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# Spatial Variability of Micronutrient Status in Miyawaki Forest Development

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aim:** This study aims to quantitatively analyze the spatial variability in the micronutrient status of soil by conducting a comparative assessment of soil samples from Miyawaki forest and adjacent barren land. By focusing on key parameters such as soil pH, organic matter content and micronutrient levels, the changes brought by the Miyawaki method of afforestation is being studied.
**Study Design:** Soil samples were collected from the first Miyawaki forest established in Kerala and a comparative study was done with neighbouring undisturbed plot to analyse the changes that was brought about by the establishment of Miyawaki forest in the area.
**Place and Duration of Study:** The Miyawaki forests selected for study was located in Puliyarakonam in Thiruvananthapuram district of Kerala, India.
**Methods:** Representative soil samples were collected from the Miyawaki forest lands and neighbouring undisturbed plot from two depths and was subjected to various analyses.
**Results:** The various soil chemical parameters were found to be enhanced by this method of afforestation indicating an improved soil fertility and soil health.

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**Conclusion:** The study highlights the significant benefits of Miyawaki forest restoration techniques on soil properties, which have far-reaching implications for both soil health and biodiversity. A higher OM (4.13%), available micronutrients (B-0.83 mg $kg^{-1}$, Fe- 39.65 mg $kg^{-1}$, Mn-30.53 mg $kg^{-1}$, Zn-12.44 mg $kg^{-1}$, Cu-8.90 mg $kg^{-1}$) and pH (5.35) was observed in the Miyawaki forest in the surface soil. It was found that while the pH increased in the subsurface soil all the micronutrient concentration decreased with depth.

*Keywords: Miyawaki forest; afforestation; micronutrient dynamics.*

## 1. INTRODUCTION

The approach of Miyawaki forests, popularized by the Japanese botanist Akira Miyawaki, holds much promise as a means to enhance urban greening and ecological restoration. It specifically targets the establishment of dense, native forest ecosystems that can grow rapidly, thereby significantly increasing biodiversity and enhancing soil health. This study focuses on the alteration in the physical and chemical properties of soil resulting from the establishment of such forests compared to adjacent areas devoid of these forests. Miyawaki forests, with their special planting styles, employ a variety of native species and rehabilitation techniques for the soil. Not only does this approach encourage a diverse community of microbes within the soil, which is crucial for soil fertility and nutrient cycling, but also expands growth in the forest.

Soil is a vital component of terrestrial ecosystems, playing a crucial role in nutrient cycling, water retention, and overall ecosystem health. The establishment of a Miyawaki forest may alter these properties through processes such as increased organic matter accumulation, changes in soil pH, and enhanced microbial activity. However, empirical data quantifying these changes remain limited.

Studies have shown that the introduction of these forests leads to significant improvements in soil organic carbon content, nutrient availability, and pH levels, thereby creating a more favorable environment for plant growth compared to control sites with barren land (Deepalakshmi and Umadevi, 2023, Guo, 2018). For instance, research indicates that Miyawaki forest soils exhibit higher pH values and increased nutrient content when compared to control soils, which often remain more acidic and less fertile (Deepalakshmi and Umadevi, 2023). Reforestation efforts, such as the Miyawaki technique, have demonstrated potential in rehabilitating degraded forest lands and improving soil fertility status (Akbar et al., 2010).

Micronutrient dynamics in forest soils are influenced by various factors, including soil organic matter (SOM), pH, and seasonal changes. SOM plays a crucial role in modifying physiochemical reactions that affect micronutrient availability, favouring reduced environments and enhancing the accessibility of micronutrient cations (Dhaliwal et al., 2019). Climate, parent material, and topography are key drivers of spatial patterns in soil nutrient concentrations, including both macro- and micronutrients (Sun et al., 2022). Long-term studies have shown that forest development can lead to significant changes in soil chemical properties, with increases in soil acidity and depletion of exchangeable cations like calcium and magnesium over time Richter (Richter, 1994).

Understanding these dynamics is crucial in advancing afforestation techniques for degraded landscapes and sustainable urban ecosystems growth that resist climatic adversities. This study aimed at determining the effects of a newly planted Miyawaki forest on the physicochemical properties of soil as compared to those properties in a control area that is not forested. Understanding the impact of this particular type of forest on soil vitality and stability by examining various soil properties, such as bulk density, nutrient composition, pH levels, and moisture content, will further improve our comprehension of the ecological benefits produced because of the afforestation measures taken in the urban areas. The conclusions will also guide prospective restoration efforts of the forest.

