

Coupling Soil nutrient fluxes with photosynthetic functioning in Mangrove ecosystem

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Abstract

Mangrove ecosystems are influenced by a complex interaction of edaphic factors, among which soil nutrient availability plays a pivotal role in regulating photosynthetic productivity. The present study focuses on the productivity patterns of selected mangrove species of Kannur district, Kerala. For this study, three mangrove rich sites of various degrees of nutrient availability and ecological conditions were selected.

Analysis of Chlorophyll a, Chlorophyll b, and total chlorophyll content revealed clear habitat-dependent variations, influenced by environmental factors and the concentrations of key nutrients such as nitrogen, phosphorus, potassium, magnesium, iron, and manganese. The results indicate a clear gradient in productivity, with Site 1 showing the highest and Site 2 the lowest, despite its relatively nutrient-rich profile. This paradox suggests that pollution-induced stress limit the physiological utilization of nutrients, thereby suppressing overall photosynthetic efficiency. Among the nutrients analyzed, potassium, magnesium, and iron emerged as key contributors to enhanced productivity, supporting their fundamental roles in chlorophyll synthesis, stomatal regulation, and enzymatic activity. The result reveals, the highest productivity, and ecological adaptability of *Kandelia candel* due to the efficient nutrient uptake mechanisms. The study focuses on the significance of balancing nutrient utilisation and ecological stress related to the functioning of mangrove ecosystem. The study of edaphic factors and its relation to physiological functioning of mangroves helps to formulate conservation and restoration practices in the most fragile ecosystem.

Introduction

Mangrove ecosystems are ecologically significant coastal wetlands that serve as vital interfaces between terrestrial and marine environments. They provide a range of ecosystem services, including shoreline stabilization, carbon sequestration and nutrient cycling (Fries et. al., 2020). Their ability to thrive in saline, waterlogged, and nutrient-variable conditions is largely attributed to their specialized physiological and morphological adaptations. Among these, photosynthetic functioning, often assessed through chlorophyll content, serves as a key indicator of plant health and productivity (Naskar and Palit, 2015).

Chlorophyll pigments, primarily Chlorophyll a and Chlorophyll b are vital for light absorption and energy transfer during photosynthesis. Their concentration in leaf tissue can be influenced by a range of factors including species-specific traits, environmental conditions, and critically, soil nutrient availability. Nutrients such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), iron (Fe), and manganese (Mn) are essential not only for chlorophyll biosynthesis but also for maintaining overall physiological efficiency in mangrove plants (Alongi, 2021). While mangroves are known to persist in nutrient-poor environments, variations in nutrient dynamics across different sites, especially those affected by anthropogenic activity, can significantly alter their photosynthetic performance.

Understanding this relationship is essential for assessing ecosystem health, managing degraded habitats, and supporting effective conservation strategies.

The present study investigates the photosynthetic responses of selected true mangrove species across three contrasting wetland sites in Kannur district, Kerala, by analysing variations in Chlorophyll a, Chlorophyll b, and total chlorophyll content in relation to soil nutrient profiles. This research aims to elucidate the ecophysiological link between nutrient availability and photosynthetic capacity, with implications for mangrove adaptation, productivity and habitat quality.

Materials and Methods

The present study was carried out in three mangrove wetland sites located in Kannur district, Kerala, representing distinct geographic zones: ie; the northern zone, Koduvally (Site 1), the middle zone, Valapattanam (Site 2), and the southern zone, Kunhimangalam (Site 3). These sites were selected based on their ecological characteristics, nutrient status, and varying levels of environmental stress. Eight true mangrove species including *Bruguiera cylindrica*, *Avicennia officinalis*, *Avicennia marina*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Kandelia candel*, *Aegiceras corneculatum* and *Sonneratia alba* were selected for analysis. Mature, healthy leaves were collected from each species at their respective sites for chlorophyll estimation.

Chlorophyll a, Chlorophyll b, and total chlorophyll content were quantified using the standard method of Arnon (1949). Fresh leaf samples (0.5 g) were homogenized in 80% acetone, and the extract was centrifuged to obtain a clear supernatant. Absorbance was measured at 645 nm and 663 nm using a spectrophotometer. The concentrations of chlorophyll a and b were calculated using standard equations, and the results were expressed in milligrams per gram (mg/g) of fresh tissue.

