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Seasonal Dynamics of Soil Chemical Properties under Different Jhum Cultivation Cycles in Mizoram

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A B S T R A C T

Shifting cultivation remains a dominant traditional agricultural practice in Mizoram, where soil fertility dynamics are strongly influenced by seasonal variation and fallow duration. The present study assessed seasonal and depth wise changes in soil pH, nitrogen (N), phosphorus (P), and potassium (K) under current jhum, short fallow, long fallow, and undisturbed forest systems in Nghalchawm, Mamit District, Mizoram. Results showed acidic soil conditions across all land use systems, with pH generally increasing with depth. Phosphorus was highest in current jhum sites due to ash deposition following burning, whereas undisturbed forest soils contained higher nitrogen and potassium, due to continuous litter input and nutrient recycling. Nutrient concentrations declined progressively with increasing soil depth. Long fallow systems demonstrated greater recovery of soil nutrients compared to short fallow systems, indicating improved soil restoration with extended fallow periods.

Introduction

With the increasing demand for food and limited economic opportunities in many rural communities, shifting cultivation is often considered a practical approach for sustaining livelihoods and ensuring food security. Although the practice is often associated with environmental concerns, it continues to persist due to socioeconomic dependence and the lack of accessible alternative sources of income for local communities. For centuries, jhum cultivation has served as the principal source of food production, livelihood security, and socio-cultural identity for indigenous tribal communities inhabiting the mountainous landscapes of Northeast India (Pandey *et al.,* 2022). Despite increasing modernization and policy interventions promoting settled agriculture, jhum cultivation continues to remain ecologically and economically significant in many rural areas of Mizoram (Tawnenga *et al.,* 1997; Vanlalhluna and Sahoo, 2021).

The shifting cultivation systems in Northeast India were characterized by long fallow cycles ranging from 15 to 30 years, which enabled sufficient recovery of vegetation, restoration of soil fertility, and maintenance of ecological stability (Lallawmkima *et al.,* 2023; Hazarika *et al.,* 2024). However, rapid population growth, increased demand for agricultural land, urban expansion, and changing socio-economic conditions have drastically shortened fallow cycles to as little as 3–5 years in certain parts of the region. Reduction in fallow duration has emerged as a major ecological concern and shortened recovery periods are often insufficient for rebuilding soil organic matter and replenishing essential nutrients removed during cultivation (Williams *et al.,* 2022). Consequently, shortened jhum cycles have been associated with declining crop productivity, accelerated soil erosion, nutrient depletion, loss of biodiversity and forest degradation (Toky and Ramakrishnan, 1983; Singh *et al.,* 2010).

Soil fertility constitutes one of the most critical factors controlling the sustainability and productivity of shifting cultivation systems. Soil nutrients regulate plant growth, microbial activity, litter decomposition, and ecosystem functioning in tropical hill environments. Among the essential macronutrients, nitrogen (N), phosphorus (P), and potassium (K) play particularly important roles in determining crop productivity and nutrient cycling processes (Lal, 2005; Liu *et al.,* 2022). The availability and transformation of these nutrients in jhum ecosystems are strongly influenced by burning intensity, ash deposition, microbial mineralization, litter decomposition, vegetation succession, rainfall patterns, and fallow duration (Brady and Weil, 2016; Islam *et al.,* 2025).

Burning of vegetation during jhum preparation temporarily increases soil pH and releases considerable quantities of mineral nutrients through ash deposition (Arunrat *et al.,* 2024). This initial nutrient flush may enhance short-term soil fertility and crop growth. However, repeated cultivation under shortened fallow conditions often results in rapid nutrient loss through surface runoff, leaching, volatilization, and erosion, especially in steep hill slopes receiving intense monsoonal rainfall (Bhattacharyya *et al.,* 2015; Molla *et al.,* 2022). Tropical soils of Northeast India are generally acidic and highly weathered, making them particularly vulnerable to nutrient depletion under continuous disturbance. It is known that shortened jhum cycles significantly reduce soil organic carbon, microbial biomass, and nutrient availability compared to long fallow or undisturbed forest systems (Jhumuria and Tripathi, 2012; Vanlalhluna and Sahoo, 2021; Kumar *et al.,* 2023).