## 2. MATERIALS AND METHODS

### 2.1 Study Location

The study area was located in Puliyarakonam in Thiruvananthapuram district of Kerala, India. The first effort at using the Miyawaki method of afforestation in Kerala was in the Puliyarakonam Miyawaki forest. The land was mostly rocky and sloped downward. On January 31, 2018, 397 plants totalling over 100 distinct varieties of plant

Miyawaki forest in Puliyarakonam (Lat 8.541083° Long 77.011213°)

Reference plot in Puliyarakonam ( Lat 8.542163°Long 77.010956°)

**Fig. 1. Study locations**

**Table 1. The determination methods of soil chemical parameters**

| Soil parameters | Analysis method |
|---|---|
| pH | pH meter (1:2.5 soil water ratio) (Jackson, 19732) |
| Organic carbon | Walkley and Black method (Walkley, 1934) |
| Available B | Hot water extraction and estimation in spectrophotometer Azomethane H reagent method) (Gupta, 1972) |
| Available Fe, Mn, Zn, Cu | 0.1 N HCl extraction and estimation using atomic absorption spectrophotometer (Sims, 1991) |

saplings were planted in 175 square meters. Within a year the rocky landscape transformed itself into a buzzing forest. And a growth rate of 30 feet in three years was observed (Crowd Foresting, 2024).

## 2.2 Laboratory Analysis

The laboratory analysis carried out on the soil samples included chemical analyses like determination of pH, organic matter content, micronutrient concentration like S, B, Fe, Mn, Zn, Cu.

# 3. RESULTS AND DISCUSSION

## 3.1 Chemical Properties of Miyawaki Soil in Surface Soil (0-15 cm)

A higher pH was observed in Miyawaki forest (5.35) compared to control (4.52). The pH ranged from 5.3 to 5.41 in Miyawaki forest while in control plots it varied from 4.45 to 4.56. Afforestation tends to neutralize soil pH, lowering it in alkaline soils and raising it in acidic soils. Afforestation could lead to soil pH neutralization over the long term by altering the balance between soil hydrogen ion generation and consumption during nutrient cycle. Environmental factors like climate, soil inorganic carbon, and nitrogen deposition also influence soil pH in planted forests (Hong et al., 2018). The soil organic matter content in Miyawaki forests was found to be significantly higher than that of control. It varied from 4.07% to 4.13% with a mean of 4.13% in Miyawaki forest while in control plots it ranged from 0.69% to 0.83% with a mean of 0.75%. In a study conducted in Kathmandu significantly higher SOC was recorded in forest soil (98 t/ha) compared to barren land (83.6 t/ha) (Bhandari and Bam, 2013). A higher soil organic carbon and nitrogen stocks were reported in forested sites compared to deforested areas (Ammal, 2022). The appreciable amount of organic matter content recorded in the soils could be ascribed to the decomposition of plant remains from dead soil macrofauna and micro-organisms in the forest (Opeyemi, 2020).

The available micronutrient content was remarkably higher in soil under Miyawaki forests when compared to the control plots. Available boron content varied from 0.81-0.84 mg $kg^{-1}$ in Miyawaki forests to 0.50-0.53 mg $kg^{-1}$ in control plots. Available iron content varied from 39.5-39.70 mg $kg^{-1}$ in Miyawaki forests to 21.66-22.50

mg kg$^{-1}$ in control plots. Available manganese content varied from 30.40-30.63 mg kg$^{-1}$ in Miyawaki forests to 23.38-23.45 mg kg$^{-1}$ in control plots. Available zinc content varied from 12.36-12.52 mg kg$^{-1}$ in Miyawaki forests to 3.13-3.36 mg kg$^{-1}$ in control plots. Available copper content varied from 8.78-9.00 mg kg$^{-1}$ in Miyawaki forests to 3.96-4.05 mg kg$^{-1}$ in control plots. As organic matter contains chelating agents, the availability of metal ions (Fe, Cu) rises as organic matter content rises (Meena and Sharma, 2006). In a study conducted in North western India it was reported that forest soils contained the highest levels of micronutrients (Fe, Mn, Zn, Cu) compared to other land use systems, with concentrations decreasing with soil depth (Dhaliwal et al., 2023).

