Environment and Ecology 44 (2) 416—425, April—June 2026
Article DOI: https://doi.org/10.60151/envec/AQBZ1814
ISSN: 0970-0420 (Print), ISSN: 3049-3625 (Online)

A Comparative Analysis of Soil Characteristics of Tropical Lowland and Montane Forests of Mizoram, Indo-Burma Biodiversity Hotspots

Emilynruwaka Lamare, Basanta Moirangthem, Salam Suresh Singh, Shri Kant Tripathi

Received 29 April 2026, Accepted 3 June 2026, Published on 20 June 2026

ABSTRACT

A comparative analysis of soil properties in tropical lowland forest (TLF) and tropical montane forest (TMF) was conducted to understand the influence of distinct ecosystems on soil health. While physical properties, such as bulk density, remained consistent, significant variations occurred in soil biochemical properties. TMF soil exhibited markedly superior fertility, characterized by significantly higher soil organic carbon (SOC) concentrations. This enriched SOC content was directly linked to greater retention of essential macronutrients (P, K, Ca, Mg) and a stronger buffering capacity against acidification. In contrast, TLF soil displayed signs of advanced weathering, with higher levels of aluminium and exchangeable acidity. Biologically, TMF soils have significantly higher microbial biomass carbon (MBC), dehydrogenase activity (DHA), and nitrate levels. This study concludes that TMF can foster superior soil health compared to TLF due to increased SOC accumulation. This highlights the critical role of regional climatic and vegetative factors in dictating soil quality.

Keywords Tropical lowland forest, Tropical montane forests, Soil health, Nutrient cycling, Soil organic carbon.

INTRODUCTION

Soil serves as the living foundation of terrestrial ecosystems, a complex medium where minerals, air, water, organic matter, and a variety of organisms interact to provide the conditions necessary for many life forms (Manpoong and Tripathi 2019, Singh and Tripathi 2020). Soil health is defined as the ability of soil to function as a vital ecosystem, which is essential for sustainable land management, ecological restoration, and the conservation of overall ecosystem resilience (Bhaduri *et al.* 2022, Devi *et al.* 2025).

Emilynruwaka Lamare[1], Basanta Moirangthem[2], Salam Suresh Singh[3], Shri Kant Tripathi[4]*

[1,2,3]PhD Research Scholar. [4]Senior Professor
Department of Forestry, Mizoram University, Aizawl 796004, Mizoram, India

Email: sk_tripathi@rediffmail.com
*Corresponding author

Assessing soil health requires a comprehensive analysis of the interrelated physical, chemical, and biological characteristics of soil. Physical characteristics influence the soil structure and its ability to promote root growth and water transport, including texture, aggregation, moisture content, and bulk density (Baizán *et al.* 2021, Bharathi *et al.* 2024). The fertility of soil and its ability to support plant and microbial life are significantly influenced by its chemical characteristics, such as pH, organic matter content, and nutrient availability (N, P, and K) (Lal 2016, Mebrate *et al.* 2022). Microbial communities, enzyme activity, and metabolic processes are examples of biological indicators that are becoming more widely acknowledged as practical means of comprehending the dynamic processes of nutrient cycling and decomposition that propel ecosystem functioning (Singh *et al.* 2025, Upadhyay *et al.* 2026, Devi *et al.* 2026, Tripathi *et al.* 2026, Moirangthem *et al.* 2026).

The importance of maintaining soil health is particularly pronounced in tropical lowland forests (TLF) and tropical montane forests (TMF), as they comprise 16% of the Earth's surface area, and are home to the planet's most biodiverse ecosystems, providing essential ecological functions, such as water storage, erosion prevention, and carbon sequestration (Anbarashan and Parthasarathy 2013, Tripathi *et al.* 2025). The soil, which serves as a vital centre for the close nutrient cycles that drive biomass growth, is essentially responsible for the enormous productivity of these forests (Tripathi *et al.* 2008; Hedin *et al.* 2009, Cheng *et al.* 2019). An excellent illustration of this crucial area is the Indian state of Mizoram, which ranks second nationally in forest cover density, with forests occupying an astounding 85.34% of its mountainous terrain (ISFR 2023).

Considering the vital role soil plays in maintaining these globally important ecosystems, a thorough evaluation of soil quality is necessary to develop effective conservation policies and adaptive management plans (Bünemann *et al*. 2018). Thus, the purpose of this study was to examine the physicochemical and biological properties of soils in TLF and TMF ecosystems. The central objectives of this study are to identify significant differences in soil characteristics across two forests and to formulate targeted strategies to conserve the region's long-term soil health.

