CYANOBACTERIA IN BIOLOGICAL CRUSTS OF VARIOUS SOIL TYPES OF THRISSUR DT., KERALA

Dissertation submitted to the

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Submitted by

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CERTIFICATE

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I, Sruthi K hereby declare that this dissertation entitled "**Cyanobacteria in biological crusts of various soil types of Thrissur dt., Kerala**" is submitted by me under the supervision and guidance of Mrs. Shaheedha T.M Assistant Professor, M.E.S Asmabi college, P. Vemballur for partial fulfilment of the requirements for the degree of Master of Science in Botany, in Calicut University and that no part of this dissertation has been presented earlier for any degree or diploma in any of the Universities.

SRUTHI K

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ABSTRACT

Cyanobacteria in biological crusts of various soil types of Thrissur dt., Kerala were analysed in the present investigation. The 7 types of soil samples from Thrissur district were collected by scraping of surface soil in open ground devoid of vegetation, stored in sterile zip lock bags and transported to the laboratory for analysis. The samples were cultured in BG 11 medium for isolating single species. cyanobacteria were identified using Monograph and documented with digital photographs.

A total of 72 species of cyanobacteria under 20 genera were recorded. The species belongs to 8 families under 3 orders. Nostocales is the prominent order with 3 families. Most number of genera belong to Oscillatoriaceae family (42 species). Among 65 species of identified cyanobacteria, 25 species from kole soil; 16 species from pokkali soil, 12 species from forest soil, 10 species from laterite non gravel, 9 species from laterite gravel soil and 7 species from riverine alluvial soil. The dominant order is Nostocales with 51 species, (42 species Oscillatoriaceae, 8 species Nostocaceae and one species Rivulariaceae), followed by Chroococcales with 15 species. Third dominated order is Stigonematales with 6 species each.

KEY WORDS: Cyanobacteria, Various soil types, Diversity

CONTENTS

1. INTRODUCTION

Cyanobacteria, often referred to as blue-green algae, are a diverse group of photosynthetic bacteria found in a wide range of aquatic and terrestrial environments. They are among the oldest life forms on Earth, with fossil records dating back approximately 3.5 billion years. This remarkable longevity highlights their significant role in shaping the planet's atmosphere and ecology. Cyanobacteria are unique in their ability to perform oxygenic photosynthesis, a process that converts carbon dioxide and water into organic compounds and oxygen using sunlight. This ability not only sustains their own growth but also contributes to the global oxygen supply, having played a crucial role in the great oxygenation event that transformed earth's atmosphere and allowed the evolution of aerobic life forms. These are also notable for their contributions to nitrogen fixation, converting atmospheric nitrogen into forms that can be utilized by living organisms, thus enriching ecosystems with essential nutrients. However, under certain conditions, they can proliferate excessively, leading to harmful algal blooms that produce toxins and deplete oxygen in water bodies, posing risks to both environmental and human health. These microorganisms exhibit a variety of morphologies, ranging from unicellular forms to complex multicellular structures. They thrive in diverse habitats, including oceans, freshwater bodies, soil, and even extreme environments such as hot springs and deserts. Some species form symbiotic relationships with plants, fungi, and animals, enhancing their ecological importance.

Cyanobacteria are a diverse group of photosynthetic bacteria that play crucial roles in various ecosystems, including soil. These microorganisms are renowned for their ability to perform photosynthesis, utilizing sunlight to convert carbon dioxide and water into organic compounds, while releasing oxygen as a byproduct. In soil environments, cyanobacteria are often found in the upper layers, where they contribute to soil fertility, nutrient cycling, and overall ecosystem health. In soil, cyanobacteria form intricate networks of filaments or colonies, known as biofilms, which adhere to soil particles or surfaces. These biofilms not only stabilize soil structure but also aid in moisture retention, erosion prevention, and nutrient availability. Additionally, cyanobacteria possess the capability to fix atmospheric nitrogen, converting it into a form that can be utilized by plants, thereby enhancing soil fertility and promoting plant growth. Furthermore, cyanobacteria exhibit remarkable adaptability to diverse environmental conditions, ranging from arid deserts to aquatic habitats. Their ability to thrive in harsh environments makes them essential players in soil ecosystems, where they contribute to soil stabilization in arid regions and participate in the formation of biological crusts, which protect the soil surface from erosion and promote ecosystem resilience.

Found in a wide range of habitats, from oceans to freshwater bodies, and even extreme environments like deserts and hot springs, cyanobacteria play pivotal roles in ecosystem dynamics, global nutrient cycling, and the evolution of life on our planet. Cyanobacteria are primary producers, utilizing photosynthesis to convert sunlight into organic compounds, thus serving as the foundation of many aquatic and terrestrial food webs. Their ability to fix atmospheric nitrogen enables them to thrive in nitrogen-limited environments, contributing significantly to nitrogen cycling and ecosystem productivity. Furthermore, some cyanobacterial species form symbiotic relationships with various organisms, such as lichens and corals, further shaping ecological communities. Cyanobacteria hold immense significance as the ancestors of chloroplasts, the organelles responsible for photosynthesis in plants and algae. The endosymbiotic theory posits that a symbiotic relationship between early eukaryotic cells and cyanobacteria led to the incorporation of cyanobacterial ancestors into the cells of plants, giving rise to the photosynthetic machinery found in modern plants.

Beyond their ecological and evolutionary importance, cyanobacteria have notable commercial applications. Certain species are cultivated for the production of biofuels, pharmaceuticals, and bioplastics. Additionally, cyanobacteria are being explored as potential agents for bioremediation, aiding in the cleanup of polluted environments by metabolizing various pollutants. In the medical field, cyanobacteria produce a plethora of bioactive compounds with pharmaceutical potential. These include antibiotics, anti-cancer agents, immunosuppressants, and neurotoxins. Research into cyanobacterial secondary metabolites continues to unveil novel compounds with therapeutic properties, offering promising avenues for drug discovery and development. Moreover, cyanobacteria contribute to human nutrition through the production of high-quality protein and essential nutrients. Spirulina and other cyanobacterial supplements are valued for their nutritional content, providing a sustainable source of protein, vitamins, and minerals, particularly in regions facing food insecurity.

Solar radiation, water, and temperature stand out as the primary abiotic influencers governing the distribution, metabolism, and life cycles of soil algae, while factors like pH, redox potential, and soil texture play somewhat lesser roles (Metting, 1981). Within the soil profile, most algae thrive in the upper few millimeters or centimeters, with subterranean flora primarily consisting of dormant stages or inactive cells transported by seepage water, agricultural activities, root growth, or soil-dwelling organisms. Algal populations exhibit micro-stratification within the upper layers of soil profiles, rocks, or gravel deposits (Friedmann and Galum, 1974; Metting, 1981). In semiarid environments, cyanobacteria predominantly colonize the upper surface (0-2cm), while the highest concentrations of Chlorophyceae and Bacillariophyceae are found at depths of 4-6cm (Nordin and Blinn, 1972). Blue-green algae dominate desert regions, forming surface crusts; Oscillatoriaceae are prevalent in both cultivated and uncultivated deserts in Arizona, while other cyanophytes thrive in virgin or fallow areas (Cameron, 1963). *Schizothrix calcicola* emerges as the most abundant blue-green algae in various tropical regions.

Algae play a crucial role in soil stabilization by binding soil particles together, thus preventing erosion. Additionally, they enrich the soil with essential nutrients. Cyanobacterial crusts, in particular, assist in retaining fine soil particles like silt and clay, leading to a reorganization of soil structure. These crusts significantly enhance soil fertility by increasing the levels of organic carbon and nitrogen. Moreover, they improve water penetration into the soil, mitigate erosion, and create favourable conditions for seed germination. Terrestrial blue-green algae exhibit remarkable adaptability to thrive in environments where water availability is limited, often surviving extended periods of drought. Temperature variations play a significant role in regulating algal growth in soil ecosystems (Mohan and Kumar, 2019). In soil environments, they contribute significantly to nutrient cycling, soil stabilization, and nitrogen fixation. Research in this field delves into the diversity, distribution, and ecological significance of soil cyanobacteria, shedding light on their interactions with other soil microorganisms, plants, and environmental factors. By exploring their physiological adaptations to various soil conditions and their responses to environmental changes, these studies provide valuable insights into the resilience and sustainability of terrestrial ecosystems. Additionally, investigations into the biotechnological applications of soil cyanobacteria offer promising avenues for agricultural and environmental practices, including soil restoration and biofertilization. Overall, understanding soil cyanobacteria is fundamental for elucidating the intricate dynamics of soil ecosystems and advancing strategies for their conservation and management.

In Kerala, a southwestern state of India known for its rich biodiversity and varied landscapes, cyanobacteria exhibit remarkable diversity across different types of soils. Kerala's soils range from the coastal regions with sandy soils to the Western Ghats, characterized by rich, loamy soils. Each soil type harbours unique environmental conditions, shaping the composition and distribution of cyanobacteria within them. Coastal sandy soils in Kerala provide a niche habitat for cyanobacteria adapted to high salinity and intense sunlight. Here, species like *Nostoc* and *Anabaena* thrive, forming specialized communities capable of nitrogen fixation and contributing to soil fertility in otherwise nutrient-poor environments. In contrast, the Western Ghats' soils, characterized by their rich organic content and moisture retention capacity, support a different array of cyanobacterial species. Here, genera such as *Microcoleus* and *Oscillatoria* dominate, often forming intricate mats in moist areas like streambeds and forest floors. These cyanobacteria play crucial roles in soil stabilization and nutrient cycling, especially in the nutrient-rich forest ecosystems of Kerala's mountainous regions.

Furthermore, anthropogenic activities and land use patterns in Kerala, such as agriculture and urbanization, influence cyanobacterial diversity in soils. Agricultural practices can introduce cyanobacteria associated with nitrogen fixation, aiding in soil fertility management. However, pollution from urban areas may lead to shifts in cyanobacterial communities, favouring species tolerant to environmental stressors like heavy metals and pollutants. Understanding cyanobacterial diversity in Kerala's soils is not only essential for ecological research but also for sustainable land management practices. Harnessing the beneficial traits of cyanobacteria, such as nitrogen fixation and soil stabilization, can contribute to ecosystem health and agricultural productivity in this biodiverse region.

Cyanobacteria in biological crusts of various soil types of Thrissur dt., Kerala has not been studied so far and hence the present work has been undertaken. Biological crusts, often referred to as cryptogamic or microbiotic crusts, are communities of cyanobacteria, algae, lichens, mosses, and fungi that colonize the soil surface in arid and semi-arid regions. These crusts play crucial roles in soil stabilization, nutrient cycling, and water retention.

In the context of Thrissur District in Kerala, India, where the climate tends to be more humid compared to arid and semi-arid regions, biological crusts may not be as prevalent. However, it's not uncommon to find cyanobacteria in various soil types, as cyanobacteria are known to adapt to diverse environments. Such studies can provide valuable insights into the ecology and functioning of biological crusts in humid tropical regions like Thrissur District, contributing to our understanding of soil ecosystems and their importance for ecosystem health and sustainability.

OBJECTIVES

- Diversity of cyanobacteria in different soils in Trissur district.
- Providing baseline data for future research on cyanobacteria and soil ecology in the region.
- Assessing the diversity and abundance of cyanobacteria species present in the biological crusts.
- Understanding the ecological significance of cyanobacteria in maintaining soil health and fertility in different soil types.

SIGNIFICANCE

Studying cyanobacteria in the biological crusts of various soil types in Thrissur District, Kerala, provides valuable insights into ecological dynamics, soil health, climate change impacts and biodiversity conservation, with implications for both scientific research and practical applications.