Considering the content of soil available micronutrients, the order of abundance of the micronutrients was Iron> Manganese>Zinc> Copper>Boron. Simple correlation analysis revealed that the iron, manganese, zinc, copper are significantly and positively correlated with soil organic matter. There also was a significant positive correlation between copper, manganese and zinc. Organic matter was consistently positively correlated with micronutrients iron, manganese, zinc, copper in a study conducted in forest zones of Cameroon and the micronutrients also showed positive correlations with each other, particularly Zn with Cu and Fe (Njukeng et al., 2023).

### 3.2 Chemical Properties of Miyawaki Soil in Subsurface Soil (15-30 cm)

A higher pH was observed in Miyawaki forest when compared to control. The pH ranged from 5.38 to 5.41 in Miyawaki forest while in control plots it varied from 4.61 to 4.77. The pH was observed to be higher in subsurface soil

**Table 2. Soil reaction, organic matter and micronutrient content of the studied soils at the surface (0-15cm)**

| Parameters | Miyawaki forest | | Control soil | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| pH | 5.3-5.41 | 5.35 | 4.45-4.56 | 4.52 |
| Organic matter (%) | 4.07-4.13 | 4.13 | 0.69-0.83 | 0.75 |
| Available B (mg kg$^{-1}$) | 0.81-0.84 | 0.83 | 0.50-0.53 | 0.51 |
| Available Fe (mg kg$^{-1}$) | 39.5-39.70 | 39.65 | 21.66-22.50 | 22.02 |
| Available Mn (mg kg$^{-1}$) | 30.40-30.63 | 30.53 | 23.38-23.45 | 23.41 |
| Available Zn (mg kg$^{-1}$) | 12.36-12.52 | 12.44 | 3.13-3.36 | 3.23 |
| Available Cu (mg kg$^{-1}$) | 8.78-9.00 | 8.90 | 3.96-4.05 | 4.04 |

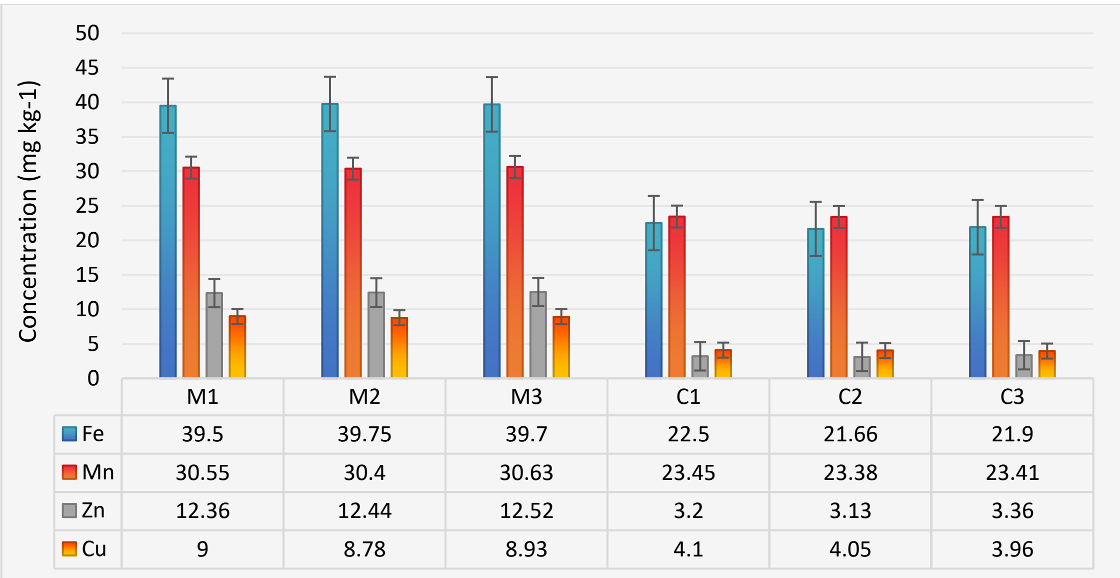


**Fig. 2. Spatial variation in status of micronutrients in Miyawaki forests and control soil in surface soil**

*M1; M2; M3: sampling points in Miyawaki forest C1; C2; C3: sampling points in Control plot*

