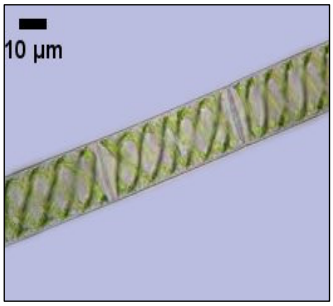


Phylum-Charophyta
Class-Conjugatophyceae
Order-Zygnemales
Family-Zygnemataceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

15. Spirogyra Link

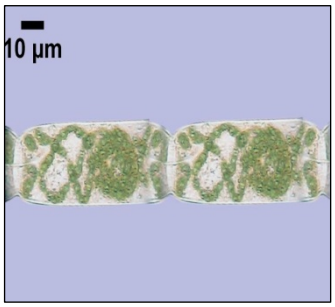
Phylum-Charophyta
Class-Conjugatophyceae
Order-Zygnemales
Family-Zygnemataceae
(Guiry and Guiry 2014, http://www.algaebase.org.)

15.1. *Spirogyra* type 5



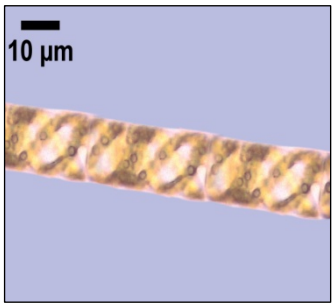
Unbranched uniseriate filaments, slimy to touch; cells cylindrical, 14-17 µm broad, 70-75 µm long; chloroplasts two, six to seven turns per cell, ribbon like, coiled, end wall replicate.

15.2. *Spirogyra* type 6



Unbranched uniseriate filaments, slimy to touch; cells cylindrical, 25-27 µm broad, 92-98 µm long; chloroplasts two, three to four turns per cell, ribbon like, coiled, end wall replicate.

15.3. *Spirogyra* type 7



Unbranched uniseriate filaments, slimy to touch; cells cylindrical, 11-14 µm broad, 66-70 µm long; chloroplasts two, three to five turns per cell, ribbon like, coiled, end wall plane.

5.2 Distribution of filamentous algae in Kuttanad

Variations occurred in the number of species and their frequency of occurrence through the agronomic zones. The number of species was generally high in Kayal lands followed by lower Kuttanad and North Kuttanad. The least number of species were observed in Purakkad (Fig. 5.2).

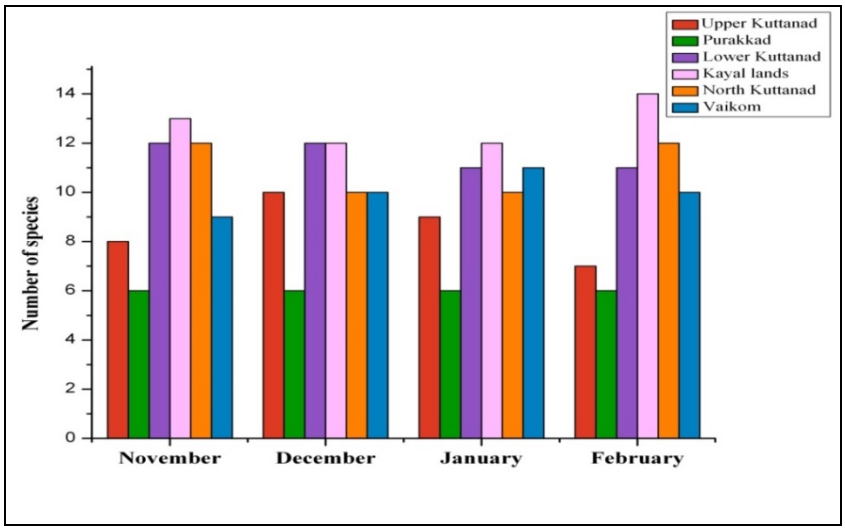


Fig.5.2 Species richness across cropping season in the six agronomic zones of Kuttanad

The diversity of filamentous algae was restricted to blue-green and green algae of which the higher species spectrum was exhibited by blue-green algae (Fig. 5.3).

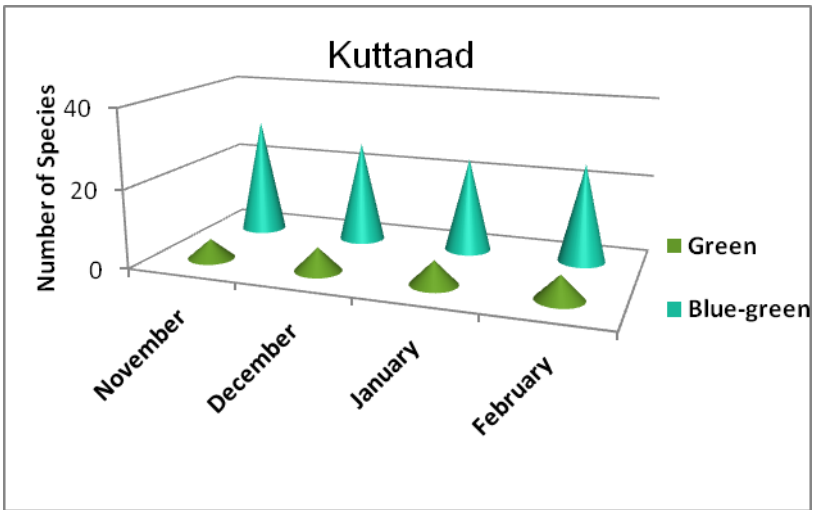


Fig.5.3 Occurrence of filamentous algae in Kuttanad

The frequency of distribution of each species along the agronomic zones and their constancy class is represented in Table 5.3. According to this *Spiogyra* type 4 and *Oscillatoria tenuis* fall in the constancy class V and hence these are the most widely distributed species with 83% occurrence. *Lyngbya bergi, Oscillatoria splendida* and *Phormidium tenue* fall in the constancy class IV with 67% occurrence. Twenty five species fall in the consistency class I with 17% occurrence and are the least distributed species.

Table 5.3 Occurrence of filamentous algae in the agronomic zones of Kuttanad

No	Species	Upper Kuttand	Purakkad	Lower Kuttanad	Kayal lands	North Kuttanad	Vaikom	% / Constancy Class
1	***Lyngbya***							
	1. *L. bergi*	-	-	+	+	+	+	67/IV
	2. *L. magnifica*	-	-	-	-	-	+	17/I
	3. *L. hieronymusii*	+	-	-	-	-	-	17/I
	4. *L. major*	-	-	-	-	+	-	17/I
	5. *L. shackletonic*	-	-	+	-	-	-	17/I
	6. *L. martensiana*	-	-	-	-	+	-	17/I
	7. *L. semiplena*	-	-	+	-	-	-	17/I
2	***Oscillatoria***							
	8. *O. splendida*	+	+	-	-	+	+	67/IV
	9. *O. acuminate*	-	-	-	+	-	-	17/I
	10. *O. princeps*	-	-	-	+	+	+	50/III
	11. *O. subbrevis*	-	+	-	-	-	-	17/I
	12. *O. tenuis*	+	+	-	+	+	+	83/V
	13. *O. limosa*	-	-	+	-	-	-	17/I
	14. *O. sancta*	-	-	-	+	+	-	33/II
	15. *O. vizagapatensis*	-	-	-	-	-	+	17/I
	16. *O. perornata*	+	-	-	-	-	-	17/I
	17. *O. proboscidea*	-	-	+	-	-	-	17/I
	18. *O. laete-virens*	-	-	+	-	-	-	17/I
	19. *O. formosa*	-	-	-	+	-	-	17/I
	20. *O. rubescens*	-	-	-	-	+	-	17/I
3	***Spirulina***							
	21. *S. princeps*	-	-	+	+	-	-	33/II
	22. *S. gigantea*	-	-	-	-	+	-	17/I
4	***Phormidium***							

	23. *P. tenue*	+	+	-	-	+	+	67/IV
	24. *P. retzii*	-	-	+	-	-	-	17/I
	25. *P. uncinatum*	-	-	-	-	-	+	17/I
5	***Nostoc***							
	26. *N. linckia*	-	-	+	-	-	+	33/II
	27. *N. commune*	-	-	-	+	+	-	33/II
6	***Anabaena***							
	28. *A. naviculoides*	-	+	-	-	-	-	17/I
	29. *A. sphaerica*	+	-	-	+	+	-	50/III
	30. *A. ballyganglii*	-	-	+	+	-	-	33/II
7	***Scytonema***							
	31. *S. cincinnatum*	-	-	-	+	-	-	17/I
8	***Cladothrix***							
	32. C. contarenii	-	-	-	-	+	-	17/I
9	***Sirogonium***							
	33. Sirogonium sp.	+	-	-	-	-	-	17/I
10	***Spirogyra***							
	34.1. *Spirogyra* type1	+	-	-	+	+	-	50/ III
	34.2. *Spirogyra* type 2	-	-	+	+	-	+	50/III
	34.3. *Spirogyra* type3	+	+	-	-	-	-	33/II
	34.4. *Spirogyra* type4	-	+	+	+	+	+	83/V
11	***Zygnema***							
	35. *Zygnema sp.*	-	-	-	-	+	-	17/I
12	***Oedogonium***							
	36.*O.brevicingulatum*	+	-	-	-	-	-	17/I
13	***Rizoclonium***							
	37.*Rizoclonium sp.*	-	-	-	+	-	-	17/I

5.2.1 Filamentous algae in the six agronomic zones of Kuttanad

❖ Upper Kuttanad

Ten species of algae were observed in the Upper Kuttanad zone. *O. splendida, O. tenuis, P. tenue, A. spherica, Spirogyra* type1 and Spirogyra type 3 were found throughout cropping season. *L. heironymusii* and *O. perornata* were observed from the month of November to January and *Sirogonium sp*. were observed in the middle of cropping season. *O. brevicingulatum* was found only in the month of December and February (Fig.5.4).

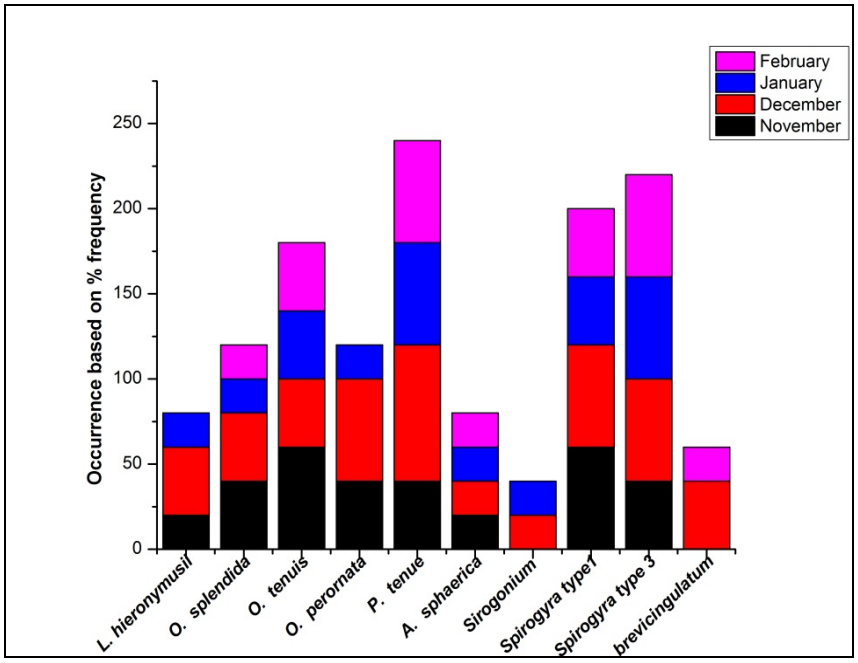


Fig.5.4 Species occurrence in Upper Kuttanad

Among the sites of Upper Kuttanad P. *tenue* showed highest frequency followed by *Spirogyra* type 3, *Spirogyra* type 1 *and O. tenuis.* The lowest frequency was showen by *Sirogonium sp.* (Fig.5.5).

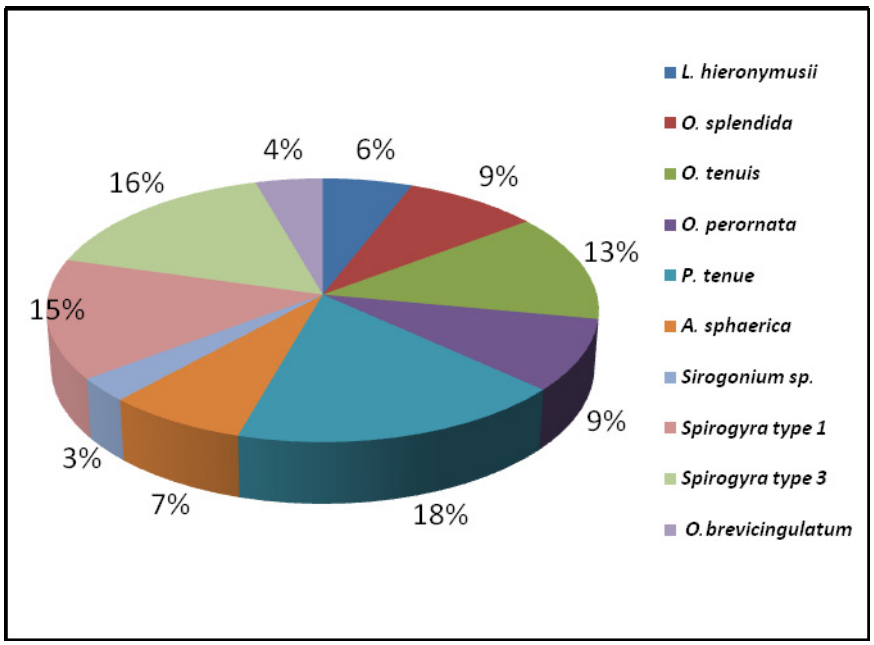


Fig. 5.5 Species distribution frequency - Upper Kuttanad

❖ Purakkad

Seven species of filamentous algae were obtained from Purakkad. Among these *O.splendida, O. tenuis, P. tenue, Spirogyra* type 3 and *Spirogyra* type 4 were found in all the sampling months. *O. subbrevis* was found up to the month of January whereas *A.naviculoides* was found only at the end of the cropping season (Fig.5.6).

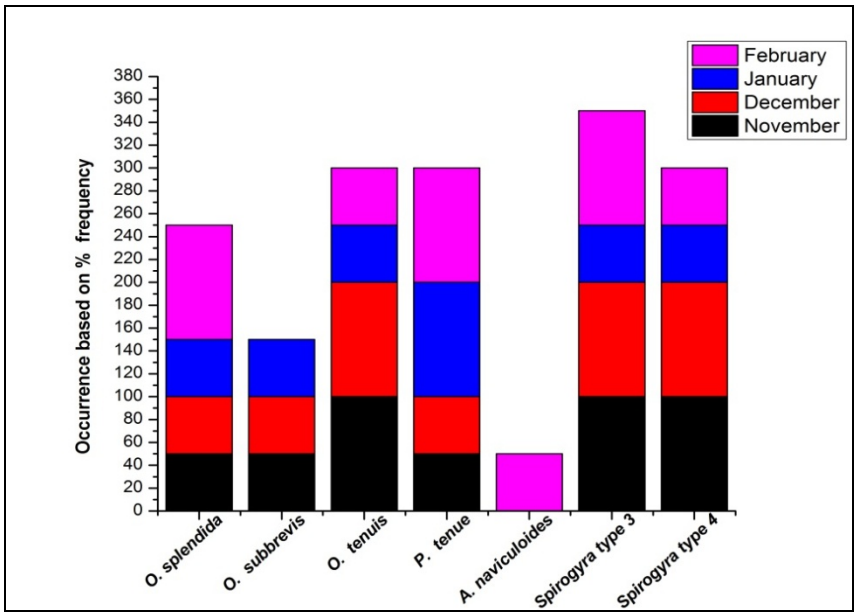


Fig.5.6 Species occurrence in Purakkad

Among the algal species observed at Purakkad *Spirogyra* type 3 showed the highest frequency. It was followed by *Spirogyra* type 4,*O. tenuis* and *P. tenue*. *A.naviculoides* showed the lowest frequency (Fig.5.7).

❖ Lower Kuttanad

Twelve species of filamentous algae were obtained from Lower Kuttanad. *L. bergi , L. shackletonic , L. semiplena O. limosa, O. proboscidea, S. princeps, P. retzii, A. ballyganglii, Spirogyra* type 2 and *Spirogyra* type 4 were observed during the period of cropping. *O. laete-virens* was not obtained in January. *N. linckia* did not occure in the month of February (Fig.5.8).

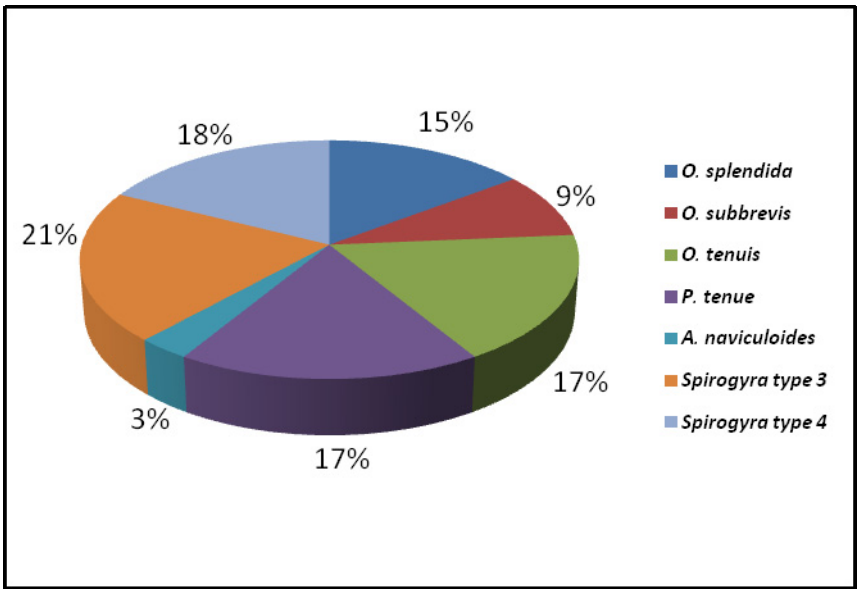


Fig.5.7 Species distribution frequency – Purakkad

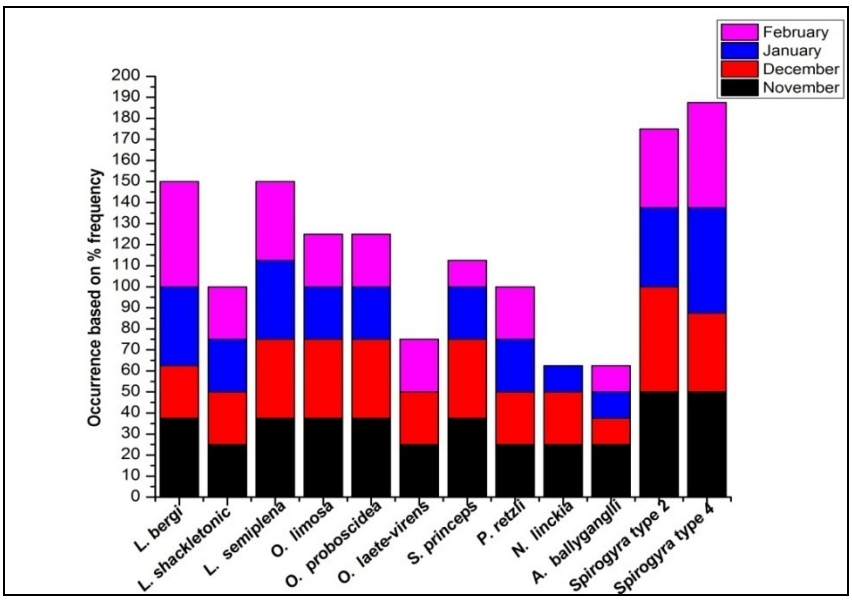


Fig.5.8 Species occurrence in Lower Kuttanad

In Lower Kuttanad *Spirogyra* type 4 showed the highest frequency distribution during the sampling period. *N. linckia* and *A. ballyganglii* were least distributed (Fig.5.9).

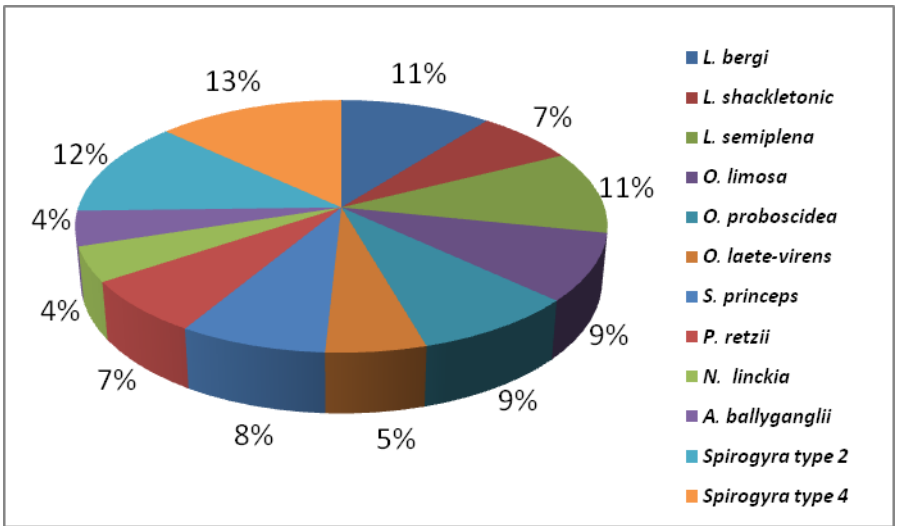


Fig.5.9 Species distribution frequency - Lower Kuttanad

❖ **Kayal land**

Altogether fifteen species of algae were observed in Kayal lands. *L. bergi, O. acuminata, O. princeps, O. tenuis, O. sancta, O. formosa, S. princeps, Spirogyra* type1, *Spirogyra* type 2 and *Spirogyra* type 4 were found throughout the cropping season. *N. commune* was present only in the month of November, and *A. sphaerica, A. ballyganglii* were found in the month of December onwards. *S. cincinnatum* and *Rizoclonium sp*. were observed at the beginning and end of crop season (Fig.5.10).

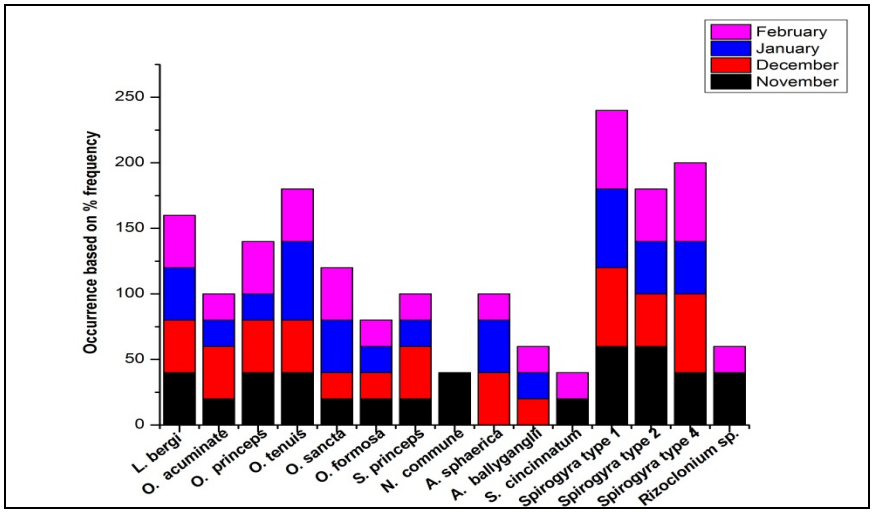


Fig.5.10 Species distribution in Kayal land

In Kayal lands *Spirogyra* type1 showed the highest frequency distribution. The lowest distributed species were *N.commune* and *S. cincinnatum* (Fig.5.11).

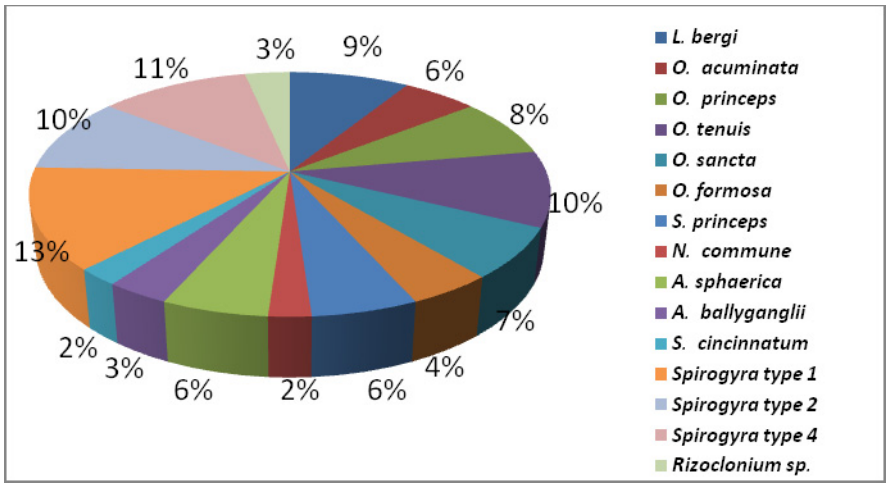


Fig. 5.11 Species distribution frequency – Kayal land

❖ **Norh Kuttanad**

Sixteen species of filamentous algae were observed in North Kuttanad. Among these *L. bergi, O. princeps, O. tenuis, P. tenue, Spirogyra* type 1 and *Spirogyra* type 4 were present throughout the cropping season. *N. commune, C. contarenii* and *Zygnema sp*. were observed only in the month of November, February and January respectively (Fig. 5.12).

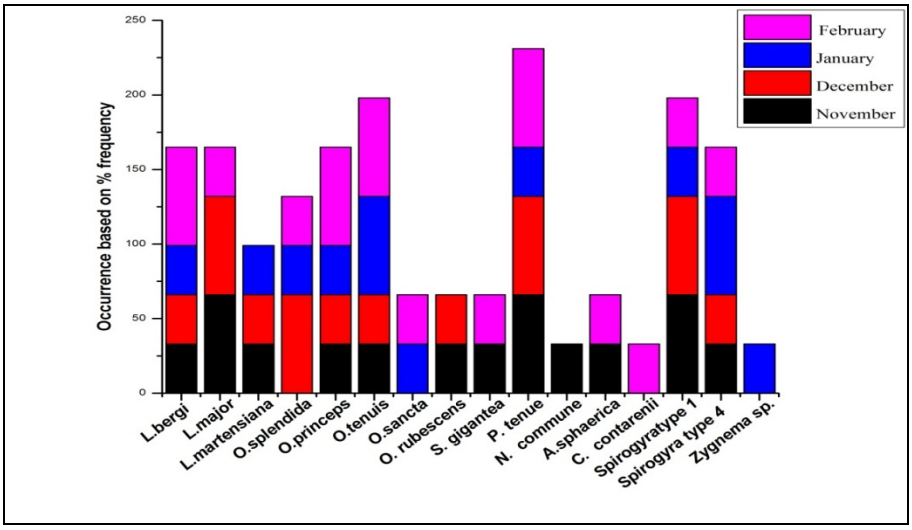


Fig.5.12 Species occurrence in North Kuttanad

P. tenue was the most widely distributed species in this area and was followed by *O. tenuis* and *Spirogyra* type 1. *N. commune, C. contarenii* and *Zygnema sp.* showed the lowest frequency of distribution (Fig. 5.13).

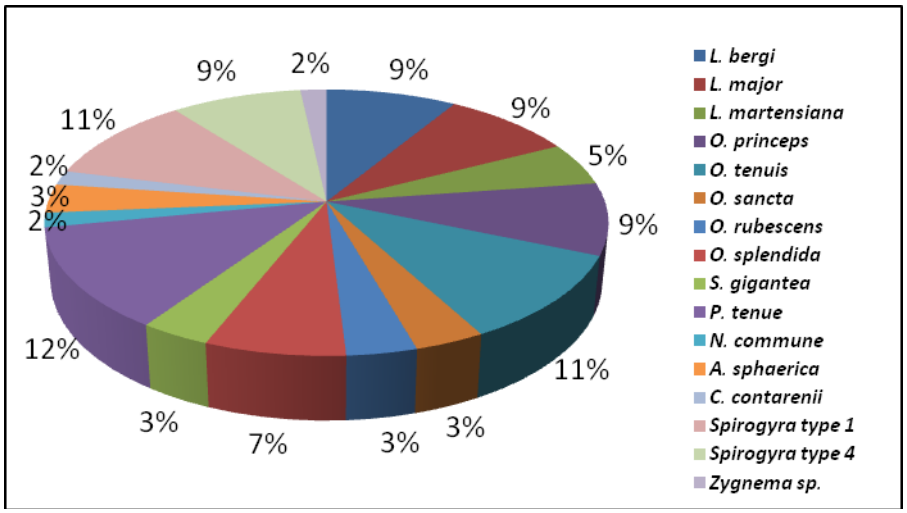


Fig.5.13 Species distribution frequency – North Kuttanad

❖ **Vaikom**

Eleven species of algae were observed from Vaikom. *L.bergi,O. princeps, O. tenuis, P. tenue, P. uncinatum, Spirogyra* type 2 and *Spirogyra* type 4 were present throughout the cropping season. *L. magnifica* was observed in all the sampling except in the month of December. During the sampling in the cropping season O. *splendida* and *N. linckia* were observed in the month of December onwards (Fig.5.14).