MATERIALS AND METHODS

Study area

The study was conducted in Mizoram, a state in

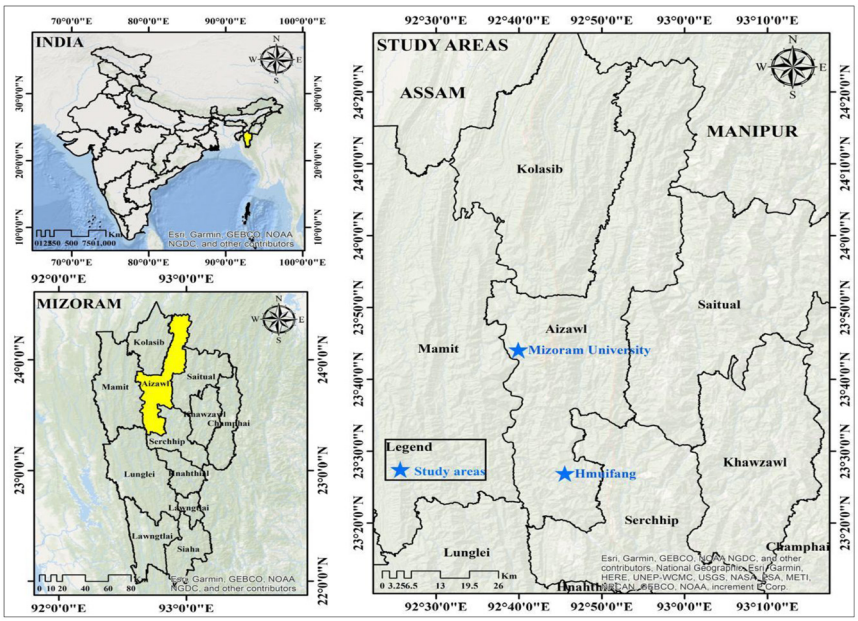

Fig. 1. Map of the study sites

Northeast India, situated between Myanmar and Bangladesh, with a geographical area of 21,087 km² and a forest cover of 75% (Tripathi *et al.* 2017). The state is located between 21º 56'-24º 31' N latitude and 92º 16'-93º 26' E longitude (Monsang *et al.* 2024). The state features a monsoon climate, characterized by a cold and dry winter (December to February), a warm summer (March to June), a humid monsoon season (July to September), and a cool post-monsoon period (October to November). The TLF and TMF sites were in Mizoram University and the Hmuifang community reserve forests, respectively (Fig. 1). The university is located near Tanhril village, approximately 10 kilometres from Aizawl city, with an average elevation of 710 m a.m.s.l and the total annual precipitation of 2161 mm (Wapongnungsang *et al.* 2021, Chanda *et al.* 2024, Chanda *et al.* 2026). The Hmuifang community reserve forest, located approximately 50 kilometres south of Aizawl city, at an elevation of 1620 m a.m.s.l and with a total annual rainfall of approximately 2564 mm. Both forest areas are protected with minimal disturbance and have semi-evergreen vegetation, as described in detail by Lamare *et al.* (2024).

Experimental setup

The two study sites (TLF and TMF) were demarcated with six plots, each measuring 12 m × 12 m. Soil samples were collected from three random locations per plot. After removing the unconsolidated surface leaf material, three soil samples were collected from the top 5 cm of soil in each plot by digging a hole of 10 cm × 10 cm at a depth of 5 cm. Soil samples were spread on a polyethene sheet, and leaves and roots were removed and brought to the laboratory for further analysis. Immediately upon arrival in the laboratory, the samples were separated into two subsamples and sieved through a 2 mm mesh screen. One sub-sample was allowed to air-dry and was stored for chemical analysis, while the other was kept in a zip-lock bag at -20 °C for biological analysis.

Soil analysis

Physical properties of soil

The soil moisture content (%) was estimated using the gravimetric method, which involved drying a known weight of fresh soil in an oven at 105˚C for 24 hours. For the determination of soil bulk density (g cm^{-3}), a soil core of known inner volume was used. Soil collected was oven-dried, and the dry weight was converted to g soil cm^{-3}.

Chemical properties of soil

The soil pH was determined by preparing a soil-water suspension (1:2.5 soil-to-water ratio) and measuring it with a pH meter. Available nitrogen (N_{avail}) was determined using the alkaline permanganate method (Subbiah and Asija 1956). Ammonium-nitrogen (NH_4-N) was determined using the indophenol-blue method (Rowland 1983) and the nitrate-nitrogen (NO_3-N) using the phenol disulphonic acid method (Harpe 1924). Available phosphorus (P_{avail}) was analysed with the Bray I reagent and quantified by the blue color development technique (Bray and Kurtz 1945). Soil organic carbon (SOC) was measured by the chromic acid wet oxidation method developed by Walkley and Black (1934). Exchangeable potassium (K) in soil was analysed by shaking soil with 1 N neutral ammonium acetate (Metson 1956) and determining the concentration by flame photometry. Exchangeable calcium (Ca) and Magnesium (Mg) in soil were determined by the EDTA titration method (Tucker and Kurtz 1961). A DTPA soil test was used to analyse iron (Fe) and manganese (Mn) in soil, in which 10 g of soil was mixed with 20 mL of extractant and shaken for 2 hours. The filtrate was then measured using Atomic Absorption Spectrophotometry (Lindsay and Norvell 1978). Using the KCl method, the total exchangeable acidity (EA) and exchangeable Aluminium (Al) were measured by extracting 20 g of soil for 2 hours with 100 mL of 1 M KCl (Pionke and Corey 1967).

Biological properties of soil

Microbial biomass carbon (MBC) was estimated using the chloroform fumigation-extraction technique (Vance *et al.* 1987). Microbial biomass phosphorus (MBP) was measured using the chloroform fumigation-extraction technique followed by Bray-1 extraction (Oberson *et al.* 1997). Dehydrogenase enzyme activity (DHA) was assayed using a modified 2,3,5-triphenyl tetrazolium chloride reduction method

(Casida Jr. *et al.* 1964, Casida Jr, 1977).