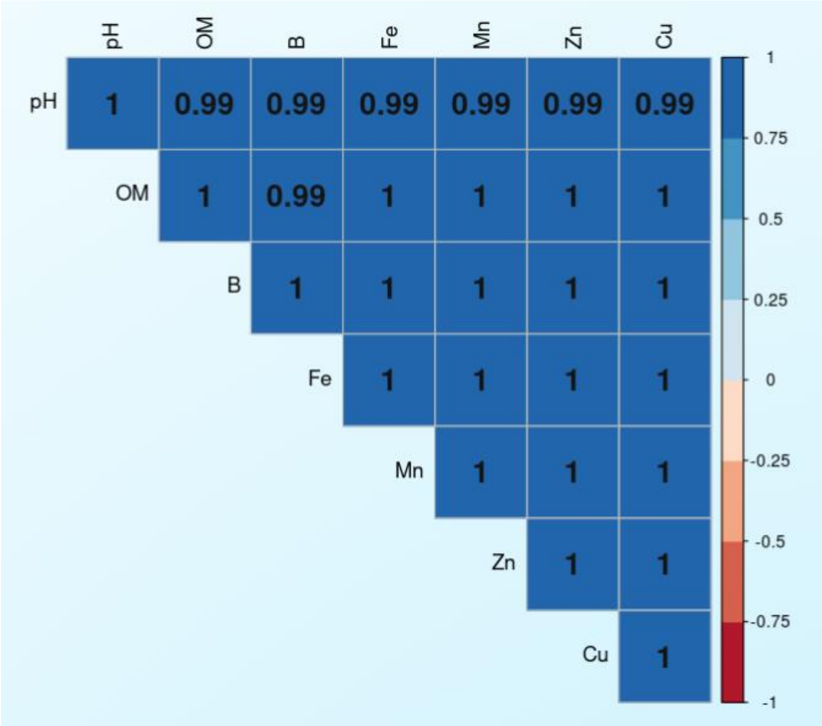


**Fig. 3. Correlogram depicting interaction between soil reaction, organic matter content and available soil micronutrient status in surface soil**

compared to the surface soil. The soil organic matter content in Miyawaki forests was found to be significantly higher than that of control. It varied from 3.97% to 4.05% with a mean of 3.99% in Miyawaki forest while in control plots it ranged from 0.30% to 0.32% with a mean of 0.31%. Research consistently shows that organic matter content decreases with soil depth in forest ecosystems. This trend was observed in fir and redwood forests (Durgin,1980), as well as in various forest types across Denmark (Vejre et al., 2003). The decline in carbon concentration with depth is more rapid than that of organic matter, resulting in a decreasing carbon-to-organic matter ratio as depth increases (Huntington et al., 1989).

The micronutrient levels also decreased with depth. The variation in surface and subsurface layers may be attributed due to the root distributional patterns and pH variation along the depths (Ali et al., 2016). Available boron content varied from 0.50-0.63 mg $kg^{-1}$ in Miyawaki forests to 0.42-0.44 mg $kg^{-1}$ in control plots. Available iron content varied from 39.00-39.5 mg $kg^{-1}$ in Miyawaki forests to 21.00-21.20 mg $kg^{-1}$ in control plots. The surface horizons have a higher concentration of iron because their organic carbon levels were found to be substantially higher (Shah et al., 2012, Wang et al., 2007).

Available manganese content varied from 21.80-21.86 mg $kg^{-1}$ in Miyawaki forests to 10.73-10.84 mg $kg^{-1}$ in control plots. Available zinc content varied from 8.82-8.87 mg $kg^{-1}$ in Miyawaki forests to 3.10-3.30 mg $kg^{-1}$ in control plots. Available copper content varied from 7.55-7.67 mg $kg^{-1}$ in Miyawaki forests to 3.30-3.38 mg $kg^{-1}$ in control plots. Studies in Bangladesh, Ethiopia, and North Bihar found that iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) were generally more abundant in the top 0-15 cm of soil than in deeper layers (Sanaullah and Akhtaruzzaman, 2020, Menna, 2022, Sarker et al., 2020). This pattern was observed in both forested and cultivated lands, with forests typically containing higher amounts of micronutrients than agricultural areas (Sanaullah and Akhtaruzzaman, 2020). It was observed that agroforestry systems increased micronutrient contents at both 15 cm and 30 cm soil depths. These studies collectively suggest that forest ecosystems, including Miyawaki forests, can remarkably enhance soil micronutrient content, potentially due to increased organic matter and improved soil properties associated with diverse vegetation cover (Sarker et al., 2020).