The monsoon climate of Mizoram, characterized by heavy rainfall and high humidity, strongly affects nutrient availability and mobility. During the rainy season, enhanced soil moisture stimulates microbial decomposition and nutrient mineralization; however, excessive rainfall also accelerates nutrient leaching and surface runoff. Dry pre-monsoon conditions may reduce microbial activity and limit nutrient transformation processes, seasonal fluctuations in temperature, moisture, and litter input therefore contribute significantly to temporal variation in soil nutrient status across different land-use systems. Understanding these seasonal nutrient dynamics is essential for evaluating the ecological sustainability of jhum cultivation under changing environmental conditions (Singh and Mishra, 2014; Devi and Yadava, 2006; Behera *et al.,* 2017).

The present study was therefore undertaken in Nghalchawm village to evaluate seasonal and depth wise variation in soil nutrient characteristics under current jhum (J), short fallow (SF), long fallow (LF), and undisturbed forest (UD) systems. The study aims to provide nutrient restoration processes associated with fallow succession and to assess the ecological implications of shortened jhum cycles on soil fertility in tropical hill ecosystems.

Materials and Methods

Study site

The present study was conducted in Nghalchawm villages located under Mamit District, Mizoram. Mamit district experiences a tropical monsoon climate with warm humid summers and heavy rainfall during the monsoon season (Thachunglura *et al.,* 2024). Agriculture, particularly shifting cultivation, constitutes one of the major livelihood activities of the local population.

The study area represents a typical shifting cultivation landscape comprising current jhum fields, short fallow areas, long fallow areas, and undisturbed forest patches. The region experiences a humid subtropical climate with distinct pre-monsoon, monsoon, and post-monsoon seasons, making it suitable for studying seasonal variation in soil nutrient dynamics under different land use systems.

Soil sampling

Soil sampling was carried out during 2022 and 2023 from shifting cultivation landscapes in Nghalchawm village under four different jhum cultivation cycles, such as current jhum (J), short fallow (SF, 2–3 years), and long fallow (LF, 7–8 years).Undisturbed forest (UD) soils were taken as the control sites for comparison and were selected from forest patches adjacent to the long fallow areas in order to represent relatively undisturbed natural forest conditions. Soil samples were collected during three major seasons of the year, namely pre-monsoon, monsoon, and post-monsoon, to assess seasonal variation in soil nutrient dynamics under different stages of shifting cultivation cycles. At each jhum cultivation cycle, soil samples were collected randomly with three replicates from each site to ensure representative sampling and minimize spatial variability. Samples were obtained from three soil depths: 0–10 cm (a), 10–20 cm (b), and 20–30 cm (c). The collected samples were designated as Ja, Jb, and Jc for current jhum soils; SFa, SFb, and SFc for short fallow soils; LFa, LFb, and LFc for long fallow soils; and UDa, UDb, and UDc for undisturbed forest soils. Soil samples from each depth were collected using a soil auger after carefully removing surface litter and debris.

Sample Collection and Processing

The samples samples were air dried under room temperature, gently crushed using a wooden mortar and pestle, and passed through a 2 mm sieve to remove stones, roots, and other coarse materials prior to analysis. The processed soil samples were analyzed for physicochemical and nutrient parameters. Soil pH was determined using a digital pH meter in a soil water suspension prepared at a ratio of 1:2.5 (soil: distilled water). The suspension was stirred thoroughly and allowed to equilibrate before measurement (Jackson, 1973). Total nitrogen (N) content of the soil samples was estimated by the Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982). Available phosphorus (P) was determined using Olsen's extraction method, extraccted using sodium bicarbonate solution (0.5 M $NaHCO_3$), and the phosphorus concentration in the extract was measured colorimetrically (Olsen *et al.,* 1954). Available potassium (K) content was estimated using flame photometry after extraction with neutral normal ammonium acetate solution. The extracted potassium concentration was measured with a flame photometer and expressed as kg ha^{-1} (Jackson, 1973).

Statistical Analysis

Analysis of variance (ANOVA) was carried out using IBM SPSS Statistics software package for data processing, statistical computation, and graphical interpretation of results (IBM Corp., 2023) to determine the significance of differences among the different jhum cultivation cycles and seasonal variations in soil properties. The analysis helped identify the influence of cultivation stage and seasonal changes on soil nutrient dynamics. Significant differences among means were interpreted at the 5% probability level ($p < 0.05$) following standard statistical procedures described by Gomez and Gomez (1984). Pearson correlation analysis was further performed to examine the relationships among soil nutrient parameters such as pH, nitrogen, phosphorus, and potassium. Correlation coefficients were used to determine the degree and direction of association between the measured soil variables under different jhum cultivation cycles (Zar, 2010).

