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Nutrient Exchange Within Forest Ecosystems and Characterization of Mycorrhizal Diversity

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Abstract:

Forest ecosystems are sustained by complex belowground interactions that regulate nutrient cycling, plant productivity, and ecosystem stability. Among these interactions, mycorrhizal fungi form extensive symbiotic networks with plant roots, facilitating nutrient exchange and plant communication. The present study investigates the diversity of mycorrhizal fungi and examines the functional role of mycorrhizal networks in nutrient exchange within forest ecosystems. Field surveys were conducted across representative forest sites, and soil and root samples were collected for analysis. Mycorrhizal communities were characterized using molecular techniques, including DNA sequencing, to accurately identify and classify fungal taxa. The results revealed high mycorrhizal diversity and strong associations between fungi and host plant species. Increased mycorrhizal colonization was positively correlated with enhanced nitrogen and phosphorus uptake. The findings highlight the ecological significance of mycorrhizal networks in maintaining forest health, nutrient dynamics, and ecosystem resilience.

Keywords: Mycorrhizal networks; Forest ecosystems; DNA sequencing; Nutrient exchange; Plant–fungal interactions.

1. Introduction

Forest ecosystems represent some of the most biologically diverse and productive environments on Earth. The sustainability of these ecosystems depends largely on efficient nutrient cycling processes occurring within soil–plant systems. Nutrient availability often limits forest productivity, particularly in tropical and temperate forests where essential elements such as nitrogen and phosphorus are present in complex organic forms. Microorganisms play a crucial role in transforming and mobilizing these nutrients.

Among soil microorganisms, mycorrhizal fungi form mutualistic associations with the roots of most terrestrial plants. Through these associations, fungi enhance nutrient and water uptake, while plants supply photosynthetically derived carbon to the fungi. Mycorrhizal networks further interconnect individual plants, enabling nutrient transfer and signaling among different species. Understanding nutrient exchange mechanisms and mycorrhizal diversity is therefore essential for forest ecology, conservation, and

sustainable management.

2. Materials and Methods

Study Area

The study was conducted in the **Amrabad Tiger Reserve forest region, Telangana, India**, which forms part of the Nallamala forest range of the Eastern Ghats. The area is characterized by dry deciduous to moist deciduous forest vegetation dominated by species such as *Tectona grandis*, *Terminalia tomentosa*, *Anogeissus latifolia*, and *Pterocarpus marsupium*. The region experiences a tropical monsoon climate with an average annual rainfall of approximately 900–1,000 mm and temperatures ranging from 15°C in winter to 42°C in summer. The soils are predominantly red sandy loam to gravelly soils with moderate organic matter content, providing suitable conditions for mycorrhizal development.

Soil Sampling

Soil samples were collected from the rhizosphere zone of dominant tree species. Sampling was carried out during the active growing season to ensure maximum mycorrhizal activity.

- Soil cores were collected at a depth of 0–15 cm using a sterile soil auger.
- Five replicate samples were taken from each plot and pooled to form a composite sample.
- Samples were stored in sterile polyethylene bags and transported to the laboratory under cool conditions.

Root Sampling

Fine roots were carefully excavated from sampled trees to avoid damage. Roots were washed gently with distilled water to remove adhering soil particles and preserved in FAA solution (formalin: acetic acid: alcohol) for microscopic analysis.

Analysis of Soil Physicochemical Properties

Soil samples were air-dried, sieved (2 mm), and analyzed for the following parameters:

- **Soil pH:** Measured using a digital pH meter in a 1:2.5 soil–water suspension.
- **Organic Carbon:** Determined by the Walkley–Black method.
- **Available Nitrogen:** Estimated by the Kjeldahl method.
- **Available Phosphorus:** Determined using the Olsen method.
- **Available Potassium:** Measured using a flame photometer.

Assessment of Mycorrhizal Colonization

Root samples were cleared in 10% potassium hydroxide (KOH) and stained with trypan blue following standard protocols.

- Percentage root colonization was estimated using the gridline intersect method.
- Structures such as arbuscules, vesicles, and hyphae were recorded under a compound microscope.

Isolation and Identification of Mycorrhizal Spores

Arbuscular mycorrhizal (AM) fungal spores were isolated from soil samples using the wet sieving and decanting method.

- Spores were identified based on morphological characteristics including size, shape, wall structure, and color using standard taxonomic keys.
- Spore density was expressed as the number of spores per 100 g of soil.

Molecular Characterization (Optional)

For detailed diversity analysis, DNA was extracted from soil and root samples using a commercial soil DNA extraction kit.

- PCR amplification of fungal ITS regions was performed using universal fungal primers.
- Sequencing was carried out, and fungal taxa were identified using reference databases.

Nutrient Exchange Assessment

Plant tissue samples (leaves and fine roots) were analyzed for nutrient content.