2. REVIEW OF LITERATURE

GENERAL CHARACTERISICS ON CYANOBACTERIA

Cyanobacteria are photosynthetic prokaryotes that can be found in most, but not all, illuminated environments. They are also among the most abundant organisms on the planet. They all produce chlorophyll a, and water is usually the electron donor during photosynthesis, resulting in the evolution of oxygen. Most produce the phycobilin pigment, phycocyanin, which gives the cells a bluish colour when present in sufficient concentrations and is responsible for the common name, blue-green algae; in some cases, the red accessory pigment, phycoerythrin, is also formed. It has long been recognized that cyanobacteria in freshwater and soils are much more diverse and abundant at higher pH levels. However, there are a large number of records with lower pH values. Cyanobacteria are ubiquitous in biocrust communities and were the first to colonize terrestrial ecosystems. They play a variety of roles in the soil, including C and N fixation and exopolysaccharide synthesis, which increases soil fertility and water retention while also improving soil structure and stability. Nowadays, numerous studies are being conducted in the fields of diversity, ecology, and advancement, among others.

CYANOBACTERIAL STUDIES IN INDIA

Thajuddin and Subramanian (1992) conducted a survey of the cyanobacterial flora along India's southern east coast. The survey identified 163 species from 48 genera and 14 families of cyanobacteria. 32 species from 13 genera, all of which were non-heterocystous, were considered versatile because they were found in all areas of various regions. Among these, *Phormidium tenue* was the most adaptable species, appearing not only in all areas but also in all regions studied. Maske *et al.,* (2009) investigated the density and diversity of cyanobacteria and cyanotoxins in lakes in Nagpur, Maharashtra. This study investigates the seasonal variation of toxic cyanobacteria in Lake Ambazari and Lake Phutala, Maharashtra, India. It identifies dominant cyanobacterial genera, such as *Microcystis,* and correlates their abundance with nutrient levels. Microcystin-RR is consistently found, indicating a link with *Microcystis* blooms. Blooms peak between the post-monsoon and summer seasons, necessitating additional research into nutrient dynamics and allelopathic effects of microcystins. Prasanna *et al.,* (2009) explores cyanobacteria in rice rhizosphere and their ecological significance. The study identified *Nostoc* and *Anabaena* as the dominant cyanobacteria in rice rhizospheres, with the potential to promote wheat growth. When evaluated using HipTG primer, their varied profiles indicate potential candidates for inoculants that promote plant growth.

The significance of cyanobacterial diversity in various ecological conditions was investigated by Syiem *et al.* (2010) in Meghalaya. A total of 75 samples from ten different ecosystems were tested. The 65 cyanobacterial strains from 11 genera that have been identified include *Nostoc, Anabaena, Calothrix, Cylindrospermum, Gleocapsa, Fischerella, Plectonema, Tolypothrix, Stigonema, Loriella,* and *Westiellopsis.* This study found strains of cyanobacteria that are able to survive and grow in acidic environments. A colonization study also identified some potential biofertilizer strains from the region, including *Nostoc punctiforme, Nostoc muscurum,* and *Anabaena azollae*, which could be beneficial in acidic crop fields. Nikam *et al.* (2013) studied cyanobacterial diversity in Maharashtra's Western Ghats region. 94 cyanobacterial species from 38 genera, 14 families, and 5 orders were identified through screening of 627 soil samples collected from different locations within the aforementioned regions. *Myxosarcina spectabilis* Geitler had a less frequent distribution. The genera with the highest population density were *Nostoc* (Nostocaceae), *Chroococcus* (Chroococcaceae), and *Anabaena* (Nostocaceae). The information gathered will be useful in exploiting cyanobacteria for biotechnological, pharmaceutical, and other applications. The study by Sakthivel and Kathiresan (2013) focused on cyanobacterial diversity from 3 different mangrove sediments along south east coast of India. A total of 68 species from 28 genera and 10 families were recorded. There were 58 non-heterocystous and 10 heterocystous cyanobacteria species identified. The dominant family was Oscillatoriaceae, which had 34 species (75.8%). *Oscillatoria* (14 spp.) dominated among the 28 genera. Thirteen species were found to be common across all three mangrove areas. Singh *et al.,* (2014) studies on diversity and distribution pattern analysis of cyanobacteria isolated from paddy fields of Chhattisgarh. The study examined 29 strains of cyanobacteria from Chhattisgarh, analysing their phenotypic characteristics and environmental influences. Results highlighted strain-specific attributes and the impact of environmental factors on cyanobacterial distribution, aiding future molecular diversity studies and documentation of Chhattisgarh's cyanobacteria. Khattar *et al.,* (2014) documented limnology and cyanobacterial diversity of high-altitude lakes of Lahaul-Spiti in Himachal Pradesh. The analysis identified 20 cyanobacterial species across 11 genera. Groups formed based on habitat preference: high-nutrient, warm; oligotrophic, cold with high pH; and adaptable. Some species were widespread without specific habitat association. Subudhi *et al.,* (2017) analysed shift in cyanobacteria community diversity in hot springs of India. Study contrasts cyanobacterial diversity in

Taptapani (48°C) and Atri (58°C) hot springs. Taptapani hosts mesophilic *Arthronema* (83.81%), while Atri has thermophilic *Leptolyngbya* (96.25%). Differences in phylum-level presence linked to physiochemical factors like temperature. Richness, evenness, and Shannon diversity indices vary between springs.

Yadav *et al.,* (2023) conducted study on enhancing biocrust development and plant growth by inoculating desiccation-tolerant cyanobacteria in various soil textures. This study highlights cyanobacteria's efficacy in land rehabilitation. Inoculating nutrient-deficient substrates with *Nostoc calcicola* BOT1, *Scytonema* sp. BOT2, and their consortia improved soil fertility, especially in coarse and fine sand. Consortia outperformed individual strains, fostering higher plant growth in loamy soil. Cyanobacteria also promoted biocrust formation, vital for preventing erosion and desertification. Their ability to persist in soil even after desiccation suggests their sustainable potential for restoring degraded land. Delilah *et al.,* (2023) conducted a review of the distribution of microalgae collected from paddy fields in India. It highlights their role in soil fertility, diverse community, and applications like bioremediation. It emphasizes sustainable practices for agricultural productivity and environmental conservation. Mendhekar (2023) studied isolation, purification and principles of cyanobacteria. Cyanobacteria utilize oxygen-producing photosynthesis for nutrient uptake, thriving in diverse habitats. They uniquely fix nitrogen aerobically via heterocysts. The antibacterial drug Imipenem reduces heterotrophic bacterial contaminants during cyanobacteria isolation, aiding axenic culture growth. The summary effectively captures cyanobacteria's ecological significance and research techniques, emphasizing their nitrogen-fixing ability and antibiotic use for purification. Bibi *et al.,* (2024) studied applications, advancements, and challenges of cyanobacteria-based biofertilizers for sustainable agro and ecosystems in arid climates. Growing global food demands stress conventional agriculture. Cyanobacteria offer sustainable solutions, thriving in harsh conditions, enhancing soil quality, nutrient availability, and plant resilience. Knowledge gap understanding terrestrial cyanobacteria's response to climate change crucial for biofertilizer development.

CYANOBACTERIAL STUDIES IN KERALA

Parukkutty (1940) pioneered research into Kerala's cyanobacterial flora, reporting 51 forms of 'Myxophyceae' from the Travancore state's central and southern regions. Cyanobacterial flora of paddy fields from various Districts of Kerala were investigated by Anand and Hopper (1987) and a preliminary report of 30 cyanobacterial species were published. They later conducted a detailed study on the cyanobacteria of Kerala (Anand and Hopper, 1995) and described 158 cyanobacterial species coming under 33 genera, from various agricultural fields. A similar work was carried out by Shaji and Panicker (1994) who reported only 32 species coming under 3 genera. Dominic (1997) reported 92 cyanobacterial taxa from 31 genera and this work also was carried out in the paddy fields of Kerala.

Easa (2004) compiled a list of 190 identified cyanobacterial species in Kerala. The vast majority of the species he listed were either synonymized, merged, or moved to another genus. The study identified 204 species, 149 of which were new to Kerala. Umamaheswari (2005) conducted study on Isolation and characterisation of Nostocales cyanobacteria of the paddy fields of Kerala. The investigation showed that all the three cyanobacteria (*Nostoc linckia*, *Nostoc muscorum* and *Calothrix marchica* var. *intermedia*) thrive with lower chemical fertilizer levels, promoting growth and nitrogen fixation efficiency. Phosphorus, notably from super phosphate, enhances growth, while urea inhibits nitrogen-fixing cyanobacteria. Optimal fertilization is crucial for balancing growth benefits and environmental impact. John (2008) investigated the algal flora of the Idukki District and discovered 48 cyanobacterial species classified into six families. The majority of the representation came from unicellular cyanobacteria found in Idukki's freshwater ecosystems. Tessy and Sreekumar (2010) discovered cyanobacterial diversity in Thrissur District's "Kol" wetlands. Throughout the investigation, members of the Oscillatoriaceae dominated the other families. They also discovered that non-heterocystous filamentous cyanobacterial types outperformed unicellular and heterocystous cyanobacteria.

Sebastian and Joseph (2013) conducted an investigation into the filamentous microflora of the Thodupuzha river. They identified nine cyanobacterial species across five genera. *Oscillatoria* dominated with five species, followed by *Lyngbya, Nostoc, Phormidium, and Scytonema*, each with one species. The study investigated by Vijayan and Ray (2015) based on ecology and diversity of cyanobacteria in Kuttanadu paddy wetlands, Kerala, India and about 64 species of blue – green algal diversity recorded. The report reveals rich blue-green-algal diversity in Kuttanadu, with Oscillatoriales dominant. Lower Kuttanadu, Virippu season, and panicle stage show highest ecological parameters. Positive correlations exist between species richness, diversity, and crop seasons, linked to soil nitrogen and phosphorus. Smitha and Ammini (2015) Study on filamentous algae in Kuttanad and Kole lands, reveals dominance of blue-green algae, *Spirogyra* blooms, and their inhibitory effects on rice seed germination and vigor, impacting yield. 32 species of blue-green algae and eight species of green algae were identified from Kuttanad. Among the 32 species of blue-green algae 25 species are non-heterocystous and seven species are heterocystous. 28 species of blue-green and six species of green algae were identified from Kole lands, twenty-one species are non-heterocystous, and only seven species are heterocystous filamentous algae. Twelve cyanobacterial taxa were found in the mangrove forests of Kottayam District by Ram and Shamina (2015). During this investigation, Oscillatoriaceae members were discovered to be dominating over other families. Shamina and Ram (2014) described *Oscillatoria ornata* Var. crassa from marine habitats.

The study by Philip *et al.,* (2016) on cyanobacterial diversity in Nelliyampathy, Kerala, identifies 15 species across families like Chroococcaceae and Nostocaceae. Methodology includes specimen collection from various sources and microscopic examination. Economic importance, like phytoremediation potential, is emphasized, enriching scientific understanding. Ram and Shamina, (2017) conducted a survey of the cyanobacterial biodiversity of seven mangrove environments in Kerala, including Vallikunnu, Kadalundi, Kallayi, Mangalavanam, Kumbalam, Kumarakom, and Mekkara. In total, 31 species of cyanobacteria coming under 10 genera and 4 families were recorded in all mangrove environments. The genus *Oscillatoria* was observed with maximum distribution (13 species), followed by *Nostoc* (5 species) and *Lyngbya* (3 species). The genera *Aphanocapsa, Microcoleus*, and *Scytonema* each have two species, while *Chroococcus, Aphanothece, Merismopedia*, and *Phormidium* have one species each. Except for Mangalavanam and Mekkara, all mangrove environments contained at least three species: *Oscillatoria salina, Oscillatoria ornata*, and *Oscillatoria vizagapatensis*. *Trentepohlia dialepta* (Nylander) Hariot is a terrestrial alga from Southern Western Ghat region of Kerala studied by Thomas *et al.,* (2017). The green alga *Trentepohlia dialepta* thrives epiphytically on *Madhuca neriifolia* in Kerala's Pathanamthitta district, differing from its usual corticolous growth. This first report from the Southern Western Ghats reveals its unique morphological variations and ecological adaptability.