Results and Discussion

The present study investigated seasonal variation in soil chemical properties under different land use systems, namely jhum cultivation (J), short fallow (SF), long fallow (LF), and undisturbed forest (UD) in Nghalchawm village, Mamit District. Soil samples collected during pre-monsoon, monsoon, and post-monsoon seasons were analyzed to evaluate the influence of shifting cultivation and fallow duration on soil fertility dynamics. One-way ANOVA was employed to assess the significance of variation among land-use systems for each season. The findings demonstrated substantial seasonal and site-wise variation in soil pH, total nitrogen, available phosphorus, and available potassium.

Soil pH

Soil pH remained acidic throughout all seasons and land-use systems, reflecting the typical characteristics of tropical hill soils subjected to high rainfall and intense weathering. During pre-monsoon season, pH values ranged from 5.45 in SF to 6.26 in UD. In monsoon season, pH ranged from 5.73 in LF to 6.39 in UD, whereas post-monsoon values varied from 5.71 in SF to 6.25 in UD. Among the three seasons, significant variation in pH was observed during pre-monsoon ($F = 16.326$, $p = 0.0009$) and monsoon seasons ($F = 4.308$, $p = 0.0438$), while post-monsoon variation remained statistically non-significant ($F = 3.403$, $p = 0.0738$). The comparatively higher pH values recorded in UD indicate improved buffering capacity and greater organic matter accumulation under undisturbed vegetation. In contrast, lower pH values in short fallow systems suggest nutrient depletion and enhanced leaching associated with continuous land use. The temporary increase in pH observed in active jhum systems during monsoon and post-monsoon seasons may be linked to residual ash deposition after slash-and-burn activities, which contributes basic cations to the soil. Ramakrishnan (1992) reported that shifting cultivation can substantially modify soil reaction and accelerate nutrient loss in tropical hill ecosystems. Shortened fallow periods and intensive land use disrupt soil structure, reduce organic carbon content, and increase erosion. Consequently, the long-term sustainability of traditional jhum systems becomes increasingly vulnerable.

Total Nitrogen (N)

Total nitrogen content showed moderate seasonal fluctuation among land-use systems. During pre-monsoon season, nitrogen ranged from 0.28% in SF to 0.47% in UD. In monsoon season, values varied from 0.34% in SF to 0.58% in J, while post-monsoon nitrogen ranged from 0.36% in SF to 0.51% in J. Despite apparent differences in mean values, ANOVA results indicated non-significant variation among sites during all seasons: pre-monsoon ($F = 0.767$, $p = 0.544$), monsoon ($F = 0.749$, $p = 0.553$), and post-monsoon ($F = 0.488$, $p = 0.7001$). The relatively higher nitrogen concentrations in J and UD systems may be attributed to ash incorporation after burning and continuous litter decomposition under forest vegetation, respectively. Lower nitrogen content in short fallow systems suggests insufficient recovery of soil fertility due to shortened fallow duration. Nitrogen dynamics in shifting cultivation ecosystems are strongly influenced by microbial mineralization, rainfall, and decomposition processes, which may explain the absence of statistically significant seasonal variation. Similar findings were reported by Toky and Ramakrihnan (1983) and Nye and Greenland (1960), who observed gradual nitrogen depletion under repeated cultivation cycles.

Available Phosphorus (P)

Available phosphorus exhibited noticeable seasonal and site-wise variation. During pre-monsoon season, phosphorus ranged from 7.52 in UD to 15.66 in J. Monsoon values ranged from 4.48 in LF to 7.51 in UD, whereas post-monsoon values ranged from 8.94 in UD to 12.86 in SF.ANOVA analysis revealed significant variation only during pre-monsoon season ($F = 4.15$, $p = 0.0477$), while monsoon ($F = 2.029$, $p = 0.1885$) and post-monsoon ($F = 1.93$, $p = 0.2033$) seasons showed non-significant variation among sites. Elevated phosphorus levels in active jhum sites during pre-monsoon season may be associated with ash deposition following biomass burning, which converts organically bound phosphorus into readily available inorganic forms. The decline in phosphorus during monsoon season is likely due to runoff, erosion, and leaching under heavy rainfall conditions. Comparatively lower phosphorus in undisturbed forest systems may be associated with immobilization within plant biomass and litter layers. Similar observations were documented by Juo and Manu (1996), who reported rapid phosphorus enrichment immediately after burning followed by gradual depletion during rainy periods.