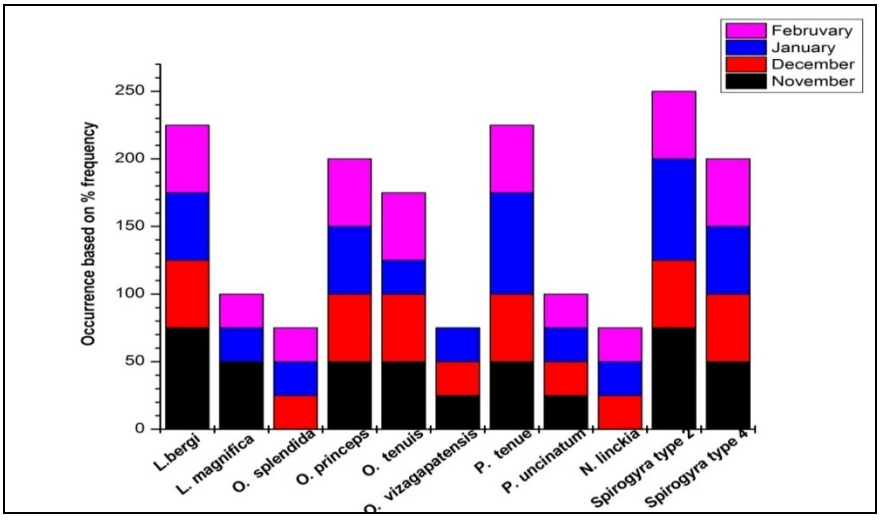


Fig.5.14 Species occurrence in Vaikom

Spirogyra type 2 was highly distributed in this area. *O. vizagapatensis* and *N. linckia* showed the least distribution frequency (Fig.5.15).

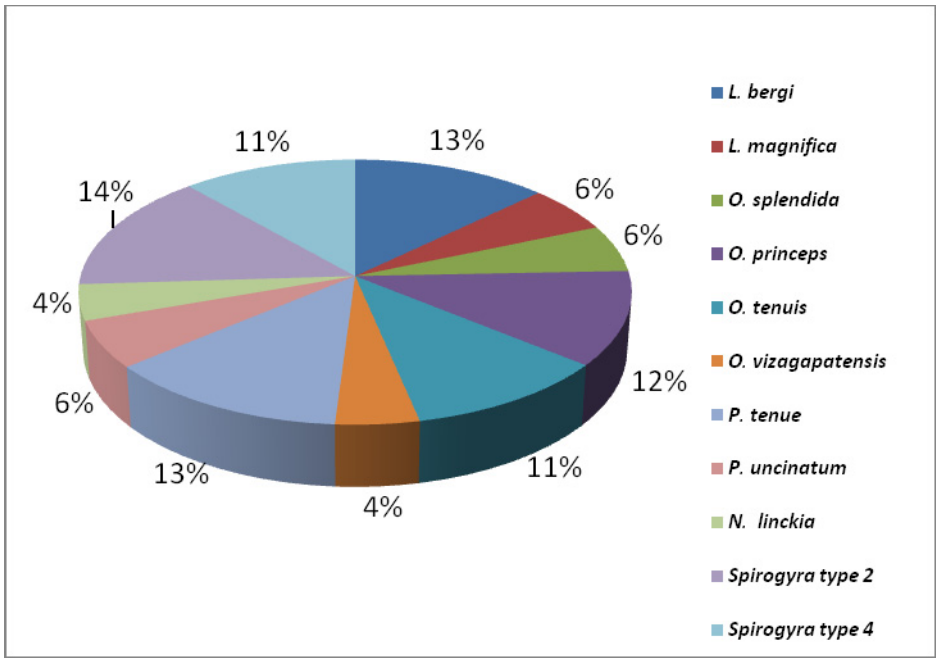


Fig.5.15 Species distribution frequency – Vaikom

5.2.2 Similarity of algal flora

The similarity of filamentous algal flora along the different agronomic zones of Kuttanad, is represented through dendrogram in Fig. 5.16. According to this dendrogram the most similar pairs of populations were observed in Upper Kuttanad and Lower Kuttanad, they together form cluster 1 and was followed by Kayal lands and North Kuttanad forming cluster 2. Purakkad and Vaikom together form cluster 3. Cluster 2 and 3 showed more similarities and together form a large cluster which includes the populations of Upper Kuttanad and Lower Kuttanad.

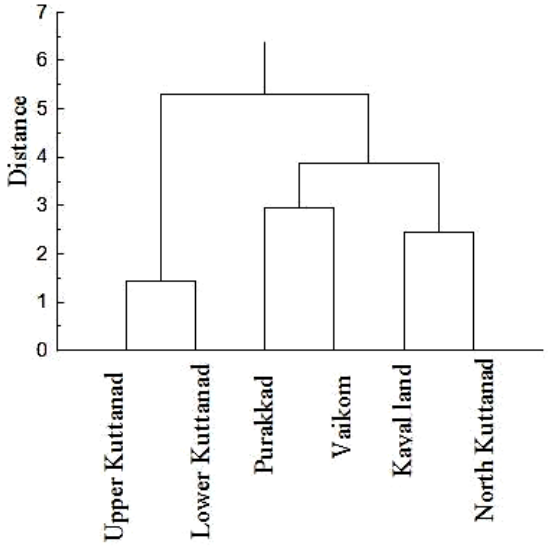


Fig.5.16 Dendrogram of similarity of filamentous algae between agronomic zones of Kuttanad

5.3 Distribution of filamentous algae in Kole lands

In the sampling locations of Kole lands the highest number of filamentous algal species was observed in Palakkal followed by Muriyad and Nedupuzha, and the lowest number was at Puzhakkal throughout the cropping season. The occurrence of species in the sampling locations is given below (Fig. 5.17).

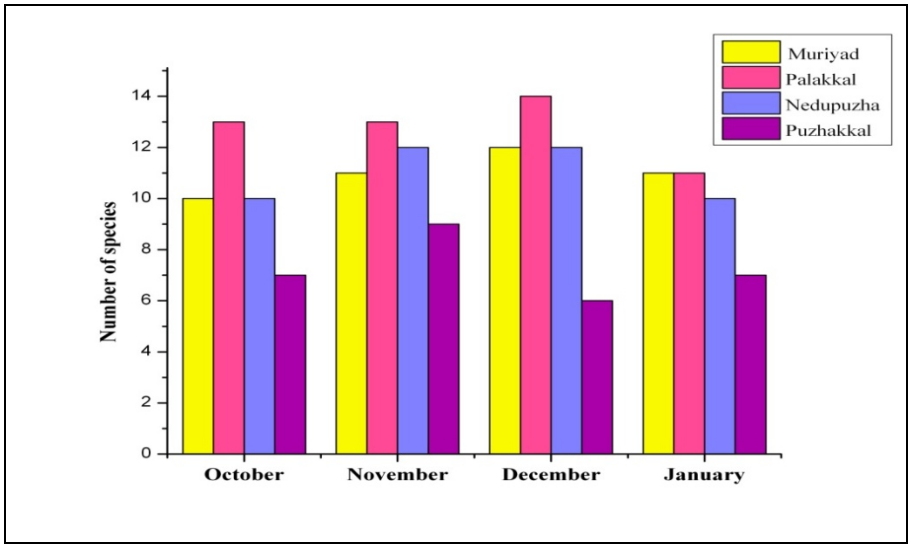


Fig.5.17 Species richness in the sampling locations of Kole lands

The diversity of filamentous algae in the sampling locations of Kole lands were dominated by blue-green algae. The occurrence of filamentous algal species are given below (Fig. 5.18).

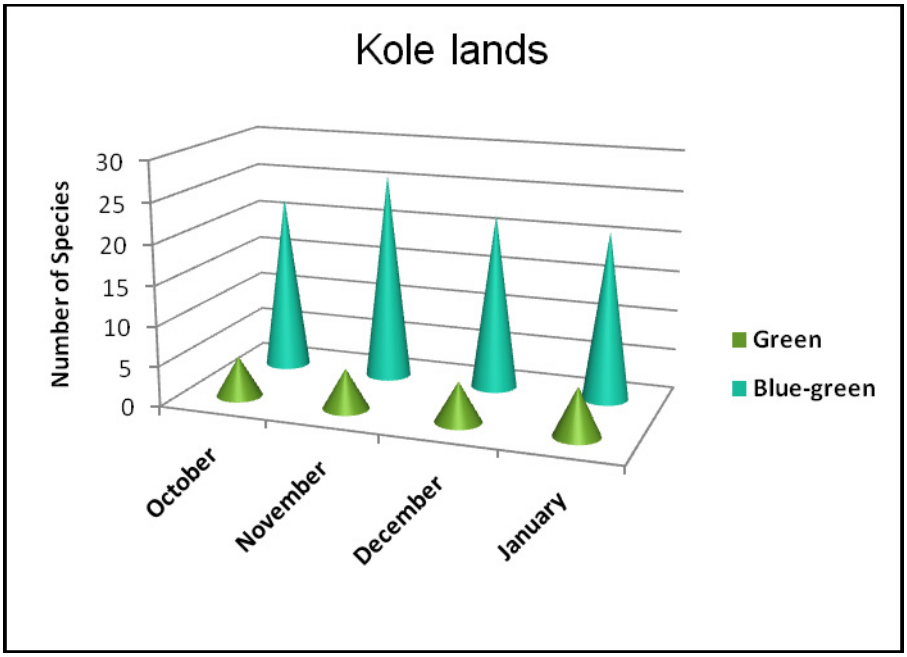


Fig.5.18 The occurrence of filamentous algae in Kole lands

The frequency of distribution of each species in Kole lands and their constancy class is represented in Table 5.4. According to this *Spiogyra type*3 falls under the constancy class IV *i.e.*100% occurrence, and therefore is assumed to be present throughout Kole lands. *Lyngbya bergi and Lyngbya palmarum* fall under the constancy class III with 75% occurrence. Twenty two species fall in the consistency class I with 25% occurrence and are the least distributed.

Table 5.4 Occurrence of filamentous algae in Kole lands

No.	Species	Muriyad	Palakkal	Nedupuzha	Puzhakkal	%/ Constancy Class
1	***Lyngbya***					
	1. *L. bergi*	+	+	-	+	75/III
	2. *L. hieronymusii*	+	+	-	-	50/II
	3. *L. major*	+	-	-	-	25/I
	4. *L. dendrobia*	-	+	-	-	25/I
	5. *L. palmarum*	-	+	+	+	75/III
2	***Oscillatoria***					
	6. *O. splendida*	-	+	+	-	50/II
	7. *O. accuminata*	-	-	-	+	25/I
	8. *O. princeps*	-	+	+	-	50/II
	9. *O. subbrevis*	+	-	-	-	25/I
	10. *O. perornata*	-	+	+	-	50/II
	11. *O. laete-virens*	-	-	+	-	25/I
	12. *O. limosa*	+	-	+	-	50/II
	13. *O. proboscidea*	-	+	-	+	50/II
	14. *O. raoi*	+	-	+	-	50/II
	15. *O. chalybea*	-	+	-	-	25/I
	16. *O. boryana*	+	-	-	-	25/I
	17. *O. amoena*	+	-	-	-	25/I
3	***Spirulina***					
	18. *S. subsalsa*	-	+	-	-	25/I
4	***Phormidium***					
	19. *P. tenue*	+	+	-	-	50/II
	20. *P. retzii*	-	-	+	-	25/I
	21. *P. inundatum*	-	-	-	+	25/I
5	***Cylindrospermum***					
	22. *C. indicum*	-	-	+	-	25/I
6	***Nostoc***					
	23. *N. punctiforme*	-	-	+	-	25/I
	24. N. commune	+	-	-	-	25/I
7	***Anabaena***					
	25. *A. circinalis*	+	-	-	-	25/I
	26. *A.naviculoides*	-	-	-	+	25/I
8	***Scytonema***					
	27. *S. myochrous*	-	-	+	-	25/I
9	***Hapalosiphon***					
	28. *H. welwitschii*	-	-	-	+	25/I
10	***Mougeotia***					
	29. *Mougeotia sp.*	-	+	-	-	25/I
11	***Spirogyra***					
	30.1 *Spirogyra* type 1	-	+	-	-	25/I
	30.2 *Spirogyra* type 3	+	+	+	+	100/IV
	30.3 *Spirogyra* type 5	+	+	-	-	50/II
	30.4 *Spirogyra* type 6	-	-	-	+	25/I
	30.5 *Spirogyra* type 7	-	-	+	-	25/I

5.3.1 Filamentous algae in the sampling locations of Kole lands

❖ **Muriyad**

Thirteen species of filamentous algae were observed in Muriyad. *L. bergi, L. hieronymusii, L. major, O.boryana, O. subbrevis, P. tenue, Spirogyra* type 3 and *Spirogyra* type 5 were present throughout the cropping season. *O. limosa* was present only in the month of December (Fig.5.19).

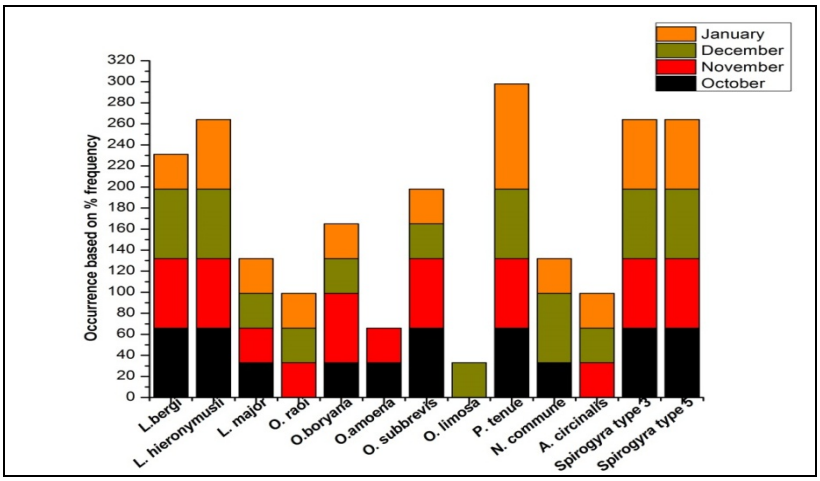


Fig. 5.19 Species occurrence in Muriyad

The highly distributed species in Muriyad was *P.tenue*; *O.limosa* comprised only 2% of the population and this was the least distributed one (Fig.5.20).

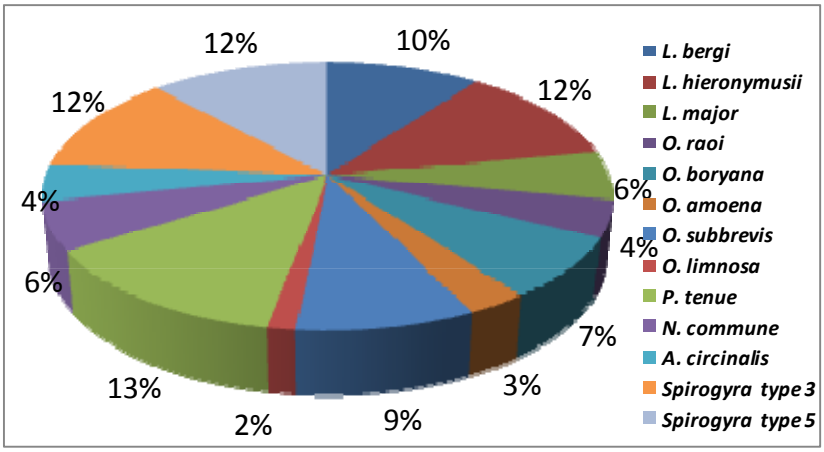


Fig.5.20 Species distribution frequency – Muriyad

❖ Palakkal

Fifteen species of algae were observed at Palakkal. Among these eight species were present throughout the cropping season. They were *L. bergi, L. hieronymusii, O. splendida, O.princeps, P.tenue, Spirogyra* type.1, *Spirogyra* type 3 and *Spirogyra* type 5 (Fig.5.21).

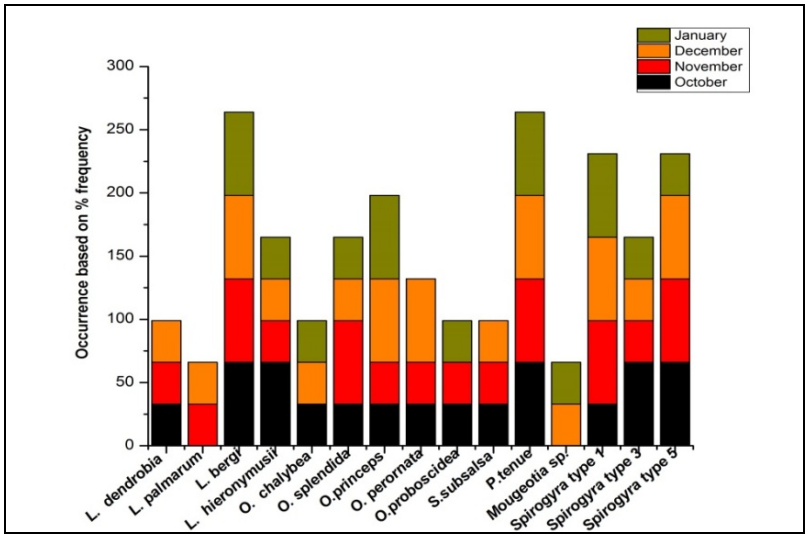


Fig.5.21 Species occurrence in Palakkal

L.bergi and P.tenue were highly distributed in these regions. *Mougeotia sp.* and *L. palmarum* had the least frequency (Fig.5.22).

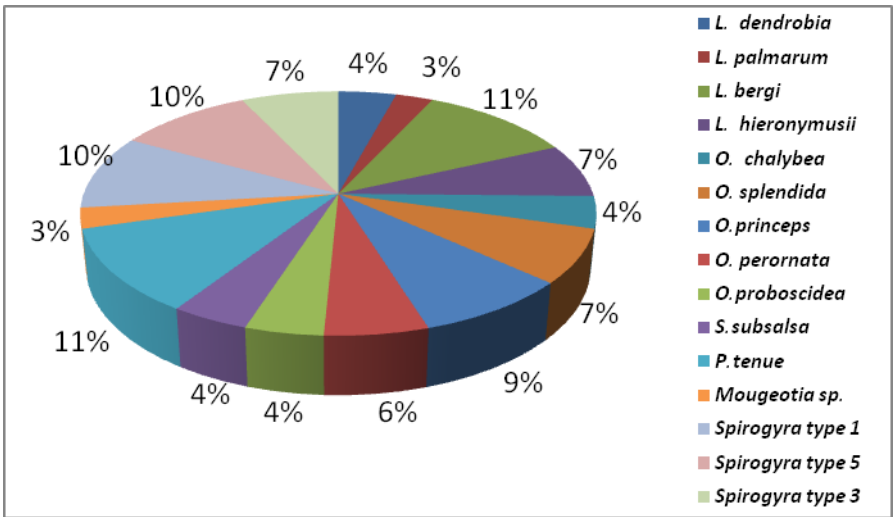


Fig.5.22 Species distribution frequency – Palakkal

❖ Nedupuzha

Thirteen species of algae were obtained from Nedupuzha. *L. palmarum, O. raoi, O.splendida, O.princeps, O.limosa, P.retzii, Spirogyra* type 3 and *Spirogyra* type 7 were present throughout the season. *O.laete-virens*, *C.indicum* were obtained only in the middle of crop season. *S. myochrous* was observed in the month of December and January only (Fig.5.23).

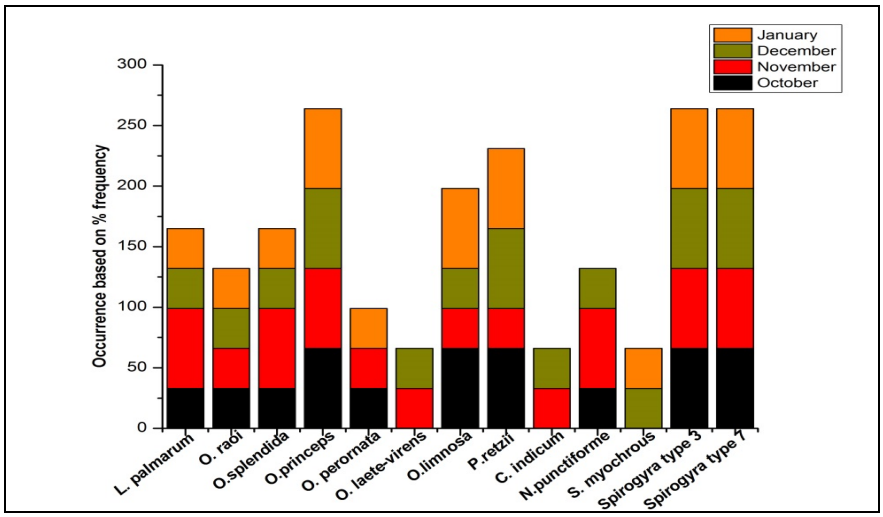


Fig.5.23 Species occurrence in Nedupuzha

In Nedupuzha *Spirogyra* type 3 and *Spirogyra* type 7 showed highest distribution frequency. *O. laete-virens, C. indicum* and *S. myochrous* were least distributed (Fig.5.24).

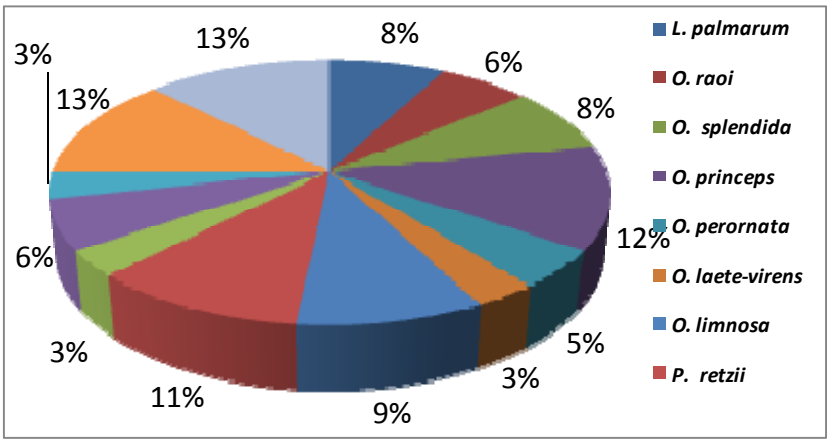


Fig. 5.24 Species distribution frequency – Nedupuzha

❖ Puzhakkal

Nine species of algae were observed in this area. Only four species were present throughout the cropping season. They are *L. bergi, O. proboscidea, Spirogyra* type 3 and *Spirogyra* type 6. *H. welwitscchii* was observed at the middle of the season whereas *A. naviculoides* was present in the first half period (Fig. 5.25).

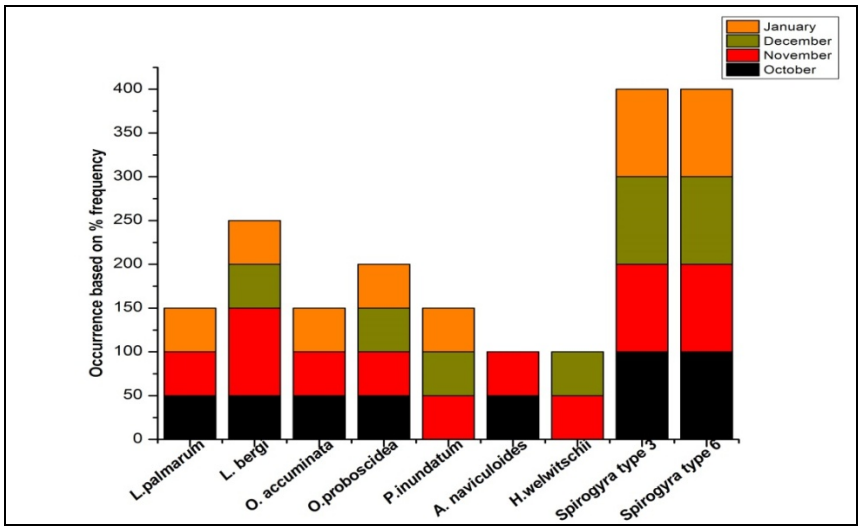


Fig.5.25 Species occurrence in Puzhakkal

Spirogyra type.3 and 6 showed highest distribution frequency in Puzhakkal, whereas *A. naviculoides* and *H.welwitschii* were least distributed (Fig. 5.26).

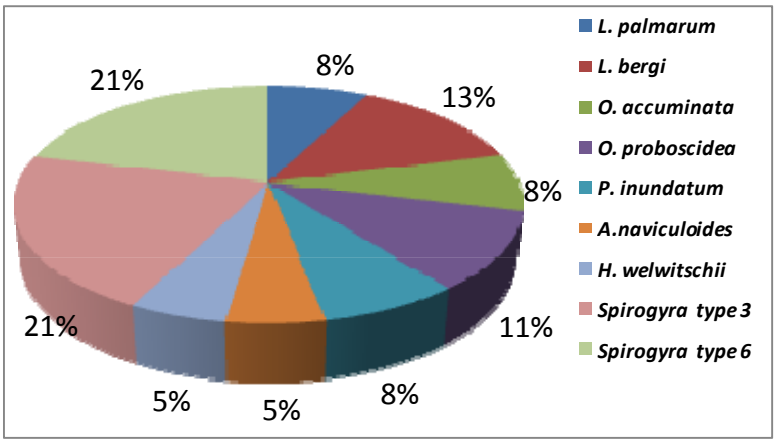


Fig.5.26 Species distribution frequency – Puzhakkal

5.3.2. Similarity of algal flora

The similarity of filamentous algal flora in the sampling locations of Kole lands is represented through dendrogram in Fig.5.27. The species distribution of algal filaments closely resembles in all the four locations as they form very close clusters with Muriyad and Palakkal forming cluster 1. Nedupuzha is closely connected to it and all three together are connected to Puzhakkal.

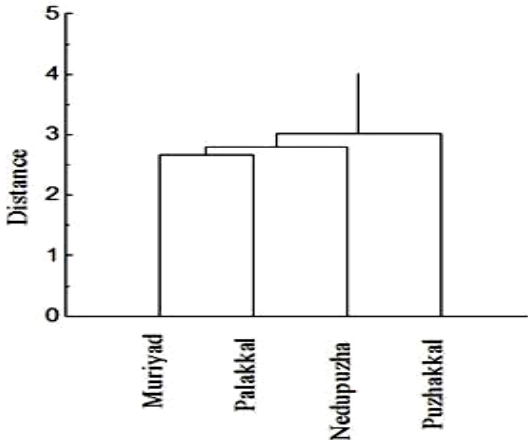


Fig.5.27 Dendrogram of similarity of filamentous algae between sites of Kole

5.4 Distribution of soil chlorophyll

The soil chlorophyll a is a useful quantitative indicator of soil algae. In this study the chlorophyll *a* has been distinguished from phaeopigments by following the acidification procedure. Therefore the biomass estimated should reflect the quantity of active cells at the time of sampling.

5.4.1 Chlorophyll *a* in Kuttanad soil

The chlorophyll *a* of the soil samples collected from Kuttanad ranged from 0.76 to 14.16 µg/g dry weight of the soil (Table 5.5 & 5.6). The mean chlorophyll *a* was lowest in Vaikom and highest in kayal lands during the cropping season. Spatial distribution of chlorophyll *a* in the different agricultural zones is shown in Fig. 5.28. The highest range of mean value of chlorophyll *a* was observed in two sampling locations of Kayal lands and North Kuttanad. Lowest range was observed in two sampling locations in Upper Kuttanad and one site in Purakkad. The active biomass of soil algae in various

Table 5.5 Chlorophyll *a* (µg/g) of sampling locations during the cropping period of December 2010 to February 2011

Site	Agronomic Zone	December µg/g	January µg/g	February µg/g	Mean µg/g
1	Upper Kuttanad	2.62	1.86	2.00	2.16
2		0.76	3.34	4.91	3.00
3		4.34	4.53	4.72	4.53
4		9.30	3.58	2.19	5.02
5		3.96	9.39	7.20	6.85
6	Purakkad	10.63	1.43	4.86	5.64
7		1.14	2.57	3.15	2.29
8	Lower Kuttanad	14.16	7.68	6.58	9.47
9		8.77	5.48	4.91	6.39
10		4.34	4.05	5.58	4.66
11		13.49	5.44	7.63	8.85
12		2.00	2.38	3.00	2.46
13		6.77	5.24	5.72	5.91
14		9.11	3.19	4.67	5.66
15		8.73	5.39	2.05	5.39
16	Kayal land	0.91	1.14	9.11	3.72
17		3.00	5.15	9.06	5.74
18		9.68	10.87	10.30	10.28
19		11.06	4.34	8.30	7.90
20		3.24	3.77	9.87	5.63
21	Vaikom	3.81	2.96	6.48	4.42
22		3.39	5.44	5.29	4.71
23		4.05	1.81	2.19	2.68
24		1.05	3.19	2.38	2.21
25	North Kuttanad	3.53	5.01	8.73	5.76
26		6.48	6.44	10.20	7.71
27		1.53	1.86	6.53	3.31

Table 5.6 Mean chlorophyll *a* (µg/g) of soil samples in the sampling localities of Kuttanad

S.I. No.	Agronomic Zones	Mean chlorophyll *a* (µg/g)	Algal biomass (µg/g)
1	Upper Kuttanad	4.31	289
2	Purakkad	3.96	265
3	Lower Kuttanad	6.10	409
4	Kayal Lands	6.65	446
5	Vaikom	3.50	235
6	North Kuttanad	5.59	375

agronomic zones of Kuttanad ranged from 235 - 446 µg/g (Table 5.6) with a mean of 337 µg/g.