Statistical analysis

Data for all soil physicochemical and biological properties were presented as mean ± 1 SE. A two-way analysis of variance (ANOVA) was conducted to assess for significant differences among the study sites. When the ANOVA indicated a significant effect, means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p \leq 0.05$. All statistical analyses were carried out using OPSTAT (a free Online Agriculture Data Analysis Tool developed by O. P. Sheoran, Computer Programmer at CCS HAU, Hisar, India).

Table 1. Summary of two-way ANOVA for soil physical, chemical and biological properties across plots and tropical lowland (TLF) and tropical montane forests (TMF).

Parameter	Sources of	F-value	P-value
Degree of freedom- Plots (5), Forest types (2), and Plots × Forest plots (5)			
	Plots	0.79	0.55
Soil moisture content (%)	Forest types	4.39	0.04*
	Plot × Forest	2.07	0.10
	Plots	0.87	0.52
Bulk density (g cm $^{-3}$)	Forest types	1.94	0.18
	Plot × Forest	0.24	0.93
	Plots	1.49	0.23
Soil pH	Forest types	1.09	0.31
	Plot × Forest	1.04	0.41
	Plots	2.56	0.05
Soil organic carbon (%)	Forest types	186.47	0.001*
	Plot × Forest	2.36	0.07
	Plots	6.69	0.001*
Available phosphorus (mg kg^{-1})	Forest types	14.42	0.001*
	Plot × Forest	5.67	0.002*
	Plots	9.61	0.001*
Available nitrogen (mg kg^{-1})	Forest types	3.81	0.06
	Plot × Forest	1.08	0.4
Potassium (mg kg^{-1})	Plots	5.90	0.001*
	Forest types	166.01	0.001*
	Plot × Forest	7.99	0.001*
	Plots	1.48	0.24
Iron (mg kg^{-1})	Forest types	15.15	0.0007*
	Plot × Forest	2.32	0.08
	Plots	4.10	0.008*
Manganese (mg kg^{-1})	Forest types	160.77	0.001*
	Plot × Forest	3.59	0.015*
	Plots	3.85	0.01*
Calcium (mg kg^{-1})	Forest types	390.13	0.001*
	Plot × Forest	4.74	0.004*
	Plots	6.89	0.0005*
Magnesium (mg kg^{-1})	Forest types	500.64	0.001*
	Plot × Forest	9.92	<0.001*
	Plots	28.65	0.001*
Aluminium (mg kg^{-1})	Forest types	1066.77	0.001*
	Plot × Forest	17.99	0.001*
	Plots	2.11	0.10
Exchangeable acidity (mg kg^{-1})	Forest types	100.62	0.001*
	Plot × Forest	2.25	0.08
	Plots	0.56	0.73
Ammonium (mg kg^{-1})	Forest types	0.041	0.84
	Plot × Forest	1.44	0.25
	Plots	12.23	<0.001*
Nitrate (mg kg^{-1})	Forest types	1409.96	<0.001*
	Plot × Forest	11.67	<0.001*
	Plots	10.98	<0.001*
Microbial biomass carbon (µg g^{-1})	Forest types	599.84	<0.001*
	Plot × Forest	10.36	<0.001*
	Plots	6.98	0.0004*
Microbial biomass phosphorus (µg g^{-1})	Forest types	36.23	<0.001*
	Plot × Forest	5.12	0.002*
	Plots	0.58	0.71
Dehydrogenase enzyme activity (µg g^{-1})	Forest types	38.72	<0.001*
	Plot × Forest	1.03	0.42

RESULTS AND DISCUSSION

Soil biogeochemical properties were significantly higher at the TMF site than at TLF, except that the soil physical parameters remained uniform across both sites (Table 1). TMF soil exhibited markedly enhanced fertility and biological activity, as indicated by elevated levels of SOC, critical macronutrients (P, K, Ca, Mg), and microbial markers (MBC, DHA, NO_3^-). These findings underscore the substantial influence of regional climate and vegetation on soil quality.

SMC did not differ significantly between the two sites (Fig. 2). Further, SMC did not vary across plots or interact with forest type, indicating stable soil moisture trends within forests. Similarly, BD did not vary significantly among forest types, plots, or their interaction, maintaining a uniform range of 1.19 to 1.27 g cm^{-3} (Fig. 2). This suggests that both forest soils possess a comparable and resilient physical structure, lacking differential compaction (Saha *et al.* 2010). The uniformity of the physical structure indicates that biogeochemical processes, rather than physical limitations, account for the considerable

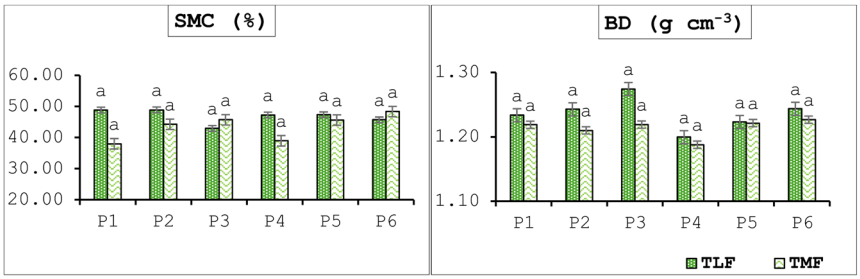

Fig. 2. Soil physical properties in tropical lowland and montane forests. Values represent mean ± 1SE. Different lowercase letters denote significant differences among plots at p <0.05.

differences in the chemical and biological properties of the soil.