Manu Philip (2020) studied on Cyanobacterial diversity of western ghat forests of Kerala. The study revealed high cyanobacterial diversity in Kerala, with 203 species identified. Heterocystous cyanobacteria dominated, *Chroococcus* was the most adaptable genus, and 31 new species were found. The study highlights the importance of documenting cyanobacteria for biotechnological and ecological research. Ram (2021) conducted a review on the distribution records of mangrove-associated heterocytous cyanobacteria. This study reviews 33 publications (1977-2020) on heterocytous cyanobacteria in mangrove ecosystems, identifying 70 species. The dominant family is Nostocaceae (27 species), followed by Calotrichaceae, Rivulariaceae, Scytonemataceae and others. This enhances understanding of cyanobacterial diversity and supports future taxonomic and ecological research.

Arun and Tessy (2022) documented the Mangrove-Associated Cyanobacteria of *Nostoc* spp. *(Nostocales, Nostocaceae)* from Kerala State. The study reveals nine previously unreported *Nostoc* species in Kerala's mangroves, providing detailed descriptions, distributions, and habitat information. This contributes significantly to our understanding of cyanobacterial diversity and aids in conservation efforts for these vital ecosystems. Ninan and Thomas (2022) the focus was on investigating cyanobacteria, a tool for planetary engineering. This delves into the journey of cyanobacteria, tracing their origins and evolution, and highlighting their pivotal role in the history of life on Earth. It begins with an exploration of ancient Earth, a time marked by extreme climatic conditions, and examines how cyanobacteria managed to survive and thrive. The paper discusses in detail the various survival mechanisms employed by cyanobacteria, including their evolution of photosynthesis and their adaptations to environmental stress. Additionally, this provides insights into the future prospects of cyanobacteria, emphasizing their potential applications and contributions. Ram and Paul (2024) documented the list of cyanobacteria (Coleofasciculales, Oscillatoriales, Pleurocapsales, Pseudanabaenales and Spirulinales) from the Mangrove Ecosystems. This revises cyanobacteria species in mangrove environments, identifying 196 species from 48 genera across six orders. Oscillatoriales dominate with 137 taxa. The primary families are Oscillatoriaceae (79 species) and Microcoleaceae (39 species). Pseudanabaenaceae (18 species), Gomontielleaceae (8 species), Dermocarpellaceae, Hyellaceae, Xenococcaceae and Spirulinaceae (7 species each) Geitlerinemataceae, Wilmottiaceae and Hydrococcaceae (4 species each), Borziaceae (2 species) and Coleofasciculaceae (1 species). Data was compiled from 64 publications spanning 1889-2020.

CYANOBACTERIAL STUDIES IN SOIL

Johansen and Shubert (2001) studied the algae in soils. They gave comprehensive insight into the diversity, distribution, and ecological roles of soil algae. Their significance for soil fertility, nutrient cycling, and ecosystem functioning is emphasized. The review emphasizes the need for more investigation to completely understand the role that algae play in soil ecosystems and the potential uses of algae in environmentally friendly agriculture and conservation. Tripathy and Pramila (2006) conducted eco physiological studies on drought tolerant cyanobacteria in different soils. The study elucidates light's crucial role, pH's influence, and salt tolerance in cyanobacterial growth and carbohydrate dynamics. It highlights their adaptive strategies to environmental stressors, enriching our understanding of their metabolic responses in varied conditions. The study by Prasanna and Nayak (2007) explores soil pH's impact on cyanobacterial abundance and diversity in rice fields. The study explores how soil pH influences cyanobacteria in rice soils, revealing highest abundance at pH 8.1 and diversity at pH 6.9, with implications for sustainable agriculture and biofertilizers. They isolated 166 different forms of cyanobacteria. Prasanna and Nayak (2007) analysed influence of diverse rice soil ecologies on cyanobacterial diversity and abundance. The study assessed cyanobacterial diversity in Indian rice paddies, highlighting Jeypore's rich diversity, 20 cyanobacterial forms, spanning 9 genera were isolated. *Nostoc* and *Anabaena* dominated, suggesting their ecological importance. Tailoring region-specific inocula could optimize crop benefits.

Ray and Thomas (2012) conducted a study on the ecology and diversity of green algae in tropical *oxicDystrustepts* soils, examining the relationship with various soil parameters and vegetation. This study explores green algae biodiversity in the Western Ghats' *OxicDystrustepts* soils, revealing 17% new species. It correlates soil physico-chemical parameters with algae diversity across natural forests, teak, and rubber plantations, emphasizing the need for immediate studies to document biodiversity before degradation occurs. Singh *et al.,* (2014) conducted study on cyanobacteria and agricultural crops. Cyanobacteria offer agricultural benefits like nitrogen fixation, plant growth regulation, soil fertility enhancement, agrochemical degradation, and pathogen control, promoting sustainable crop production, soil health, and reduced chemical inputs. Belnap *et al.,* (2016) by Biological Soil Crusts as an Organizing Principle in Drylands. Biocrusts, vital in dryland ecosystems for billions of years, mediate soil processes, nutrient cycling, water distribution, and plant community structure. Understudied roles include nutrient capture, biodiversity hotspots, and indicators of soil health, urging further research for deeper understanding and conservation.

Dhanya and Ray (2015) investigated the paddy fields of Kuttanadu and Alappuzha, identifying 64 cyanophycean members belonging to 22 genera and representing all three types of cyanobacterial groups. Ram and Shamina (2015) reported cyanobacterial association with orchid roots, such as *Dendrobium crumenatum.* They discovered six distinct cyanobacterial species, five of which were heterocystous. The study found no unicellular cyanobacterial members. Another study by Ram and Shamina (2015) reported 2 species of cyanobacterial association from the roots of the terrestrial orchid, *Spathoglottis plicata* Blume. Two Oscillatoriaceae cyanobacterial species (*Phormidium bohneri* and *Oscillatoria foreaui*) were found on the underground roots of the orchid *Spathoglottis plicata.* This study is the first to report species-level cyanobacterial associations with this terrestrial orchid, influenced by plant growth conditions.

Another study conducted by Thomas *et al.,* (2017) investigated the influence of pH on the diversity of soil algae. The study at Catholicate College, Kerala, identified thirteen soil algae species, highlighting soil pH as a key factor. Green algae thrived in acidic soils (pH 4.6-5.7), while blue-green algae dominated neutral to alkaline soils (pH 7.2-7.8). Pringsheim's medium was effective for green algae growth. Studies on in vitro culturing and biochemical properties of green and blue-green algae in the laterite soil by Thomas *et al.,* (2018). The study of green and blue-green algae from Pathanamthitta's laterite soils revealed that soil pH and specific nutrient media (BG11 and Pringsheim's) influence algal growth. Green algae had higher chlorophyll, while blue-green had more carotenoids. These algae's bioactive compounds hold commercial potential. Chamizo *et al.,* (2018) reviewed the potential of soil inoculation with cyanobacteria for promoting agricultural sustainability in drylands. Cyanobacteria offer sustainable solutions in agriculture, improving soil stability, nutrient availability, and moisture retention. Their application, especially in dryland regions, enhances crop productivity while conserving natural resources and safeguarding the environment. The study by Mohan and Kumar (2019) focused on the cyanobacterial diversity in agriculturally fertile soil of Patna and their population density. An investigation into Patna's fertile soils revealed 187 cyanobacteria species from 45 genera and three groups of agriculturally fertile soils. Group A having 138, Group B 135, and Group C 129 species. Population density ranged from 560×10^3 to 1650×10^3 cells/g, peaking in the rainy season. Kour *et al.,* (2023) studied response of distinct soil types to cyanobacterial biofertilizer inoculation. This study examined the impact of cyanobacterial biofertilizers on soil fertility in seven soil types, finding significant increases in cyanobacteria and beneficial gene markers, especially in KAR (Karnal, Typic Natrustalf) and IARI (Indian Agricultural Research Institute, Typic Haplustepts) soils, under light-dark and dark cycles, highlighting soil-specific benefits for microbial contributions to fertility.

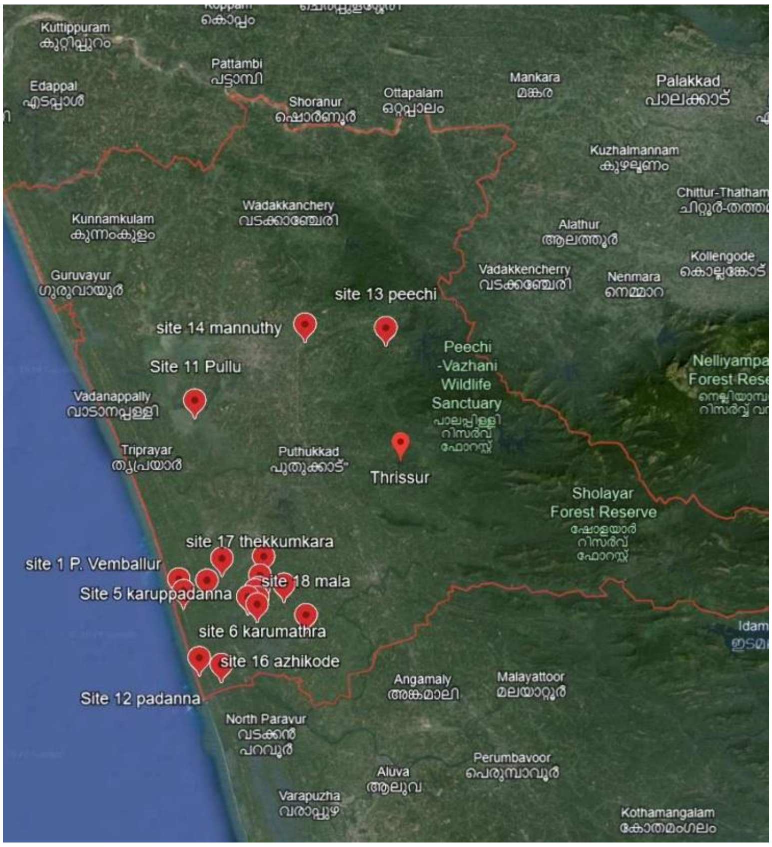
3. MATERIALS AND METHODS

Study area

Kerala, nested in the southwest of India, boasts nearly 600km of stunning Arabian Sea coastline along the tropical Malabar Coast. Kerala state lies at the south western edge of peninsular India, stretching from around 8° 17' 30" to 12° 47'40" north latitudes, and 74° 27'47" to 77° 37'12" east longitudes. Kerala's varied rainfall, temperature, wet and dry conditions, and fast-flowing rivers create unique vegetation and soil types.

The current study was undertaken in different type of soils in Thrissur district. There are mainly 7 types of soils like coastal sandy soil, Pokkali soil, Kole soil, riverine alluvial soil, forest soil, laterite gravel and laterite non – gravel soil.

Cyanobacteria are known to play an important role in terrestrial habitats and organism communities. Soil crusts containing cyanobacteria can stabilize soil, preventing erosion and retaining water.



Soil type

Coastal sandy: Sandy soils of marine origin typically exhibit deep and efficient drainage. They are characterized by low levels of organic matter and often lack essential plant nutrients. These soils have a limited ability to retain both water and nutrients.

Pokkali soil: A unique type of saline-tolerant soil found in the coastal regions, high salinity levels and rich in organic matter and have a unique composition that supports the growth of salt-tolerant crops in the brackish water ecosystem prevalent in these coastal areas.

Kole soil: Formed from sediment deposits brought by rivers and are characterized by their fertility and ability to support diverse agricultural activities such as paddy cultivation. Kole soils are typically well-drained and rich in organic matter, making them suitable for growing a variety of crops, including rice and vegetables. They play a significant role in the agrarian economy of Kerala, particularly in areas like Thrissur and Malappuram districts, where kole lands are prevalent.

Riverine alluvial: Highly profound, acidic, superbly drained, lacking gravel, and displaying a diverse texture (ranging from sandy loam to clay loam), originating from sedimentary deposits of rivers.

Gravelly laterite: Rocky, excellently drained, highly acidic, low water-holding capacity, significant phosphorus fixation, deficient in basic nutrients. While possessing favourable physical characteristics, it is susceptible to erosion, with a dense laterite layer at lower depths hindering root penetration.