5.4.2 Chlorophyll *a* in Kole land soil

In Kole lands the chlorophyll *a* of the soil samples ranged from 1.06 to 13.50 µg/g (Table 5.7&5.8). The highest value was observed in Muriyad *i.e.* 5.11 µg/g and lowest value was observed in Puzhakkal *i.e.*3.22 µg/g. Spatial distribution of chlorophyll *a* in the sampling localities of Kole lands is shown in Fig 5.29. According to this the fields of Puzhakkal lie in the lower range of Chlorophyll *a*, that of Palakkal and Nedupuzha is in the range 4.35 to 4.73 µg/g and Muriyad lies in the high range group *i.e.* 4.73 to 5.11 µg/g chlorophyll *a*. The active biomass of soil algae in sampling locations of Kole lands ranged from 216 - 342 µg/g (Table 5.8) with a mean of 292 µg/g.

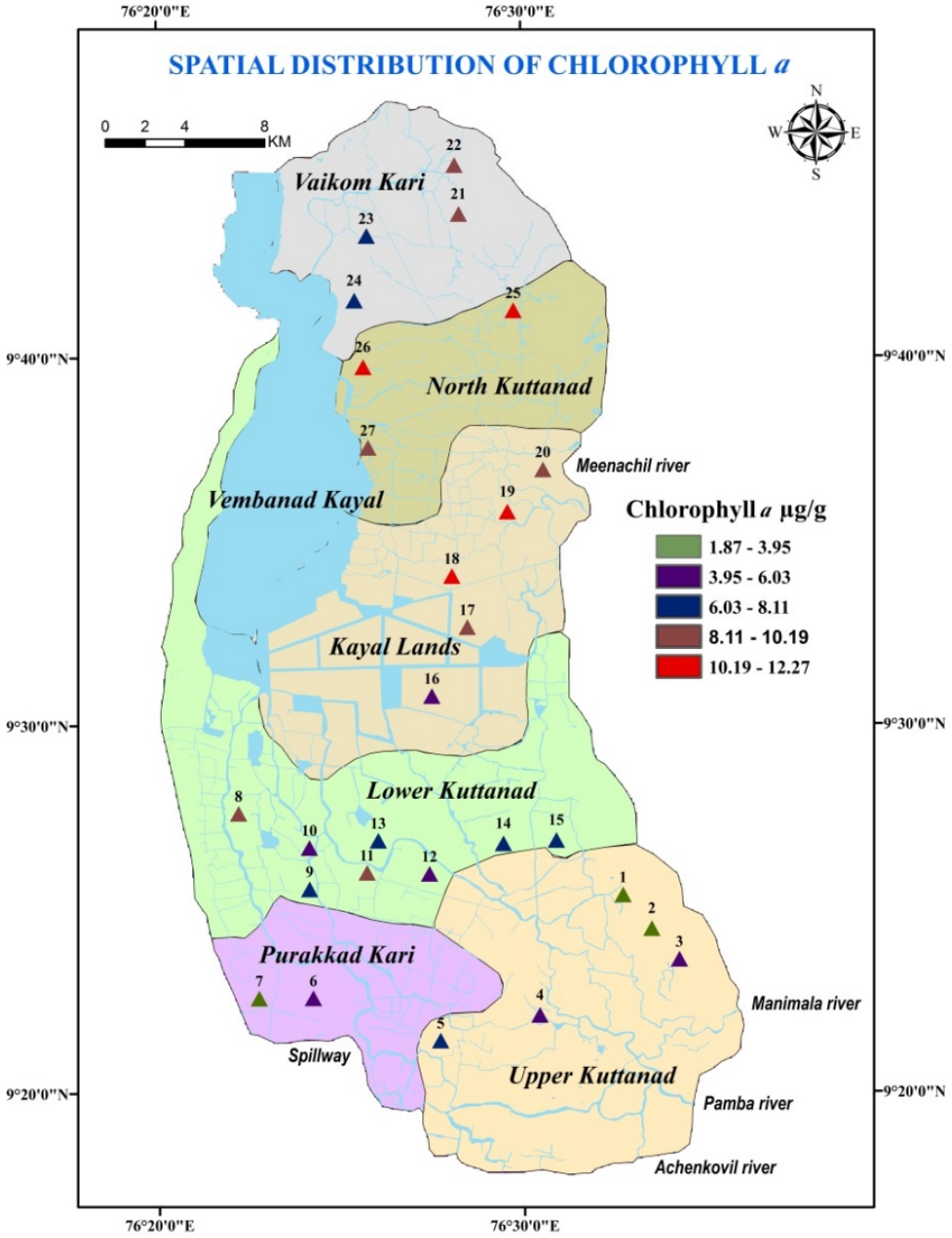


Fig. 5.28 Spatial distribution of Chlorophyll *a* in Kuttanad

Table 5.7 Chlorophyll a (µg/g) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October	November	December	January	Mean µg/g
1	Puzhakkal	3.02	3.58	1.06	3.17	2.71
2		3.02	3.02	5.89	1.41	3.34
3		2.87	3.68	3.27	4.69	3.63
4	Muriyad	5.84	3.73	4.58	4.84	4.75
5		3.58	3.02	8.36	2.22	4.30
6		4.48	2.97	4.18	13.50	6.28
7	Nedupuzha	3.22	1.41	3.53	5.89	3.51
8		1.71	4.38	5.99	4.08	4.04
9		8.82	5.24	2.82	6.45	5.83
10	Palakkal	1.41	3.32	3.53	6.75	3.75
11		3.07	6.50	5.69	2.92	4.55
12		7.81	3.48	5.54	5.54	5.59

Table 5.8 Mean chlorophyll *a* (µg/g) of soil samples in the sampling localities of Kole lands

S.I No.	Sampling locations	Mean chlorophyll *a* (µg/g)	Algal biomass (µg/g
1	Puzhakkal	3.22	216
2	Muriyad	5.11	342
3	Nedupuzha	4.46	299
4	Palakkal	4.63	310

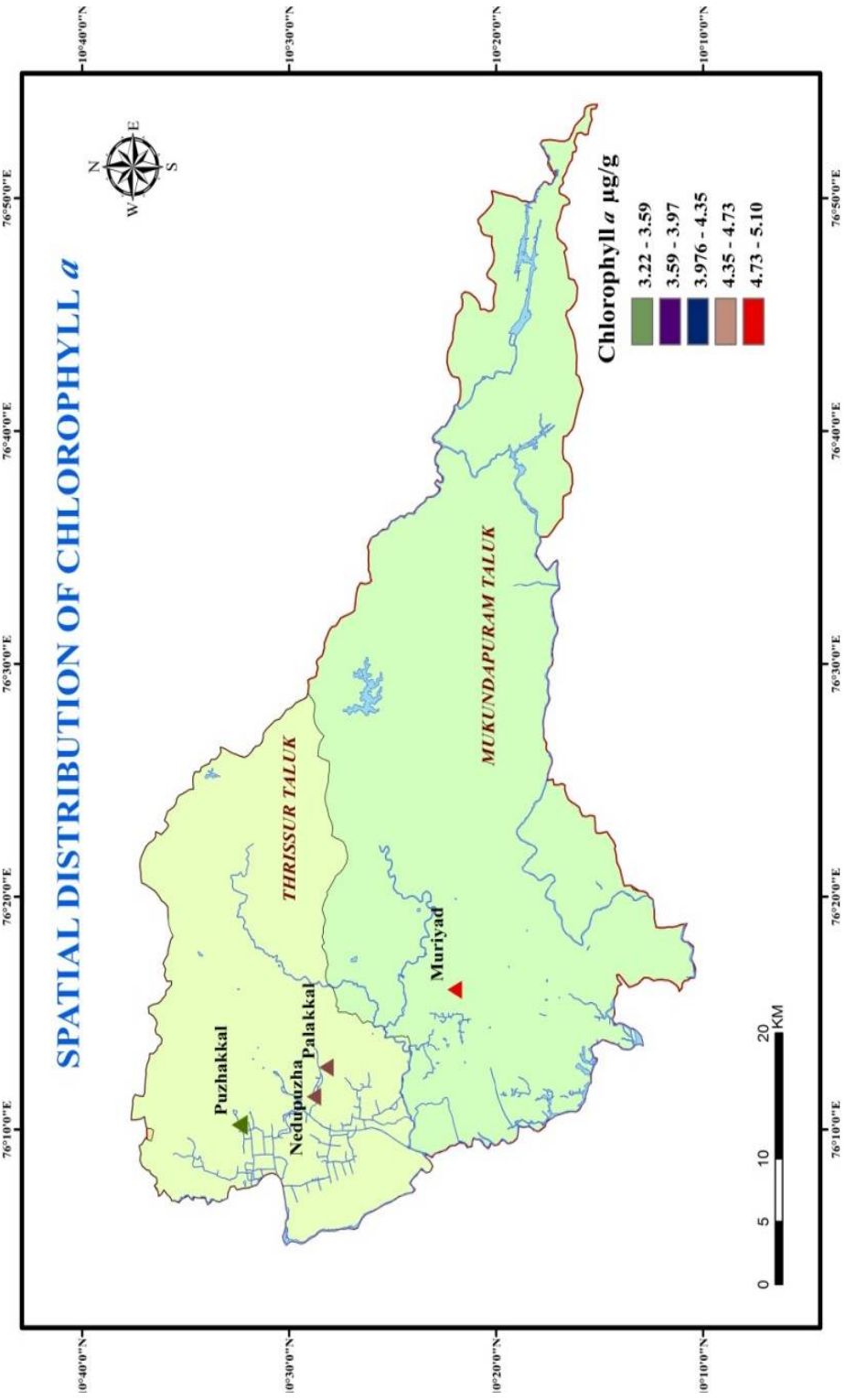


Fig.5.29 Spatial distribution of chlorophyll *a* in Kole lands

5.5 Soil Fertility

5.5.1 Fertility of paddy fields of Kuttanad

- **Soil Texture**

Soil texture represents the relative proportion of mineral particles of different sizes (sand, silt and clay). The textural analysis done in this investigation showed that type of soil was either silt loam or sandy loam in the sampling locations (Table 5.9).

Table 5.9 Soil texture in the sampling locations of Kuttanad

S.I. No	Agronomic zone	Sand %	Silt %	Clay %	Textural class
1	Upper Kuttanad	32	57	9	Silt loam
2	Purakkad	55	35	9	Sandy loam
3	Lower Kuttanad	42	50	7	Silt loam
4	Kayal lands	85	11	3	Sandy loam
5	Vaikom	31	65	2	Silt loam
6	North Kuttanad	71	26	2	Sandy loam

- **Soil pH**

Soil pH is the measure of hydrogen ion concentration in the soil. It indicates the acidic and alkaline nature of soil. In Kuttanad the pH of the soil samples ranged from 3.01 to 5.94 (Table 5.10). The mean pH was lower in Upper Kuttanad compared to the other agronomic zones (Table. 5.11). 73% of the soil samples collected from Kuttanad were extremely acidic, 25% of the samples were strongly acidic and 2% of the sample were moderately acidic (Table 5.12).

Table 5.10 pH of sampling locations in Kuttanad during the cropping period of December 2010 to February 2011

SITE	Agronomic Zone	December	January	February	Mean pH
1	Upper Kuttanad	4.21	4.35	4.31	4.29
2		3.27	3.23	3.25	3.25
3		3.60	3.83	3.22	3.55
4		4.30	4.21	4.51	4.34
5		3.25	3.92	3.95	3.71
6	Purakkad	4.21	4.15	4.31	4.22
7		5.08	4.23	4.74	4.68
8	Lower Kuttanad	4.84	5.25	5.14	5.08
9		4.70	4.80	4.80	4.77
10		4.67	3.65	4.31	4.21
11		3.91	4.62	4.42	4.32
12		3.01	3.11	3.12	3.08
13		4.32	4.59	4.41	4.44
14		4.49	4.41	4.26	4.39
15		4.76	4.20	4.94	4.63
16	Kayal land	4.59	4.27	4.13	4.33
17		4.32	4.62	4.52	4.49
18		5.60	5.94	5.21	5.58
19		3.31	3.59	3.78	3.56
20		4.25	4.32	5.14	4.57
21	Vaikom	4.60	4.29	3.98	4.29
22		3.25	3.63	4.32	3.73
23		4.16	4.43	4.13	4.24
24		4.65	4.62	4.34	4.54
25	North Kuttanad	3.90	3.70	3.55	3.72
26		4.30	4.54	3.90	4.25
27		5.40	5.50	5.20	5.37

Table 5.11 Mean and range of pH in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	3.83	3.22 - 4.51
Purakkad	4.45	4.15 - 5.08
Lower Kuttanad	4.36	3.01 - 5.25
Kayal Lands	4.51	3.31 - 5.94
Vaikom	4.20	3.25 - 4.65
North Kuttanad	4.44	3.55 - 5.50

Table 5.12 Measured pH of the soil samples and soil reaction rating (DAC, 2011)

S.I. NO.	PH Range	Soil Reaction Rating	Range (No. of samples; %)
1	<4.6	Extremely acid	3.01 - 4.59 (59;73)
2	4.6-5.5	Strongly acid	4.62 - 5.50 (20;25)
3	5.6-6.5	Moderately acid	5.60 - 6.00 (2;2)
4	6.6-6.9	Slightly acid	……
5	7.0	Neutral	……
6	7.1-8.5	Moderately alkaline	……
7	>8.5	Strongly alkaline	……

- **Soil Electrical Conductivity**

Electrical Conductivity gives a clear idea of the soluble salts present in the soil and physical properties of the particles which make up the soil. In Kuttanad the conductivity of the soil samples ranged from 0.07 mS/cm to 0.97 mS/cm (Table 5.13). The mean value was highest in Vaikom and lowest in Upper Kuttanad (Table 5.14). The relationship between Electrical conductivity and percentage of salt in the soil samples is given in Table 5.15. According to the results the soils are salt free.

Table 5.13 Electrical Conductivity of sampling locations during the cropping period of December 2010 to February 2011

SITE	Agronomic Zone	December	January	February	Mean mS/cm
1	Upper Kuttanad	0.20	0.42	0.67	0.43
2		0.33	0.97	0.29	0.53
3		0.68	0.21	0.32	0.40
4		0.65	0.40	0.35	0.47
5		0.21	0.57	0.24	0.34
6	Purakkad	0.23	0.52	0.61	0.45
7		0.17	0.65	0.59	0.47
8	Lower Kuttanad	0.86	0.75	0.87	0.83
9		0.30	0.51	0.61	0.47
10		0.18	0.47	0.41	0.35
11		0.19	0.86	0.62	0.56
12		0.20	0.91	0.07	0.39
13		0.17	0.59	0.66	0.48
14		0.39	0.62	0.52	0.51
15		0.27	0.40	0.52	0.40
16	Kayal land	0.53	0.76	0.42	0.57
17		0.70	0.82	0.21	0.58
18		0.17	0.82	0.91	0.63
19		0.19	0.92	0.87	0.66
20		0.22	0.31	0.95	0.49
21	Vaikom	0.18	0.72	0.90	0.60
22		0.27	0.80	0.90	0.66
23		0.21	0.91	0.70	0.61
24		0.46	0.92	0.86	0.75
25	North Kuttanad	0.75	0.81	0.86	0.81
26		0.19	0.88	0.65	0.57
27		0.48	0.07	0.72	0.42

Table 5.14 Mean and range of conductivity in the agronomic zones of Kuttanad

Agronomic Zones	Mean (mS/cm)	Range
Upper Kuttanad	0.34	0.20 - 0.97
Purakkad	0.45	0.17 - 0.65
Lower Kuttanad	0.50	0.07 - 0.91
Kayal Lands	0.59	0.17 - 0.95
Vaikom	0.65	0.18 - 0.92
North Kuttanad	0.60	0.07 - 0.88

Table 5.15 Measured Electrical Conductivity of the soil samples and % of salt content (DAC, 2011)

Soil	Electrical Conductivity (mS/cm)	Total salt content %	Range (No. of samples; %)
1. Salt free	0 - 2	<0.15	0.07 - 0.97 (81; 100)
2. Slightly saline	4 - 8	0.15 - 0.35	__
3. Moderately saline	8 - 15	0.35 - 0.65	__
4.Highly saline	>15	>0.65	__

- **Organic carbon**

The organic carbon in the soil defines the fertility status of the soil. The organic carbon in the soil samples of Kuttanad ranged from 1.45 to 5.93% (Table 5.16). The mean organic carbon was lowest in Purakkad and highest in Kayal lands (Table 5.17). Depending upon the organic carbon content, the soil nutrient status was graded as low, medium and high and all the samples were in high category. The fertility level of the soil samples and ranges are given in Table 5.18. Spatial distribution of organic carbon in the different agricultural zones is shown in Fig. 5.30. The fertility rating was high in all the sampling locations of Kuttanad.

Table 5.16 Organic carbon (%) of sampling locations during the cropping period of December 2010 to February 2011

Site	Agronomic Zone	December	January	February	Mean (%)
1	Upper Kuttanad	3.54	3.32	3.32	3.39
2		2.95	2.72	2.50	2.72
3		3.47	2.06	2.58	2.70
4		2.07	2.58	2.73	2.46
5		2.58	2.44	2.44	2.49
6	Purakkad	2.14	1.99	1.99	2.04
7		1.62	1.85	1.84	1.77
8	Lower Kuttanad	1.84	1.69	1.99	1.84
9		1.62	1.99	1.77	1.79
10		2.36	2.21	2.29	2.29
11		3.76	3.62	3.54	3.64
12		4.21	3.91	3.99	4.04
13		3.91	2.66	2.36	2.98
14		2.58	4.21	4.06	3.62
15		3.99	4.04	4.49	4.17
16	Kayal land	5.93	3.94	4.16	4.68
17		5.72	4.15	5.64	5.17
18		5.78	4.98	2.27	4.34
19		3.19	3.25	2.59	3.01
20		4.65	2.98	2.24	3.29
21	Vaikom	5.90	2.51	3.47	3.96
22		4.65	1.45	2.98	3.03
23		5.46	2.44	2.21	3.37
24		2.36	3.25	1.99	2.53
25	North Kuttanad	2.21	3.21	4.19	3.20
26		3.54	3.76	4.27	3.86
27		4.19	3.98	5.49	4.55

Table 5.17 Mean and range of Organic carbon (%) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range(%)
Upper Kuttanad	2.75	2.06 - 3.54
Purakkad	1.91	1.62 - 2.14
Lower Kuttanad	3.05	1.62 - 4.49
Kayal Lands	4.10	2.24 - 5.93
Vaikom	3.22	1.45 - 5.90
North Kuttanad	3.87	2.21 - 5.49

Table 5.18 Estimated Organic carbon content and soil fertility level in the soil samples (DAC, 2011)

S.I No.	Organic Carbon %	Fertility level	Range (No. of samples; %)
1	< 0.50	Low	…..
2	0.50 - 0.75	Medium	…..
3	> 0.75	High	1.45 - 5.93 (81 ; 100)

- **Available Phosphorus**

Phosphorus is an essential macronutrient, which regulates protein synthesis. In Kuttanad, the available phosphorus content ranged between 33 to 149kg/ha (Table 5.19). The mean value of available phosphorus was comparatively higher in Kayal lands (Table 5.20). Out of the eighty one samples analysed 96% were in the very high fertility level and 4% in high fertility level as per the soil quality rating of Dorahy *et al.*(2004)(Table 5.21). Spatial distribution of available phosphorus based on mean value of each sampling location in the different agricultural zones is shown in Fig. 5.31. All the sampling locations were in very high fertility rating.

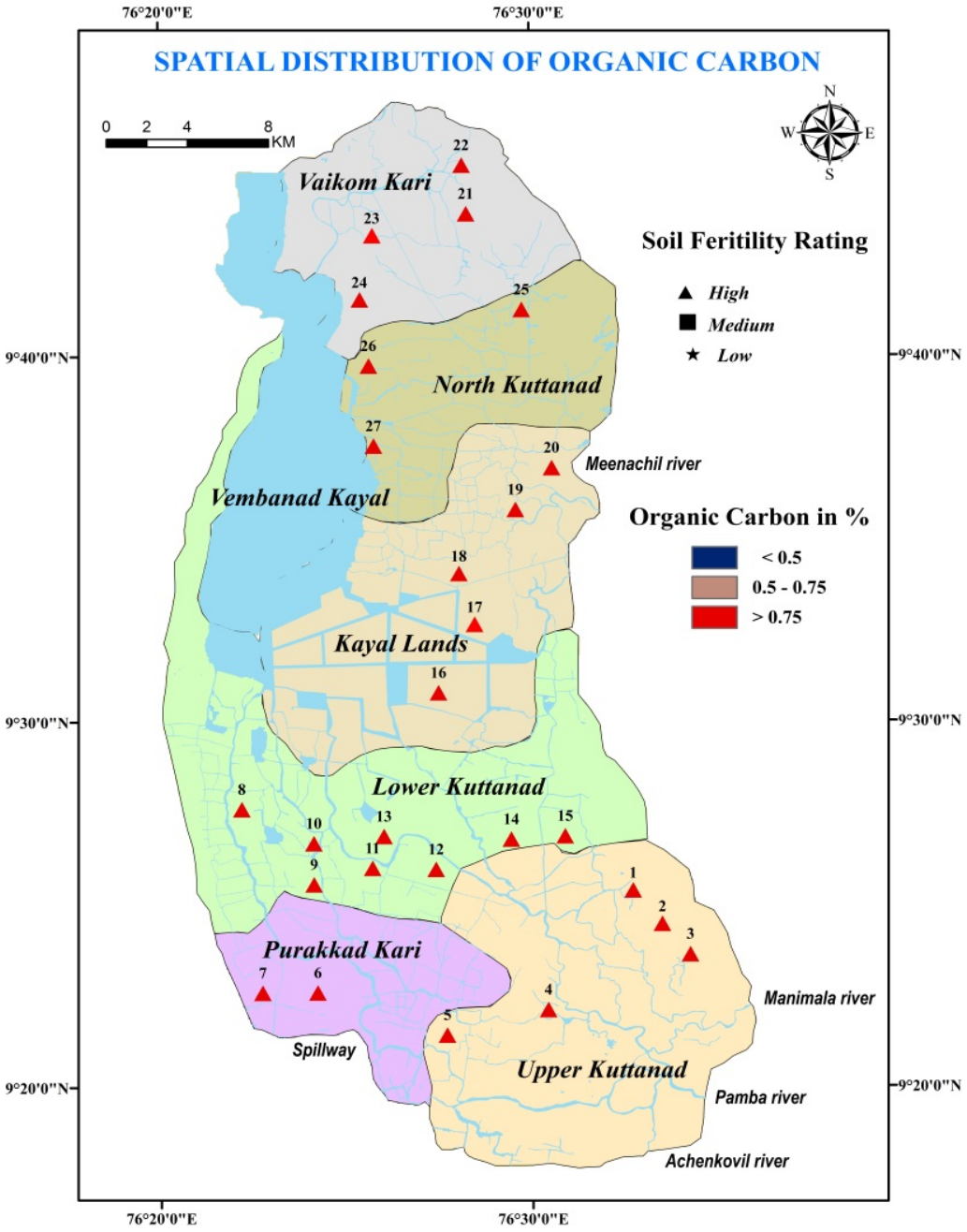


Fig. 5.30 Spatial distribution of Organic carbon in Kuttanad

Table 5.19 Available phosphorus (kg/ha) of sampling locations during the cropping period of December 2010 to February 2011

SITE	Agronomic Zone	December (kg/ha)	January (kg/ha)	February (kg/ha)	Mean (kg/ha)
1	Upper Kuttanad	82.50	115.5	66.00	88.00
2		82.50	115.5	115.5	104.5
3		99.00	66.00	82.50	82.50
4		49.50	115.5	82.50	82.50
5		99.00	82.50	132.0	104.5
6	Purakkad	99.00	82.50	66.00	82.50
7		82.50	82.50	99.00	88.00
8	Lower Kuttanad	99.00	66.00	82.50	82.50
9		82.50	148.5	66.00	99.00
10		66.00	49.50	132.0	82.50
11		49.50	66.00	82.50	66.00
12		66.00	132.0	82.50	93.50
13		33.00	82.50	66.00	60.50
14		82.50	132.0	115.5	110.0
15		66.00	115.5	66.00	82.50
16	Kayal land	115.5	82.50	132.0	110.0
17		99.00	115.5	66.00	93.50
18		148.5	132.0	82.50	121.0
19		99.00	132.0	66.00	99.00
20		99.00	115.5	82.50	99.00
21	Vaikom	33.00	66.00	66.00	55.00
22		33.00	66.00	49.50	49.50
23		99.00	82.50	99.00	93.50
24		49.50	66.00	49.50	55.00
25	North Kuttanad	148.5	66.00	82.50	99.00
26		49.50	132.0	115.5	99.00
27		49.50	99.00	99.00	82.50

Table 5.20 Mean and range of available phosphorus (kg/ha) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	92.40	49.50 - 115.5
Purakkad	85.25	66.00 - 99.00
Lower Kuttanad	84.56	33.00 - 148.5
Kayal Lands	104.5	66.00 - 148.5
Vaikom	63.25	33.00 - 99.00
North Kuttanad	93.50	49.50 - 148.5

Table 5.21 Estimated available phosphorus (kg/ha) and soil fertility level (Dorahy *et al.,* 2004)

S.I No.	Avail. P kg/ha	Fertility level	Range (No. of samples; %)
1	< 8.25	Very Low	.....
2	8.25 - 16.50	Low	.....
3	16.50 - 33.00	Moderate	.....
4	33.00 - 41.50	High	33(3;4)
5	> 41.25	Very High	49.50 - 148.5 (78 ; 96)

- **Available Potassium**

Potassium is an essential nutrient for plant growth, associated with movement of water, nutrients, and carbohydrates in plant tissue. Depending upon the concentration of potassium in the soil, the quality of soil may be graded as low, medium and high (DAC, 2011). In Kuttanad, the potassium content ranged from 259 to 578 kg/ha (Table5.22). The mean value of potassium was lowest in Purakkad and highest in Kayal lands (Table 5.23). The fertility level was medium in 10% of samples and high in 90% (Table 5.24). Spatial distribution of available potassium based on mean value of each sampling location in the different agricultural zones is shown in Fig. 5.32.

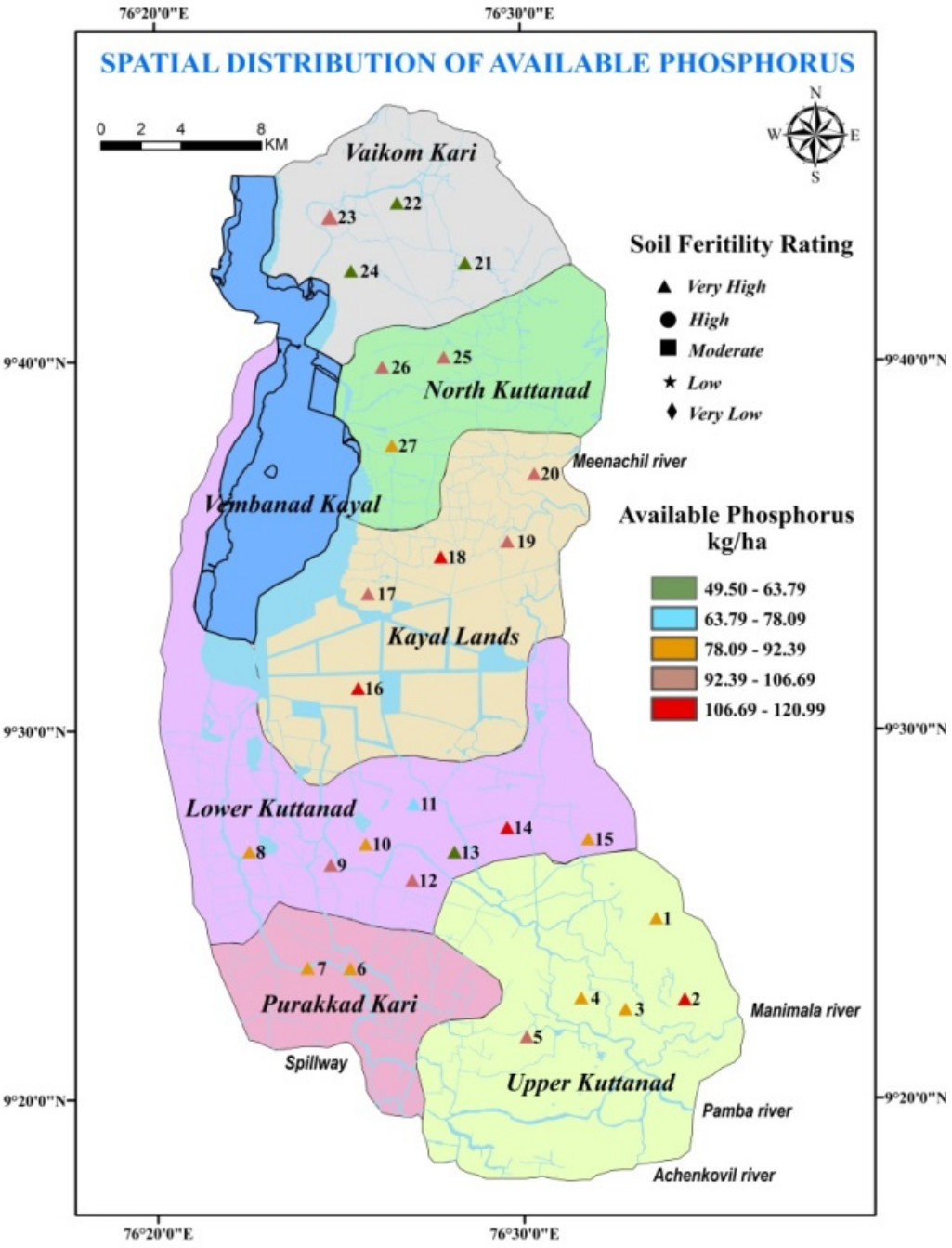


Fig. 5.31 Spatial distribution of available phosphorus in Kuttanad

Table 5.22 Available potassium (kg/ha) of sampling locations during the cropping period of December 2010 to February 2011

SITE	Agronomic Zone	December (kg/ha)	January (kg/ha)	February (kg/ha)	Mean (kg/ha)
1	Upper Kuttanad	289.0	292.0	275.5	285.5
2		308.5	312.5	311.5	310.8
3		309.5	313.5	378.5	333.8
4		346.5	362.0	361.0	356.5
5		276.0	273.0	283.5	277.5
6	Purakkad	263.5	266.5	259.0	263.0
7		278.0	298.0	269.0	281.6
8	Lower Kuttanad	346.5	379.5	363.0	363.0
9		429.0	458.0	439.5	442.8
10		478.5	461.0	427.0	455.5
11		379.5	327.0	311.5	339.3
12		462.0	429.0	396.0	429.0
13		461.0	471.5	463.5	465.3
14		429.0	427.0	478.5	444.8
15		379.5	363.0	358.0	366.8
16	Kayal land	527.0	554.0	537.0	539.3
17		363.0	379.5	362.0	368.1
18		379.5	429.0	396.5	401.6
19		412.5	462.0	451.0	441.8
20		578.0	562.0	549.0	563.0
21	Vaikom	379.5	363.0	396.0	379.5
22		429.0	428.0	461.0	439.3
23		444.5	454.5	438.5	445.8
24		327.0	361.0	345.5	344.5
25	North Kuttanad	418.5	429.0	405.5	417.6
26		478.5	429.0	413.0	440.8
27		362.0	346.5	313.0	340.5

Table 5.23 Mean and range of available potassium (kg/ha) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	312.8	273.0 - 378.5
Purakkad	272.3	259.0 - 298.0
Lower Kuttanad	413.3	311.5 - 478.5
Kayal Lands	462.8	362.0 - 578.0
Vaikom	402.9	327.0 - 461.0
North Kuttanad	399.4	313.0 - 478.5

Table 5.24 Estimated available potassium and fertility level of the soil samples (DAC, 2011)

S.I No.	Avail. K (kg/ha)	Fertility level	Range (No. of samples; %)
1	< 108	Low	…..
2	108 - 280	Medium	259.0 - 278.0 (8; 10)
3	> 280	High	283.5 - 578.0 (73 ; 90)

- **Total Inorganic Nitrogen**

Nitrogen is a major plant nutrient, absorbing as ammonium ions through the paddy roots. Most of the nitrogen is used by plants to produce protein and nucleic acids. In Kuttanad, the inorganic nitrogen content in the soil ranged between 363 to 759 kg/ha (Table 5.25). The mean value of inorganic nitrogen was lowest in Vaikom (Table 5.26). Spatial distribution of inorganic nitrogen in the different agricultural zones is shown in Fig. 5.33.