Soil pH was consistently acidic in both ecosystems (ranging from 4.81 to 5.13 in TLF and 4.62 to 5.53 in TMF), with no significant difference (p>0.05). This acidity is typical in leaching-prone soils found in humid forest habitats. SOC was significantly ($p < 0.05$) higher in the TMF (4.43 to 4.79%) compared to the TLF (3.12 to 3.83%). In contrast to the continuously hot and humid tropical environment, the lower breakdown rates at TMF limit microbial metabolic activity, allowing organic matter to persist longer and resulting in a higher buildup of SOC (Davidson and Janssens 2006, Lal 2016). These variations are crucial because SOC directly affects soil structure and nutrient availability, both of which are essential for forest resilience and productivity (Ortiz *et al.* 2025). In addition, the consistently high temperatures and microbial activity in tropical forests promote rapid decomposition rates, thereby reducing SOC accumulation, in contrast to the slower decomposition in TMF (Ghosh and Tripathi 2021, Tripathi *et al.* 2025, Singh *et al.* 2025). A significant ($p < 0.05$) interaction between plots and sites was observed for Pavail in TMF soils containing substantially more Pavail (1.37-5.24 mg kg^{-1}) than TLF soils (0.88-2.01 mg kg^{-1}). Similarly, K concentrations were significantly ($p < 0.05$) higher in the TMF (100.27-215.84 mg kg^{-1}) than in the TLF (54.14-89.24 mg kg^{-1}). The essential base cations, Ca and Mg, were also significantly ($p < 0.05$) more abundant in the TMF. These findings align with the

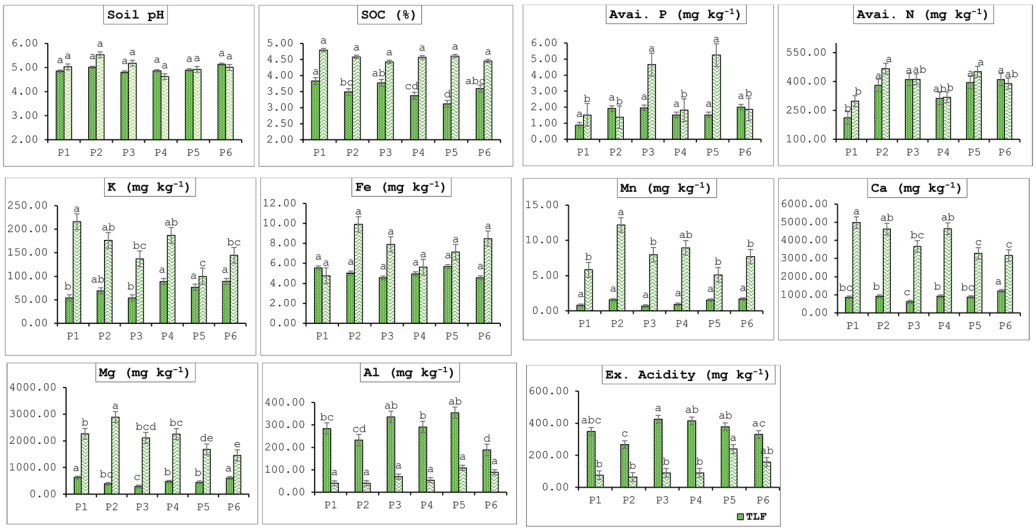

Fig. 3. Soil chemical properties in tropical and sub-tropical forests. Values represent mean ± SE, and different lowercase letters denote significant differences among plots at p <0.05.