**Table 3. Soil reaction, organic matter and micronutrient content of the studied soils at the subsurface (15-30 cm)**

| Parameters | Miyawaki forest | | Control soil | |
|---|---|---|---|---|
| | **Range** | **Mean** | **Range** | **Mean** |
| pH | 5.38-5.41 | 5.40 | 4.61-4.77 | 4.70 |
| Organic matter (%) | 3.97-4.05 | 3.99 | 0.30-0.32 | 0.31 |
| Available B (mg kg$^{-1}$) | 0.50-0.63 | 0.58 | 0.42-0.44 | 0.43 |
| Available Fe (mg kg$^{-1}$) | 39.00-39.5 | 39.23 | 21.00-21.20 | 21.06 |
| Available Mn (mg kg$^{-1}$) | 21.80-21.86 | 21.83 | 10.73-10.84 | 10.78 |
| Available Zn (mg kg$^{-1}$) | 8.82-8.87 | 8.84 | 3.10-3.30 | 3.20 |
| Available Cu (mg kg$^{-1}$) | 7.55-7.67 | 7.61 | 3.30-3.38 | 3.34 |

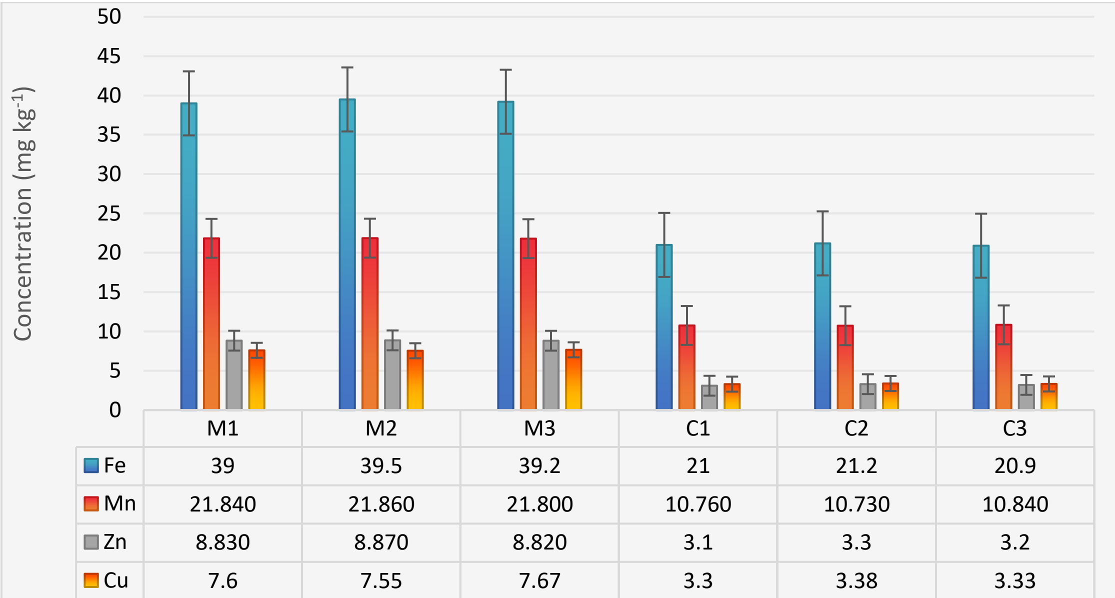


**Fig. 4. Spatial variation in status of micronutrients in Miyawaki forests and control soil in subsurface soil**

*M1; M2; M3: sampling points in Miyawaki forest C1; C2; C3: sampling points in Control plot*

## 4. CONCLUSION

The comparative analysis of chemical parameters within the Miyawaki forest and an adjacent undisturbed plot suggests that the establishment of the Miyawaki forest has prominently increased the fertility and quality of the soil. It can be concluded that high values noticed in Miyawaki forest soils reflect improvements in nutrient availability, soil structure, and the overall condition of the ecosystem. Various environmental factors and specific management practices contribute to the spatial variability of micronutrient status in these forests. Understanding these dynamics is essential for enhancing forest health and ensuring sustainable development through this innovative afforestation technique. This study indicated that Miyawaki forest restoration methods are beneficial for soils; hence, such efforts could be pivotal in enhancing soil quality and promoting biodiversity.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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