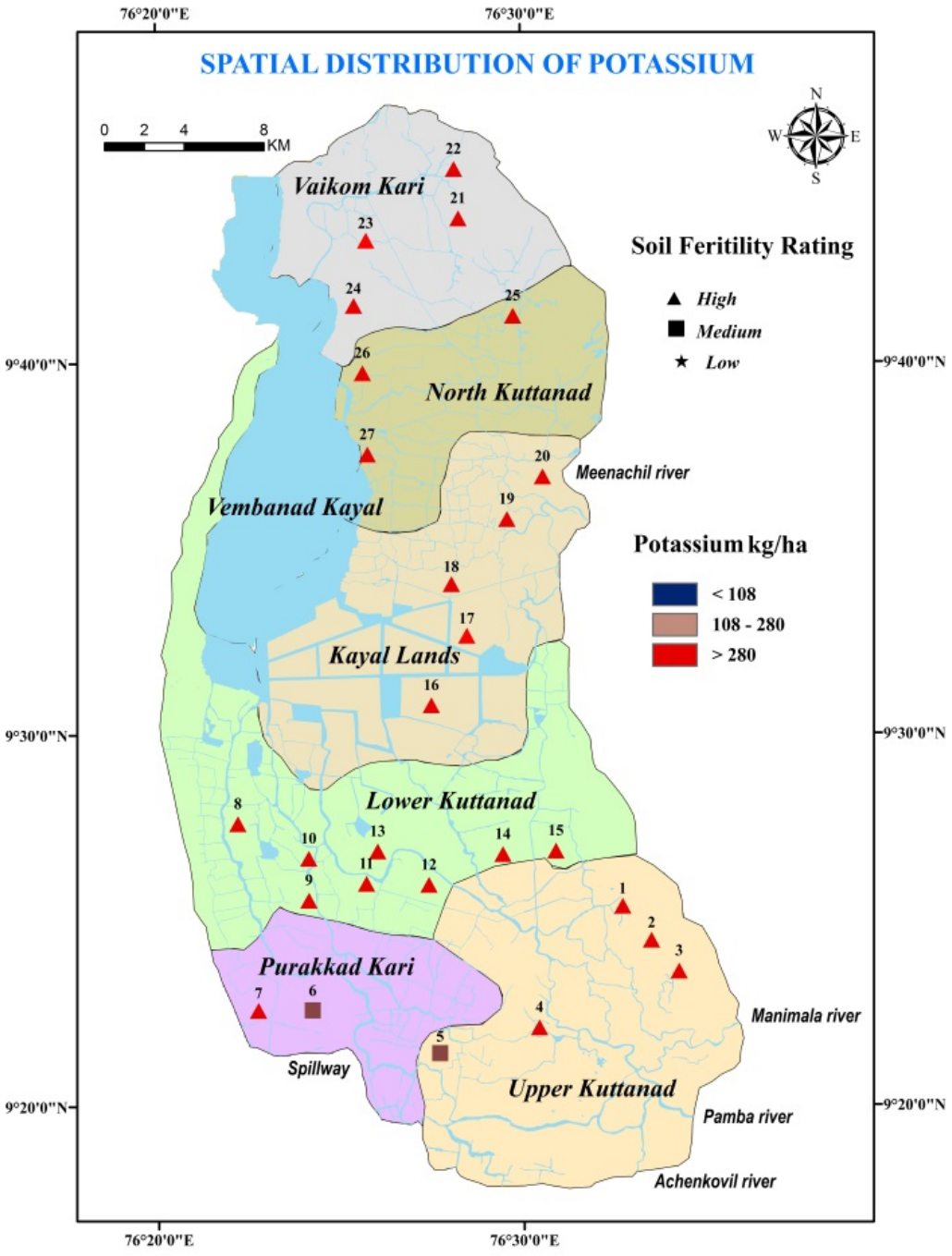


Fig. 5.32 Spatial distribution of available potassium in Kuttanad

Table 5.25 Total inorganic nitrogen (kg/ha) of sampling locations during the cropping period of December 2010 to February 2011

Site	Agronomic Zone	December (kg/ha)	January (kg/ha)	February (kg/ha)	Mean (kg/ha)
1	Upper Kuttanad	561.0	561.0	627.0	583.0
2		528.0	610.5	528.0	555.5
3		610.5	594.0	577.5	594.0
4		676.5	726.0	627.0	676.5
5		577.5	610.5	511.5	566.5
6	Purakkad	594.0	544.5	544.5	561.0
7		561.0	561.0	577.5	566.5
8	Lower Kuttanad	561.0	544.5	561.0	555.5
9		577.5	594.0	577.5	583.0
10		594.0	594.0	544.5	577.5
11		577.5	594.0	643.5	605.0
12		610.5	627.0	561.0	599.5
13		528.0	610.5	528.0	555.5
14		726.0	627.0	693.0	682.0
15		594.0	561.0	643.5	599.5
16	Kayal land	412.5	561.0	577.5	517.0
17		462.0	577.5	396.0	478.5
18		594.0	396.0	561.0	517.0
19		676.5	594.0	759.0	676.5
20		528.0	561.0	577.5	555.5
21	Vaikom	429.0	379.5	462.0	423.5
22		528.0	462.0	561.0	517.0
23		478.5	379.5	379.5	412.5
24		363.0	445.5	462.0	423.5
25	North Kuttanad	561.0	544.5	693.0	599.5
26		544.5	610.5	610.5	588.5
27		379.5	610.5	462.0	484.0

Table 5.26 Mean and range of inorganic nitrogen (kg/ha) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	595.1	511.5 – 726.0
Purakkad	563.7	544.5 – 594.0
Lower Kuttanad	594.7	528.0 – 726.0
Kayal Lands	548.9	396.0 – 759.0
Vaikom	444.1	363.0 – 561.0
North Kuttanad	557.3	379.5 – 693.0

- **Available Calcium**

Calcium plays a very important role in plant growth and nutrition, as well as in cell wall deposition. In Kuttanad, the available calcium content in the soil ranged between 521 to 893 kg/ha (Table5.27). The mean value of calcium was lower in lower Kuttanad and highest in Purakkad (Table 5.28). Spatial distribution of calcium in the different agricultural zones is shown in Fig. 5.34. The highest range of calcium values were observed in one site each of North Kuttanad, Purakkad and Upper Kuttanad. Out of the eighty one samples analysed, the fertility level was medium in 11% of the samples and high in 89% (Table 5.28a).

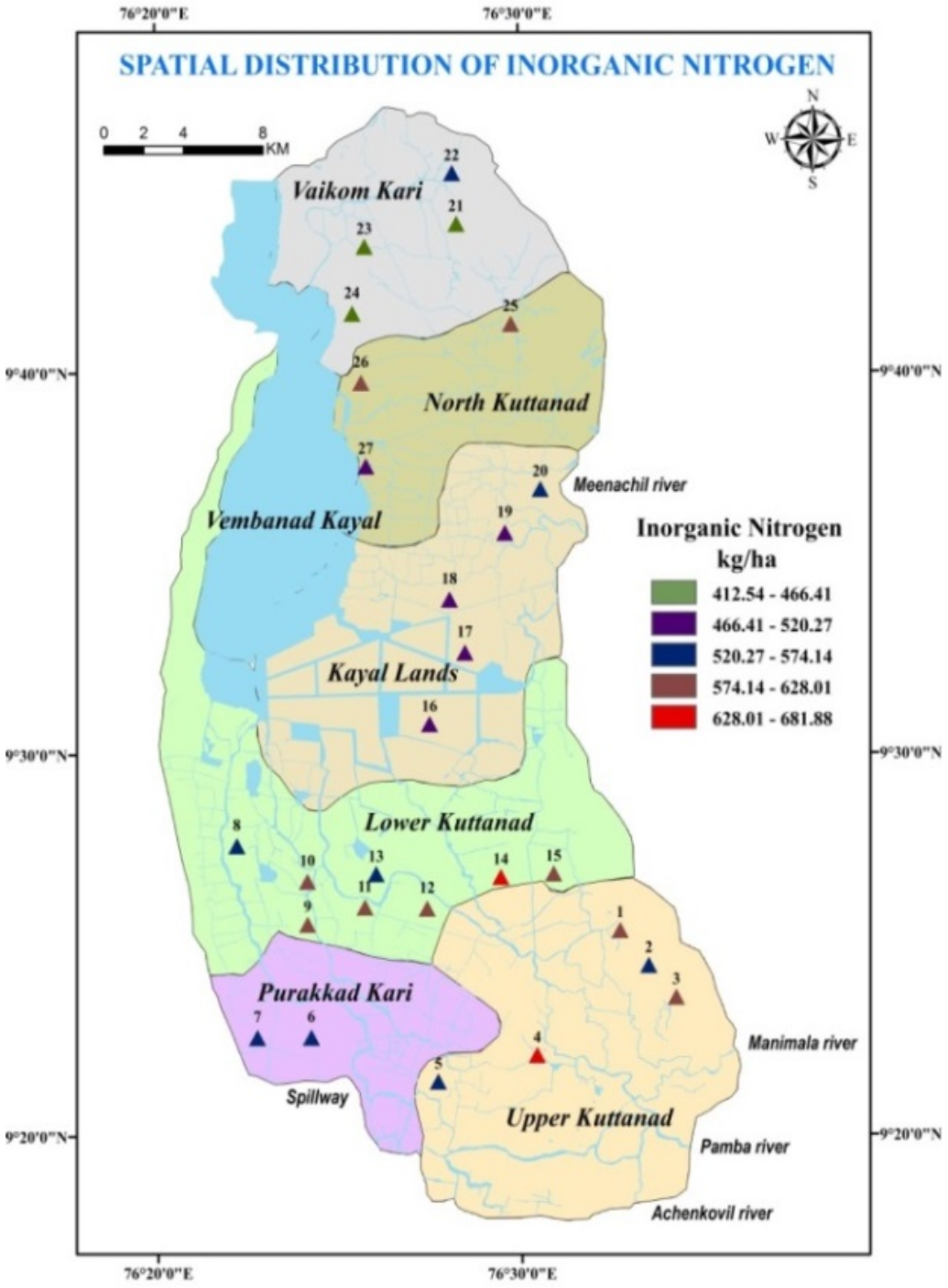


Fig. 5.33 Spatial distribution of inorganic nitrogen in Kuttanad

Table 5.27 Available calcium (kg/ha) of sampling locations during the cropping period of December 2010 to February 2011

SITE	Agronomic Zone	December (kg/ha)	January (kg/ha)	February (kg/ha)	Mean (kg/ha)
1	Upper Kuttanad	783.0	763.0	732.0	759.3
2		721.0	719.0	713.0	717.7
3		735.0	745.0	765.0	748.3
4		843.0	842.0	847.0	844.0
5		654.0	649.0	629.0	644.0
6	Purakkad	773.0	761.0	739.0	757.7
7		873.0	862.0	893.0	876.0
8	Lower Kuttanad	723.0	718.0	704.0	715.0
9		748.0	739.0	731.0	739.3
10		783.0	743.0	749.0	758.3
11		682.0	694.0	643.0	673.0
12		597.0	574.0	547.0	572.7
13		624.0	627.0	615.0	622.0
14		652.0	647.0	635.0	644.7
15		692.0	674.0	662.0	676.0
16	Kayal land	793.0	769.0	782.0	781.3
17		757.0	736.0	736.0	743.0
18		721.0	737.0	723.0	727.0
19		583.0	571.0	568.0	574.0
20		748.0	729.0	715.0	730.6
21	Vaikom	759.0	751.0	795.0	768.3
22		521.0	538.0	516.0	525.0
23		718.0	703.0	691.0	704.0
24		767.0	758.0	725.0	750.0
25	North Kuttanad	692.0	659.0	648.0	666.3
26		754.0	733.0	728.0	738.3
27		859.0	843.0	827.0	843.0

Table 5.28 Mean and range of available calcium (kg/ha) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	742.6	629 - 847
Purakkad	816.8	739 - 893
Lower Kuttanad	675.1	547 - 783
Kayal Lands	711.2	568 - 793
Vaikom	686.8	516- 795
North Kuttanad	749.2	648 - 859

Table 5.28a Estimated available calcium (mg/kg) and fertility level of the soil samples

S.I No.	Available Calcium(mg/kg)	Fertility level	Range mg/kg (No. of samples; %)
1	< 150	Low	…..
2	150-300	Medium	258-299 (9 ;11)
3	> 300	High	308 - 447 (72 ; 89)

- **Available Magnesium**

Magnesium plays an important role in the formation of chlorophyll and in photosynthesis. In Kuttanad, the available magnesium content in the soil ranged between 328 to 597 kg/ha (Table 5.29). The mean value of available magnesium was lowest in lower Kuttanad and highest in Purakkad (Table. 5.30). Spatial distribution of available magnesium in the different agricultural zones is shown in Fig.5.35. Fertility level of available magnesium was high in all the sampling locations of Kuttanad (Table 5.30a).

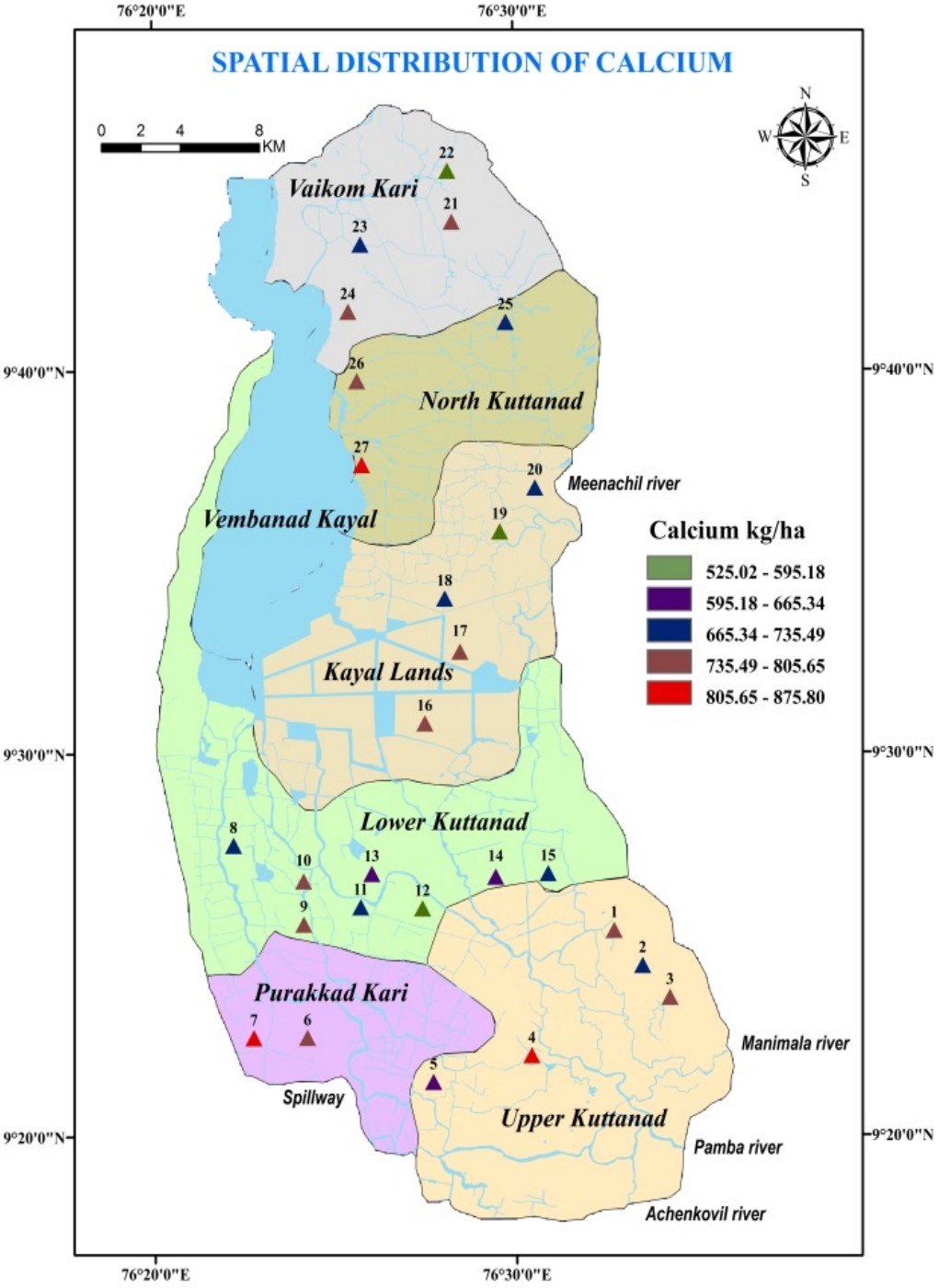


Fig. 5.34 Spatial distribution of available calcium in Kuttanad

Table 5.29 Available Magnesium (kg/ha) of sampling locations during the cropping period of December 2010 to February 2011

Site	Agronomic Zone	December (kg/ha)	January (kg/ha)	February (kg/ha)	Mean (kg/ha)
1	Upper Kuttanad	549.0	529.0	482.0	520.0
2		472.0	459.0	476.0	469.0
3		572.0	549.0	554.0	558.3
4		582.0	578.0	597.0	585.7
5		392.0	376.0	387.0	385.0
6	Purakkad	572.0	521.0	517.0	536.7
7		592.0	548.0	573.0	571.0
8	Lower Kuttanad	517.0	536.0	492.0	515.0
9		528.0	539.0	547.0	538.0
10		572.0	548.0	559.0	559.7
11		476.0	458.0	437.0	457.0
12		328.0	349.0	371.0	349.3
13		387.0	369.0	373.0	376.3
14		448.0	439.0	428.0	438.3
15		476.0	498.0	478.0	484.0
16	Kayal land	549.0	561.0	538.0	549.3
17		583.0	569.0	572.0	574.70
18		476.0	451.0	439.0	455.3
19		385.0	391.0	387.0	387.7
20		521.0	548.0	496.0	521.7
21	Vaikom	593.0	589.0	563.0	581.7
22		389.0	394.0	379.0	387.3
23		497.0	482.0	494.0	491.0
24		572.0	585.00	549.0	568.7
25	North Kuttanad	382.0	397.0	406.0	395.0
26		548.0	569.0	536.0	551.0
27		579.0	588.0	546.0	571.0

Table 5.30 Mean and range of available magnesium (kg/ha) in the agronomic zones of Kuttanad

Agronomic Zones	Mean	Range
Upper Kuttanad	503.6	376 - 597
Purakkad	553.8	517 - 592
Lower Kuttanad	464.7	328 - 559
Kayal Lands	497.7	385 - 583
Vaikom	507.2	379 - 593
North Kuttanad	505.7	382 - 588

Table 5.30a Estimated available magnesium (mg/kg) and fertility level of the soil samples

S.I No.	Available Magnesium(mg/kg)	Fertility level	Range mg/kg (No. of samples; %)
1	< 50	Low	…..
2	50-100	Medium	…..
3	> 100	High	164 - 299 (81 ; 100)

- **Soil fertility status**

The soils of Kuttanad were classified based on the fertility status as computed through nutrient index (Table 5.31). According to this the paddy fields are grouped into high category based on organic carbon, available phosphorus available potassium, available calcium and available magnesium.

Table 5.31 Nutrient index value for the soil samples of Kuttanad

Characteristics	Nutrient index value	Remarks
Organic carbon	3.0	High
Available Phosphorus	3.0	High
Available Potassium	2.9	High
Available Calcium	2.9	High
Available Magnesium	3.0	High

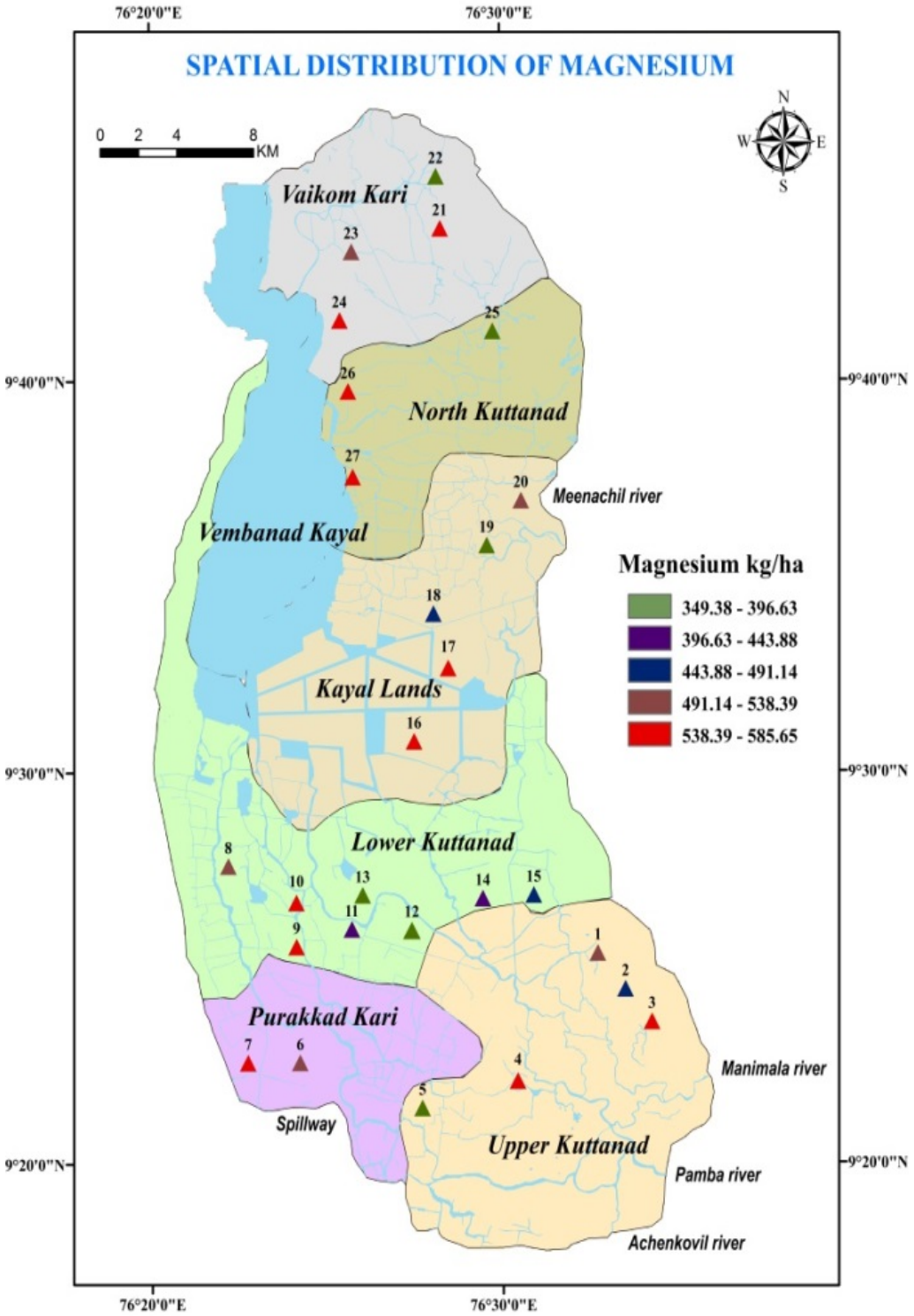


Fig. 5.35 Spatial distribution of available magnesium in Kuttanad

5.5.2 Fertility of paddy fields of Kole lands

- **Soil Texture**

The textural analysis done in this investigation showed that type of soils in the sampling locations of kole lands were sandy loam (Table 5.32).

Table 5.32 Soil texture in the sampling locations of Kole lands

S.I. No	Sampling locations	Sand %	Silt %	Clay %	Textural class
1	Puzhakkal	65	17	12	Sandy loam
2	Muriyad	69	10	8	Sandy loam
3	Nedupuzha	60	20	10	Sandy loam
4	Palakkal	63	19	15	Sandy loam

- **Soil pH**

In the sampling locations of kole lands the pH of the soil samples ranged from 3.79 to 5.82 (Table 5.33). The mean pH was highest in Puzhakkal compared to the other sampling locations (Table 5.34). 58% of the soil samples collected from Kole lands were extremely acidic, 34% strongly acidic, and 8% moderately acidic (Table 5.35).

Table 5.33 pH of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October	November	December	January	Mean
1	Puzhakkal	5.60	5.40	5.72	5.53	5.56
2		4.90	5.52	5.82	5.68	5.48
3		4.10	4.60	4.40	4.80	4.48
4	Muriyad	4.12	4.32	4.28	4.39	4.28
5		4.38	4.56	4.64	4.28	4.47
6		4.67	4.59	4.62	4.47	4.59
7	Nedupuzha	4.64	4.29	4.38	4.47	4.45

8		3.79	4.75	4.39	4.27	4.30
9		4.64	4.21	4.32	4.45	4.41
10		4.65	5.21	4.84	4.82	4.88
11	Palakkal	4.12	4.28	4.19	4.08	4.17
12		3.84	3.97	4.26	4.13	4.05

Table 5.34 Mean and range of pH in the sampling locations of Kole lands

S.I No.	sampling sites	Mean	Range
1	Puzhakkal	5.17	4.10 - 5.82
2	Muriyad	4.44	4.12 - 4.67
3	Nedupuzha	4.38	3.79 - 4.75
4	Palakkal	4.37	3.84 - 5.21

Table 5.35 Measured pH of the soil samples and soil reaction rating in Kole lands (DAC, 2011)

S.I. No.	pH Range	Soil Reaction Rating	Range (No. of samples; %)
1	<4.60	Extremely acid	3.79 - 4.59(28;58)
2	4.60 - 5.50	Strongly acid	4.60 - 5.40(16;34)
3	5.60 - 6.50	Moderately acid	5.60 - 5.82(4;8)
4	6.60 - 6.90	Slightly acid	……
5	7.00	Neutral	……
6	7.10 - 8.50	Moderately alkaline	……
7	>8.50	Strongly alkaline	……

- **Soil Electrical Conductivity**

In Kole lands the electrical conductivity of the soil samples ranged from 0.14 to 0.59 mS/cm (Table 5.36). The mean value was highest in Palakkal (Table 5.37). The soils are salt free in all the sampling locations (Table 5.38).