***Forest soil**:* The soils are non-gravelly, deep, superbly drained, acidic, and contain a loamy or clayey texture enriched with organic matter. They exhibit reddish-brown to dark brown topsoils, with subsoils ranging from clay loam to clay texture.

Laterite non – gravel: Extremely deep, gravel-free, acidic, well-drained, clayey red soils with no plinthite layer in the lower strata.

Sample stations

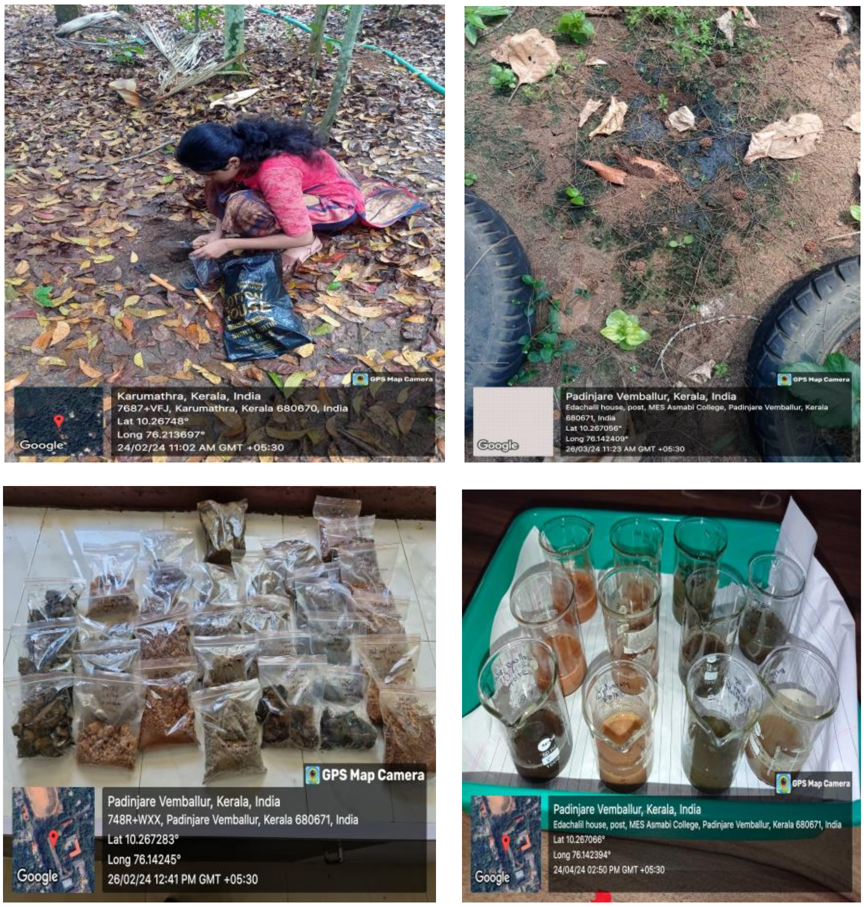
samples were gathered from various location in Thrissur. Samples are collected from different sites like P.Vemballur, Puthenchira, Kadalayi, Karumathra, Mannothy, Peechi, Pullut, Thekkumkara, Kovilakathukunnu, Narayanamangalam, Karupadanna, Sreenarayanapuram, Azhikode, Padanna, Poklayi, Mathilakam etc.

Sample collection

Crust samples were collected from the upper surface of dry soils from all the above categories of soils in replicates of three. Scraping of surface soil in open ground devoid of vegetation (in the immediate area) was collected, stored in sterile zip lock bags and transported to the laboratory for analysis. Soil crust samples were wetted with sterile water and examined under light microscope. Within 12 to 24h of wetting cyanobacterial filaments could be visualized; however, isolation and culturing under defined conditions was required for their identification. A pinch of each crust was transferred to agarized BG11 medium (Rippka *et al.,* 1979) with combined nitrogen and incubated at 25^0C under continuous light from fluorescent tubes at an intensity 2000 lux.

The dominant organism in each soil sample was purified following standard methods (Venkataraman, 1969) and axenic culture of the cyanobacteria was used in the experiments.

Morphometric analysis of each species was made and identified following Desikachary (1959). Bright field- illuminated photomicrographs of the cyanobacterial species were taken with a trinocular research microscope using a digital camera. Line drawing of cyanobacterial flora was made using prism type Camera Lucida (Erma-Japan).



Collection of samples

Culture techniques

Isolation of Soil Cyanobacteria: The Cyanobacteria were isolated using BG-11 media with or without combined nitrogen and these media were used in liquid or solidified form with 1.5% agar. Media were sterilized for 15min in an autoclave and then transferred into either sterile test tubes or sterile plastic Petri dishes. Dilution on solid media was chosen for algal counts: 10g of soil were transferred to 90ml of sterile water and homogenized. Then serial 4-solid dilution of homogenate in liquid BG-11 was prepared. Each Petri dish containing solidified BG-11 was inoculated with 1 ml of dilute soil suspension; 4 replications of each dilution were used (Lukesova, 1993). Incubation proceeded for 3 weeks in the environmental chamber equipped with florescent tubes. The chamber temperature was kept at 25^0C.

Sterilization

All the glass vessels conical flask (250 ml, 500 ml), standard flask (1000 ml), Petri plates, measuring jar (10 ml), pipette (10 ml), glass rod slides, cover slip, needles, inoculation loop and culture tubes were sterilized in autoclave at 121^0C for 15 minutes after washing with liquid detergent and then keeping in hot air oven (100^0C) for 30 minutes.

The culture medium used for the experiment was sterilized separately, properly for 20 minutes in the autoclave. Liquid cultures were maintained in conical flask and solid culture in petri plates.

Media preparation for culture

Preparation of BG 11 medium

The composition of BG 11 medium is given below:

SI.NO	INGREDIENTS	Wt.(g/L)
1	**STOCK 1**	
	Na_2MG EDTA	0.1g/L
	Ferric ammonium citrate	0.6g/L
	Citric acid.H_2O	0.6g/L
	Calcium chloride	3.6g/L
2	**STOCK 2**	
	Magnesium sulphate	7.5g/L
3	**STOCK 3**	
	K_2HPO_4	4.0g/L
	KH_2PO_4	3.05g/L
4	**STOCK 4: TRACE METAL SOLUTION**	
	Boric acid	2.86g/L
	Manganese chloride	1.81g/L
	Zinc sulphate	0.222g/L
	Copper sulphate	0.079g/L
	Cobalt sulphate	0.050g/L
	Sodium molybdate	0.391g/L

Stock solution Per litre of medium

Stock 1: 10ml
Stock 2: 10ml
Stock 3: 10ml
$NaNO_3$: 0.02g
Stock 4: 10ml
$NaNO_3$: 1.5g

For preparing BG 11 medium, combine above stock and chemicals make into 1000ml and adjust pH to 7.5.

Liquid media:

To approximately 900 mL of distilled H_2O the components in the order specified were added while stirring continuously and the final volume was made to 1 L by adding more distilled water. The flask was covered by non-absorbent cotton and autoclaved at 15 lb/inch2 pressure for 20 minutes. The medium was then allowed to cool and then stored at refrigerator temperature.

Similarly, the BG 11 agar medium was prepared by adding the components in the order specified while stirring continuously to 400mL of distilled water and the final volume was then adjusted to500mL by adding more distilled water. Prepare BG11 liquid medium. In 15 g of agar was added to 500 mL of liquid medium and mixed well. The flask was covered by cotton plug and autoclaved both solutions at 15lb/inch2 pressure for 20 minutes. Then cool medium to room temperature.

Serial dilution

10 ml distilled water added to 10 g of collected soil samples and prepare the homogenize. Add 1 ml homogenate to 9 ml BG11 liquid medium in culture tube and serial dilution up to 10^{-5}.

Streak plate method

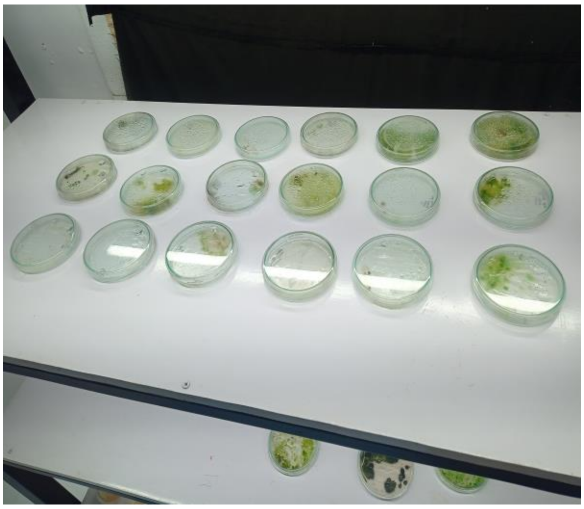
This method is employed for the separation of individual species. This method is used for obtaining monoculture. The inoculation has been done in laminar air flow for avoiding contamination after turning on UV light for 15 minutes. The plates were illuminated with 40-W cool-white fluorescent lamps.

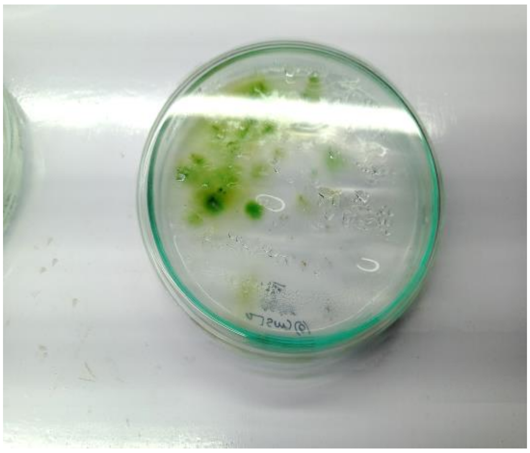
- Prepared petri plates containing solid medium.
- Flamed the inoculation loop and cool it, then streaked the samples collected back and forth, edge and cultured.
- Isolated mass were cultured in BG 11 medium.

Culture conditions

Exposure to light intensity of 2000 – 3000 lux is optimal for cultivation of microalgae. So, the culture was incubated at 23^0C under illumination of 2000 lux of cool white fluorescent light programmed for 24 hours a day is optimal. They grow optimally at room temperature between range of 20-25^0C.

Culture technique and analysis



Cyanobacterial growth in serial dilution and agar plate streaking method

4. RESULT

In course of a systematic study on soil cyanobacterial flora of seven different types of soil in Thrissur district 72 species of cyanobacteria belonging to 20 genera were recorded.