Soil samples were collected from the rhizosphere zone (0–15 cm depth) of each mangrove species using a soil core sampler. Samples were air-dried, sieved and stored for nutrient analysis. The soil nitrogen content was estimated using the chromotropic method (Clark & Jennings, 1965), while available phosphorus was determined using Olsen's method. Potassium was analyzed by flame photometry (Stanford, 1949), and magnesium (Cheng & Bray, 1951), iron (Asami & Kumadi, 1959) and manganese (Lindsay and Martens, 1990) concentrations were estimated using Atomic Absorption Spectrophotometry after acid digestion. Nutrient concentrations were initially recorded in different units and later standardized to a common unit (kg/ha) for comparative purposes.

Data obtained from chlorophyll and nutrient analyses were statistically evaluated using analysis of variance to determine significant differences among sites and species. Pearson correlation analysis was performed to assess the relationship between chlorophyll parameters and soil nutrient concentrations.

Results

The present study revealed distinct variations in chlorophyll content and soil nutrient availability across the three mangrove wetland sites- Koduvally (Site 1), Valapattanam (Site 2), and Kunhimangalam (Site 3), in Kannur district, Kerala. Chlorophyll a, Chlorophyll b, and total chlorophyll content varied significantly between sites and among species, indicating a strong influence of site-specific conditions and nutrient dynamics.

Chlorophyll variation across sites

Chlorophyll content showed notable variation among the three studied mangrove wetlands. The highest values of Chlorophyll a, Chlorophyll b, and total chlorophyll were observed in site 1, indicating superior photosynthetic activity and favourable environmental conditions. site 2 (Valapattanam) recorded the lowest chlorophyll content across most species, while site 3 (Kunhimangalam) exhibited moderate values. Among the species, *Kandelia candel* recorded the highest total chlorophyll content, particularly in site 1, followed by *Avicennia marina*, *Bruguiera cylindrica* and *Rhizophora mucronata*, indicating their high photosynthetic efficiency. In contrast, *Sonneratia alba* and *Aegiceras corniculatum* showed consistently low chlorophyll value. Site 2 exhibited low species diversity; however, *Avicennia officinalis* showed relatively higher pigment content, suggesting its better adaptability to moderate stress conditions. Chlorophyll content at site 3 appears moderate across species, falling between the values observed at site 1 and site 2. *Bruguiera cylindrica*, *Rhizophora apiculata*, *Aegiceras corniculatum*, and *Avicennia officinalis* maintain comparatively higher chlorophyll levels at this site. Overall, the variation in chlorophyll levels across sites and species reflects differences in nutrient uptake capacity and environmental tolerance.

Variation in soil nutrients profiles

The nutrient profiles of the three wetlands showed distinct variations in the concentrations of soil nutrients. Magnesium was the most abundant nutrient across all three wetlands, with concentrations decreasing from Koduvally (300 ppm) to Kunhimangalam (270 ppm) and then Valapattanam (150 ppm). Iron levels were consistently high and similar across all three sites. Nitrogen and phosphorous concentrations were relatively low at all locations, with slightly higher values observed in Koduvally. Potassium levels were highest in Valapattanam, followed by Kunhimangalam and Koduvally. Manganese was lowest in Koduvally and Kunhimangalam, but showed a notable increase in Valapattanam (40 ppm). Overall, Koduvally exhibited the most enriched nutrient profile, while Kunhimangalam and Valapattanam showed moderate nutrient levels. Notably, Valapattanam recorded comparatively higher concentrations of potassium and manganese despite lower levels of other nutrients.

Comparative analysis of chlorophyll and Soil Nutrients

The findings emphasize that photosynthetic functioning in mangroves is not solely dependent on nutrient abundance, but also on-site quality and species-specific physiological responses. Site 1

recorded more balanced nutrient profile, with adequate levels of magnesium, phosphorus, and micronutrients, supporting better chlorophyll synthesis.

A clear relationship was observed between chlorophyll content in mangrove species and the soil nutrient profiles of the three wetlands. Koduvally and Kunhimangalam wetlands, which showed higher levels of magnesium and iron, also exhibited higher chlorophyll content. This suggests that these nutrients, essential for chlorophyll formation and photosynthesis, play a key role in supporting healthy mangrove growth. In contrast, the Valapattanam wetland, despite having high potassium levels, showed relatively moderate chlorophyll values, likely due to its lower magnesium content compared to other sites. Nitrogen and phosphorus levels were generally low across all sites, and may have limited influence under the given conditions.

The results indicate a positive link between chlorophyll content and the availability of magnesium and iron in mangrove soils, underlining their importance in maintaining photosynthetic efficiency and ecological productivity in wetland ecosystems.