Table 5.36 Electrical conductivity of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October	November	December	January	Mean mS/cm
1	Puzhakkal	0.19	0.15	0.18	0.15	0.17
2		0.24	0.55	0.44	0.49	0.43
3		0.31	0.45	0.21	0.25	0.31
4	Muriyad	0.21	0.38	0.33	0.31	0.31
5		0.18	0.19	0.16	0.17	0.18
6		0.24	0.47	0.38	0.48	0.39
7	Nedupuzha	0.21	0.17	0.28	0.17	0.21
8		0.25	0.19	0.56	0.15	0.29
9		0.22	0.33	0.46	0.34	0.34
10	Palakkal	0.49	0.59	0.44	0.51	0.51
11		0.25	0.33	0.25	0.15	0.25
12		0.23	0.29	0.18	0.14	0.21

Table 5.37 Mean and range of Conductivity in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean (mS/cm)	Range
1	Puzhakkal	0.30	0.15 - 0.55
2	Muriyad	0.29	0.16 - 0.48
3	Nedupuzha	0.28	0.15 - 0.56
4	Palakkal	0.32	0.14 - 0.59

Table 5.38 Measured Electrical Conductivity of the soil samples and % of salt content (DAC, 2011)

Soil	EC (mS/cm)	Total salt content %	Range (No. of samples; %)
1. Salt free	0 - 2	<0.15	0.15 - 0.59 (48 ; 100)
2. Slightly saline	4 - 8	0.15 - 0.35	.....
3. Moderately saline	8 - 15	0.35 - 0.65	.....
4. Highly saline	>15	>0.65	.....

- **Organic carbon**

The organic carbon of all soil samples in the Kole lands were in the range 1.33 to 3.70 % (Table 5.39). The mean organic carbon in all the sampling locations and range is given in Table 5.40. Fertility level based of organic carbon was high in all the sampling locations (Table 5. 41 & Fig.5.36).

Table 5.39 Organic carbon (%) content of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October	November	December	January	Mean %
1	Puzhakkal	2.29	1.92	1.85	2.07	2.03
2		2.51	2.66	2.66	1.92	2.44
3		1.85	2.07	1.55	2.44	1.97
4	Muriyad	1.55	1.33	2.07	2.51	1.86
5		1.92	3.07	3.70	3.48	3.04
6		2.66	1.55	1.85	1.70	1.94
7	Nedupuzha	2.07	1.77	1.62	1.77	1.81
8		1.33	2.58	1.33	1.55	1.70
9		2.44	2.66	2.21	1.85	2.29
10	Palakkal	3.62	3.14	3.44	3.62	3.46
11		1.51	1.77	2.07	1.85	1.80
12		2.41	1.40	2.66	1.48	1.99

Table 5.40 Mean and range of organic carbon in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean(%)	Range
1	Puzhakkal	2.15	1.55 - 2.66
2	Muriyad	2.28	1.33 - 3.70
3	Nedupuzha	1.93	1.33 - 2.66
4	Palakkal	2.41	1.51 - 3.62

Table 5.41 Estimated organic carbon (%) content of the soil samples and fertility level (DAC, 2011)

S.I No.	Organic Carbon %	Fertility level	Range (No. of samples; %)
1	< 0.05	Low	.....
2	0.50 - 0.75	Medium	.....
3	> 0.75	High	1.33 - 3.70 (48 ; 100)

- **Available Phosphorus**

In Kole lands, the available phosphorus content ranged from 24.78 to 49.53 kg/ha (Table 5.42). The mean value of available phosphorus was comparatively lower in Nedupuzha (Table 5.43). The mean values of available phosphorus and their fertility levels are given in Table 5.44. According to this the soil samples are grouped as moderate, high and very high in fertility. Distribution of available phosphorus in the different sampling locations based on the mean value is shown in Fig. 5.37. Based on the mean value of sampling locations, Nedupuzha was in moderate fertility level and all other sampling locations were in high fertility level.

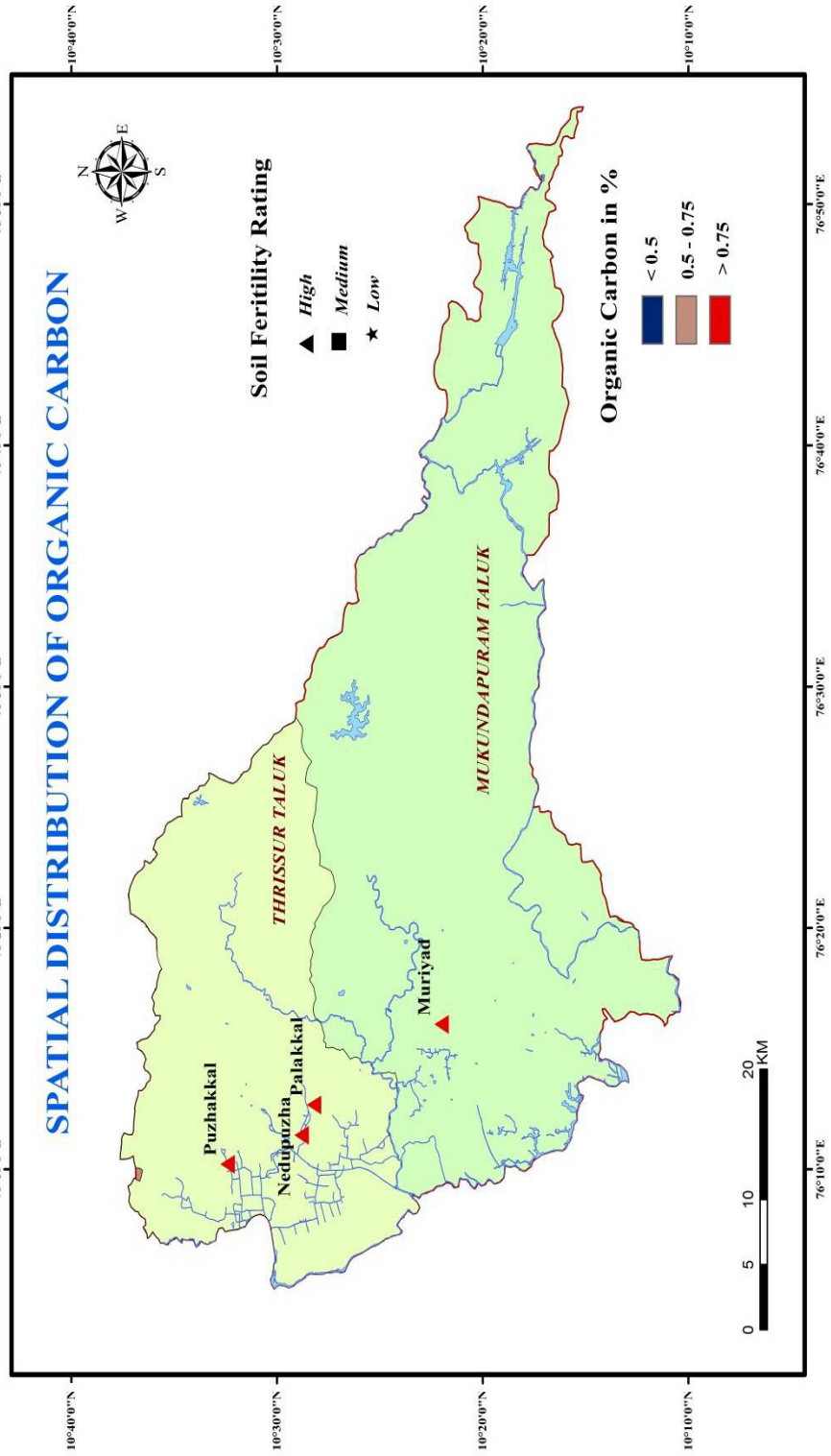


Fig. 5.36 Spatial distribution of Organic carbon in Kole lands

Table 5.42 Available phosphorus (kg/ha) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October (kg/ha)	November (kg/ha)	December (kg/ha)	January (kg/ha)	Mean (kg/ha)
1	Puzhakkal	33.74	39.51	42.76	38.82	38.71
2		35.72	33.89	38.94	38.54	36.77
3		38.93	37.91	33.85	31.62	35.58
4	Muriyad	28.72	36.87	39.78	35.81	35.30
5		34.73	42.87	46.91	44.75	42.32
6		31.59	48.42	49.53	45.82	43.84
7	Nedupuzha	24.78	28.54	32.87	31.95	29.54
8		27.92	35.46	36.87	30.65	32.73
9		28.79	30.72	32.82	36.41	32.19
10	Palakkal	29.62	36.82	39.48	35.81	35.43
11		28.56	29.43	33.81	31.79	30.90
12		33.89	38.92	37.92	39.61	37.59

Table 5.43 Mean and range of available phosphorus in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean (kg/ha)	Range
1	Puzhakkal	37.02	31.62 - 42.76
2	Muriyad	37.73	28.72 - 49.53
3	Nedupuzha	31.48	24.78 - 36.87
4	Palakkal	34.64	28.56 - 39.61

Table 5.44 Estimated available phosphorus of the soil samples and fertility level (Dorahy *et al.,* 2004)

S.I No.	Avail. P kg/ha	Fertility level	Range (No. of samples; %)
1	< 8.25	Very Low	__
2	8.25 - 16.50	Low	__
3	16.50 - 33.00	Moderate	24.78 - 32.87(14 ; 29)
4	33.00 - 41.50	High	33.81 - 39.78 (28 ; 58)
5	> 41.25	Very High	42.76 - 49.53 (6 ; 13)

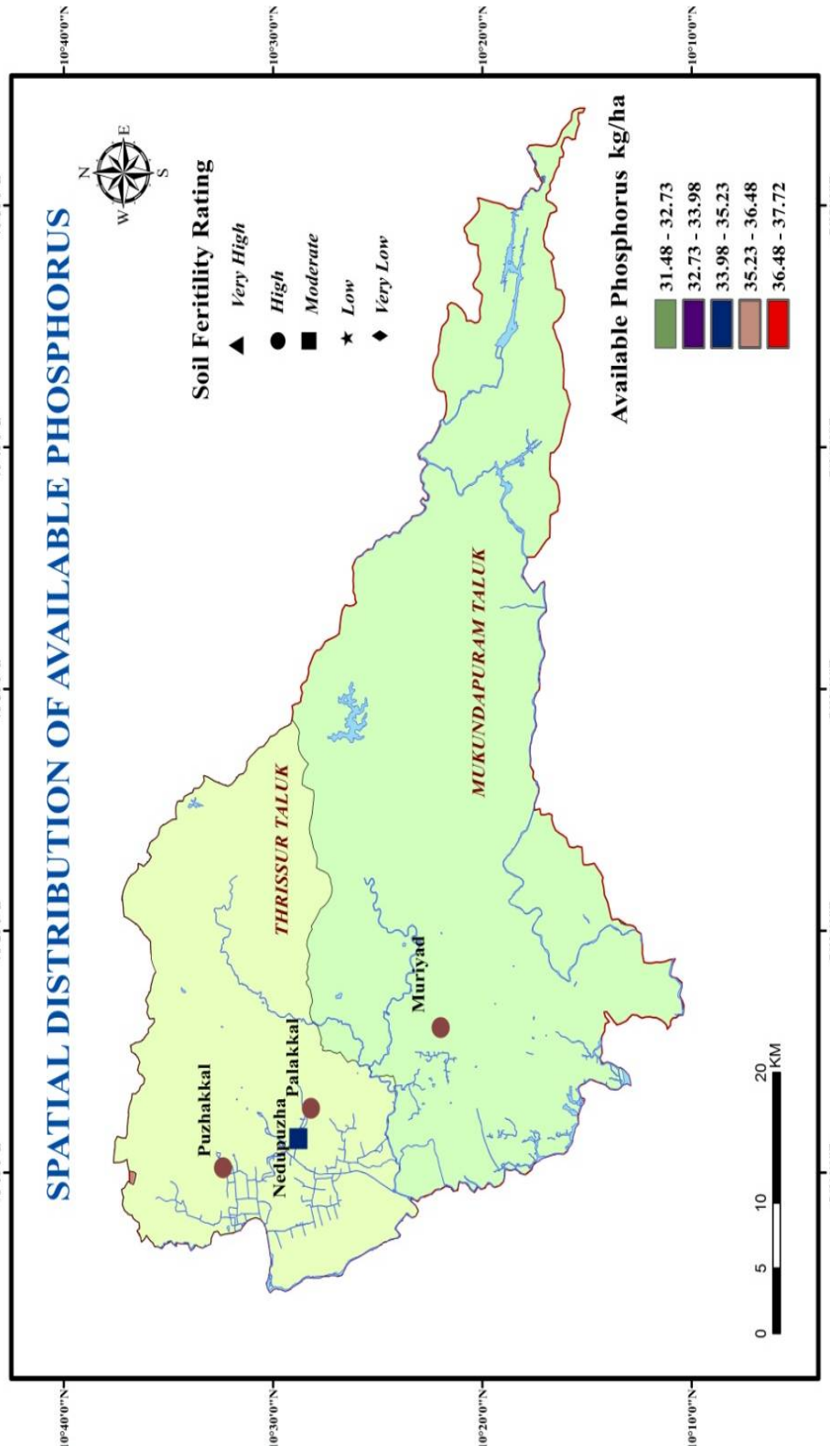


Fig. 5.37 Spatial distribution of available phosphorus in the sampling locations of Kole lands

➢ **Available Potassium**

In Kole lands, the potassium content ranged from 321.93 to 485.63 kg/ha (Table 5.45). The mean value of available potassium was highest in Muriyad and lowest in Nedupuzha (Table 5.46). Fertility level of the soil samples is given in Table 5.47 and according to this all the forty eight samples are in the high category. Spatial distribution of potassium was high in all the sampling locations (Fig. 5.38).

Table 5.45Available Potassium (kg/ha) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October (kg/ha)	November (kg/ha)	December (kg/ha)	January (kg/ha)	Mean (kg/ha)
1	Puzhakkal	328.9	383.9	382.6	378.2	368.4
2		451.8	472.8	483.6	476.6	471.2
3		416.8	438.7	444.8	442.5	435.7
4	Muriyad	462.8	479.2	485.6	483.9	477.9
5		418.9	425.6	437.8	431.9	428.6
6		432.7	457.7	462.8	451.8	451.3
7	Nedupuzha	351.8	369.5	374.8	378.9	368.8
8		326.4	336.7	339.6	341.8	336.1
9		321.9	337.9	346.8	349.7	339.1
10	Palakkal	438.58	452.7	446.9	448.3	446.6
11		395.6	407.9	418.4	410.6	408.2
12		325.7	358.2	346.9	336.8	341.9

Table 5.46 Mean and range of available potassium in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean	Range
1	Puzhakkal	425.1	328.7 - 483.6
2	Muriyad	452.6	418.9 - 485.6
3	Nedupuzha	347.9	321.9 - 378.9
4	Palakkal	398.9	325.8 - 452.7

Table 5.47 Estimated available potassium of the soil samples and fertility level (DAC, 2011)

S.I No.	Potassium kg/ha	Fertility level	Range (No. of samples; %)
1	< 108	Low	—
2	108 - 280	Medium	—
3	> 280	High	321.9 - 485.6 (48 ; 100)

- **Total Inorganic nitrogen**

In Kole lands, the inorganic nitrogen content in the soil ranged between 374.92 to 567.58 kg/ha (Table5.48). The mean value of total inorganic nitrogen was highest in Palakkal and lowest in Puzhakkal (Table 5.49). Spatial distribution of inorganic nitrogen in the sampling locations is shown in Fig. 5.39.

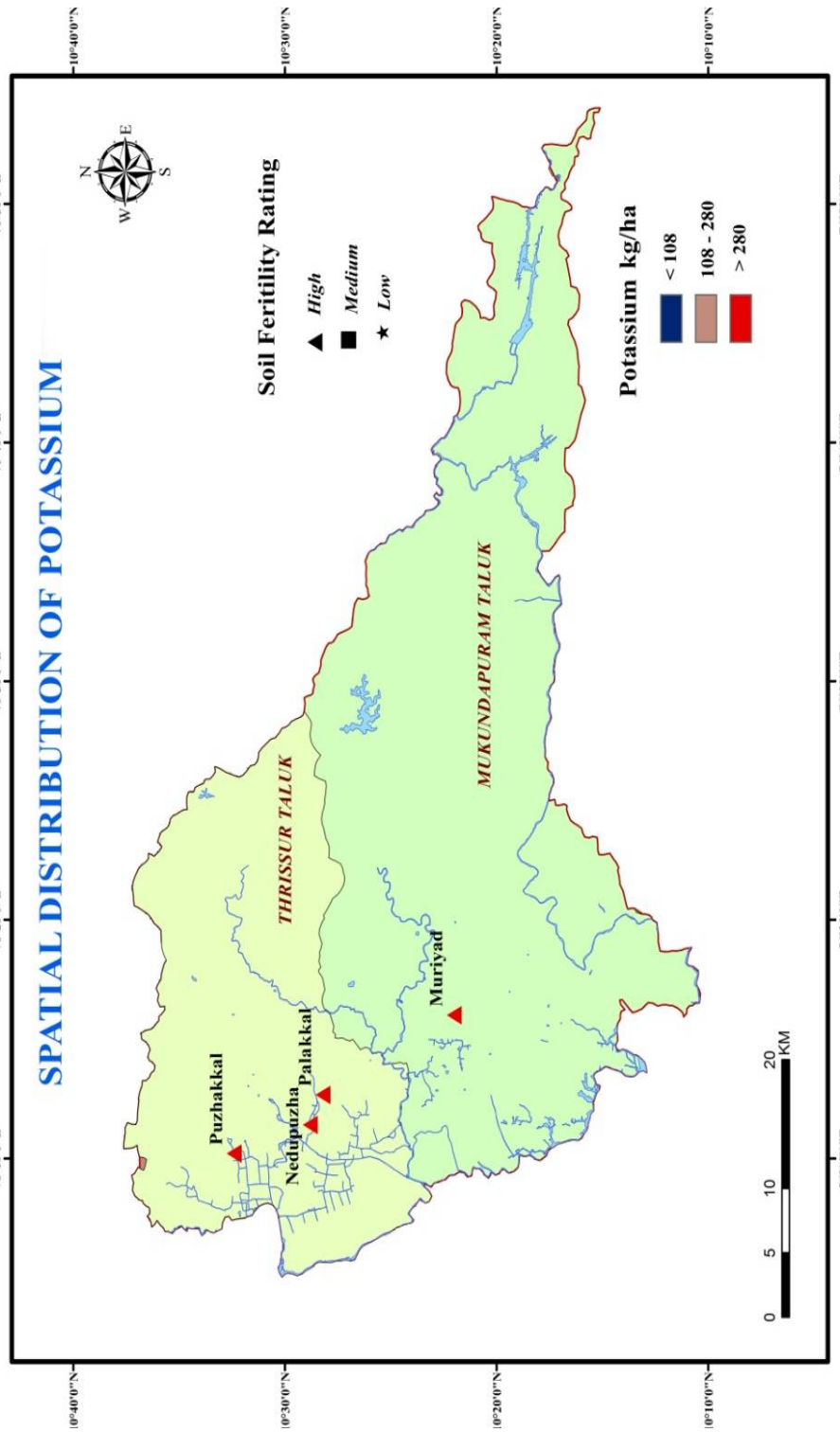


Fig. 5.38 Spatial distribution of available potassium in the sampling locations of Kole lands

Table 5.48 Total Inorganic Nitrogen (kg/ha) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October (kg/ha)	November (kg/ha)	December (kg/ha)	January (kg/ha)	Mean (kg/ha)
1	Puzhakkal	459.8	413.1	432.6	516.5	455.5
2		511.2	432.8	426.0	435.1	451.3
3		433.1	428.7	433.8	426.4	430.5
4	Muriyad	454.6	412.0	483.8	453.4	450.9
5		463.5	438.7	429.1	540.7	468.0
6		494.4	448.3	542.8	459.7	486.3
7	Nedupuzha	497.7	468.1	428.3	470.6	466.2
8		374.9	397.4	448.3	447.5	417.0
9		468.2	464.9	454.7	499.8	471.9
10	Palakkal	459.4	533.3	447.3	484.4	481.1
11		443.2	501.5	567.6	454.2	491.6
12		479.2	429.2	432.5	423.0	440.9

Table 5.49 Mean and range of total inorganic nitrogen in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean (kg/ha)	Range
1	Puzhakkal	445.8	413.1 - 516.5
2	Muriyad	468.4	412.0 - 542.8
3	Nedupuzha	451.7	374.9 - 499.8
4	Palakkal	471.2	423.0 - 567.6

- **Available calcium**

In Kole lands, the available calcium content in the soil ranged between 430 to 678 kg/ha (Table 5.50). The mean value of available calcium was lowest in Puzhakkal and highest in Muriyad (Table 5.51). Spatial distribution of available calcium in the different sampling locations is shown in Fig. 5.40. Out of the forty eight samples analysed the fertility level was medium in 85 % of the samples and high in 15 % (Table 5.51a).

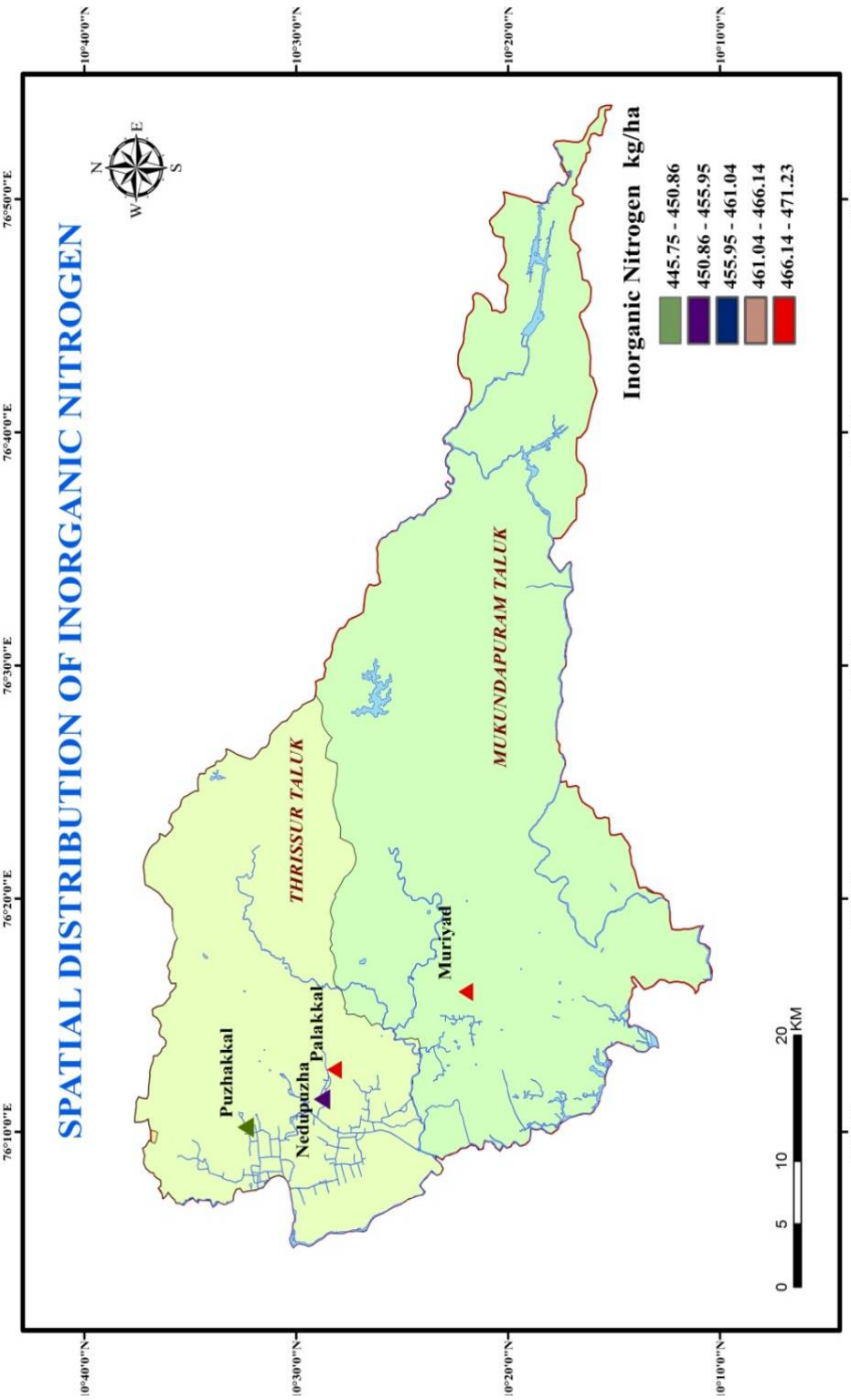


Fig.5.39 Spatial distribution of total inorganic nitrogen in the sampling locations of Kole lands

Table 5.50 Available calcium (kg/ha) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October (kg/ha)	November (kg/ha)	December (kg/ha)	January (kg/ha)	Mean (kg/ha)
1	Puzhakkal	452	472	452	430	451.5
2		529	526	547	515	529.3
3		558	572	561	539	557.5
4	Muriyad	576	581	574	571	575.5
5		523	548	529	494	523.5
6		639	678	629	612	639.5
7	Nedupuzha	461	476	461	446	461.0
8		560	573	554	551	559.5
9		539	539	546	531	538.8
10	Palakkal	607	625	618	582	608.0
11		506	492	523	501	505.5
12		522	521	532	510	521.3

Table 5.51 Mean values of calcium in the sampling locations of Kole lands and range

S.I No.	Sampling locations	Mean	Range
1	Puzhakkal	512.7	430 - 582
2	Muriyad	579.6	494 - 678
3	Nedupuzha	519.7	446 - 573
4	Palakkal	544.9	492 - 625

Table 5.51a Estimated available calcium (mg/kg) and fertility level in Kole lands

S.I No.	Available Calcium(mg/kg)	Fertility level	Range mg/kg (No. of samples; %)
1	< 150	Low	…..
2	150-300	Medium	215-291 (41 ;85)
3	> 300	High	304 - 339 (7 ; 15)

- **Available Magnesium**

In Kole lands, the available magnesium content in the soil ranged between 312 to 481 kg/ha (Table 5.52). The mean value of available magnesium was lowest in Palakkal and highest in Muriyad (Table 5.53). The distribution of available magnesium in the different sampling locations is shown in Fig 5.41. Soil fertility level of magnesium is given in Table 5.53a. According to this all the forty eight samples are in the high category.

Table 5.52 Available magnesium (kg/ha) of sampling locations in Kole lands during the period of October 2011 to January 2012

S.I. No.	Sampling locations	October (kg/ha)	November (kg/ha)	December (kg/ha)	January (kg/ha)	Mean (kg/ha)
1	Puzhakkal	378	362	351	347	359.5
2		427	389	419	405	410.0
3		381	396	384	369	382.5
4	Muriyad	421	458	436	428	435.8
5		474	481	448	433	459.0
6		415	426	369	358	392.0
7	Nedupuzha	375	383	362	372	373.0
8		391	427	401	386	401.3
9		392	387	396	381	389.0
10	Palakkal	361	376	392	376	376.3
11		391	385	418	389	395.8
12		328	347	331	312	329.5

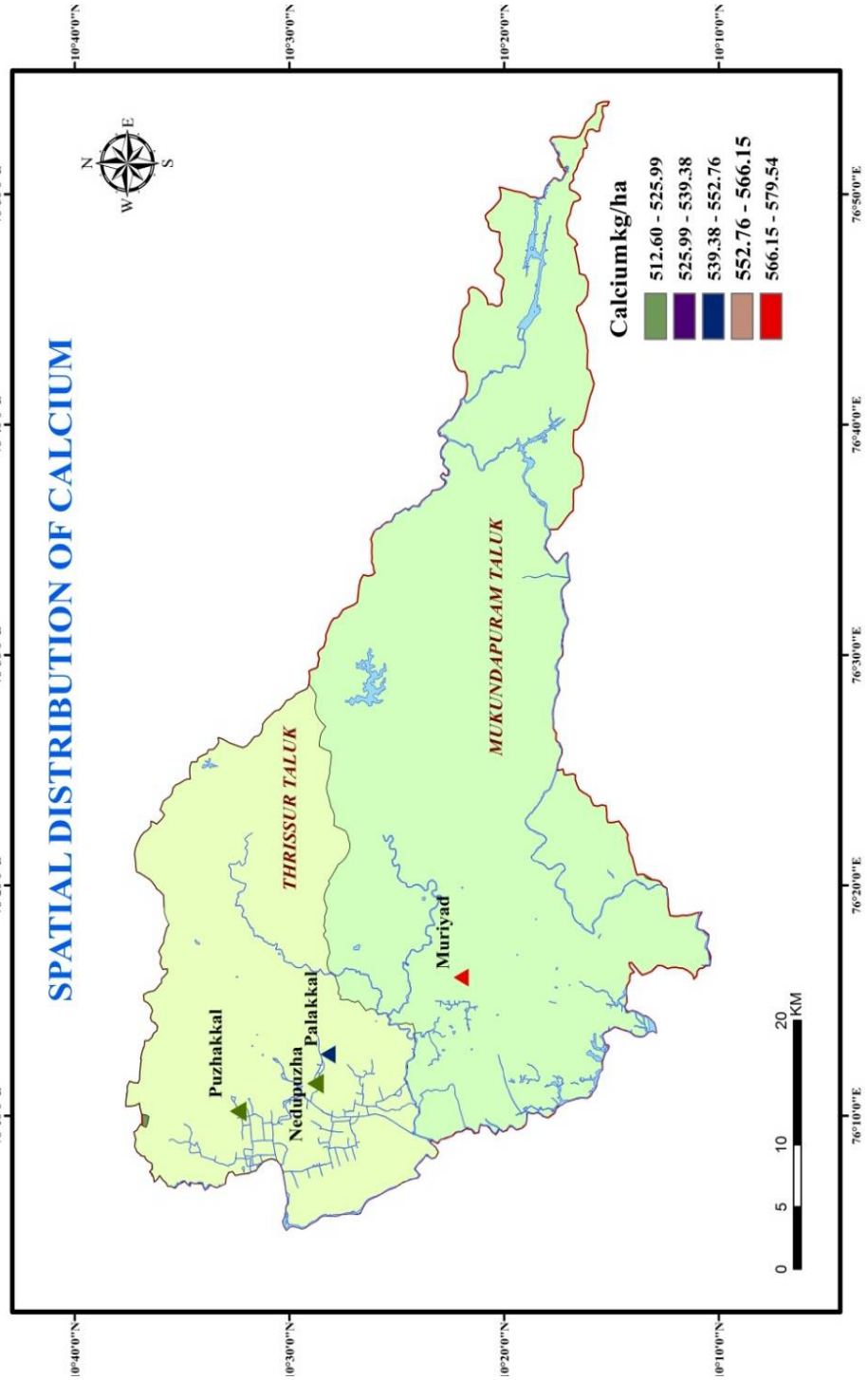


Fig.5.40 Spatial distribution of calcium in the sampling locations of Kole lands

Table 5.53 Mean and range of magnesium in the sampling locations of Kole lands

S.I No.	Sampling locations	Mean	Range
1	Puzhakkal	384.0	347 - 427
2	Muriyad	428.9	358 - 481
3	Nedupuzha	387.8	362 - 427
4	Palakkal	367.2	312 - 418

Table 5.53a Estimated available magnesium (mg/kg) and fertility level of the soil samples

S.I No.	Available Magnesium(mg/kg)	Fertility level	Range mg/kg (No. of samples; %)
1	< 50	Low	…..
2	50-100	Medium	…..
3	> 100	High	156 - 241 (48 ; 100)

- **Soil fertility status**

Sampling locations of Kole lands were classified based on the fertility status as computed through nutrient index (Table 5.54). According to this the paddy fields are grouped into high category based on organic carbon, available phosphorus, available potassium and available magnesium. The nutrient index value of available calcium is grouped in medium category.