Table : 1 Systematic order to identified cyanobacteria up to species

CLASS	ORDER	FAMILY	GENUS	SPECIES
Cyanophyta	Chroococcales	Chroococcaceae	*Microcystis*	*Microcystis marginata*
			Chroococcus	*Chroococcus turgidus*
				Chroococcus macrococcus
				Chroococcus pallidus
				Chroococcus indicus
				Chroococcus minutus
				Chroococcus giganteus
			Gloeocapsa	*Gloeocapsa decorticans*
				Gloeocapsa punctata
				Gloeocapsa pleurocapsoides
				Gloeocapsa magma
				Gloeocapsa nigrescens
			Aphanocapsa	*Aphanocapsa koordersi*
			Gomphosphaeria	*Gomphosphaeria aponina*
		Entophysalidaceae	*Chlorogloea*	*Chlorogloea fritschii*
	Nostocales	Oscillatoriaceae	*Arthospira*	*Arthospira jenneri*
				Arthospira massartii
				Arthospira platensis
			Spirulina	*Spirulina meneghiana*
				Spirulina princeps
			Oscillatoria	*Oscillatoria quadripunctulata*

Cyanophyta				*Oscillatoria princeps*
				Oscillatoria geitleriana
				Oscillatoria homogenea
				Oscillatoria Formosa
				Oscillatoria vizagapatensis
				Oscillatoria irrigua
				Oscillatoria fremyii
				Oscillatoria subbrevis
				Oscillatoria laete-virens
				Oscillatoria salina
				Oscillatoria curviceps
				Oscillatoria psuedogeminata
				Oscillatoria animalis
				Oscillatoria tenuis
				Oscillatoria proteus
				Oscillatoria amoena
				Oscillatoria limosa
			Phormidium	*Phormidiumambiguum*
				Phormidium corium
				Phormidium uncinatum
				Phormidiumcalcicola
				Phormidium fragile
				Phormidium jenkelianum
				Phormidium retzii
				Phormidium ceylanicum
			Lyngbya	*Lyngbya rubida*
				Lyngbya polysiphoniae
				Lyngbya digueti
				Lyngbya ceylanica
				Lyngbya palmarum
				Lyngbya

Cyanophyta				*Lyngbya martensiana*
				Lyngbya kashyapii
				Lyngbyal imnetica
			Schizothrix	*Schizothrix telephorcides*
			Symploca	*Symploca muscorum*
		Nostocaceae	*Nostoc*	*Nostoc linckia*
				Nostoc carneum
				Nostoc ellipsosporum
				Nostoc spongiaeforme
			Anabaena	*Anabaena variabilis*
				Anabaena naviculoides
				Anabaena doliolum
				Anabaena fiillebornii
		Rivulariaceae	*Rivularia*	*Rivularia dura*
	Stigonematales	Mastigocladopsidaceae	*Mastigocladopsis*	*Mastigocladopsis jogensis*
		Mastigocladaceae	*Mastigocladus*	*Mastigocladus laminosus*
		Stigonemataceae	*Hapalosiphon*	*Hapalosiphon intricatus*
				Hapalosiphon fontinalis
				Hapalosiphon welwitschii
			Westiellopsis	*Westiellopsis prolifica*

Altogether 72 species of cyanobacteria belonging to 20 genera were recorded from seven different types of soil in Thrissur district. The number of species found in each soil group varied significantly based on the ecological conditions. Cyanobacteria can grow in any environment that provides moisture and sunlight. However, specific cyanobacterial species thrive in particular conditions, leading to variations in their distribution, ecology, periodicity, and occurrence. When favourable climatic conditions arise, certain cyanobacterial species become dominant, thereby enhancing soil fertility.

Cyanobacteria	**Coastal sandy soil**	**Kole soil**	**Riverine alluvial soil**	**Forest soil**	**Laterite-gravel soil**	**Laterite non-gravel soil**	**Pokkali soil**
Microcystis marginata	-	-	-	-	-	-	+
Chroococcus turgidus	+	-	-	-	-	-	+
Chroococcus macrococcus	-	-	+	-	-	-	-
Chroococcus pallidus	-	+	-	-	-	-	-
Chroococcus indicus	-	+	-	-	-	-	-
Chroococcus minutus	-	-	-	+	-	-	-
Chroococcus giganteus	-	-	-	-	-	+	-
Gloeocapsa decorticans	+	-	-	-	-	-	-
Gloeocapsa punctata	-	+	-	-	-	-	-
Gloeocapsa pleurocapsoides	-	-	-	-	-	-	+
Gloeocapsa magma	-	-	+	-	-	-	-
Gloeocapsa nigrescens	-	+	-	-	-	-	-
Aphanocapsa koordersi	-	-	+	-	-	-	-
Gomphosphaeria aponina	-	-	-	+	-	-	+
Chlorogloea fritschii	+	-	-	-	-	-	-
Arthospira jenneri	+	-	-	-	-	-	-
Arthospira massartii	+	+	+	+	-	+	+
Arthospira platensis	-	-	-	-	-	-	+
Spirulina meneghiana	-	-	+	-	-	-	+
Spirulina princeps	-	-	-	-	-	-	+
Oscillatoria quadripunctulata	+	-	-	-	-	-	-

Oscillatoria princeps	-	+	-	-	+	+	-
Oscillatoria geitleriana	-	+	-	-	-	-	-
Oscillatoria homogenea	-	-	-	-	+	-	-
Oscillatoria formosa	-	-	-	-	-	+	-
Oscillatoria vizagapatensis	-	+	-	-	-	+	-
Oscillatoria irrigua	-	+	-	-	-	+	-
Oscillatoria fremyii	-	-	-	+	-	-	-
Oscillatoria subbrevis	-	+	-	+	-	-	-
Oscillatoria laete-virens	-	-	-	+	-	-	-
Oscillatoria salina	-	-	-	-	-	-	+
Oscillatoria curviceps	-	-	+	-	+	-	+
Oscillatoria psuedogeminata	-	-	-	-	-	+	+
Oscillatoria animalis	-	-	-	-	-	-	+
Oscillatoria tenuis	-	+	-	-	-	-	+
Oscillatoria proteus	-	+	-	-	-	-	-
Oscillatoria amoena	-	+	-	-	-	-	-
Oscillatoria limosa	-	-	+	-	-	+	-
Phormidium ambiguum	+	+	-	-	-	+	-
Phormidium corium	+	+	-	-	-	-	-
Phormidium uncinatum	-	-	-	-	-	-	+
Phormidium calcicola	-	-	-	-	+	-	-
Phormidium fragile	-	-	-	+	-	-	-
Phormidium jenkelianum	-	-	-	-	+	-	-
Phormidium retzii	-	-	-	-	-	-	+
Phormidium ceylanicum	-	+	-	-	-	-	-
Lyngbya rubida	-	+	-	-	-	-	-
Lyngbya polysiphoniae	-	+	-	-	-	-	-
Lyngbya digueti	-	+	-	-	-	-	-
Lyngbyaceylanica	-	-	-	-	-	-	+
Lyngbya palmarum	-	-	-	-	-	+	-
Lyngbya bipunctata	-	-	-	+	-	-	-
Lyngbya martensiana	-	-	-	-	-	-	-

Lyngbya kashyapii	-	-	-	+	-	-	-
Lyngbya limnetica	-	+	-	-	-	-	-
Schizothrix telephorcides	+	-	-	-	-	-	-
Symploca muscorum	-	-	-	+	+	-	-
Nostoc linckia	-	+	-	-	-	-	-
Nostoc carneum	-	-	-	+	-	-	-
Nostoc ellipsosporum	-	+	-	+	-	-	-
Nostoc spongiaeforme	-	+	-	-	-	-	-
Anabaena variabilis	+	-	-	-	-	-	-
Anabaena naviculoides	-	+	-	-	-	-	-
Anabaena doliolum	-	+	-	-	-	-	-
Anabaena fiillebornii	-	-	-	-	+	-	-
Rivularia dura	+	-	-	-	-	-	-
Mastigocladopsis jogensis	+	-	-	-	-	-	-
Mastigocladus laminosus	+	-	-	-	+	-	-
Hapalosiphon intricatus	-	-	-	-	+	-	-
Hapalosiphon fontinalis	+	-	-	-	-	-	-
Hapalosiphon welwitschii	+	-	-	-	-	-	-
Westiellopsis prolifica	+	-	-	-	-	-	-

Table-2. Cyanobacteria flora founded in seven different types of soil.

From the results (Table-2) it is evident that a comparatively large number of cyanobacterial species was recorded from Kole soil (25 species), followed by the soils coastal sandy and Pokkali soil (16 species), forest soil (12 species), laterite non gravel (10 species), laterite gravel (9 species) and riverine alluvial (7 species). *Hapalosiphon fontinalis, H. welwitschia, Westiellopsis prolifica, Mastigocladopsis jogensis, Rivularia dura, Anabaena variabilis, Schizothrix telephorcides, Oscillatoria quadripunctulata, Gloeocapsa decorticans* were recorded only from coastal sandy soil. *Anabaena doliolum, A. naviculoides, Nostoc spongiaeforme, N. linckia, Lyngbya limnetica, L. digueti, L. polysiphoniae, L. rubida, Phormidium ceylanicum, Oscillatoria proteus, O. amoena, O. geitleriana, Chroococcus pallidus, Chroococcus indicus, Gloeocapsa punctata, Gloeocapsa nigrescens* were recorded only from Kole soil. *Gloeocapsa magma, Chroococcus micrococcus* were recorded only from riverine alluvial soil. *Nostoc carneum, Lyngbya kashyapii, Lyngbya bipunctata, Phormidium* *fragile, Oscillatoria laete-virens, Oscillatoria fremyii, Chroococcus minutus* were recorded only from forest soil. *Hapalosiphonin tricatus, Anabaena fiillebornii, Phormidium jenkelianum, Phormidium calcicole, Oscillatoria homogenea* were recorded only from laterite gravel soil. *Chroococcus giganteus, Lyngbya palmarum, Oscillatoria Formosa* were recorded only from laterite non-gravel soil. *Lyngbya ceylanica, Phormidium retzii, Phormidium uncinatum, Oscillatoria animalis, Oscillatoria salina, Spirulina princeps, Arthospira platensis, Gloeocapsa pleurocapsoides, Microcystis marginata* were recordrd only from pokkali soil. *Arthospira massartii*, *Phormidium ambiguum, Oscillatoria curviceps, Oscillatoria princeps*were recorded from large number of soil types.

The diverse soil types in Thrissur create favourable conditions for a wide range of cyanobacterial biodiversity. Soil habitats are crucial non-aqueous ecosystems for algae, as noted by Zenova *et al.*, (1995). Algae play a significant role in soil formation, enhancing the stability of mature soils (Metting, 1981) and contributing to the energy and matter fluxes within ecosystems (Kuzyakhmetov, 1998). Additionally, soil algae are important for nitrogen fixation, enriching the soil's nitrogen content through biological processes (Goyel, 1997).

Green and blue-green algae, which are abundant and diverse in upper topsoil, provide essential services to soil ecosystems and agriculture (Metting, 1981; Starks *et al.,* 1981; Ruble and Davis, 1988). A key advantage of algae in terrestrial environments is their photoautotrophic ability to produce organic matter from inorganic substances (Alexander, 1977).