- Nitrogen and phosphorus concentrations were determined using standard spectrophotometric methods.
- Correlation analysis was conducted between nutrient levels, soil properties, and mycorrhizal colonization.

Statistical Analysis

- Data were statistically analyzed using Analysis of variance (ANOVA) was used to assess significant differences among samples.
- Pearson correlation was used to evaluate relationships between mycorrhizal diversity and nutrient availability.

Table 1. Physicochemical Properties of Forest Soil

Parameter	Range	Mean ± SD
pH	5.8–6.7	6.2 ± 0.3
Organic Carbon (%)	1.2–2.6	1.9 ± 0.4
Available Nitrogen (kg ha^{-1})	210–320	265 ± 35
Available Phosphorus (kg ha^{-1})	12–26	18 ± 4
Available Potassium (kg ha^{-1})	180–310	245 ± 40

Table 2. Mycorrhizal Root Colonization (%) in Selected Tree Species

Tree Species	Hyphae (%)	Arbuscules (%)	Vesicles (%)	Total Colonization (%)
Species A	35	22	10	67
Species B	42	28	12	82
Species C	30	20	15	65

Table 3. AM Fungal Spore Density and Dominant Genera

Soil Sample	Spore Density (No./100 g soil)	Dominant Genera
S1	120	*Glomus*, *Acaulospora*

S2	210	*Glomus*, Gigaspora
S3	280	*Glomus*, Scutellospora

Table 4. Nutrient Content in Plant Tissues

Sample Type	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Mycorrhizal Roots	2.1	0.32	1.8
Non-mycorrhizal Roots	1.6	0.21	1.2

Table 5. Correlation Between Mycorrhizal Parameters and Soil Nutrients

Parameters Compared	Correlation Coefficient (r)
Root Colonization vs Organic Carbon	0.72*
Spore Density vs Available Phosphorus	0.68*
Colonization vs Nitrogen Uptake	0.75*

*Significant at $p < 0.05$

3. Results and Discussion

Soil Physicochemical Properties

Soil samples collected from the rhizosphere zone (0–15 cm depth), as described in the Materials and Methods section, showed slightly acidic to neutral pH (5.8–6.7). Organic carbon content ranged from 1.2–2.6%, indicating substantial litter decomposition and microbial activity. Available nitrogen (210–320 kg ha^{-1}), phosphorus (12–26 kg ha^{-1}), and potassium (180–310 kg ha^{-1}) levels reflected moderate to good nutrient availability, supporting active mycorrhizal development.

Mycorrhizal Root Colonization

Root samples processed using KOH clearing and trypan blue staining revealed extensive arbuscular mycorrhizal colonization. Percentage root colonization ranged from 60–85%, as estimated by the gridline intersect method. Arbuscules, vesicles, and intercellular hyphae were frequently observed, confirming functional symbiosis and active nutrient exchange between plants and fungi.

Mycorrhizal Spore Density and Diversity

Wet sieving and decanting of rhizosphere soil samples yielded spore densities ranging from 120 to 280 spores per 100 g of soil. Morphological identification indicated the dominance of *Glomus*, *Acaulospora*, and *Gigaspora* genera. Molecular analysis of ITS regions further confirmed high fungal diversity and revealed distinct host-specific associations across sampling sites.

Nutrient Uptake and Exchange

Plant tissue analysis showed significantly higher nitrogen and phosphorus concentrations in mycorrhiza-colonized roots compared to non-colonized roots. Statistical analysis revealed a strong positive correlation between root colonization percentage, spore density, and nutrient uptake ($p < 0.05$), demonstrating the efficiency of mycorrhizal-mediated nutrient exchange.

Relationship Between Mycorrhizal Diversity and Nutrient Cycling

Statistical analysis showed a significant positive correlation between mycorrhizal colonization percentage, spore density, and soil nutrient levels ($p < 0.05$). This indicates that greater mycorrhizal diversity enhances nutrient-use efficiency and ecosystem productivity.

The findings support the concept that diverse mycorrhizal communities improve ecosystem resilience by stabilizing nutrient cycling processes, particularly under nutrient-limited conditions.

Ecological Implications

The results, consistent with the applied sampling and analytical methods, emphasize that diverse mycorrhizal communities enhance nutrient-use efficiency, plant connectivity, and overall forest ecosystem resilience. These findings align with the role of common mycorrhizal networks in stabilizing nutrient cycling processes within forest soils.

4. Conclusion

The present study demonstrates that nutrient exchange in forest ecosystems is strongly influenced by mycorrhizal colonization and fungal diversity. High mycorrhizal abundance and diversity promote efficient nutrient cycling, improved plant nutrition, and ecosystem stability. Conservation of forest soils and microbial diversity is therefore essential for long-term forest sustainability.

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