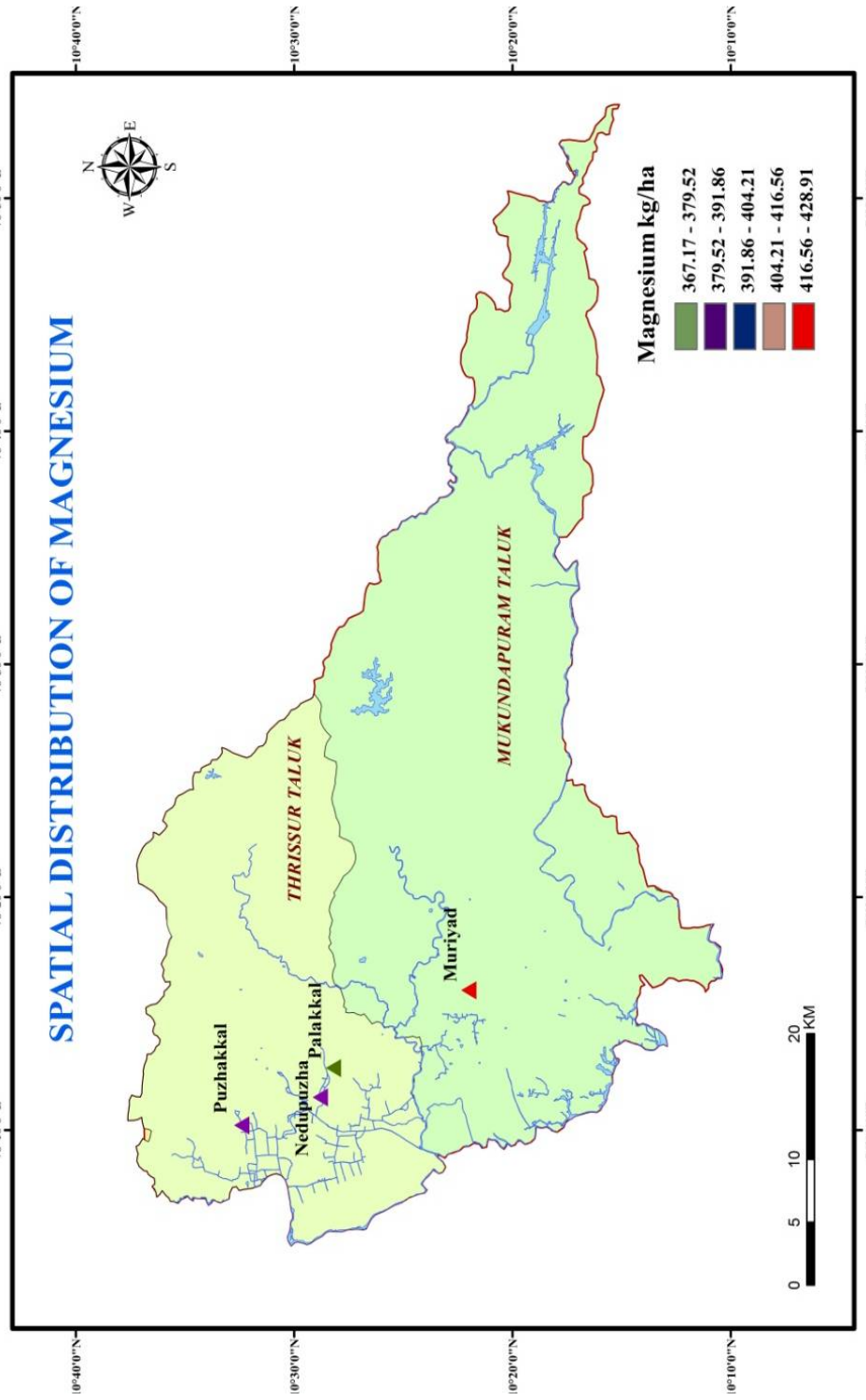


Fig. 5.41 Spatial distribution of magnesium in the sampling locations of Kole lands

Table 5.54 Nutrient index value for the soil samples of Kole lands

Characteristics	Nutrient index value	Remarks
Organic carbon	3.0	High
Available Phosphorus	2.7	High
Available Potassium	3	High
Available Calcium	2.2	Medium
Available Magnesium	3.0	High

5.6 Correlation of soil properties with algae

The correlation analysis of soil physico-chemical parameters revealed that in general calcium, magnesium and pH are positively correlated. The associations among the other parameters are not consistent. No distinct trend was observed in the relation between soil chlorophyll *a* or species richness of filamentous algae with the soil characteristics. The correlation matrixes for the various sampling locations are presented below and the associations between the parameters are given in detail.

5.6.1 Correlation of soil physico-chemical and biological properties in Kuttanad

- **Upper Kuttanad**

Correlation analysis of physico chemical and biological properties of the soils of Upper Kuttanad is given in table 5.55. The results of the study showed that total inorganic nitrogen is positively correlated with available potassium. Available calcium showed significant positive correlation with pH, available potassium and total inorganic nitrogen. Available magnesium has showed positive correlation with available potassium, total inorganic nitrogen and available calcium. Chlorophyll *a* is negatively correlated with organic carbon. Occurrence of filamentous algae among the sites of Upper Kuttanad showed significant positive correlation with organic carbon and negatively correlated with available potassium and available calcium.

- **Purakkad**

The results of the correlation study of soil among the sites of Purakkad showed that organic carbon is negatively correlated with pH and total inorganic nitrogen is positively correlated with available phosphorus (Table 5.56).

- **Lower Kuttanad**

Among the sites of lower Kuttanad the results of correlation studies showed that organic carbon is negatively correlated with pH. Available calcium is positively correlated with pH and negatively correlated with organic carbon. Available magnesium is positively correlated with pH and negatively correlated with organic carbon. Occurrence of filamentous algae in the Lower Kuttanad is positively correlated with calcium and magnesium and negatively correlated to total inorganic nitrogen (Table 5.57).

- **Kayal lands**

The results of the correlation studies of soil among the sites of Kayal Lands showed that total inorganic nitrogen showed negative correlation with organic carbon. Available calcium is positively correlated with pH and organic carbon and negatively correlated with total inorganic nitrogen. Available magnesium showed positive correlation with organic carbon and calcium and negatively correated to total inorganic nitrogen. Chlorophyll a is negatively correlated to available magnesium. Occurrence of filamentous algae in Kayal lands showed positive correlation with pH and calcium (Table 5.58).

- **Vaikom**

Correlation of soil properties in Vaikom showed that organic carbon is negatively correlated to electrical conductivity. Available calcium is positively correlated with pH and negatively correlated with potassium and total inorganic nitrogen. Available magnesium is positively correlated with pH and available calcium and negatively correlated to available potassium and total inorganic nitrogen. Chlorophyll *a* is positively correlated with total inorganic nitrogen (Table5.59).

- **North Kuttanad**

Correlation studies of soils of North Kuttanad showed that total inorganic nitrogen is negatively correlated to pH. Calcium is positively correlated to pH and negatively correlated with total inorganic nitrogen. Significant positive correlation is existed among available calcium, magnesium, available potassium and occurrence of filamentous algae (Table 5.60).

Table 5.55 Correlation matrix of soil physico-chemical and biological properties of Upper Kuttanad

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	-0.09	1								
Organic C	0.07	0.05	1							
Available P	-0.18	0.02	0.27	1						
Available K	0.13	0.09	-0.24	-0.28	1					
Inorganic N	0.42	0.42	-0.24	-0.29	0.54*	1				
Available Ca	0.55*	0.09	0.07	-0.41	0.77*	0.65*	1			
Available Mg	0.44	0.05	0.19	-0.40	0.73*	0.51*	0.92*	1		
Chlorophyll *a*	0.11	0.22	-0.60*	-0.23	-0.10	0.21	-0.25	-0.30	1	
Species richness of Filamentous algae	-0.37	-0.18	0.49*	0.27	-0.68*	-0.75	-0.60*	-0.41	-0.23	1

*significant at $p<0.05$ level

Table 5.56 Correlation matrix of soil physico-chemical and biological properties of Purakkad

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	-0.44	1								
Organic C	-0.84*	0.15	1							
Available P	0.13	-0.32	0.13	1						
Available K	0.10	0.17	-0.52	0.02	1					
Inorganic N	0.11	-0.45	0.23	0.87*	-0.02	1				
Available Ca	0.69	-0.04	-0.76	0.44	0.64	0.31	1			
Available Mg	0.73	-0.68	-0.50	0.65	0.25	0.70	0.72	1		
Chlorophyll *a*	-0.41	-0.30	0.75	0.37	-0.42	0.69	-0.43	0.10	1	
Species richness of Filamentous algae	-0.68	-0.04	0.83	-0.24	-0.73	-0.16	-0.98	-0.62	0.52	1

*significant at $p<0.05$ level

Table 5.57 Correlation matrix of soil physico-chemical and biological properties of Lower Kuttanad

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1.00									
EC	0.35	1.00								
Organic C	-0.49*	-0.28	1.00							
Available P	-0.05	0.31	0.00	1.00						
Available K	-0.26	-0.34	-0.16	0.06	1.00					
Inorganic N	-0.09	0.04	0.32	0.22	0.07	1.00				
Available Ca	0.61*	0.07	-0.66*	-0.01	-0.04	-0.22	1.00			
Available Mg	0.58*	0.04	-0.60*	0.06	-0.14	-0.19	0.95*	1.00		
Chlorophyll *a*	0.37	0.03	-0.35	-0.19	-0.37	-0.16	0.33	0.30	1.00	
Species richness of Filamentous algae	0.28	0.08	-0.36	-0.24	-0.21	-0.50*	0.58*	0.56*	0.16	1.00

*significant at $p<0.05$ level

Table 5.58 Correlation matrix of soil physico-chemical and biological properties of Kayal lands

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	0.15	1.00								
Organic C	0.27	-0.45	1.00							
Available P	0.25	-0.19	0.34	1.00						
Available K	-0.18	-0.03	-0.27	0.01	1.00					
Inorganic N	-0.49	0.11	-0.68*	-0.13	0.08	1.00				
Available Ca	0.52*	-0.17	0.53*	0.14	0.22	-0.69*	1.00			
Available Mg	0.18	-0.22	0.53*	-0.03	0.15	-0.58*	0.85*	1.00		
Chlorophyll *a*	0.31	-0.04	-0.28	-0.02	-0.42	0.23	-0.32	-0.52*	1.00	
Species richness of Filamentous algae	0.75*	0.02	0.32	0.37	-0.02	-0.40	0.61*	0.17	0.14	1

*significant at $p<0.05$ level

Table 5.59 Correlation matrix of soil physico-chemical and biological properties of Vaikom

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	0.15	1.00								
Organic C	-0.03	-0.76*	1.00							
Available P	0.07	0.21	-0.20	1.00						
Available K	-0.45	0.02	0.13	0.41	1.00					
Inorganic N	-0.48	-0.04	0.32	-0.35	0.42	1.00				
Available Ca	0.65*	-0.01	0.11	0.22	-0.62*	-0.66*	1.00			
Available Mg	0.68*	-0.04	0.12	0.01	-0.77*	-0.63*	0.96*	1.00		
Chlorophyll *a*	-0.42	0.14	0.21	-0.08	0.36	0.65*	-0.30	-0.32	1.00	
Species richness of Filamentous algae	0.17	-0.16	0.36	0.20	-0.01	-0.37	0.56	0.51	0.20	1

*significant at $p<0.05$ level

Table 5.60 Correlation matrix of soil physico-chemical and biological properties of North Kuttanad

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1.00									
EC	-0.33	1.00								
Organic C	0.53	-0.01	1.00							
Available P	-0.22	0.59	-0.25	1.00						
Available K	-0.62	-0.28	-0.68	-0.05	1.00					
Inorganic N	-0.83*	0.45	-0.23	0.40	0.51	1.00				
Available Ca	0.97*	-0.48	0.55	-0.27	-0.58	-0.84*	1.00			
Available Mg	0.76	-0.47	0.58	-0.21	-0.21	-0.45	0.81*	1.00		
Chlorophyll *a*	-0.49	0.19	0.36	0.21	0.18	0.74	-0.40	0.01	1.00	
Species richness of Filamentous algae	-0.54	-0.11	-0.36	0.26	0.83*	0.66	-0.48	0.07	0.56	1.00

*significant at $p<0.05$ level

5.6.2 Correlation of soil physico-chemical and biological properties in Kole

- **Puzhakkal**

The results of the correlation study showed that a significant positive correlation existed between available potassium and electrical conductivity. Available calcium showed positive correlation with pH and available magnesium. Available magnesium is positively correlated with electrical conductivity, available potassium and available calcium. Occurrence of filamentous algae showed positive correlation with electrical conductivity, organic carbon and available magnesium (Table 5.61).

- **Muriyad**

Among the sites of Muriyad the results of correlation analysis showed that available calcium is positively correlated with electrical conductivity. Magnesium is negatively correlated with electrical conductivity. Occurrence of filamentous algae showed significant positive correlation with calcium and negative correlation with magnesium (Table 5.62).

- **Nedupuzha**

The results of the correlation studies showed that available calcium showed negative correlation with available potassium. Magnesium showed significant positive correlation with calcium and was negatively correlated with available potassium. Occurrence of filamentous algae showed significant positive correlation with available calcium and available magnesium and negatively correlated to total inorganic nitrogen (Table 5.63).

- **Palakkal**

The results of the correlation studies among the sites of Palakkal showed that electrical conductivity showed significant positive correlation with pH. Organic carbon and available potassium showed significant positive correlation with pH and electrical conductivity. Calcium showed significant positive correlation with pH, electrical conductivity, organic carbon and available potassium. Magnesium showed significant positive correlation with available potassium. Occurrence of filamentous algae showed significant negative correlation with pH, electrical conductivity, organic carbon, available potassium and available calcium (Table 5.64).

5.7 Discussion

Algal diversities are natural occurrences and may occur with stability depending on vegetation type, nutrient level, soil properties, humidity and climatic conditions of particular habitat (Quesada *et al*., 1995, Kumar and Sahu, 2012). The paddy fields of India are reported to support a variety of algae both unicellular and filamentous comprising members of Cyanophyceae, Chlorophyceae, Euglenophyceae and Bacillariophyceae (Gupta, 1966; Kaul *et al*., 1978; Anand and Hopper, 1995; Ahmed *et al.,* 2013). Most authors have given importance to the blue-green algae in context of their contribution to soil nitrogen (Mishra and Pabbi, 2004; Dey *et al.,* 2010; Selvi and Sivakumar, 2011). According to Venkataraman (1975) the tropical rice soils of India harbour low component of N_2- fixing forms. As explained by Roger *et al*. (1980) widespread use of nitrogen fertilisers especially through broadcasting of urea has resulted in the suppression of algal nitrogen fixation. In this

Table 5.61 Correlation matrix of soil physico-chemical and biological properties of Puzhakkal

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	0.09	1.00								
Organic C	0.36	0.40	1.00							
Available P	0.30	-0.08	-0.37	1.00						
Available K	-0.12	0.75*	0.31	-0.16	1.00					
Inorganic N	0.07	-0.34	0.18	-0.06	-0.23	1.00				
Available Ca	-0.65*	0.57	0.08	-0.32	0.75*	-0.39	1.00			
Available Mg	-0.08	0.60*	0.44	-0.20	0.69*	0.04	0.64*	1.00		
Chlorophyll *a*	-0.11	0.11	0.52	-0.36	0.27	-0.14	0.39	0.28	1.00	
Species richness of Filamentous algae	0.39	0.66*	0.59*	-0.06	0.71	0.12	0.25	0.77*	0.06	1

*significant at $p<0.05$ level

Table 5.62Correlation matrix of soil physico-chemical and biological properties of Muriyad

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1.00									
EC	0.15	1.00								
Organic C	0.30	-0.69	1.00							
Available P	0.50	0.37	0.22	1.00						
Available K	-0.36	0.57	-0.51	-0.08	1.00					
Inorganic N	0.04	-0.07	0.18	0.22	-0.14	1.00				
Available Ca	0.43	0.76*	-0.58	0.13	0.34	0.00	1.00			
Available Mg	-0.17	-0.60*	0.30	-0.30	-0.29	-0.47	-0.55	1.00		
Chlorophyll *a*	0.10	0.32	-0.08	0.15	0.06	-0.23	0.12	-0.56	1.00	
Species richness of Filamentous algae	0.61	0.64	-0.32	0.36	-0.04	0.32	0.84*	-0.74*	0.28	1.00

*significant at $p<0.05$ level

Table 5.63 Correlation matrix of soil physico-chemical and biological properties of Nedupuzha

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	-0.14	1.00								
Organic C	0.52	-0.13	1.00							
Available P	0.20	0.54	-0.06	1.00						
Available K	0.12	-0.20	-0.26	0.05	1.00					
Inorganic N	0.43	0.05	0.20	-0.10	0.32	1.00				
Available Ca	-0.19	0.35	0.16	0.36	-0.85*	-0.46	1.00			
Available Mg	0.20	0.19	0.36	0.36	-0.63*	-0.45	0.79*	1.00		
Chlorophyll *a*	0.51	0.15	0.31	0.35	-0.28	0.38	0.15	0.08	1.00	
Species richness of Filamentous algae	-0.25	0.06	-0.38	0.25	-0.48	-0.69*	0.65*	0.61*	-0.15	1

*significant at $p<0.05$ level

Table 5.64 Correlation matrix of soil physico-chemical and biological properties of Palakkal

	pH	EC	Org. C	Avail. P	Avail. K	Inorganic N	Avail. Ca	Avail. Mg	Chlorophyll *a*	Species richness
pH	1									
EC	0.88*	1.00								
Organic C	0.78*	0.77*	1.00							
Available P	0.18	0.01	0.12	1.00						
Available K	0.80*	0.78*	0.61	-0.23	1.00					
Inorganic N	0.31	0.37	0.20	-0.24	0.47	1.00				
Available Ca	0.89*	0.86*	0.88*	0.28	0.66*	0.17	1.00			
Available Mg	0.31	0.31	0.12	-0.43	0.76*	0.59	0.13	1.00		
Chlorophyll *a*	-0.29	-0.26	-0.11	0.17	-0.42	0.25	-0.37	-0.26	1.00	
Species richness of Filamentous algae	-0.91*	-0.91*	-0.89*	-0.14	-0.76*	-0.16	-0.95*	-0.21	0.34	1

*significant at $p<0.05$ level

investigation the majority of filamentous algae observed comprised of blue-green. Among the thirty two species of blue-green algae collected from Kuttanad, twenty five species are non-heterocystous, and only seven species are heterocystous. Among the twenty eight species of blue-green algae collected from Kole lands twenty one species are non-heterocystous, and only seven species are heterocystous filamentous algae. Earlier reports from this region has documented the presence of heterocystous (Choudhary, 1999; Nayak and Prasanna, 2004) and non-heterocystous members (Prassanna and Nayak, 2007). The most widespread genus of blue-green in this study is *Oscillatoria*, followed by *Lyngbya, Phormidium* and *Anabaena.* Anand and Hopper (1995) reported predominance of genus *Oscillatoria, Phormidium* and *Lyngbya* in rice fields of Kerala. So the observations of this investigation do not depart from the previous studies, and only confirms the temporal stability of the biodiversity.

Although the species richness is lower than that of blue-green algae the presence of green filamentous algae was strongly visible in both Kuttanad and Kole. Alexander *et al.* (2010) while investigating the environmental perspective of Kainakari panchayat in Kuttanad wetland have reported that among the phytoplankton Chlorophyceae form the most dominant group. Kumar and Sahu (2012) reported Chlorophyceae with wide range of thallus structure belonging to orders *Chlorococcales, Ulotrichales, Cladophorales, Oedogoniales* and *Zygnematales* in Paddy Fields of Lalgutwa, Jharkhand. Paul (2012) reported 391 species of Chlorophyceae, from Kole lands of Thrissur district. During the present study widespread blooms of *Spirogyra* sp. were observed in the second phase of the sampling (2011-2012) in Kuttanad paddy fields. Towards the end of sampling in Kole lands also similar blooms were observed in the adjoining canals. It is well established that under favorable environmental conditions such as high nutrient concentration, warm temperature, shallow and slow moving water, the algal growth is stimulated in the water bodies resulting in formation of algal blooms. At very high phosphorus and combined nitrogen concentrations in the water, green algae can

effectively compete with nitrogen fixing cyanobacteria (Wetzel, 2001). Blue-green algae have lower growth and loss rates and have a lower demand for nutrients when compared to green algae. So it is assumed that balance between the rates of net growth and loss may be the key factor which could explain why green algae outcompete the blue-green algae at high phosphorus concentration in shallow ponds and lakes (Jensen *et al*., 1994). O'Neal and Lembi (1998) reported that addition of nitrogen and phosphorus in the lake ecosystem may significantly increase the *Spirogyra* population. McKernan and Juliano (2001) reported that *Spirogyra* living in an environment with enhanced nutrient level will have an accelerated growth rate compared to algae living in water with ambient level of nitrogen and phosphorus.

The presence of algal growth is evidenced by the soil chlorophyll *a*. Earlier reports on quantification of soil chlorophyll is not available for Kuttanad and Kole lands. The range of chlorophyll *a* in Kuttanad varied from 0.76 to 14.16 µg/g, and in Kole lands it varied from 1.06 to 13.50 µg/g dry weight of the soil. Tsujimura *et al*. (2000) have reported the level of chlorophyll *a* in crop land soil ranged from 1.3 to 6.9 µg/g while that in virgin land soil it ranged from 0.3 to 7.0 µg/g. Compared to this the level of chlorophyll *a* is high in both Kuttanad and Kole lands which indicates high fertility of soil. The contribution of active algal biomass is 337 µg/g in Kuttanad and 292 µg/g in Kole. Considering the mean soil organic matter in Kuttanad is 6.44 %, the contribution of algal organic matter is 0.5 %. In the paddy fields of Kole with average of soil organic matter of 4.4 %, the contribution of algal organic matter is 0.7 %.

Kuttanad and Kole lands are considered as highly fertile paddy growing wetlands. The soils are acidic (Indira and Thampttii, 2013) and prepared for cultivation by liming. It is well known that the solubility and availability of nutrients fluctuates in response to pH of soil. When the acidity increases, the losses of these nutrients by chemical precipitation rises and their availability to crops decreases (Deshmukh, 2012). Thomas *et al.* (2001) reported that the pH

of Kuttanad wetland vary from 5.01 to 6.93. Thomas *et al*. (2003) reported that the soils of Muriyad wetlands are acidic in nature ranging from 4.9 to 6.6. For the optimum growth and diversity of cyanobacteria, neutral to slightly alkaline pH is generally favored (Singh, 1961; Koushik, 1994). Acidic soils are therefore stressed environments for cyanobacteria, and eukaryotic algae flourish under these conditions (Selvi and Sivakumar, 2011). There are some reports available to the existence of cyanobacteria at low pH although they are intolerant to acidic range (Hunt *et al*., 1979; Dominic and Madhusoodanan, 1999). Application of agrochemicals and agricultural practices may affect the salt content in soil. KSCSTE (2007) reported that electrical conductivity of Kuttanad varied from 2.3 to 3.95 dS/m, and that of Kole lands varied from 0.16 to 15.00 dS/m. These results are comparatively higher than that obtained in the present study. The maximum electrical conductivity observed during the study was 0.97 mS/cm in Kuttanad, and 0.59 mS/cm in Kole lands, and are inferred to be salt free and suitable for cultivation.

The organic matter is a vital store house for available nutrients. During the present study in all the sampling locations organic carbon was in high category. It helps to sustain soil fertility by improving soil structure, retention of mineral nutrients, increasing water holding capacity, water infiltration, drainage, aeration and root penetration. It also helps to increase the amount of soil flora and fauna (Jain, 2010). Ponnamperuma (1972) reported that Kuttanad wetland soils are rich in available potassium, calcium and magnesium even when low amount of them is expected for acid soils. Thampatti (1997) studied the morphological, physical and chemical characterization of the soils of North Kuttanad and reported that the study area was rich in essential nutrients except phosphorus. Indira and Thampatti (2013) studied the acidity characteristics of acid sulphate soils of Kuttanad and reported that the organic content, potassium, calcium and magnesium content of the soil samples were high, but due to high phosphorus fixation, these soils were deficient in available phosphorus. During the present study of available phosphorus in Kuttanad, 96 % of the soil samples

were in very high fertility level (>41.25 kg/ha) and 4 % were in high fertility level (33 to 41.5 kg/ha) whereas in Kole lands 29 % of soil samples were in moderate fertility level (24 to 33 kg/ha), 58 % of the samples were in high fertility level (33 to 40 kg/ha) and 13 % of the samples were in very high fertility level (42 to 50 kg/ha). In the case of available potassium, 10% of the samples were in medium fertility level (259 to 278 kg/ha) and 90% of them were in high fertility level (283 to 578 kg/ha) in Kuttanad whereas in Kole lands all the samples were in high fertility level (321 to 486 kg/ha). The range of calcium (Kuttanad: 521 to 893 kg/ha; Kole: 430 to 678 kg/ha) and magnesium (Kuttanad: 328 to 597 kg/ha; Kole:312 to 481 kg/ha) was also in high range in both sampling locations. Similar ranges of values were reported by Ray *et al.* (2014) for calcium and magnesium but the available potassium is comparatively higher in the present study. The total inorganic nitrogen in Kuttanad was estimated to range between 363 to 759 kg/ha; whereas in Kole lands, it ranged from 374 to 567 kg/ha. KSCSTE (2007) has reported the level of available nitrogen (Kuttanad: 242 to 256 kg/ha, Kole: 200 kg/ha), available phosphorus (Kuttanad: 6.85 kg/ha to 10.9 kg/ha, Kole: 11.5kg/ha) and available potassium (Kuttanad: 60 to 208 kg/ha, Kole:144 kg/ha). Theses values are comparatively lower than that of the present study.

The nutrient index obtained for Kuttanad and Kole lands, are high based on organic carbon, available phosphorus, available potassium, available calcium and available magnesium. A general trend of fertility status of Indian soils in three years (1967, 1977 and 1997) was reported by Pathak (2010). According to him in Kerala, nitrogen fertility status has declined (from 2.11 to 1.66 %); but phosphorus fertility status increased (from 1.11 to 2.35 %). Nutrient index value of potassium was 1.00 in 1967, and has increased to 2.00 in 1977, but again decreased to 1.98 in 1997. In the present study it is revealed that the phosphorus fertility status of Kuttanad is 3 and that of Kole is 2.7. The nutrient index of organic carbon (which indicates nitrogen availability) is 3 for both sites. The fertility index of potassium is 2.9 and 3.0 for Kuttanad and Kole

respectively. This reveals that the fertility level of paddy fields of these wetlands are on the increase.

The quantitative assessment of algae estimated as chlorophyll *a* may be taken as a biotic indicator of the soil quality; but the relationship between the soil nutrient concentration and algal biomass is ill defined. In general acid soil conditions are not considered ideal for the growth of blue-green algae; however in this study abundance of blue- green algae were observed. The effect of pH is generally difficult to evaluate as it is often correlated to other factors. In rice fields, shallow water and relatively high nutrient system provides ideal condition for the growth of Cyanobacteria and mat forming green algae (Spencer and Lembi, 2007). Roger and Kulasooriya (1980) reported that temperature also influences algal biomass, composition and productivity. It is a key variable for the development of algal biomass because it regulates the rate of cellular metabolism and growth (Munn *et al.*, 1989).

Paddy fields are places of intensive anthropogenic activity, including tillage and the application of fertilizers, pesticides, and herbicides. Such activities affect the physico-chemical and chemical environment of soils and thus lower the diversity of soil algae. Mohan *et al*. (2014) reported that the geochemistry of Kuttanad agricultural system has been affected by the stoppage of natural flooding due to the construction of barrage. Hence the natural flush out ceased and artificial flooding and dewatering has caused accumulation of more anthropogenic materials in the system. The higher fertility status and nutrient index values obtained could be related to the increased inputs and low flushing. This is again evidenced by the observation of blooms of filamentous green algae in both Kuttanad and Kole lands. Therefore, it is necessary to establish scientific fertilizer management, and adopt appropriate water management practices for sustainable agriculture.