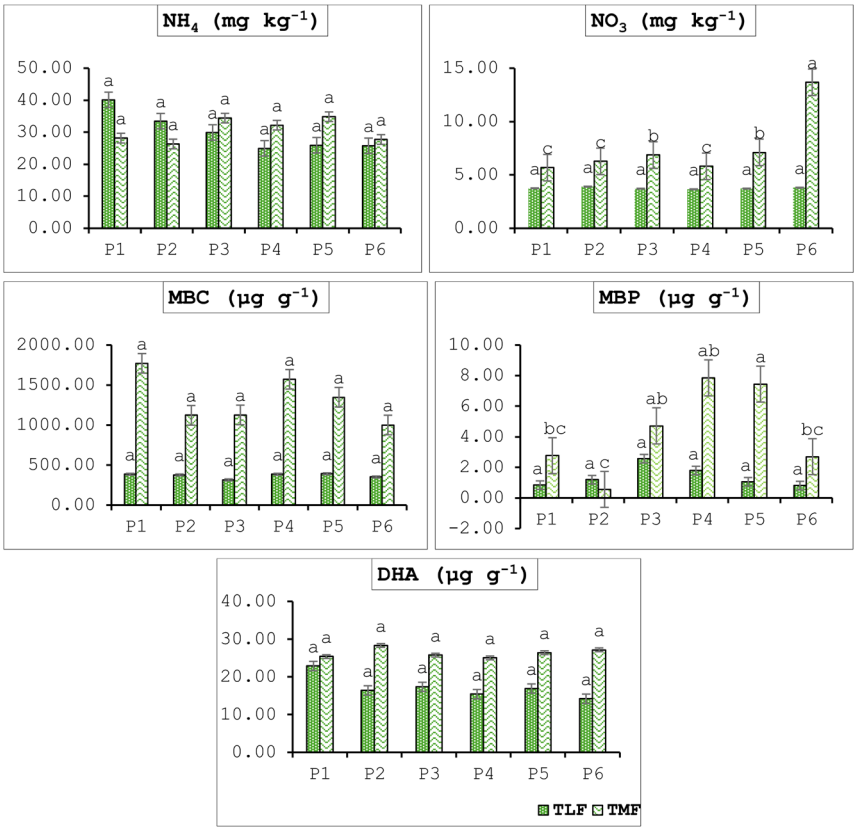

Fig 4. Soil biological properties in tropical lowland and montane forests. Values represent mean ± SE, and different lowercase letters denote significant differences among plots at p <0.05.

documented function of SOC in augmenting cation exchange capacity and nutrient retention, therefore mitigating their loss via leaching (Brady and Weil 2017). Navail showed significant variation among plots but not between forest types, suggesting that N dynamics may be influenced more by localized factors within each forest. Fe and Mn were significantly ($p < 0.05$) higher in the TMF; the opposite was true for indicators of soil acidity. Al and EA were significantly ($p < 0.05$) higher in the TLF (Fig. 3). This paradox is a standard indicator of soil health; lower levels of base cations (Ca, Mg) and higher levels of soluble Al in the TLF suggest a more heavily weathered, acidified soil with a greater concentration of toxic substances. In tropical environments, for instance, long-term chemical weathering reduces the supply of soil nutrients derived from rocks, restricting microbial and plant access to vital components (Bukombe *et al.* 2021). According to Ussiri and Lal (2017), the TMF has superior buffering capacity against acidification due to its higher SOC and base cations.

The biological health of the soil, directly indicative of its chemical richness, was evaluated. While NH_4+ concentrations showed no significant ($p > 0.05$) differences, NO_3− levels were significantly ($p < 0.05$) higher in the TMF (5.68-13.68 mg kg^{-1}) compared to the TLF (3.66-3.90 mg kg^{-1}). This implies that the richer substrate is probably the primary cause of the more active nitrifying microbial population at TMF (Paul *et al,* 2015). MBC was substantially and significantly ($p < 0.05$) greater in the TMF (1001.2 to 1771.5 µg g^{-1}) than in the TLF (315.5 to 391.5 µg g^{-1}). MBP also showed significant variation, indicating a larger microbial sink for nutrients in the TMF. DHA, a key indicator of total microbial activity, was

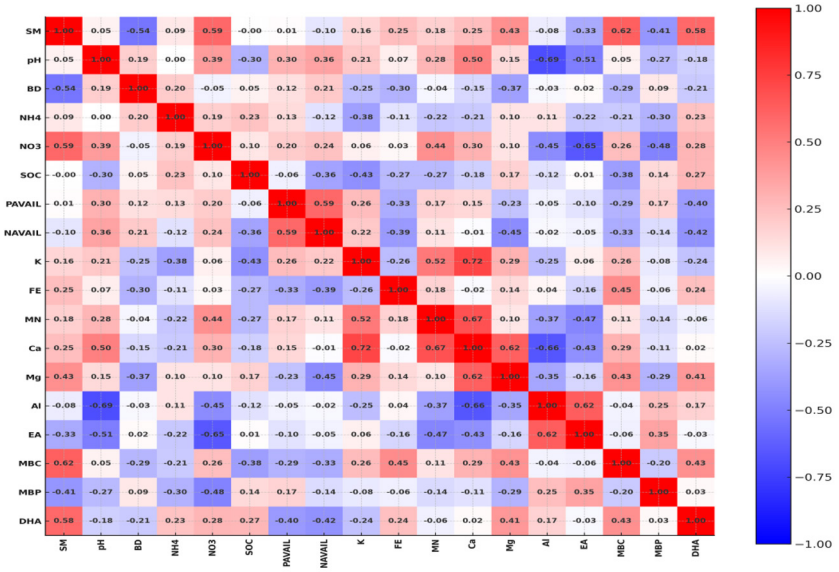

Fig. 5. Correlation between soil physico-chemical and biological properties in TLF.

significantly ($p<0.05$) higher in the TMF (25.0 to 28.3 μg g^{-1}) versus the TLF (14.19 to 22.86 μg g^{-1}) (Fig. 4). According to Nannipieri *et al.* (2017), these biological markers show that the TMF soil represents a larger microbial population (as reflected by higher MBC) and they are metabolically active (greater DHA). This is supported by the higher SOC and nutrient availability, which drive more efficient nutrient cycling and contribute to the overall superior health of the TMF soil.