Discussion

The observed variations in chlorophyll content among mangrove species across different sites indicate a strong dependence on local soil conditions and environmental quality. The highest chlorophyll content at Site 1 suggests optimal nutrient balance and lower stress, whereas reduced pigment levels at Site 2 may be attributed to pollution or suboptimal growing conditions. Chlorophyll biosynthesis is directly linked to the availability of essential nutrients such as nitrogen (N), magnesium (Mg), and potassium (K), which play crucial roles in photosynthetic enzyme activation and pigment stability (Lichtenthaler, 1996; Taiz & Zeiger, 2010).

Kandelia candel, with its consistently high chlorophyll content, appears to possess efficient nutrient uptake mechanisms and physiological resilience, making it a promising species for restoration in variable or nutrient-limited environments. Similar observations were made by Alongi (2002), who highlighted species-specific nutrient responses in mangrove physiology. In contrast, *Sonneratia alba* and *Aegiceras corniculatum* showed lower pigment values, which may indicate sensitivity to environmental stress or limitations in nutrient assimilation. Previous studies have reported that reduced chlorophyll content often corresponds with increased oxidative stress or nutrient imbalance in mangrove species (Parida & Jha, 2010; Reef et al., 2010; Kathiresan & Bingham, 2001). This supports the view that both nutrient availability and habitat must be considered when assessing mangrove health.

Conclusion

Understanding the link between nutrient availability and photosynthetic performance is crucial for evaluating mangrove health and ecological resilience. The present investigation revealed that, distinct site-specific variations in chlorophyll a, chlorophyll b, and total chlorophyll content among seven true mangrove species across three wetland sites in Kannur district. Site 1 exhibited the highest productivity,

corresponding with better nutrient status and minimal stress, whereas Site 2 showed the lowest chlorophyll levels, likely due to moderate pollution and nutrient limitations. Site 3 displayed intermediate values, with species like *Bruguiera cylindrica*, *Rhizophora apiculata*, and *Avicennia officinalis* maintaining relatively stable pigment content. Notably, *Kandelia candel* demonstrated the highest overall productivity, reflecting efficient nutrient utilization and adaptability. Among the nutrients analysed, magnesium and iron identified as key elements influencing the photosynthetic efficiency and primary productivity in mangrove ecosystems, whereas, nitrogen remained the major limiting factor. In addition to that, photosynthetic functioning in mangroves is not merely a function of nutrient abundance, but also reflects species-specific physiology and environmental stress gradients. These insights are valuable for conservation and sustainable management of mangrove ecosystems under changing environmental conditions.