Chapter - 6

EFFECT OF *SPIROGYRA* SP. ON GERMINATION AND YIELD OF PADDY (*ORYZA SATIVA*)

6.1 Introduction

Rice is one of the prominent food crops globally, and is the staple diet of nearly half of the human population of the world. The wet paddy fields are described as "temporary aquatic environment" (Roger, 1996) which is influenced and maintained by farmer's activities. Paddy fields provide all necessary requirements for the growth of algae such as light, water and nutrients. Algae occur even at 20cm depth with pronounced effect on the surface soil layer (Goyal, 1996). They have gained importance in agriculture as an input, which helps in better crop nutrient management (Goyal and Goyal, 1998).

Cyanobacteria are one of the major components of paddy field algae and they play an important role to build-up soil fertility through nitrogen fixation thereby increasing the yield. Several studies have noted that the inoculation of farm soils with algae increases grain yields by 15-25% (Gurung and Prasad, 2005; Song *et al*., 2005). Kaushik (2007) reported that cyanobacteria excrete complex organic compounds that bind to the soil particle and improve the structure and permeability of soil. Roger and Watanabe (1982) studied the paddy and blue-green algae relationship. He stated that besides increasing nitrogen fertility, blue-green algae have benefitted paddy plants by the production of growth-promoting substances. Presoaking of paddy seedlings in extracts of *Phormidium* has been shown to accelerate germination (Gupta and Lata, 1964). Though the occurrence of green algae in the paddy field soil is

reported, their effect on the soil fertility and growth of crop has received less attention. The presence of algal mats in rice fields of California have been related to uprooting of seedling, when the mats dislodge from the soil surface (Spencer and Linqist, 2014). Such observations are lacking or fragmentary from tropical soils.

There are reports of chemical composition of green algae but their effect on paddy plants are less investigated. Sterol and polysaccharide composition of some *Spirogyra* and *Mougeotia* species were investigated by Mitova *et al*. (1999) and Stefanov *et al*. (1996). Sugars, amino acids and some aliphatic amines were also identified in *Spirogyra* sp. (Cannel *et al*., 1988). Singh and Chaudhary (2011) have reported the allelopathic effect of alga *Pithophora oedogonia* on *Oryza sativa*. Bioactivity of the green filamentous algae *Spirogyra, Chara* and *Cladophora* on bacteria and fungi were demonstrated by Patil *et al*. (2011), Ansari *et al*. (2012) and Shatha *et al.* (2015).

This study on the effect of alga *Spirogyra* is undertaken following the observation of extensive growth of different morphotypes of *Spirogyra* in the rice fields of Kuttanad and Kole lands.

6.2 Materials and Methods

6.2.1 Preparation of algal extract

The algal scums of *Spirogyra* sp. were collected from the paddy fields of the sampling sites in lower Kuttanad. The samples were washed repeatedly to remove sediment and other organisms if any. They were blotted dry. These samples were air dried at 26^0C - 32^0C in the laboratory for seven days to ensure that the moisture content is <10 %. The moisture content of the air dry sample was determined in terms of % weight loss when dried at 105^0C. The air dried samples were stored in polythene bags in desiccator.

The samples were crushed in a glass mortar, and extracted for eight hours with 90% ethanol in soxhlet apparatus. The extracts were evaporated in rotary

vaccum evaporator and dried in vaccum desiccator. The dry residue was weighed in an electronic balance. Five grams of the residue was dissolved in 100ml of 1% acetone.

6.2.2 Seed Treatment

The seeds of the *Oryza sativa* (cultivar 'Uma') were procured from farmers. The seeds were soaked in a graded dilution series of the extract of *Spirogyra* sp. The dilutions were 5 %, 2.5 %, 1.25 %, and 0.625 %. Four replicates of ten seeds each were exposed to the extract for 12 hours. Control set were maintained in distilled water, and the solvent of extraction *i.e.* 1 % acetone.

6.2.3 Seed Germination Test

The treated seeds including the control were sown in clean washed soil taken in petridish. Each treatment had four replicates of ten seeds each. Germination was evaluated by counting the number of germinated seeds at 24 hours interval over a period of seven days. The length of seedling was measured on the 7^{th} day. The data of the treatments were corrected for the solvent control applying the Abbott's equation (Abbott, 1925).

$$\text{Corrected \%} = (1 - \frac{\text{Number of seeds trated, after treatment}}{\text{Number of seeds in control, after treatment}}) \times 100$$

The effect of extract of the *Spirogyra* sp. was assessed in terms of germination percentage, germination index, mean germination time, vigour index and time to 50 % germination (T_{50}).

Germination percentage was calculated using the following formula:

$$\text{Germination percentage} = (\frac{\text{Number of seeds germinated}}{\text{Number of seeds sown}}) \times 100$$

The germination index (GI) was calculated by applying the formula (AOSA, 1983):

$$\text{GI} = \frac{\text{No.of germinated seed}}{\text{Days of first count}} + - - + \frac{\text{No.of germinated seed}}{\text{Days of final count}}$$

Mean germination time (MGT) was calculated based on the following equation (Ellis and Roberts, 1981)

$$\text{MGT} = \frac{\Sigma \text{Dn}}{\Sigma n}$$

Where n is the number of seeds, which germinated on day D, and D is number of days counted from the beginning of germination.

The Vigour Index was calculated using the equation of Abdul baki and Anderson (1973).

Vigour Index = Seedling length (cm) × Germination percentage

The time to 50 % germination (T_{50}) was calculated according to the following formula of Coolbear *et al.* (1984) modified by Farooq *et al.* (2005).

$$\text{T}_{50} = \text{ti} + \frac{\left\{\left(\frac{\text{N}}{2}\right) - \text{ni}\right\}(\text{ti} - \text{tj})}{\text{ni} - \text{nj}}$$

Where N is the final number of germination and ni, nj cumulative number of seeds germinated by adjacent counts at times ti and tj when ni<N/2<nj.

The data on germination percentage and vigour index were evaluated statistically by ANOVA followed by Tukey multiple comparison using the software KyPlot. The effective concentration of the extract of *Spirogyra* sp. that inhibited germination of seeds (EC_{50}) was computed using the software 'R' (version 3.1.0.).

6.2.4 Evaluation of yield

The growth of the treated seedlings was evaluated by pot experiments. Soil was collected from the farm, washed and filled in eight pots. Healthy and even sized seedlings of seeds treated with 5 % extract were planted in four pots

at the rate of four seedlings per pot. The rest of the four pots were similarly planted with the seedlings of the untreated water control.

The pots were exposed to sunlight and watered regularly in the field conditions. Fertilization was done as per the farmer practice by applying urea and NPK mixture at the time of tillering, and before the time of panicle initiation. Growth of the plants was monitored till the harvest of the crop.

The effect of the extract was evaluated in terms of the biomass of grain produced, and percentage of empty grains (unfilled grains) upon harvest. The grain yield was determined in terms of the weight of the air dried filled grains of moisture content <10 %. The percentage of empty grain was calculated by counting the number of empty grains, and total number of grains from the subsamples of the produce of each treatment. Percentage of empty grain was calculated by using the formula:

$$\%\ \text{of Empty grains} = \left(\frac{\text{Number of Empty grains}}{\text{Total Number of grains}}\right) \times 100$$

The significance of difference in biomass and percentage of empty grains between treated and control plants were evaluated by Student's-t test.

6.3 Results

The results of the germination study revealed that the extract of *Spirogyra* sp. inhibited the germination of rice plants and the effect was concentration dependent. As the concentration of algal extract increased the number of seeds germinated decreased (Fig. 6.1).

The germination percentage ranged from 90 % in control to 43.5 % in 5 % extract. The germination index decreased with the increasing concentration of the extract. There was no discernable effect on the MGT and T_{50}. However the ANOVA - Tukey comparison revealed that there is no significant difference in germination % of control, 0.625 % and 1.25 % *Spirogyra* extract. The analysis of vigour index revealed that the control has significantly higher value

than those treated at 0.625 % extract. Further significant reduction of vigour index occurs at ≥ 2.5 % (Table 6.1).

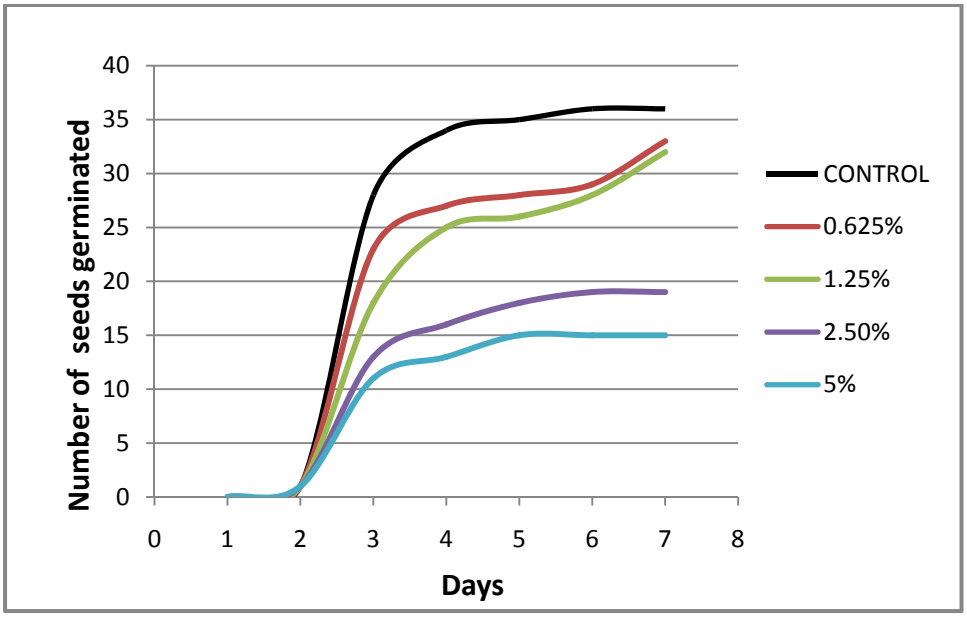


Fig.6.1 Effect of *Spirogyra* sp. extract on seed germination

Table 6.1 Effect of *Spirogyra* sp. extract on germination of paddy cultivar 'Uma'

Treatments	Germination %	GI	MGT (day)	VI	T_{50} (day)
Control	90 a	11.16	3.33	1623 a	2.64
0.625%	88 a	9.29	3.77	1459 b	2.76
1.25%	86 a	8.85	3.73	1418 b	2.94
2.50%	53.5 b	5.47	3.33	819 c	2.80
5%	43.5 b	4.57	3.00	642 d	2.77

* Figures not sharing the same letters in the same column differ significantly at $P < 0.05$

The Effective Concentration (EC_{50}) of the extract that inhibited 50% seed germination was estimated as 3.07 % (95 % confidence level 2.135 – 4.006). The seeds treated with 5 % *Spirogyra* extract was grown to the seed stage and harvested along with control plants. The treatment of seeds with 5 % extract of *Spirogyra* sp. did not visibly affect the growth of the plants (Fig.6.2). However the biomass of the filled grain was 38 % lower in treated plants compared to

control. The difference was significant (P<0.01). The proportion of empty grains in the treated plants was 26 % higher than the control with a significance level at P <0.01(Table 6.2).

Table 6.2 Effect of 5 % extract of *Spirogyra* sp. on grain production (Pot experiment) and results of student's t-test

S.I No.	Biomass of grain/pot (g)		% of empty grain	
	Control	Treated	Control	Treated
1	19.1	10.6	29	38
2	18.5	10.5	33	38
3	19.5	13.1	33	41
4	19.6	13.2	32	43
Mean	19.18	11.85	31.75	40
Variance	0.249	2.257	3.583	6.00
P value	0.0008*		0.0018*	

* significant at 0.01 level

6.4 Discussion

The present experiment clearly showed that *Spirogyra* sp. can negatively affect the seed germination, seedling vigour and the yield of rice. Shatha *et al.* (2015) reported that the alcoholic extracts of *Spirogyra* sp. contain terpenoid, flavonoids, phenols, saponins and alkaloids. They have observed antimicrobial and antifungal activity in this extract. Water extracts of *Spirogyra jugalis* has stimulatory effect on seed germination, root and shoot development in tomato (Mahadik and Jadhav, 2015). According to Brahmbhatt and Kalasariya (2015) *Spirogyra* species can promote growth of *Medicago sativa* better than *Oscillatoria* species but need more study for formulation as biofertiliser.

In the present experiment *Spirogyra* sp. did not visually affect the vegetative growth of plants. The results of pot experiments revealed that the biomass of the filled grain was 38 % lower in treated plants and proportion of empty grains was 26 % higher than control. These results do not agree with the earlier reported observations on stimulatory effect of *Spirogyra* extracts.

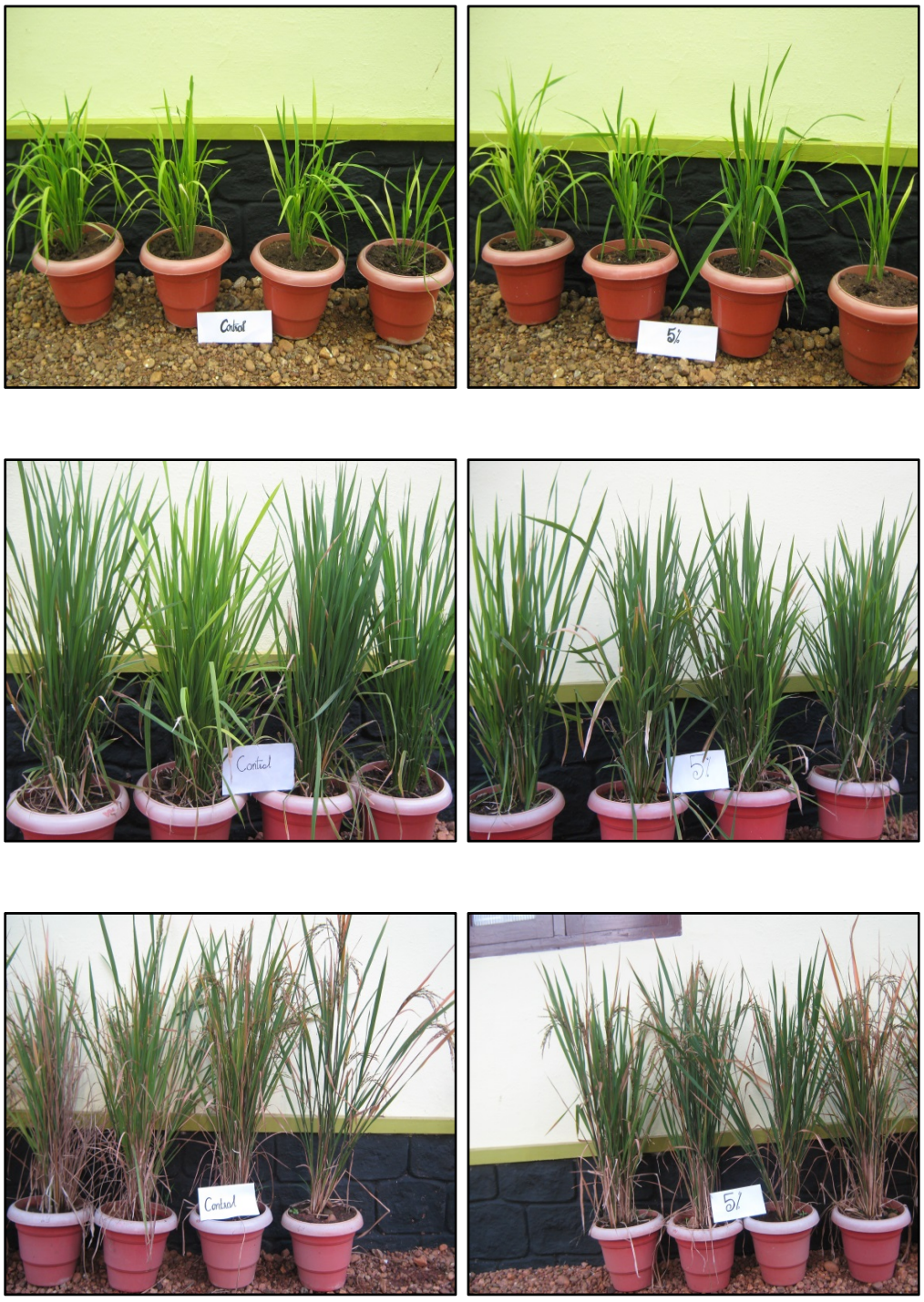


Fig.6.2 Pot experiment to study the effect of *Spirogyra* extract on paddy yield

Devi and Panikkar (1994) reported twenty seven species of *Spirogyra* from ponds and paddy fields in Quilon district, Kerala. Paul (2012) reported twelve species of *Spirogyra* from Kole lands of Thrissur. In the present study seven morphotypes of *Spirogyra* were identified, as it was unable to identify the species due to lack of spore bearing filaments in the collection. The samples collected for this experiment was composed of solely two morphotypes *i.e*. *Spirogyra* type 2, and *Spirogyra* type 4. Some of the metabolites reported in the alcoholic extracts of *Spirogyra* sp. (Shatha *et al.*, 2015) have allelopathic property. So it may be assumed that the *Spirogyra* bloom observed in this study contains water soluble metabolites which may negatively affect the paddy plants. The metabolites in the extract can be elucidated by biochemical analysis. In order to relate the biochemical nature of the extract to its source species and to its allelopathic effect, pure culture of concerned morphotypes of *Spirogyra* species has to be developed. Therefore, further research on isolation of the morphotypes and biochemical characterization of their extracts is suggested.

Chapter - 7

SUMMARY AND CONCLUSION

Paddy fields are artificial wetlands characterized by monoculture, shallow temporary water, plenty of light on the water surface, seasonal dynamics, artificial disturbance (ploughing, flooding, and harvest) and are component of a landscape with adjacent land use. They provide congenial environment for the growth of algae. The communities of algae in rice fields include those growing on soil surface or in the stagnant floodwaters or those living in the soil particles directly beneath the soil surface. Their occurrence and composition is related to climatic factors, soil properties and biotic factors. Their beneficial role in agricultural systems is recognized as excretion of organic acids that increase phosphorus availability and phosphorus uptake, provision of nitrogen by biological nitrogen fixation, increased soil organic matter, production and release of bioactive extracellular substances that may influence plant growth and development.

The present work is the study of filamentous algae in the paddy fields of Kuttanad and Kole lands of Kerala. Kuttanad is located in the fertile low-lying areas of Vembanad Estuary; much of this region lies 0.6 to 2.2 m below mean sea level. It spreads over Alappuzha, Kottayam, and Pathanamthitta districts, contributing nearly 20 % of total rice production of the state, and is called 'Rice Bowl of Kerala'. The region is divided into six agronomic zones. They are

Upper Kuttanad, Purakkad, Lower Kuttanad, Kayal lands, Vaikom and North Kuttanad. The Kole lands are a part of the unique Vembanad-Kole wetland and are located in the low lying tracts 0.5 to 1 m below mean sea level and are geographically distributed in Thrissur and Malappuram districts of Kerala.

This investigation was initiated by sampling of filamentous algae in Kuttanad during December 2010 to February 2011. A second phase of sampling was done from November 2011 to February 2012. The sampling periodicity corresponded to the crop growth starting from field preparation through sowing, and continued till the harvest. Sampling locations were selected from the active paddy cultivation regions of the six agronomic zones of Kuttanad. The number of sampling locations were proportional to the area of each zone. Algae of the Kole lands were collected during from October 2011 to January 2012. Four sampling locations were randomly selected from the Kole lands. They were Palakkal, Muriyad, Puzhakkal and Nedupuzha. Algal samples were collected once in a month from all the sampling locations. Methodology of research work comprised the systematic collection of algae from the selected paddy fields, identification of algal taxa upto species level with the help of keys, descriptions given by standard publications and websites. Direct microscopic observations of algae and enrichment method revealed the diversity of filamentous algae in the study area.

It was observed that blue-green algae dominated in both Kuttanad and Kole lands. Thirty two species of blue-green algae and eight species of green algae were identified from Kuttanad. The highest number of algal species was observed from Kayal lands in Kuttanad throughout the cropping season. Among the thirty two species of blue-green algae twenty five species are non-heterocystous and seven species are heterocystous. Twenty eight species of blue-green and six species of green algae were identified from Kole lands, and highest number of species was observed in Palakkal throughout the cropping season. Among the twenty eight species of blue-green algae collected from Kole lands twenty one species are non-heterocystous, and only seven species

are heterocystous filamentous algae. The most widespread genus of blue-green in this study is *Oscillatoria* followed by *Lyngbya, Phormidium* and *Anabaena*. Fifteen species of blue-green algae and two morphotypes of *Spirogyra* were common to both Kuttanad and Kole lands. These species are *Lyngbya bergi*, *Lyngbya hieronymusii* , *Lyngbya major, Oscillatoria splendida*, *Oscillatoria accuminata*, *Oscillatoria princeps*, *Oscillatoria subbrevis*, *Oscillatoria perornata*, *Oscillatoria laete-virens*, *Oscillatoria limnosa, Oscillatoria proboscidea*, *Phormidium tenue*, *Phormidium retzii*, *Nostoc commune, Anabaena naviculoides, Spirogyra* type1, *Spirogyra* type 3. The similarity of species distribution among the agronomic zones of Kuttanad and Kole lands were computed using similarity index of Sorenson and dendrograms were plotted.

Soil samples for analysis of soil properties were collected from all the sampling localities of Kuttanad and Kole lands during the study period, simultaneous with algal sample collection. The presence of algal growth is evidenced by the soil chlorophyll *a*. The range of chlorophyll *a* in Kuttanad varied from 0.76 to 14.16 µg/g, and in Kole lands it varied from 1.06 to 13.50 µg/g dryweight of the soil. In Kuttanad the mean value of chlorophyll *a* was highest in Kayal lands and lowest in Vaikom. In the sampling locations of Kole lands, chlorophyll *a* was highest in Muriyad and lowest in Puzhakkal. In all the soils, algae play a significant role in the sustenance of soil fertility and algae in terms are affected by the soil conditions. The soil fertility parameters analysed were soil texture, pH, electrical conductivity, organic carbon, available phosphorous, potassium, total inorganic nitrogen, available calcium and magnesium. The soils are acidic with a pH range of 3.01 to 5.94 in Kuttanad and 3.79 to 5.82 in Kole. The maximum electrical conductivity observed during the study was 0.97 mS/cm in Kuttanad, and 0.59 mS/cm in Kole lands, and are inferred to be salt free and suitable for cultivation. Organic carbon was in high category in all the sampling locations of Kuttanad and Kole. During the present study of available phosphorus in Kuttanad, 96 % of the soil samples were in

very high fertility level (>41.25 kg/ha) and 4 % were in high fertility level (33 to 41.5 kg/ha), whereas in Kole lands 29 % of soil samples were in moderate fertility level (24 to 33 kg/ha), 58 % of the samples were in high fertility level(33 to 40 kg/ha) and 13% of the samples were in very high fertility level (42 to 50 kg/ha). In the case of available potassium, 10 % of the samples were in medium fertility level (259 to 278 kg/ha) and 90 % of them were in high fertility level (283 to 578 kg/ha) in Kuttanad whereas in Kole lands all the samples were in high fertility level (321 to 486 kg/ha).The range of available calcium (Kuttanad : 521 to 893 g/ha; Kole: 430 to 678 kg/ha) and available magnesium (Kuttanad: 328 to 597 kg/ha; Kole :312 to 481kg/ha) was also in high range in both sampling locations. The total inorganic nitrogen in Kuttanad was estimated to range between 363 to 759 kg/ha; in Kole lands it ranged from 374 to 567 kg/ha. In the present study a significant correlation was observed between chlorophyll *a* and total inorganic nitrogen in Kuttanad; but none of the other parameters of soil fertility correlated with the distribution of soil chlorophyll *a*. Nutrient index value is high in both Kuttanad and Kole lands based on organic carbon, available phosphorus, potassium available calcium and magnesium. Soil fertility analysis revealed that nutrient loading was high. The higher fertility status and nutrient index values obtained could be related to the increased inputs and low flushing. Therefore, it is necessary to establish scientific fertilizer management, and adopt appropriate water management practices for sustainable agriculture.

Blooms of *Spirogyra* were observed during the second phase of sampling in Kuttanad and also in the Kole lands. They appeared as surface mats on soil within the waterlogged areas in the fields and as surface scum and benthic mats in the adjacent canals. Therefore a study on the effect of *Spirogyra* was undertaken to analyse the effect of the bloom species on rice plants. The algal scums of *Spirogyra* sp. were collected from the paddy fields of the sampling sites in lower Kuttanad. The seeds of the *Oryza sativa* (cultivar 'Uma') were procured from farmers. The seeds were soaked in a graded

dilution series of the alcoholic extract of *Spirogyra* sp. The dilutions were 5%, 2.5 %, 1.25 %, and 0.625 %. The effect of extract was assessed in terms of germination percentage, germination index, mean germination time, vigour index and time to 50 % germination. The results of the germination study revealed that the extract of *Spirogyra* sp. inhibited seed germination and reduced seedling vigour. As the concentration of algal extract increased the number of germinated seeds decreased. The vigour index also decreased significantly even at 0.625 % of extract.

The growth of the treated seedlings was evaluated by pot experiments. The seeds treated with 5 % extract of *Spirogyra* was grown to the seed stage and harvested along with control plants. The treatment of seeds with 5% extract of *Spirogyra* sp. did not visibly affect the growth of the plants. The yield of grains was significantly reduced in treated plants. The biomass of the filled grain was 38% lower in treated plants, and the proportion of empty grains was higher by 26% than the control plants. The results clearly showed that *Spirogyra* sp. can negatively affect the seed germination, seedling vigour, and the yield of rice. So it may be assumed that the *Spirogyra* bloom observed in this study contains water soluble metabolites which may negatively affect the rice plants. It was not possible to identify the bloom forming morphotypes to the level of species due to the lack of spores in the collection. Therefore the study of species identification of *Spirogyra* morphotypes that form blooms in these fields, isolation and development of pure cultures, biochemical analysis of the extracts, identification of inhibitory bioactive compounds produced and their effect on crop has to be undertaken.

Leads .....

1. The filamentous cyanobacterium ***Spirulina platensis*** is widely cultivated for its nutritional and therapeutic properties. It is interesting that three species of ***Spirulina*** were recorded in this

study. They are ***Spirulina princeps, Spirulina gigantea*** and ***Spirulina subsalsa***. It could be worth isolating these species in culture and evaluating their commercial potential.

2. The widespread occurrence of bloom of ***Spirogyra*** in both Kuttanad and Kole lands is an indication of poor nutrient management and drainage mechanism in place. A detailed study on this aspect is recommended for sustaining the agricultural productivity of this ecosystem.

3 Developing pure cultures of *Spirogyra* sp., analyzing their biochemical properties and investigating their allelopathic effect on paddy is suggested.

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APPENDIX

Publications

- Smitha, S. and Ammini, J. 2013. Filamentous Algae of a Hill stream of Kerala, India. *IOSR Journal of Environmental Science, Toxicology and Food Technology,* 4 (3):35-39.

- Dhanya, S., Smitha S. and Ammini, J. 2012. A survey of Algal Blooms in the ponds of Pallippuram, Kerala, India. *International Journal of Environmental Science,* 3(3) 1185-1193.

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Filamentous Algae of a Hill Stream Of Kerala, India

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Abstract: *The diversity of filamentous algal flora of a minor stream of Thodupuzha river, Kerala was studied. During the study period thirteen freshwater algal species were observed. They comprised species of Cyanobacteria, Chlorophyta and Charophyta. Presence of certain algae can indicate the pollution status in the stream.*

Key Words-*Stream, Cyanobacteria, Chlorophyta, Charophyta., Filamentous algae*

I. Introduction

Filamentous algae are important components of the river vegetation of small streams mostly attached to substrates as periphyton or in pools of the stream as metaphyton. Stevenson (1996) has grouped the filamentous benthic algae of river into the taxonomic groups Cyanobacteria, Rhodophyta, Chrysophyta, Xanthophyta, Phaeophyta, Bacillariophyta and Chlorophyta [1]. The functional role of filamentous algae is related to autotrophic production and support of food web (Biggs and Smith, 2002[2]; Januer and Dokulil, 2006[3]; Shields *et al*., 2008[4]). The stream algae also influence the oxygen budget as well as the nutrient cycling (Munn and Tesoriero, 2010[5]; Wetzel, 2001[6]; Ziglio *et al.,* 2006[7]).

The biomass of periphyton is related to the characteristics of the flowing water. The structure and dynamics of the periphyton communities have been used to classify waterways (Denicola *et al.*, 2004[8]; Wargo and Holt, 2004[9]). Generally warmer temperature, high nutrient load and reduced flows support their luxuriant growth (Baba *et al*., 2011[10]; Cascallar *et al*., 2003[11]; Giorgi and Malacalza, 2002[12]). Their proliferation negatively impact macro invertebrate abundance and consequently the food web (Biggs, 2000[13]; Dangles and Guerold, 1999[14]). The capacity of certain species to tolerate high nutrient state has led to their application in waste water treatment (Abdel-Raouf *et al.*, 2012[15]; Marinelarena and Giorgi, 2001[16]).Moreover in the commercial production of microalgae the filamentous forms are the better biomass producers and more economical to harvest (Christenson and Sims, 2011[17]; Khanal *et al*., 2010[18]; Markou and Georgakakis, 2011[19]).