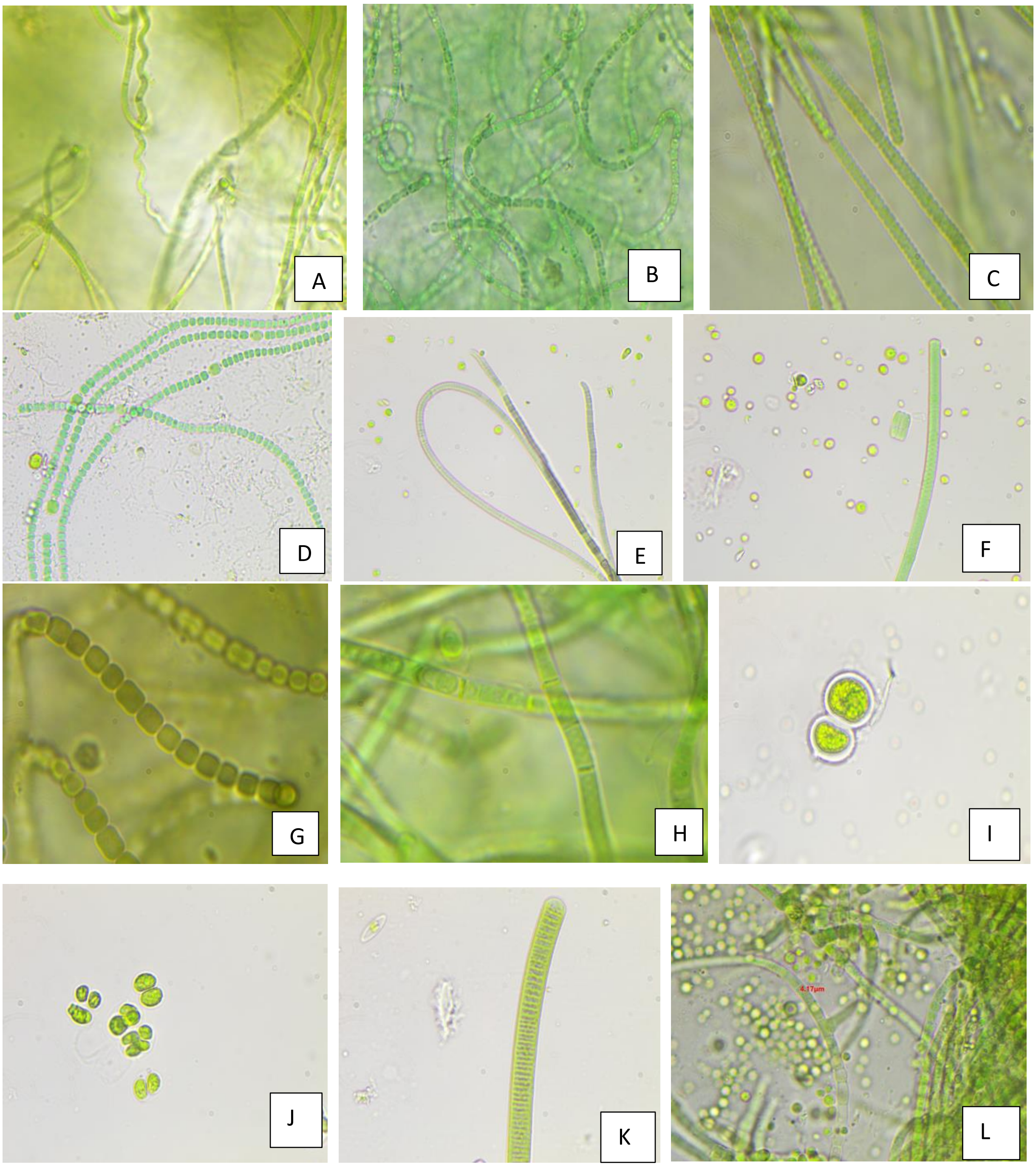


Plate 1: A. *Arthospira platensis* (Nordst.) Gomont **B.** *Oscillatoria formosa* Bory ex. Gomont **C.** *Lyngbya ceylanica* V. *constricta* Fremy (After Fremy) **D.** *Anabeanadoliolum* Bharadw. (after Bharadwaja) **E.** *Phormidium corium* (Ag.) Gom **F.** *Phormidium ambiguum* Gom. (after Fremy) **G.** *Nostoc spongiforme* Agardh ex Born.et Flah **H.** *Lyngbya rubida* Fremy (after fremy) **I.** *Chroococcus pallidus* Nag. (after wille) **J.** *Chroococcus giganteus* west **K.** *Oscillatoria curviceps* forma (after gardner) **L.** *Hapalosiphoni ntricatus*

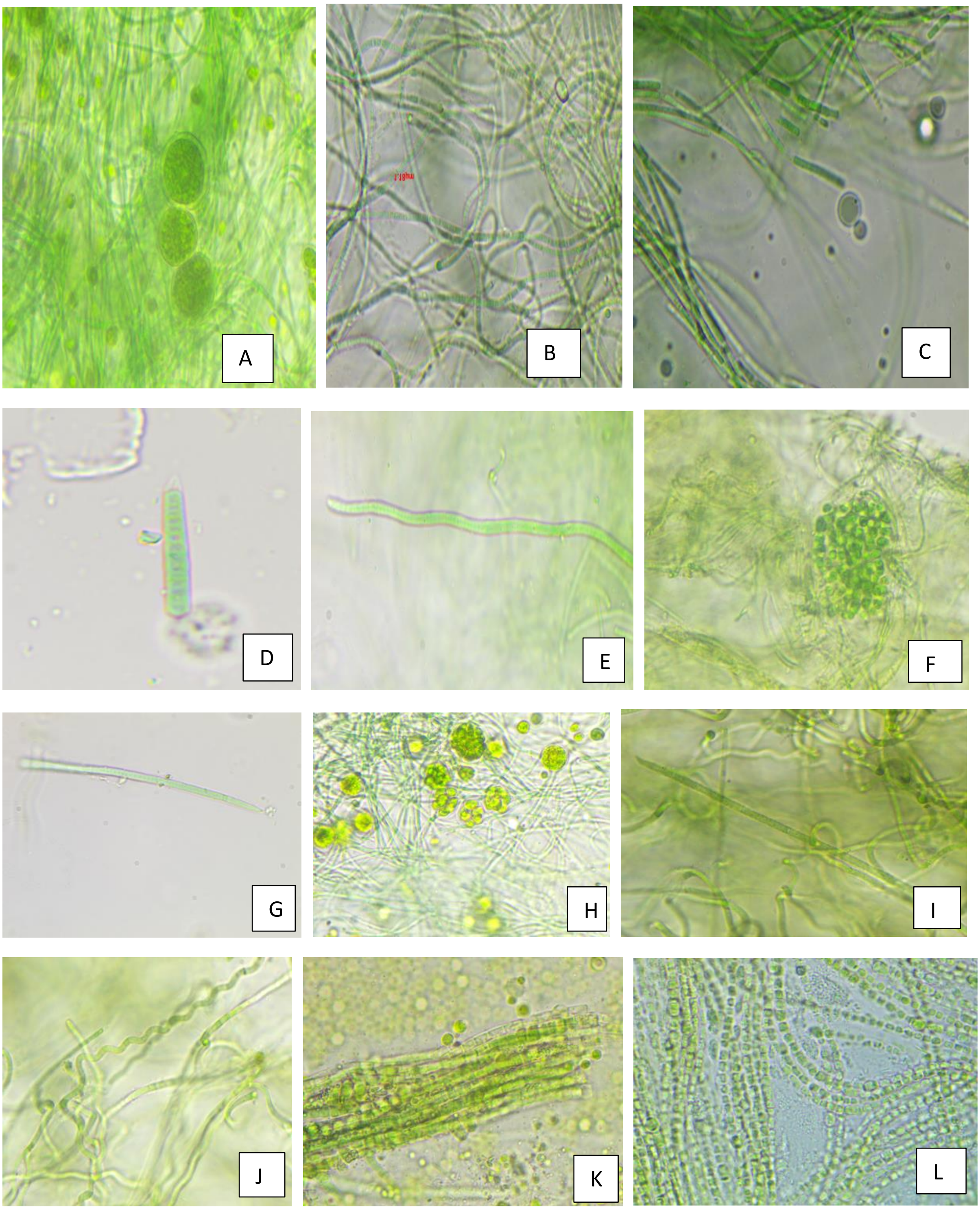


Plate 2: **A.** *Chroococcus indicus* V. epiphyticus Ghose **B.** *Oscillatoria vizagapatensis* Rao (after Rao, C. B) **C.** *Lyngbya palmarum* Bruhl et Biswas (after Bruhl & Biswas) **D.** *Phormidium ceylanicum* Wille. **E.** *Oscillatoria laete-virens* (Grouan) Gomont **F.** *Aphanocapsa koordersi* Strom **G.** *Oscillatoria animalis* Ag. Gom. **H.** *Gomphosphaeria aponina* Kutz. **I.** *Oscillatoria salina* Biswas f.major f.n.Gomont **J.** *Spirulina Meneghiniana* Zanard. ex Gomont **K.** *Symplocamus corum*Ag. Gom **L.** *Nostoc ellipsosporum* Rabenh. (after Fremy)

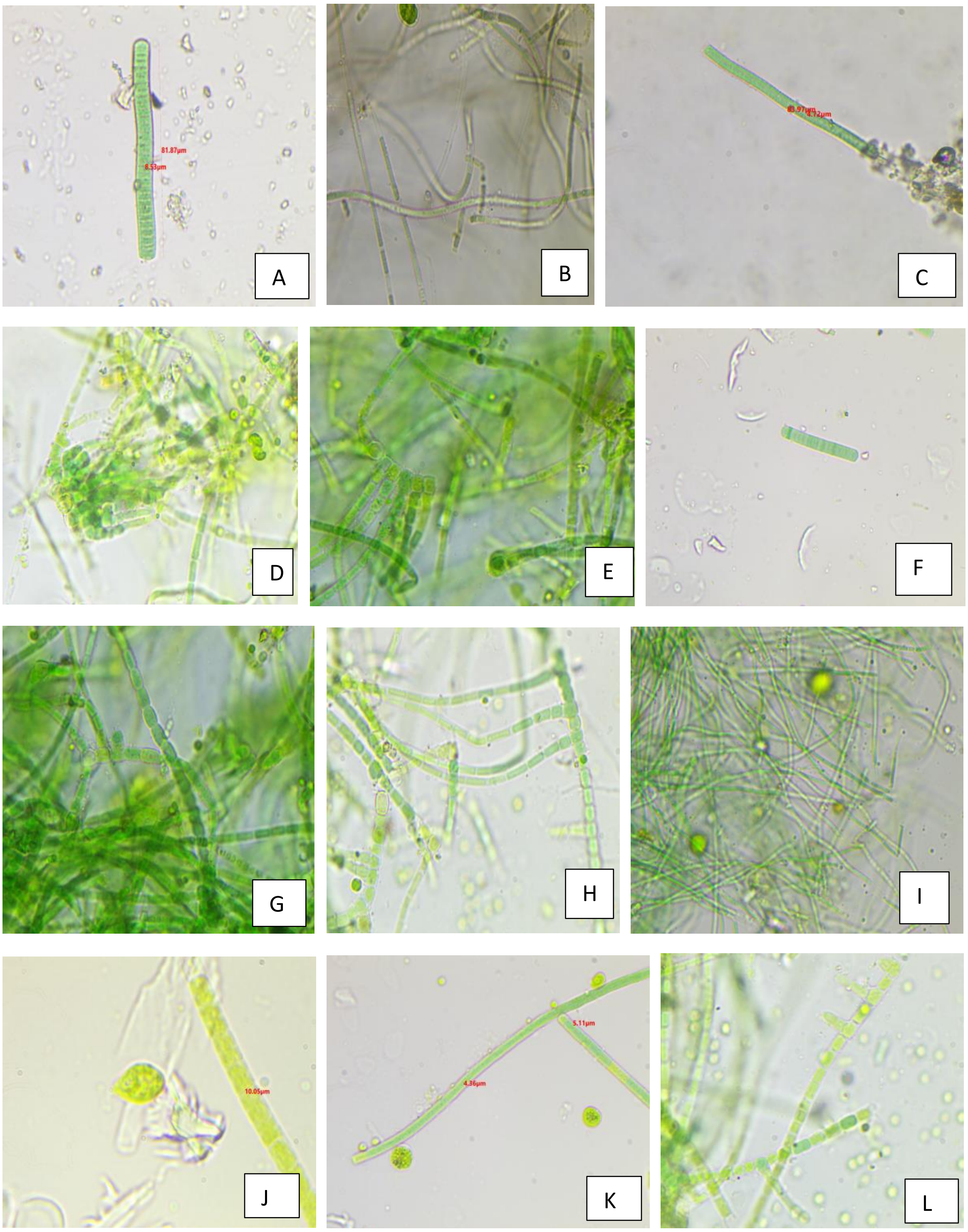


Plate 3: A. *Oscillatoria princeps*. Vaucher ex. Gomont **B.** *Lyngbya kashyapii* **C.** *Oscillatoria irrigua* (Kutz). Gomont **D.** *Rivularia dura* Roth (after fremy) **E.** *Hapalosiphon welwitschia* forma (after Rao, C. B) **F.** *Oscillatoria princeps V. Psuedolimosa* Ghose (after ghose) **G.** *Westiellopsis prolifica* Janet (after Janet) **H.** *Hapalosiphon fontinalis* (Ag.) Born. (After Fremy) **I.** *Lyngbya limnetica* Lemm. (after smith) **J.** *Lyngbya digueti* Gom. (after fremy) **K.** *Oscillatoria tenuis* f. targrstina Rabenh. (after smith) **L.** *Mastigocladopsis jogensis* yengar et Desikachary

5. DISCUSSION

The growth of cyanobacteria in soil is influenced by various factors. These microorganisms can thrive in diverse environments as long as there is adequate moisture and sunlight. Cyanobacteria contribute significantly to soil health by fixing nitrogen, which enriches the soil's nutrient content. Their distribution, ecology, and periodicity vary widely depending on the specific environmental conditions. During favourable climatic periods, certain cyanobacterial species become more prevalent, which can lead to increased soil fertility.