This distinction highlights the importance of considering regional biogeochemical characteristics when evaluating nutrient limitation and developing conservation or management strategies. The interrelationships among soil physical, chemical and

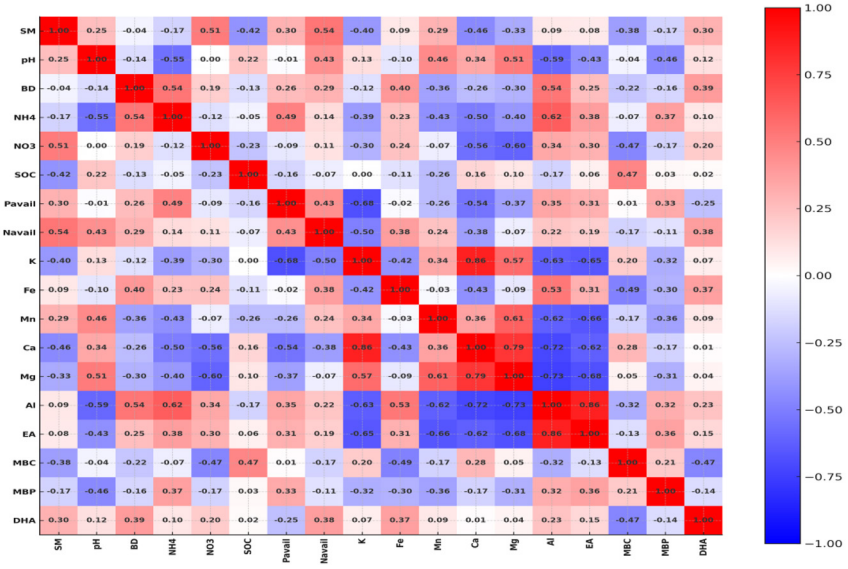

Fig. 6. Correlation between soil physico-chemical and biological properties in TMF.

biological properties in TLF and TMF are illustrated in Fig. 5 and Fig. 6, respectively. Understanding the interactions among soil physical, chemical, and biological properties is crucial for predicting soil behavior in response to changing environmental conditions and for enhancing forest productivity (Gama 2023).

CONCLUSION

The soils of the TMF in this study exhibited significantly higher health and fertility than those of the TLF, primarily due to higher SOC accumulation. The enhanced SOC facilitated a more active and diverse microbial community, enhanced nutrient retention (P, K, Ca, Mg), and mitigated the adverse effects of soil acidity, including Al toxicity. These findings indicate that local environmental conditions and vegetation inputs are more important determinants of soil fertility in TMF than those found in TLF. The study indicates that TMF ecosystems are significant hotspots for storing soil carbon and conserving biodiversity, underscoring the need for targeted strategies to preserve their distinct soil health attributes.

ACKNOWLEDGMENTS

The authors are grateful to the village councils and local authorities for granting permission to conduct this research. The authors are also thankful to the Department of Forestry, Mizoram University, and the Research Office, Directorate of Agriculture, Shillong, for providing the essential laboratory facilities for soil analysis. Special thanks are extended to the Indian Council of Agricultural Research (ICAR) for their assistance with specialized analyses.

REFERENCES

Anbarashan, M., & Parthasarathy, N. (2013). Tree diversity of tropical dry evergreen forests dominated by single or mixed species on the Coromandel coast of India. *Tropical ecology,* 54(2), 179-190.

Baizán, S., Vicente, F., & Martínez-Fernández, A. (2021). Management influence on the quality of an agricultural soil destined for forage production and evaluated by physico-chem ical and biological indicators. *Sustainability,* 13(9), 5159.

Bhaduri, D., Sihi, D., Bhowmik, A., Verma, B. C., Munda, S., & Dari, B. (2022). A review on effective soil health bio-indi cators for ecosystem restoration and sustainability. *Frontiers in Microbiology,* 13, 938481.

Bharathi, M., Sivakumar, K., Gopalakrishnan, M., Vennila, M. A., Anandham, R., & Sritharan, N. (2024). Soil physical health sustenance: strategies and perspectives-A review. *Plant Science Today,* 11, 5342.

Brady, N. C., & Weil, R. R. (2017). The Nature and Properties of Soils, 15th Edn (eBook).

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* 59(1), 39-46. https://doi.org/10.1097/00010694-194501000-00006

Bukombe, B., Fiener, P., Hoyt, A. M., Kidinda, L. K., & Döetterl, S. (2021). Heterotrophic soil respiration and carbon cycling in geochemically distinct African tropical forest soils. *SOIL*, 7(2), 639. https://doi.org/10.5194/soil-7-639-2021

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., De Goede, R., & Brussaard, L. (2018). Soil quality–A critical review. Soil Biology and Biochemistry, 120, 105-125.

Casida Jr, L. E. (1977). Microbial metabolic activity in soil as measured by dehydrogenase determinations. *Applied and Environmental Microbiology,* 34(6), 630-636. https://doi.org/10.1128/aem.34.6.630-636.1977

Casida Jr, L. E., Klein, D. A., & Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science,* 98(6), 371-376. https://doi.org/10.1097/00010694-196412000-00004

Chanda, R., Luwang, S. R., Singh, S. S., & Tripathi, S. K. (2026). Multivariate water stress-vegetation health index (MWS--VHI): Novel drought monitoring framework for forests of the Eastern Himalayan landscape. *Journal of Environmental Management,* 404, 129438.