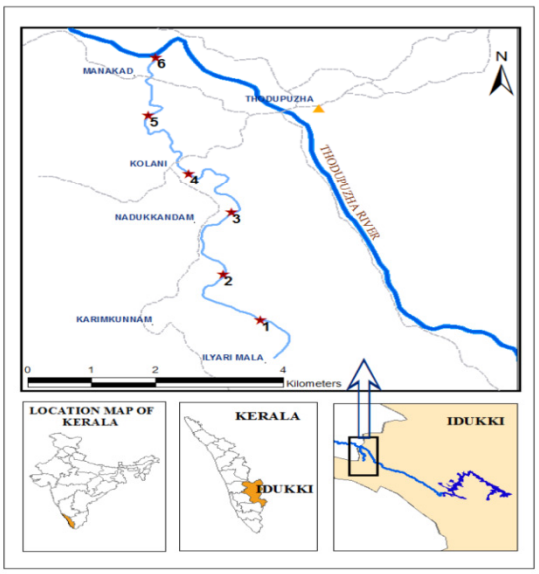

Fig.1.Location map of study area (hill- Stream of Thodupuzha River)

The present study is an investigation of the occurrence of filamentous algae in a hill stream in Kerala, India. The geographic location is 11°37′0″N 76°13′0″E. The stream under investigation is a seasonal flow

originating from the hills of Iliyari Mala of Idukki district, Kerala, India, and flows six kilometers downstream to join Thodupuzha river at Manakad (Fig.1). The lower reach of this stream gets cut off as a pond in summer when the upstream flow ceases, and the pond develops a floating scum of filamentous algae. It is this observation that led to this investigation to discover the diversity of filamentous algal species in this seasonal stream, and their probable water quality indication.

Periphyton	1	2	3	4	5	6
Oscillatoria splendida	+	-	+	+	-	-
Oscillatoria acuminata	-	+	-	+	-	-
Oscillatoria rubescens	+	-	+	+	+	-
Oscillatoria laete-virens	-	-	+	-	-	-
Oscillatoria limosa	-	+	-	-	+	-
Phormidium tenue	-	-	+	+	-	-
Lyngbya shackletoni	-	-	-	+	+	-
Nostoc commune	-	-	+	+	-	-
Scytonema cinccinatum	-	-	-	+	-	-
Oedogonium sp.	+	+	-	-	-	-
Spirogyra sp.	-	+	+	+	+	+
Zygnema sp.	-	+	-	-	-	-
Ecballocystis sp.	+	+	-	-	-	-

II. Collection Of Sample

Algal samples were collected at six locations, every kilometer of the stretch of the stream from its origin to the point where it meets the Thodupuzha river during the period February to August 2009. Samples were collected by scraping pebbles, rocks and submerged vegetation, and brought to the laboratory immediately. The samples were studied fresh as far as possible and digital images of the algae were taken. Identification of taxa was restricted to the true filaments of green and blue-green algae as they were the abundant growth in the stream. The taxa were identified based on monographs (Desikachary, 1959[20]; Prescott, 1964[21]; Anand, 1989[22]; Guiry & Guiry, 2011[23]).Table 1. Periphyton species data at six sampling locations of the stream. presence (+), absence(-)

III. Results

Thirteen species of filamentous algae were recorded in the present study (Fig.2). Among these Cyanobacteria were represented by five genera, Chlorophyta were represented by two genera, and Charophyta were represented by two genera. The occurrence of these across the river in the sampling location is given in Table 1. *Spirogyra* sp. was the most widely distributed followed by *Oscillatoria rubescens*. The genus *Oscillatoria* was represented by five species. The bloom formation downstream was that of *Spirogyra* sp. It formed wide spread scum in the nearly stagnant region of the stream which got cut off as a pond during the summer months of April and May. The bloom was washed off by the monsoon rains in June-July when stream was in flood with turbid water and poor algal growth. The morpho-taxonomic description of the taxa is given below.

3.1. *Oscillatoria splendida* Grev.ex Gomont (Fig. 2A)
(Desikachary, 1959, p. 234, Pl. 37, Fig. 7 & 8)
Thallus blue green; trichome straight or curved, not constricted at the cross walls, at the end gradually attenuated, 2-3µ broad; cells 2-3 times longer than broad rarely quadrate, 3-8µ long; ends more or less bent; end cells capitate; nearly rounded.

3.2. *Oscillatoria acuminata* Gomont (Fig. 2B)
(Desikachary, 1959, p. 240, Pl. 38, Fig.7)
Thallus blue-green; trichome more or less straight, not constricted at cross-walls, 4-5µ broad, at the ends briefly tapering, sharply pointed, bent; cells longer than broad, 6-8µ long, sometimes granulated at the cross-walls.

3.3. *Oscillatoria rubescens* DC ex Gomont (Fig. 2C)
(Desikachary, 1959, p. 235 Pl. 42, Fig.12)
Trichome straight, at the ends gradually attenuated, 6-8µ broad, not constricted at the cross walls, cells $^{1}/_{2}$-$^{1}/_{3}$ as long as broad, 3-4µ long, often granulated at the septa, with gas vacuoles; end cells capitate.

3.4. *Oscillatoria laete-virens* (crouan) Gomont (Fig. 2D)
(Desikachary, 1959, p. 213 Pl. 39, Fig. 2 & 3)
Thallus thin, green, trichome, straight, slightly constricted at the cross walls, 3-4µ broad, apices attenuated; cells nearly long as broad, 2-4µ long.

3.5. *Oscillatoria limosa* Ag. ex Gomont (Fig. 2E)
(Desikachary, 1959, p. 206, Pl. 42, Fig.11)
Thallus dark blue green, trichome more or less straight, not constricted at the cross walls, 11-12µ broad, cross walls frequently granulated; cells $^{1}/_{3}$-$^{1}/_{6}$ as long as broad, 2-4 µ long; end cells flatly rounded with slightly thickened membrane.

3.6. Phormidium tenue (Menegh.) Gomont (Fig. 2F)
(Desikachary, 1959, p. 259, Pl. 43, Fig. 13-15 & Pl. 44, Fig. 7-9)
Thallus pale blue-green, thin, membraneous, trichome straight, slightly constricted at cross- walls, attenuated at the ends, cells 2-3 times longer than broad, 3-5 µ long, 1-2µ broad; sheath thin.

3.7. *Lyngbya shackletoni* W. et G. S. West (Fig. 2G)
(Desikachary, 1959, p. 296, Pl. 53, Fig. 13)
Filaments nearly straight, 12-12.5 µ broad; sheath firm, colourless, distinctly lamellated; trichome not attenuated at the ends, 8-9 µ broad; not constructed at cross- walls, cells 2-2.5 µ long, pale blue-green; end cells conical nearly as long as broad.

3.8. *Nostoc commune* Vaucher ex Born. et Flah. (Fig. 2H)
(Desikachary, 1959, p. 387, Pl. 68, Fig. 3)
Thallus firm, gelatinous, blue green; sheath mostly distinct only at the periphery, trichome 4-5 µ broad, cells short barrel-shaped to nearly spherical, heterocysts nearly spherical, 6-7 µ broad.

3.9. *Scytonema cincinnatum* Thuret ex Born.et Flah. (Fig. 2I)
(Desikachary, 1959, p. 453, Pl. 93, Fig.1)
Thallus brownish green; filaments 16-26µ broad; false branches mostly germinate; sheath firm, brownish; trichome 14-17µ broad, distinctly at cross-walls, cells 1/3 as short as broad; heterocysts depressed or quadrate, short cylindrical.

3.10. *Oedogonium* Link ex Hirn, 1990 (Fig. 2J)
(http://www.algaebase.org)
Unbranched uniseriate filaments, occasionally free-floating. Vegetative cells generally uniform in size and shape; usually cylindrical, uninucleate, cap cells present, 21-28 µ long, 16-18µ broad, highly vacuolated, and with a large reticulate, parietal chloroplast containing many pyrenoids.

3.11. *Spirogyra* Link, 1820 (Fig. 2K)
(http://www.algaebase.org)
Thalli comprised of unbranched uniseriate filaments, cylindrical cells, 18-22µ broad; length eqaual to or several times width; chloroplast two, spirally arranged ribbon like with numerous pyrenoids**.**

3.12. *Zygnema* Agardh, 1817 (Fig. 2L)
(http://www.algaebase.org)
Filaments unbranched with short cylindrical cells, 14-17 µ broad; two satellite chloroplasts with a prominent central pyrenoid, one on either side of a centrally situated nucleus.

3.13. *Ecballocystis* Bohlin, 1897 (Fig. 2M)
(http://www.algaebase.org)
Microscopic to macroscopic aggregations of cells with one to many celled dendroid to pseudofilamentous colonies attached at base by mucilaginous pad. Cells oval to spindle shaped or cylindrical, 15-20µ broad, 40-70 µ

broad, cell walls smooth with lamellated polar thickenings. Cells with single central nucleus; parietal chloroplasts , discoid to band shaped each with single pyrenoid.

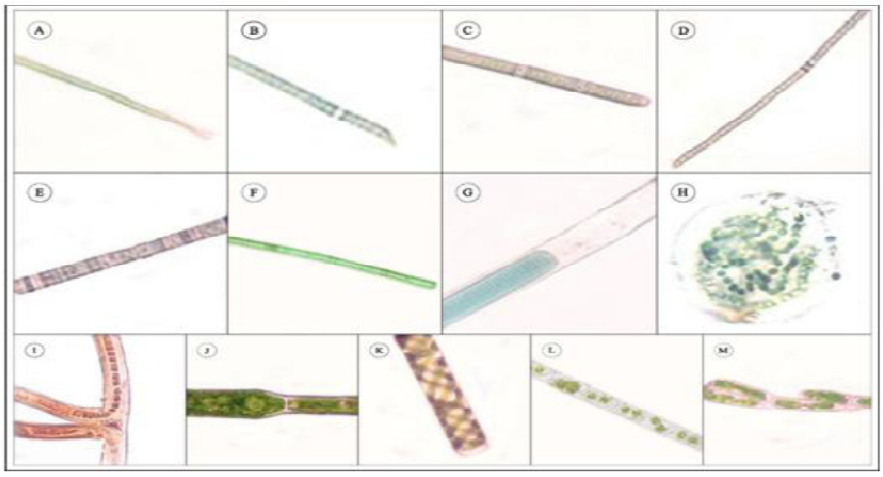

Fig.2. Filamentous algae of study site **A.** *Oscillatoria splendida* (1000X) **B.** *Oscillatoria acuminata* (1000X) **C.** *Oscillatoria rubescens* (1000X) **D.** *Oscillatoria laete-virens* (400X) **E.** *Oscillatoria limosa* (1000X) **F.** *Phormidium tenue* (1000X) **G.** *Lyngbya shackletoni* (400X) **H.** *Nostoc commune* (400X) **I.** *Scytonema cinccinatum* (1000X) **J.** *Oedogonium sp.* (1000X) **K.** *Spirogyra sp.* (400X).**L.** *Zygnema sp.* (400X) **M.** *Ecballocystis sp.* (400X)

IV. Discussion And Conclusion

Thirteen species are recorded from this stream in this investigation. All of these have been reported from elsewhere in different rivers and wetlands of Kerala (Anand and Hopper 1987[24]; Arulmurugan *et al.,* 2010[25]; Jose 2008[26]; Jose and Patel 1990[27]; Ushadevi and Panickkar 1994[28]). *Oscillatoria* has the highest representation of species while *Spirogyra* is more widespread and form the summer bloom. *Spirogyra* and other Zygnemataceous taxa have a wide ecological range and they probably prefer soft water (Cambra and Aboal, 1992[29]). According to Palmers Algal genus index(1969) pollution index of *Oscillatoria* is five and *Phormidium* is one and the presence of these genera indicates organic pollution[30]. Presence of Anabaena is also an indicator of organic pollution in the water bodies (Jafari and Gunale, 2006[31]). Water habitat with high conductivity seems to be suitable for growth and development of *Spirogyra* (Wongsawad *et al.,* 2012[32]). The observation of bloom of *Spirogyra* in the stagnant region of the hill stream is indicative of high dissolved load in the stream and that of *Oscillatoria* especially points to organic load in the system. This may be strongly correlated with human inhabitation, land use and disturbance in the uplands of Kerala such that even a hill stream is polluted. It may be concluded that many such small habitats considered pristine are left unexplored, and it may be necessary to document these ecosystems of local habitats for their conservation.

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A survey of algal blooms in the ponds of Pallippuram, Kerala, India

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ABSTRACT

A survey of ponds in the Pallippuam Panchayath of Cherthala taluk, Kerala was undertaken from October 2010 to May 2011. Out of the 873 ponds surveyed 66% are unused, while 33% are used for domestic purpose other than drinking and irrigation; 11 ponds are used as drinking water source. Among the unused ponds 48 had algal blooms comprising species of Cyanophyta and Charophyta. They were observed as scums or mat on the surface of the ponds.

Keywords: Pallippuram Panchayath, algal bloom, ponds, Cyanophyta, Charophyta.

1. Introduction

The algae and Cyanobacteria comprising the phytoplankton are the first link in the aquatic food web as primary producers. Their presence in the water is often unnoticed as they are tiny microscopic organisms. Under favorable environmental conditions such as elevated nutrient concentration, warm temperature, shallow and slow moving water, the algal growth is stimulated in the water bodies that will finally result in the formation of algal blooms (Wetzel, 2001). Anthropogenic inputs can alter the algal community such that the health of an ecosystem may be reflected in the algal community and diversity (Lowe and Pan, 1996). Though algal blooms are natural phenomenon, and have occurred throughout the recorded history, recent studies from around the world indicate that they have increased in frequency and geographic distribution over the past few decades (Rejmenkova et al., 2011, Winter et al., 2011).

The lakes have received much attention in ecological studies in relation to nutrient enrichment and algal blooms. However, the domestic land excavated ponds, though small in size, but large in numbers in certain regions are among the most human influenced systems, as well as most vulnerable. These ponds are important as water sources for drinking and irrigation in rural areas. The water quality of the domestic ponds is influenced by the land use practices in the immediate neighbourhood. According to Akasaka et al (2010) macrophyte diversity and water quality of 55 ponds in western Japan were related to land use and morphometric variables. Soni and Bhatt (2008) have described the degradation of an urban pond in Gujarath, India due to sewage disposal. The pond has become unfit for use due to proliferating algae, macrophyte and pathogens. Similar studies on changing water quality of ponds in India have been reported by many authors (Bhuiyan and Gupta, 2007, Upadhyay et al., 2010).

In Kerala state, located at the south west coast of India, village ponds had been the sole source of drinking water along the coastal regions a few decades ago. Continuous maintenance of these ponds through traditional methods ensured the water quality. As

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population increased and urbanization set in many of these ponds were reclaimed for alternate use. The rest of the ponds were neglected as and when public water supply became accessible. Considering that ponds are important freshwater ecosystems and abode of rich biodiversity, the need for their conservation is recognised. Therefore this study is undertaken in 'Pallippuram' a typical coastal village of Kerala which has high density of domestic ponds. The present investigation is part of a study on current state of the ponds, their scope of restoration and utilization. The results presented in this paper are that of the preliminary survey on the status of these ponds.

2. Materials and methods

2.1 Study area

The study area is Pallippuram Panchayath a village situated in the Alappuzha district of Kerala state located in the South West coast of India at $9^{o}45'\ 20''$N and $76^{o}21'39''$ E. It is an administrative entity that is part of an island in the Vembanadu Estuary bounded in the east, west and south by the estuary. The northern side is contiguous with the rest of the island (Fig.1 and Fig.2). The region has tropical monsoon climate with a mean annual temperature of 26.5^{o} C (minimum18^{o} C in December; maximum 35^{o} C in April) and mean annual precipitation of 2500mm. The Panchayath has a population of 27307 in an area of 25.53 km^2as per census of 2001. There are 6202 households. The predominant land use includes paddy fields, coconut gardens and residential. The drinking water source in the village was traditionally ponds. As the population increased and lifestyles changed, there occurred a shift to piped water supplies and wells. As a result, the once prevalent ponds were largely neglected or reclaimed. It is in this context that a survey of those existing ponds was undertaken to provide the primary data on the state of these ponds so as to devise steps to conserve them as clean freshwater sources.

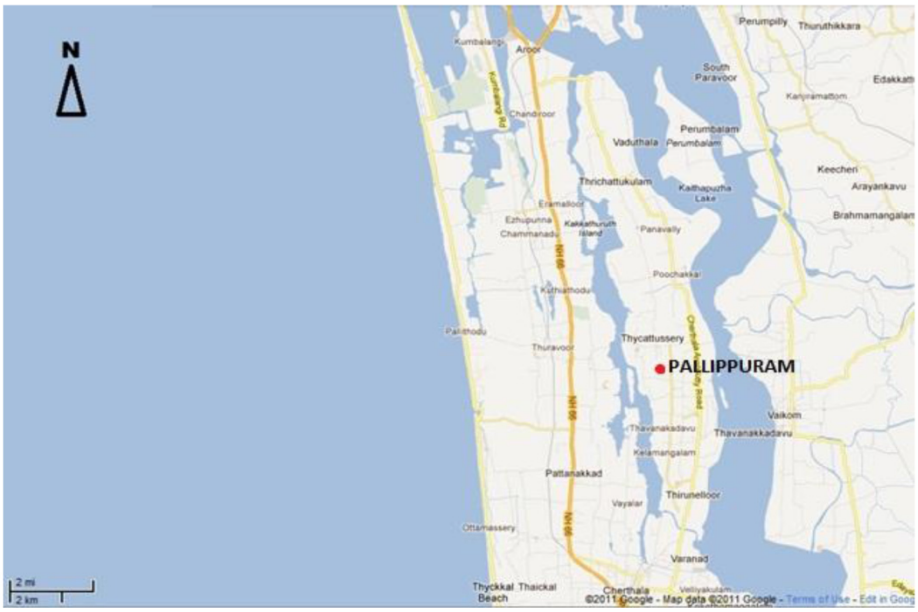


Figure 1: Google map of location of Pallippuram

Figure 2: Map of Pallippuram Panchayath showing 17 wards (ward no. 17 is recently formed from ward no. 15 and 16)

2.2 Method of study

The Pallippuram Panchayath which is a local body of the civil administration is divided into17 wards or administrative units. The survey involved collecting data of ponds in each of these 17 wards separately and then compiling it. The period of survey was October 2010 to May 2011. The preliminary survey charted the total number of ponds in each ward, their area, type of use, occurrence of algal blooms, and other aquatic vegetation.

In the second stage of the survey, algal blooms were collected from 32 ponds selected at random; brought to the laboratory, and observed under microscope. The algal blooms were identified based on the existing literature (Desikachary , 1959 , Guiry and Guiry, 2011).

3. Results

A total number of 873 ponds were recorded in the Panchayath during this survey. The area of these ponds ranged from 12 m^2 to 300m^2. The detailed survey results for each ward are given in Table1. It is found that 66% of these ponds are out of use. Eleven ponds out of the fifty one in Ward1 are used for drinking purpose; 33% of all ponds in the Panchayath are used either for irrigation or other purpose such as bathing and washing clothes. Algal blooms were observed in 48 ponds. The blooms appeared as green or blue green turbidity, floating scum, or as thick blue-green floating mats. Submerged Aquatic Vegetation (SAV) occurred in 19 ponds. The SAV comprised of *Vallisneria sp., Hydrilla verticillata and Ceratophyllum*

submersum. Floating hydrophytes were *Lemna minor, Pistia stratiotes, Eichhornia crassipes, Salvinia molesta and Azolla pinnata* (Fig.3).

Table 1: Survey results of ponds in Pallippuram Panchayath

Ward No.	No. of ponds	Area(m^2)	Type of use			No of ponds with		
			Drinking	Irrigation and other uses*	Unused	Algal bloom	SAV*	Floating hydrophytes
1	51	15-176	11	12	28	1	1	33
2	48	19-153	Nil	19	29	2	2	35
3	120	28-153	Nil	50	70	13	8	84
4	94	19-176	Nil	31	63	7	2	76
5	41	38-300	Nil	12	29	2	-	17
6	57	12-153	Nil	22	35	3	2	35
7	40	19-132	Nil	7	33	3	-	25
8	27	19-132	Nil	6	21	2	-	20
9	46	19-176	Nil	14	32	1	1	37
10	60	12-176	Nil	28	32	-	1	45
11	50	12-176	Nil	17	33	3	-	36
12	20	12-153	Nil	8	12	1	-	14
13	39	19-176	Nil	9	30	1	-	33
14	32	19-176	Nil	8	24	1	-	16
15	82	12-176	Nil	25	57	4	1	53
16	41	12-176	Nil	12	29	2	1	24
17	25	38-153	Nil	6	19	2	-	15

* Irrigation, bathing and washing * Submerged Aquatic Vegetation

Figure 3: Images of ponds

(Fig.3.1 and3.2 pond with algal bloom, Fig.3.3 and3.4 Pond with floating and submerged vegetation, Fig.3.5 Pond covered completely with *Pistia*, Fig.3.6 A Clean pond under domestic use)

Out of the thirty two ponds sampled for algal bloom, six ponds had blooms of Charophyta, and the rest of the ponds had Cyanophyta. The blooms were mostly of filamentous algae that formed thick floating surface scum or mat (Table 2).

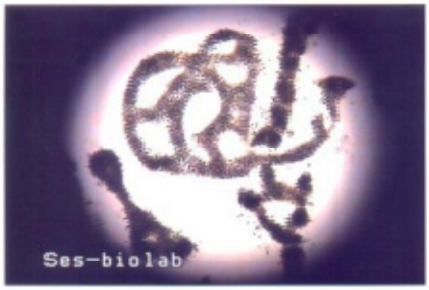
The Charophyta was represented by *Spirogyra* sp., *Klebsormidium* sp., and *Mougeotia scalaris*. *Spirogyra* bloom occurred in four ponds where as *Klebsormidium* and *Mougeotia* were present in one pond each. Blue-green algal bloom occurred in the rest of the twenty six ponds examined.

Oscillatoria occurred in nineteen ponds represented by two species. Blooms of *Microcystis aeruginosa* occurred in three ponds. The species spectrum of the bloom is presented in Fig.4 and 5. Co-existence of hydrophytes and algal bloom was observed in certain ponds.

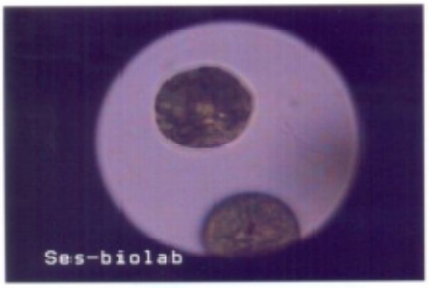
Table 2: Algal blooms in ponds of Pallippuram Panchayath

Ward No.	Pond No.	Algal species observed								
		1	2	3	4	5	6	7	8	9
3	1	-	+	-	-	-	-	-	-	-
	29	+	-	-	-	-	-	-	-	-
	38	-	-	-	-	-	-	+	-	-
	52	-	-	-	-	-	-	-	+	-
	56	-	+	-	-	-	-	-	-	-
	58	-	-	-	-	-	-	-	-	-
	65	+	-	-	-	-	-	-	-	-
	83	-	+	-	-	-	-	-	-	-
	106	-	-	-	-	-	-	+	-	-
	108	-	-	+	-	+	-	-	-	-
	112	-	+	-	-	-	-	-	-	-
	118	-	-	-	+	-	-	-	-	-
	120	-	-	+	-	-	-	-	-	-
4	10	-	-	-	-	-	-	-	-	+
	11	-	+	-	-	-	-	-	-	-
	26	-	+	-	-	-	-	-	-	-
	31	-	-	+	-	-	-	-	-	-
	33	-	+	-	-	-	-	-	-	-
	34	-	+	-	-	-	-	+	-	-
	35	-	-	-	-	-	+	-	-	-
	36	-	-	+	-	-	-	-	-	-
	49	-	+	-	-	-	-	-	-	-
	60	-	+	-	-	-	-	-	-	-
5	27	-	-	-	-	-	+	-	-	-
	39	-	+	-	-	-	-	-	-	-
6	25	-	-	-	-	-	-	-	-	-
	26	-	+	-	-	-	-	-	-	-
	27	-	-	+	-	-	-	-	-	-
	28	-	-	-	-	-	+	-	-	-
16	8	+	-	-	-	-	-	-	-	-
17	6	-	-	+	+	-	-	-	-	-
	12	+	+		-	-	-	-	-	-

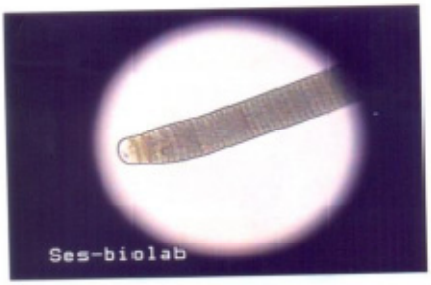
(1.Spirogyra sp. 2. Oscillatoria princeps 3. Oscillatoria subbrevis 4. Phormidium tenue 5. Anabaena sp 6. Microcystis aeruginosa 7. Coelosphaerium kuetzingianum 8.Mougeotia scalaris 9.Klebsormidium sp.)



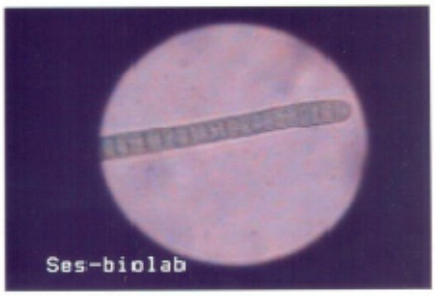
Microcystis aeruginosa-100x



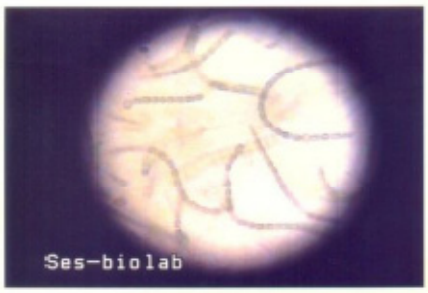
Coelosphaerium kuetzingianum -1000x



Oscillatoria princeps-400x

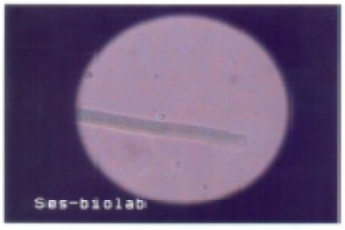


Oscillatoria subbrevis - 400x

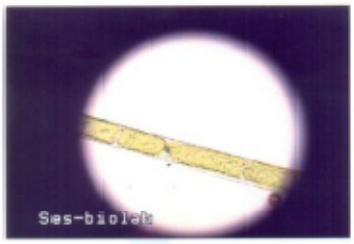


Anabaena sp. - 400x

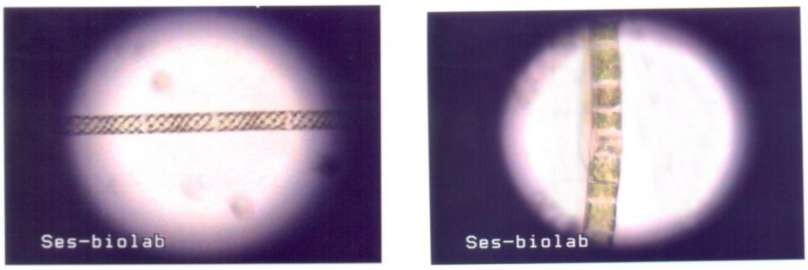
Figure 4: Species spectrum of algae



Phormidium tenue - 1000 x



Mougeotia scalaris – 400 xs



Spirogyra s. - 100x *Klebsormidium sp.- 400x*

Figure 5: Species spectrum of algal bloom

4. Discussion and conclusion

The present survey has listed the number of ponds existing in the 'Pallippuram Panchayath', their status of use, and indirectly indicated the water quality. As 66% of the ponds are now unused, it is evident that they are not essential for the community from the utilitarian point of view, and therefore grossly neglected.

The ponds that are used for drinking purpose are maintained through traditional methods with the funds provided by the civil authority. The domestic use includes mainly washing of clothes. Therefore phosphates from detergents could be a strong reason for induction of algal blooms. The region has paddy fields; both cultivated and uncultivated which could be a source of fertilizer run off. Effluents from the residential areas and the faulty sanitation systems can likely contribute excess organic matter, and consequent nutrient enrichment in the ponds. According to Akasaka et al. (2010) the land use pattern around the pond has direct effect on water quality and aquatic vegetation. The emergence of *Microcystis aeruginosa* bloom in kandy lake, Srilanka has been explained in terms of N-enrichment mainly by ammonium-N, and high turnover rates of dissolved phosphorus(Silva, 2003). Ahmed et al. (2007) relates the periodic cyanobacteria blooms in an urban river to increased dissolved organic nutrients, long sunshine hours and favorable water temperature. Species of *Oscillatoria* are reported to produce hepatotoxic microcystins (Ahmed et al., 2010). Welker et al. (2005) detected microcystins in thirty nine ponds related to occurrence of *Microcystis, Planktothrix* and *Anabaena*. The observation of potentially toxic genera of *Microcystis* and *Oscillatoria* in the present study is of concern.

Dense growth of three species of Charophyta were observed in six ponds in this survey. Charophytes are generally recognized as indicators of clean water ecosystems and they prefer hard alkaline waters rich in calcium. However Charophytes may persists under moderate fertility and turbidity (Klosowski et al., 2006). The survey has revealed the need for conservation, and the scale of restoration to be undertaken.

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