The current study exploring the diversity of cyanobacteria in biological crusts of various soil types. The samples were collected from different locations of Thrissur. During 6-month study about 72 species of cyanobacteria were identified. At all the seven types of soils, Cyanobacteria were represented with largest number of species, (25 species) from kole soil; 16 species from Pokkali soil, 12 species from forest soil, 10 species from laterite non gravel, 9 species from laterite gravel soil and 7 species from riverine alluvial soil.

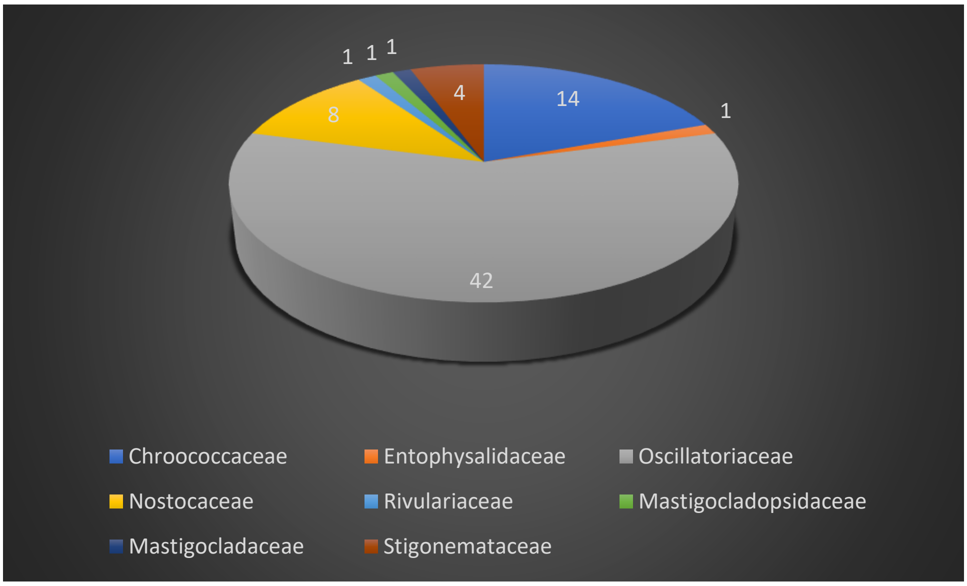


Figure 5.1 showing the family wise distribution of cyanobacteria.

During this study period, certain families are were found to be more abundant compared to others. The highest number of species identified in Oscillatoriaceae family (42 species), followed by Chroococcaceae (14 species), Nostocaceae (8 species) and Stigonemataceae (4 species). Entophysalidaceae, Rivulariaceae, Mastigocladopsidaceae, Mastigocladaceae each contain one species are identified.

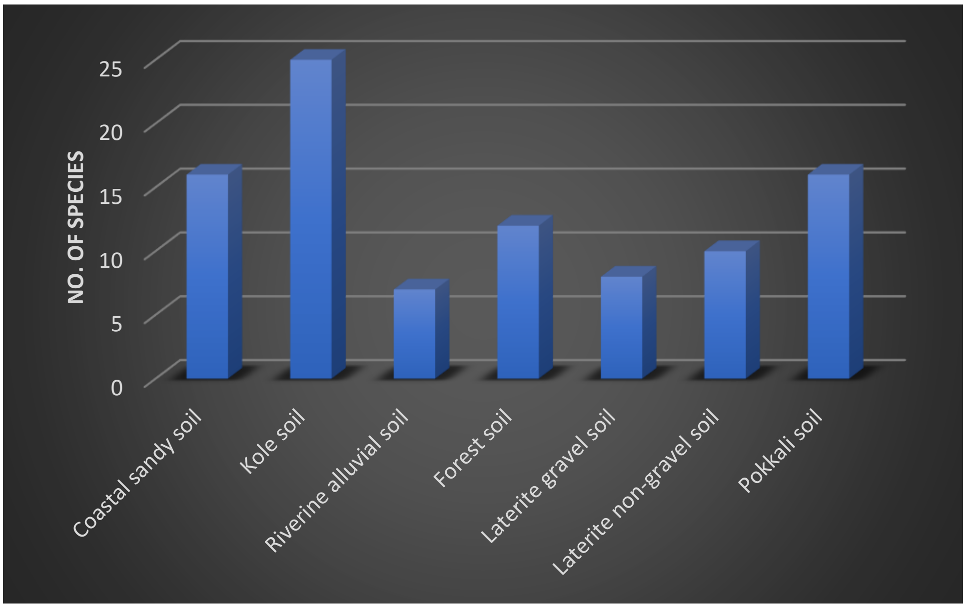


Figure 5.2. showing the cyanobacterial dominance in different soil types.

In the soil studies the highest no. of cyanobacterial species are identified in Kole soil (25 species), followed by the soils coastal sandy and Pokkali soil (16 species), forest soil (12 species), laterite non gravel (10 species), laterite gravel (9 species) and riverine alluvial (7 species). In the present study, I observed the highest no. of cyanobacterial species are found in Kole soil and the least no. of species in riverine alluvial soil.

As the similar studies on cyanobacterial diversity in agriculturally fertile soils of Patna by Mohan and Kumar (2019) recorded 187 species of cyanobacteria belonging to 45 genera. They also suggest that the agriculturally fertile soils of Patna provide favourable conditions for the growth of wide range of cyanobacterial biodiversity. Similar to previous studies on soil algae, such as those by Lukesova and Hoffmann (1995), Lukesova (2001), a wide variety of Cyanobacterial species were identified at each site. Starks and Shubert (1981) also reported a significant number of Cyanobacteria in agricultural soils.

Research on the Cyanobacterial flora of Kerala began with Parukkutty (1940), who documented 51 forms of 'Myxophyceae' in the central and southern regions of the Travancore state. Although most previous and current studies concentrate on Cyanobacterial flora in paddy fields, this work stands out as one of the few that explores areas outside of rice fields, though it still lacks extensive information on forest flora. In the present study, comprehensive soil explorations in the Thrissur district led to the identification and description of 65 species across 19 genera.

Aiyer (1965) and Amma et al. (1966) concentrated their research on the paddy fields in Kerala. Aiyer's investigation of the agricultural fields in Kuttanadu revealed 19 species and noted the widespread presence of *Aulosirafertilissima* in the region's acidic soils. Anand and Hopper (1987) studied the Cyanobacterial flora of paddy fields across various districts in Kerala, publishing a preliminary report on 30 species. They later expanded their research, detailing 158 cyanobacterial species from 33 genera in different agricultural fields (Anand and Hopper, 1995). Similarly, Shaji and Panicker (1994) identified 32 species from 3 genera. Dominic (1997) reported 92 cyanobacterial taxa from 31 genera, also focusing on the paddy fields of Kerala.

Dhanya and Ray (2015) investigated the paddy fields of Kuttanadu, Alappuzha, identifying 64 cyanophycean members from 22 genera, encompassing all three types of cyanobacterial groups. Unicellular genera observed included *Microcystis, Gloeocapsa, Gloeothece, Aphanothece, Aphanocapsa, Chroococcus, Synechocystis,* and *Merismopedia, with Chroococcus* being the most represented, showing four species. John (2008) explored the algal flora of the Idukki District, reporting 48 cyanobacterial species across six families, predominantly unicellular cyanobacteria from freshwater ecosystems. However, the genera *Arthrospira, Merismopedia,* and *Spirulina* were not represented in this study. Manu Philip (2020) conducted research on the Cyanobacterial diversity in the Western Ghats forests of Kerala, identifying 203 species, with heterocystous cyanobacteria dominating. *Chroococcus* emerged as the most adaptable genus, and the study also discovered 31 new species. Thomas *et al.,* (2017) studied the impact of pH on the diversity of soil algae at Catholicate College, Kerala, identifying thirteen species and emphasizing the importance of soil pH as a key factor. Tessy and Sreekumar (2010) investigated the Cyanobacterial diversity in the "kol" wetlands of Thrissur District, finding that members of the Oscillatoriaceae family were predominant.

Cyanobacteria, known for their adaptations to various environmental challenges, are considered to encompass the widest diversity among photosynthetic organisms across diverse habitats (Badger *et al.,* 2006). Despite this, they remain one of the most underexplored groups of organisms. The diversity of these organisms, particularly in areas with minimal human interference, has been more a matter of speculation than thorough exploration. Their significance as a major component of soil microflora in agricultural fields, crucial for soil fertility enhancement, has been extensively studied (Dhanya and Ray, 2015).

6. CONCLUSION

Cyanobacteria in soil play a crucial role in maintaining soil health and ecosystem stability. These photosynthetic microorganisms contribute significantly to soil fertility by fixing atmospheric nitrogen, which enhances nutrient availability for plants. Their ability to form symbiotic relationships with fungi and plants further improves soil structure and water retention. Cyanobacteria also produce organic matter through photosynthesis, enriching the soil with carbon compounds and promoting microbial diversity. Additionally, they help combat soil erosion by forming biofilms that stabilize soil particles. Overall, cyanobacteria are essential for sustainable agriculture and environmental conservation, making them vital components of soil ecosystems.

The study represents an identification and diversity studies of cyanobacteria in soils, about 72species under genera. The species belongs to 8 families under 3 orders. Nostocales is the 20 prominent order with 3 families. Most number of genera belong to Oscillatoriaceae family (42 species). Among 65 species of identified cyanobacteria, 25 species from Kole soil; 16 species from Pokkali soil, 12 species from forest soil, 10 species from laterite non gravel, 9 species from laterite gravel soil and 7 species from riverine alluvial soil. The dominant order is Nostocales with 51 species, (42 species Oscillatoriaceae, 8 species Nostocaceae and one species Rivulariaceae), followed by Chroococcales with 15 species. Third dominated order is Stigonematales with 6 species each.

The dominant family in the studied area is Ocillatoriaceae. These filamentous cyanobacteria contribute to soil fertility through nitrogen fixation, converting atmospheric nitrogen into forms accessible to plants. By producing extracellular polysaccharides, they enhance soil structure and water retention, aiding in soil stabilization and reducing erosion. Highest number of Oscilloriaceae family members are found in Kole soil and least in laterite gravel soil. Kole soils, known for their seasonal flooding and high organic content, benefit from the nitrogen-fixing abilities of Oscillatoriaceae, which enhance nutrient availability for crops. These cyanobacteria also contribute to soil stability by producing extracellular polysaccharides, which improve soil structure and water retention. Additionally, the organic matter produced by Oscillatoriaceae through photosynthesis supports a diverse microbial community, further enriching the soil. This microbial activity is essential for sustaining the fertility and productivity of Kole lands, making Oscillatoriaceae an integral component of the region's agricultural ecosystem.

7. REFERENCES

Aiyer R.S. (1965). Comparative algological studies in rice fields in Kerala state. *Agricultural Research Journal of Kerala 3*,100-104.

Alexander, M. (1977). Introduction to soil microbiology. *WileyNY*.

Amma P.A., Aiyer R.S. and Subramoney N. (1966). Occurrence of blue-green algae in acidic soils of Kerala. *Agricultural Research Journal of Kerala, 4,* 141-146.

Anand N. & Hopper R.S.S. (1987). Blue-green algae (cyanobacteria) from several rice fields of Kerala, India. *Hydrobiologia 144*, 223-232.

Anand N. & Hopper R.S.S. (1995). Distribution of blue-green algae in rice fields of Kerala state, India. *Phykos 34,* 54-64.

Arun, T. R., & Tessy, P. P. (2022). Mangrove-Associated Cyanobacteria of *Nostoc spp.* (Nostocales, Nostocaceae) from Kerala State, India. *International Journal on Algae*, *24*(2).