Chanda, R., Singh, S. S., Singh, N. S., Upadhyay, K. K., & Tripathi, S. K. (2024). Two-decadal climate impacts on growth of major forest types of Eastern Himalaya. Trees, Forests and People, 15, 100491.

Cheng, Y., Wang, J., Chang, S. X., Cai, Z., Müller, C., & Zhang, J. (2019). Nitrogen deposition affects both net and gross soil nitrogen transformations in forest ecosystems: A review. *Environmental Pollution,* 244, 608-616.

Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature,* 440(7081), 165-173.

Devi, K. V., Singh, S. S., Upadhyay, K. K., Chanda, R., Devi, N. R., Singh, N. S., Vanlalfakawma, D. C., & Tripathi, S. K. (2025). Interplay of biotic and abiotic components for forest functioning and productivity. In *Eco-Resilience Biology,* (pp. 34–66). https://doi.org/10.1201/9781003588580-3

Devi, K. V., Upadhyay, K. K., Chanda, R., Kumar, S., Singh, N. S., Vanlalfakawma, D. C., Tripathi, S. K., & Joshi, M. (2026). Indo-Burma Biodiversity hotspot and climate change. In Apple Academic Press eBooks (pp. 323–347). https://doi.org/10.1201/9781998511112-11

Forest Survey of India. (2023). Indian state of forest report (Vol. 2). Ministry of Environment, Forests and Climate Change, Government of India. www.fsi.nic.in

Gama, J. T. da. (2023). The Role of Soils in Sustainability, Climate Change, and Ecosystem Services: Challenges and Opportu nities. *Ecologies,* 4(3), 552 - 567.

Ghosh, S., & Tripathi, S. K. (2021). Microbial succession and changes in carbon and nitrogen during decomposition of leaf litters of Tephrosia candida (Roxb.) DC. and Oryza sativa

L. under shifting cultivation in Mizoram, northeast India. *Journal of Applied and Natural Science*, 13(3), 1032.

Harper, H. J. (1924). The accurate determination of nitrates in soils. *Industrial and Engineering Chemistry,* 16(2), 180-183. https://doi.org/10.1021/ie50170a037 https://doi.org/10.3390/ecologies4030036

Hedin, L. O., Brookshire, E. J., Menge, D. N., & Barron, A. R. (2009). The nitrogen paradox in tropical forest ecosystems. *Annual Review of Ecology, Evolution, and Systematics,* 40, 613-635.

ISFR, (2023). India State of Forest Report (2023). Forest Survey of India. Ministry of Environment, Forest and Climate Change, Government of India, Dehradun, India. https://fsi.nic.in/forest-report-2023

Lal, R. (2016). Soil health and carbon management. *Food and energy security,* 5(4), 212-222.

Lamare, E., Ao, A. & Tripathi, S. K. (2024). Tree species diversity and carbon stock of tropical and sub-tropical forests of Mizoram, Northeast India. *Environment and Ecology* 42(4), 1473-1482. https://doi.org/10.60151/envec/IINN9593

Lindsay, W. L. & Norvell, W. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal,* 42(3), 421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Manpoong, C., & Tripathi, S. K. (2019). Soil properties under different land use systems of Mizoram, North East India. *Journal of Applied and Natural Science,* 11(1): 121-125.

Mebrate, A., Kippie, T., Zeray, N., & Haile, G. (2022). Selected physical and chemical properties of soil under different agro ecological zone in Gedeo Zone, Southern Ethiopia. *Heliyon,* 8(12).

Metson, A. J. (1956). Methods of chemical analysis for soil survey samples. *Soil Science,* 83(3), 245. https://doi.org/10.1097/00010694-195703000-00016

Moirangthem, B., Chanda, R., & Tripathi, S. K. (2026). Elevation-driven climatic variation shapes detrital pathways and nutrient dynamics in forests of Eastern Himalaya: implications for ecosystem resilience. *Environmental Monitoring & Assessment,* 198, 575. https://doi.org/10.1007/s10661-026-15399-7

Monsang, N. P., Upadhyay, K. K., Chanda, R., Pandey, R., & Tripathi, S. K. (2024). Volumetric tree growth models for aboveground biomass estimation of Pinus kesiya and Toona ciliata in Northeast India. Ecological Frontiers, 44(5), 958-965.

Nannipieri, P., Ascher, J., Ceccherini, M., Landi, L., Pietramellara, G., & Renella, G. (2017). Microbial diversity and soil functions. *European Journal of Soil Science,* 68(1), 12-26.

Oberson, A., Friesen, D. K., Morel, C., & Tiessen, H. (1997). Determination of phosphorus released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. *Soil Biology and Biochemistry* 29(9-10), 1577-1583. https://doi.org/10.1016/S0038-0717(97)00049-7

Ortiz, J. C., Panichini, M., Neira, P., Henríquez-Castillo, C., Jara, R., Rodríguez, R., Mutis, A., Ramos, C., Espejo, W., Puc-Kauil, R., Zagal, E., Stolpe, N., Schoebitz, M., Sandoval, M., & Dubé, F. (2025). How Natural Regeneration After Severe Disturbance Affects Ecosystem Services Provision of Andean Forest Soils at Contrasting Timescales. *Forests,* 16(3), 456. https://doi.org/10.3390/f16030456

Paul, E. A., Robertson, G. P., & Groffman, P. M. (2015). Chapter 14–Nitrogen Transformations. *Soil Microbiology, Ecology and Biochemistry,* 421-446.