Available Potassium (K)

Available potassium exhibited the highest degree of seasonal and site-wise variation among all measured parameters. During pre-monsoon season, potassium ranged from 65.39 in SF to 434.22 in UD. Monsoon values varied from 63.36 in SF to 375.67 in UD, while post-monsoon potassium ranged from 72.62 in SF to 369.67 in UD.

ANOVA results demonstrated highly significant variation among sites during all seasons: pre-monsoon ($F = 117.388$, $p < 0.001$), monsoon ($F = 111.471$, $p < 0.001$), and post-monsoon ($F = 83.828$, $p < 0.001$). The elevated potassium content in J sites is primarily associated with ash deposition after biomass burning, which rapidly releases exchangeable potassium into the soil. Similarly, undisturbed forests maintained high potassium levels through continuous litter decomposition and nutrient recycling. Lower potassium levels in short and long fallow systems indicate nutrient depletion and inadequate replenishment during shortened fallow cycles. Potassium is highly soluble and susceptible to leaching during heavy rainfall, which may explain the gradual decline observed during monsoon and post-monsoon seasons. Comparable findings were reported by Greenland (1975) and Ramakrishnan (1992).

Statistical Analysis

The ANOVA analysis demonstrated that soil chemical properties varied considerably among land-use systems and across seasons. Soil pH showed significant variation during pre-monsoon and monsoon seasons, indicating the influence of shifting cultivation practices and rainfall on soil acidity.

Figure.1 Seasonal variation of soil pH under different Jhum cycles (J, SF, LF, and UD) during pre-monsoon, monsoon, and post-monsoon seasons.

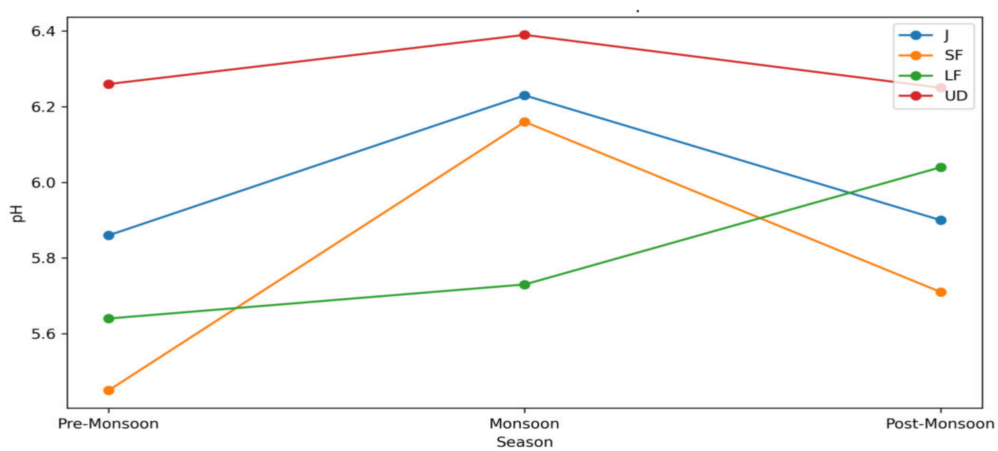


Figure.2 Seasonal variation of total nitrogen (%) under different Jhum Cycles (J, SF, LF, and UD) during pre-monsoon, monsoon, and post-monsoon seasons.