Badger M.R., Price G.D., Long B.M., and Woodger F.J., (2006). The environmental plasticity and ecological genomics of the cyanobacterial CO2 concentrating mechanism. *Journal of Experimental Botany 57(2),* 249-265.

Belnap, J., Weber, B., &Büdel, B. (2016). Biological soil crusts as an organizing principle in drylands. *Springer International Publishing,* 3-13.

Bibi, S., Saadaoui, I., Bibi, A., Al-Ghouti, M., &Dieyeh, M. H. A. (2024). Applications, advancements, and challenges of cyanobacteria-based biofertilizers for sustainable agro and ecosystems in arid climates. *Bioresource Technology Reports, 101789.*

Cameron, R. E. (1963). Algae of Southern Arizona. I. Introduction: Blue-green algae. *Reviews in Algology, 6,* 282-318.

Chamizo, S., Rodríguez-Caballero, E., Cantón, Y., & De Philippis, R. (2018). Soil inoculation with cyanobacteria: reviewing its' potential for agriculture sustainability in Drylands. *Agricultural research & technology*, *18*, 1-5.

Delilah, D., Mathew, N. M., Joseph, A., Jose, S., &Kumar, S. A. (2023). Review of the Distribution of Microalgae Collected from Paddy Fields in India.

Dhanya V. &Ray J.G. (2015). Ecology and Diversity of Cyanobacteria in Kuttanadu paddy wetlands, Kerala, India. *American Journal of Plant Sciences 6*, 2924-2938.

Dominic T.K. (1997). Isolation and Characterization of Non-symbiotic Nitrogen Fixing Cyanobacteria of Paddy Fields of Kerala. Ph.D. thesis, Calicut University. 220p.

Easa P.S. (2004). Biodiversity documentation for Kerala. *Kerala Forest Research Institute,* 71.

Friedmann, E. I. and Galun, M. (1974). Desert algae, Lichens and Fungi. In Brown, G. W. (Jr.) (ed) Desert Biology. II*, Academic Press, New York.*

Goyel, S.K. (1997). Algae and the soil environment. *Phykos*,*36*, 1-13.

Johansen, J. R., & Shubert, L. E. (2001). Algae in soils. *Nova HedwigiaBeiheft*, *123*, 297-306.

John J. (2008). An Investigation on the Fresh Water Algal Flora of Idukki District. Ph.D. Thesis, Department of Botany, Sacred Heart College, Thevara, Kochi. 314p.

Kour, B., Sharma, P., Ramya, S., Gawdiya, S., Sudheer, K., & Ramakrishnan, B. (2023). Response of distinct soil types to cyanobacterial biofertilizer inoculation.

Kuzyakhmetov, G.G., (1998). Productivity of algocenoses in Zonal arable soils of stepp and forest- stepp. *Eurasian Soil Sci. 31,* 406-410.

Lukesova, A. (2001). Soil algae in brown coal and lignite post-mining areas in Central Europe (Czech Republic and Germany). *Restoration Ecol. 9*, 341-350.

Lukesova, A.,Hoffmann, L. (1995). Soil algae from acid rain impacted forest areas of the Krusnehory Mountains. 2. Effect of pH on growth. *Algological Stud. 78*, 39-51.

Lukesova, A. (1993). Soil algae in four secondary succesional stages on abandoned fields. *Algological Stud. 71*, 81-102.

Maske, S. S., Sangolkar, L. N., & Chakrabarti, T. (2010). Temporal variation in density and diversity of cyanobacteria and cyanotoxins in lakes at Nagpur (Maharashtra State), India. *Environmental monitoring and assessment*, *169*, 299-308.

Mendhekar, S. V. (2023). Cyanobacteria: Isolation, Purification and Principles. *International Journal of Current Scientific Research and Review 6*, 2688-2696.

Metting, B (1981): The systematics and ecology of soil algae, *Bot. Rev., 47*, 195-312.

Mohan, A., & Kumar, B. (2019). Cyanobacterial diversity in agriculturally fertile soil of Patna and their population density. *Biotechnol Appl Biochem*, *5(1),* 15-32.

Nikam, T. D., Nehul, J. N., Gahile, Y. R., Auti, B. K., Ahire, M. L., Nitnaware, K. M., &Jawali, N. (2013). Cyanobacterial diversity in Western Ghats region of Maharashtra, India. *Methods*.

Ninan, M., Thomas, B. T., & T.V, P. (2022). Cyanobacteria, a tool for planetary engineering.

Nordin, R. N., & Blinn, D. W. (1972). Analysis of a saline tallgrass prairie ecosystem. IV. Preliminary investigations on soil algae. *North Dakota Academy of Science, 25*, 8-17.

Parukutty P.R. (1940). The Myxophyceae of the Travancore state, India. *Proceedings of the Indian Academy of Sciences: Mathematical Sciences 11*, 117-127.

Philip, M. (2020). Cyanobacterial diversity of western ghat forests of Kerala, India (Doctoral dissertation, University of Calicut).

Philip, M., Parambil, F. V., & Shamina, M. (2016). Diversity of Cyanobacterial Flora at Nelliyampathy, Kerala. *South Indian Journal for Biological Science (2)*, *1*, 198-202.

Prasanna, R., & Nayak, S. (2007). Influence of diverse rice soil ecologies on cyanobacterial diversity and abundance. *Wetlands Ecology and Management*, *15*, 127-134.

Prasanna, R., Jaiswal, P., Nayak, S., Sood, A., & Kaushik, B. D. (2009). Cyanobacterial diversity in the rhizosphere of rice and its ecological significance. *Indian Journal of Microbiology*, *49*, 89-97.

Prasanna, S. N. R. (2007). Soil pH and its role in cyanobacterial abundance and diversity in rice field soils. *Appl. Ecol. Environ. Res*, *5*(2), 103-113.

Ram A.T. &Shamina M., (2015). New report of cyanobacterial association on the roots of epiphytic orchid *Dendrobium crumenatum* Sw. *International Journal of Chemical and Biological Sciences 12(1),*19-21.

Ram, A. T. (2021). A review on the distribution records of mangrove-associated heterocytous cyanobacteria: An update. *Egyptian Journal of Phycology, 22(1),* 119-136.

Ram, A. T., & Paul, P. T. (2023). The List of Cyanobacteria (*Coleofasciculales, Oscillatoriales, Pleurocapsales, Pseudanabaenales and Spirulinales*) from the Mangrove Ecosystems: A Review from 1889 to 2020. *International Journal on Algae*, *26*.

Ram, A. T., & Shamina, M. (2015). Identification of cyanobacterial association from the roots of the terrestrial orchid, *Spathoglottis plicata* Blume. *Int. J. Adv. Res*, *3*(5), 1477-1479.

Ram, A. T., & Shamina, M. (2015). Mangrove Associated Cyanobacterial Diversity at Kottayam District, Kerala, India. *Int. J. Chem. Biol. Sci*, *1*(10), 20-24.

Ram, A. T., & Shamina, M. (2017). Cyanobacterial diversity from seven mangrove environments of Kerala, India. *World News of Natural Sciences*, *9*.

Ray, J. G., & Thomas, T. B. (2012). Ecology and diversity of green-algae of tropical *oxicdystrustepts* soils in relation to different soil parameters and vegetation.

Rouble, R.W., Davis, J.S. (1988). Soil algae from fallow potato fields in south Florida (USA) marl. *Nova Hedwigia, 47,* 403-414.

Sakthivel, K., & Kathiresan, K. (2013). Cyanobacterial diversity from mangrove sediment of south east coast of India. *Asian Journal of Biodiversity*, *4*(1).

Sebastian S. and Joseph A. (2013). Filamentous algae of a hill stream of Kerala, India. *Journal of Environmental Science, Toxicology and Food Technology 4(3)*, 35-39

Shaji C. and Panikkar M.V.N. (1994). Cyanophyceae of Kerala, India. *Phykos 33*, 105-112.

Shamina M. and Ram A.T. (2014). *Oscillatoria ornate* Kutz. ex Gomont. var. crassa Rao, C.B. (Oscillatoriaceae): First report to India from marine habitat. *International Journal of Advanced Research 8(2),*232-234.

Singh, H., Khattar, J. S., & Ahluwalia, A. S. (2014). Cyanobacteria and agricultural crops. *Vegetos*, *27*(1), 37-44.

Singh, S. S., Kunui, K., Minj, R. A., & Singh, P. (2014). Diversity and distribution pattern analysis of cyanobacteria isolated from paddy fields of Chhattisgarh, India. *Journal of Asia-Pacific Biodiversity, 7(4),* 462-470.

Singh, Y., Khattar, J. I. S., Singh, D. P., Rahi, P., & Gulati, A. (2014). Limnology and cyanobacterial diversity of high-altitude lakes of Lahaul-Spiti in Himachal Pradesh, India. *Journal of biosciences*, *39*, 643-657.

Smitha, S., &Ammini, J. (2015). Occurrence of filamentous algae and soil characteristics in the paddy fields of Kuttanad and Kole lands of Kerala (Doctoral dissertation, Cochin University Of Science And Technology).

Starks, T. L., Schubert, L. E., & Trainor, F. R. (1981). Ecology of soil algae: A review. *Phycologia, 20*, 65-80.

Subudhi, E., Sahoo, R. K., Gaur, M., Singh, A., & Das, A. (2018). Shift in cyanobacteria community diversity in hot springs of India. *Geomicrobiology Journal*, *35*(2), 141-147.

Syiem, M. B., Nongbri, B. B., Pinokiyo, A., Bhattacharjee, A., Nongrum, N. A., &Hynniewta, L. (2010). Significance of cyanobacterial diversity in different ecological conditions of Meghalaya, India. *Journal of Applied and Natural Science*, *2*(1), 134-139.

Tessy P.P. and Sreekumar R., (2010). Diversity of blue green algae in Thrissur Kol wetlands (part of Vembanadu- Kol, Ramsar site), Kerala, India. In: Green Path to Sustainability-Prospects and Challenges (Eds. Cheriyan R.C., Chandramohan Kumar N., Nandan B. S., Reethamma O.V., Neerakkal I. and Agustine A.) *Assumption College, Kottayam in association with Cochin university of Science and Technology, Cochin*, 50-54.

Thajuddin, N., & Subramanian, G. (1992). Survey of cyanobacterial flora of the southern east coast of India.

Thomas, B. T., Bhagya, M. V., & Thomas, V. P. (2017). *Trentepohlia dialepta* (Nylander) Hariot: A terrestrial alga from Southern Western Ghat region, Kerala, India. *Phykos*, *42*, 10-13.

Thomas, B. T., Bhagya, M. V., Mol, S. S., & Reshma, R. (2018). In vitro culturing and biochemical properties of green and blue-green algae in the laterite soil. *Vegetos*, *31*(4), 28-34.

Thomas, B. T., Rajan, R., Saranyamol, S. T., & Bhagya, M. V. (2017). Influence of pH on the diversity of soil algae. *J. Glob. Biosci*, *6*, 5088-5094.

Tripathy, P. (2006). Ecophysiological studies on drought tolerant cyanobacteria in different soils.

Umamaheswari, N. A. (2005). Isolation and characterisation of Nostocales cyanobacteria of the paddy fields of Kerala.

Venkataraman. (1969). Axenic culture of the cyanobacteria was used in the experiments.

Vijayan, D., & Ray, J. G. (2015). Ecology and diversity of cyanobacteria in Kuttanadu paddy wetlands, Kerala, India. *American Journal of plant sciences*, *6(18),* 2924-2938.

Yadav, P., Singh, R. P., Hashem, A., Abd_ Allah, E. F., Santoyo, G., Kumar, A., & Gupta, R. K. (2023). Enhancing Biocrust Development and Plant Growth through Inoculation of Desiccation- Tolerant Cyanobacteria in Different Textured Soils. *Microorganisms*, *11(10),* 2507.

Zenova, GM., Shtina, E.A., Dedysh, S.N., Glagoleva, O.B., Likhacheva, A.A., Gracheva, T.A. (1995). Ecological relations of algae in biocenoses. *Mikrobiologiya*, *64*, 121-133.