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Figures

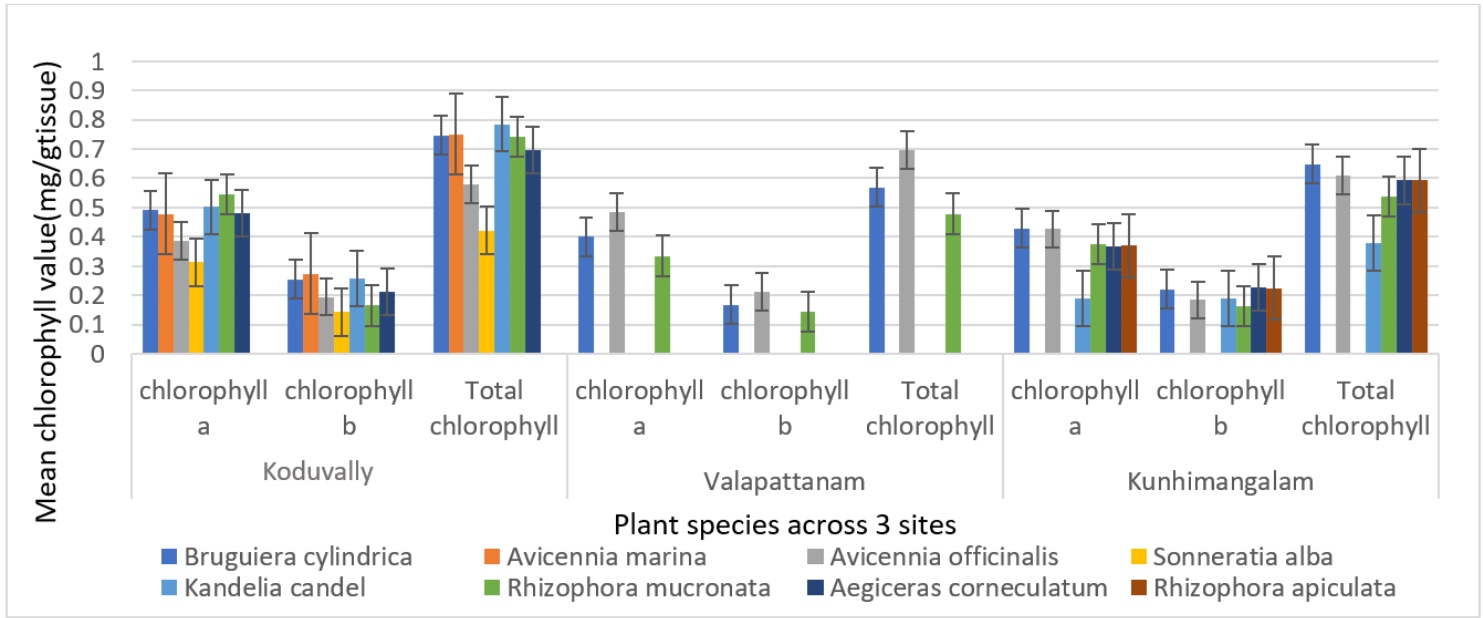


Figure 1

Comparative chlorophyll profiles of mangrove wetlands

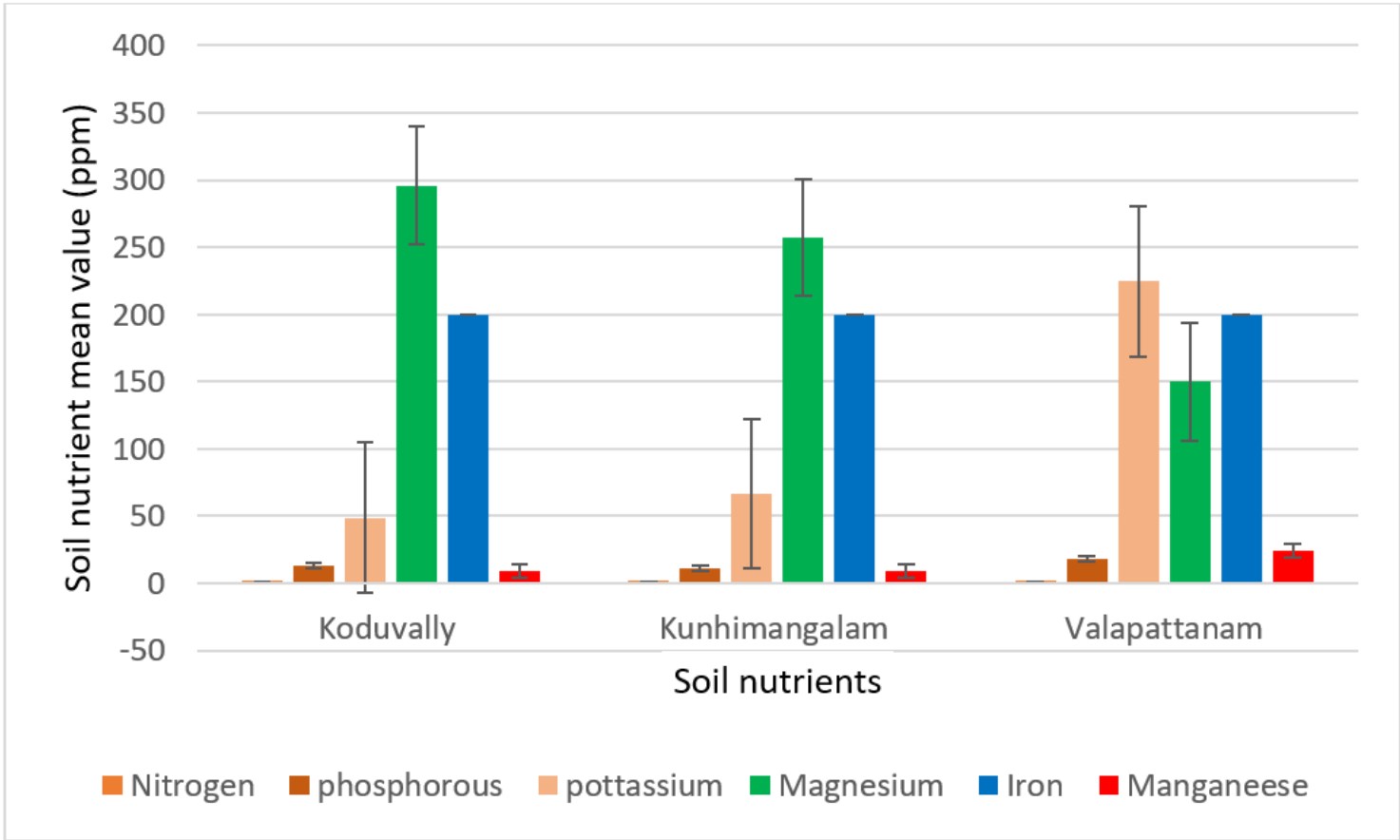


Figure 2

Soil nutrient profiles across three wetlands