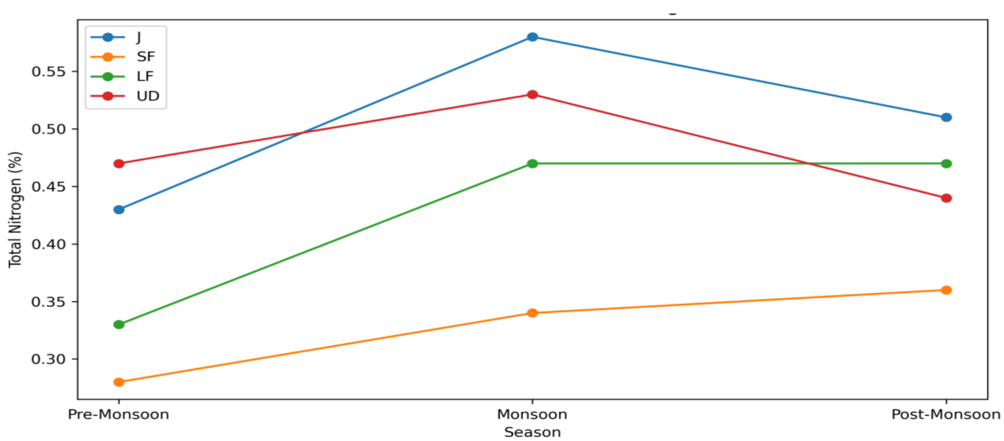


Figure.3 Seasonal variation of available P under different Jhum Cycles (J, SF, LF, and UD) during pre-monsoon, monsoon, and post-monsoon seasons.

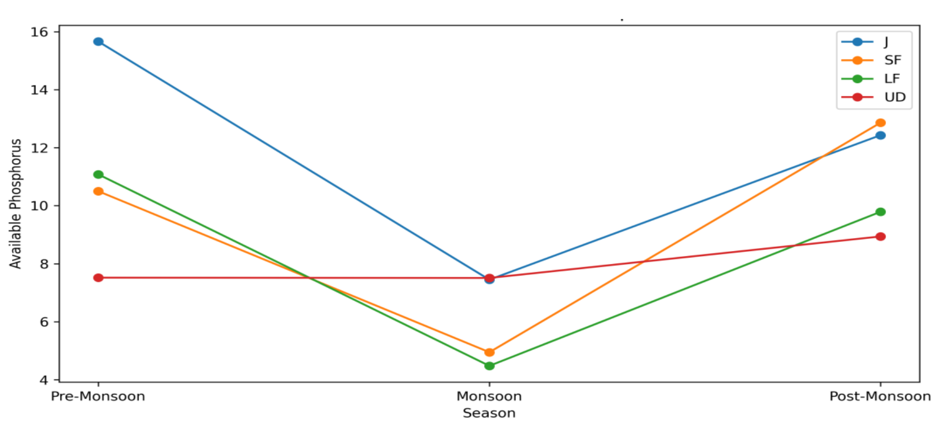
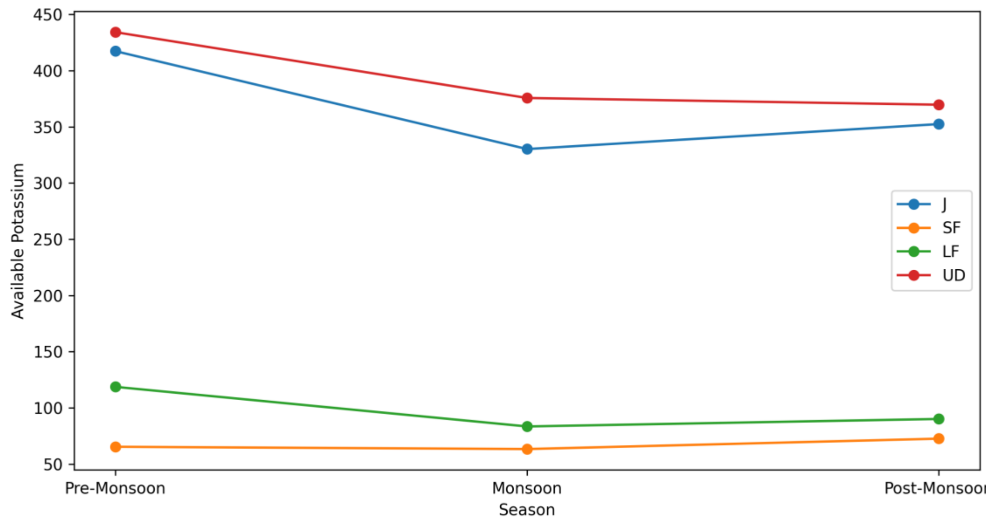


Figure.4 Seasonal variation of available K under different Jhum Cycles (J, SF, LF, and UD) during pre-monsoon, monsoon, and post-monsoon seasons.