Pionke, H. B., & Corey, R. B. (1967). Relations between acidic aluminum and soil pH, clay and organic matter. *Soil Science Society of America Journal,* 31(6), 749-752. https://doi.org/10.2136/sssaj1967.03615995003100060015x

Rowland, A. P. (1983). An automated method for the determination of ammonium-N in ecological materials. *Communications in Soil Science and Plant Analysis,*14(1), 49-63. https://doi.org/10.1080/00103628309367341

Saha, S., Chakraborty, D., Sharma, A. R., Tomoar, R. K., Bhadraray, S., Sen, U., & Kalra, N. (2010). Effect of tillage and residue management on soil physical properties and crop productivity in maize (Zea mays)–Indian mustard (Brassica juncea) system. *Indian Journal of Agricultural Sciences,* 80(8), 679-685.

Singh, N. S., Brearley, F. Q., & Tripathi, S. K. (2025). Climate control of litter decomposition and nutrient release in tropical and sub-tropical forest biomes of Northeast India. *Environmental Advances,* 20, 100634. https://doi.org/10.1016/j.envadv.2025.100634

Singh, N. S., & Tripathi, S. K. (2020) Temporal changes in soil microbial diversity of tropical and sub-tropical forests of Mizoram, Northeast India. Environ. Ecol. 38(1): 31–37.

Singh, S. S., Lamare, E., Chopade, B. A., Chanda, R., Devi, N. R., Upadhyay, K. K., & Tripathi, S. K. (2025). The hidden players: soil microbes in ecosystems sustainability. In *Climate Change and Soil Microorganisms for Environmental Sustainability* (pp. 295-320). Singapore: Springer Nature Singapore.

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science,* 25(8), 259-260

Tripathi S. K., Kushwaha, C. P., & Singh, K. P. (2008) Tropical forest and savanna ecosystems show differential impact of N and P additions on soil organic matter and aggregate structure. *Global Change Biology,* 14(11), 2572-2581

Tripathi, S. K., Chanda, R., Ao, A., Moirangthem, B., Chauhan, S., Mizo, L., & Vanlalfakawma, D. C. (2025). Elevation and management-induced vegetation and soil carbon shift in Eastern Himalayan forests: Advancing nature-based sustainability solutions (NbS). *Environmental and Sustainability Indicators,* 29, 101082. https://doi.org/10.1016/j.indic.2025.101082

Tripathi, S. K., Chanda, R., Singh, S. S., Devi, N. R., Ramtharmawi, D., K. V., Moirangthem, B., Kaguijenliu, R., Upadhyay, K. K., & Tyagi, A. (2026). Ecological analysis of shifting cultivation (jhum) in Northeast India: Challenges and opportunities. *Regional Environmental Change,* 26, 107. https://doi.org/10.1007/s10113-026-02603-0

Tripathi, S. K., Chakrobortty, S., Tyagi, A., Toushif, P. K., Singh, S. S., Upadhyay, K. K., & Chopade, B. A. (2025). The Role of Plant–Microbe Partnerships in Ecosystem Functionality. In *Climate Change and Soil Microorganisms for Environmental Sustainability* (pp. 127-151). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-3425-5_6

Tripathi, S. K., Vanlalfakawma, D. C., & Lalnunmawia, F. (2017). Shifting cultivation on steep slopes of Mizoram, India: impact of policy reforms. In *Shifting cultivation policies:*

balancing environmental and social sustainability, (pp. 393-413). Wallingford UK: CABI.

Tucker, B. B. & Kurtz, L. T. (1961). Calcium and magnesium determinations by EDTA titrations. *Soil Science Society of America Journal,* 25(1), 27-29. https://doi.org/10.2136/sssaj1961.03615995002500010016x

Upadhyay, K. K., Bareh, A., Devi, K. V., Thomte, L., Chanda, R., Singh, S. S., & Tripathi, S. K. (2026). Climate Vulnerability and Adaptive Capacity of Smallholder Farmers in Jaintia Hills Region of Meghalaya, Northeast India. *Environmental and Sustainability Indicators,* 30, 101249. https://doi.org/10.1016/j.indic.2026.101249

Ussiri, D. A., & Lal, R. (2017). *Carbon sequestration for climate change mitigation and adaptation* (pp. 287-325). Cham: Springer International Publishing.

Vance, E. D., Brookes, P. C., & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass C. *Soil biology and Biochemistry,* 19(6), 703-707.

Walkley, A. & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science ,* 37(1), 29-38. http://doi.org/10.1097/00010694-193401000-00003

Wapongnungsang, Ovung, E. Y., Tripathi, S. K. 2021. Assessment of tree diversity in tropical moist deciduous forest of Mizoram University, Northeast India. *Journal of Applied and Natural Science,* 13(1), 95-100. https://doi.org/10.31018/jans.v13i1.2436