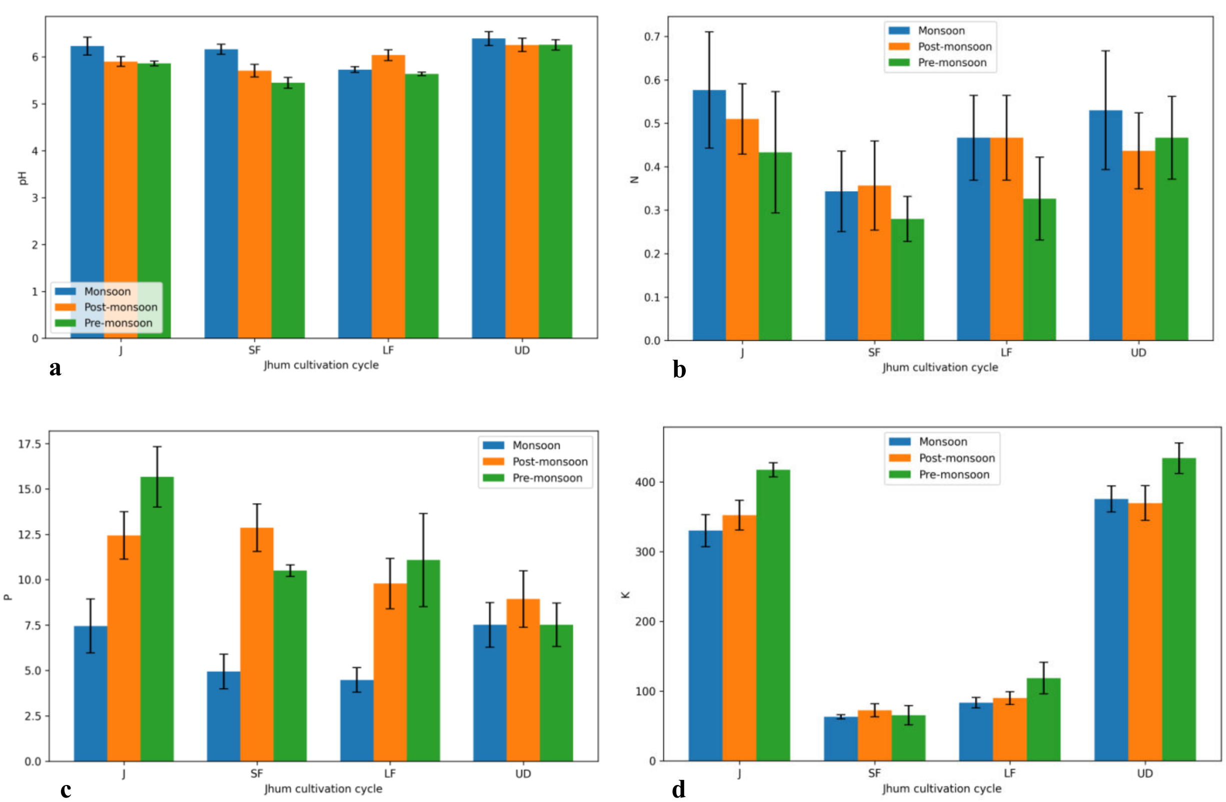


Figure 5. Seasonal variation in soil chemical properties under different jhum cultivation cycles in Mizoram. Bar graphs represent mean values ± SEM for (a) soil pH, (b) total nitrogen (%), (c) available phosphorus, and (d) available potassium across Jhum cultivation (J), Short Fallow (SF), Long Fallow (LF), and Undisturbed Forest (UD)

Table.1 One-way ANOVA showing seasonal variation in soil chemical properties under different jhum cultivation cycles in Mizoram. Significant differences were considered at p < 0.05. J = Jhum cultivation, SF = Short Fallow, LF = Long Fallow, and UD = Undisturbed Forest.

Season	Parameter	F-value	p-value	Significance
Pre-Monsoon	Soil pH	16.326	0.0009	*
	Total Nitrogen (%)	0.767	0.5440	ns
	Available Phosphorus (P)	4.150	0.0477	*
	Available Potassium (K)	117.388	<0.001	***
Monsoon	Soil pH	4.308	0.0438	*
	Total Nitrogen (%)	0.749	0.5530	ns
	Available Phosphorus (P)	2.029	0.1885	ns
	Available Potassium (K)	111.471	<0.001	***
Post-Monsoon	Soil pH	3.403	0.0738	ns
	Total Nitrogen (%)	0.488	0.7001	ns
	Available Phosphorus (P)	1.930	0.2033	ns
	Available Potassium (K)	83.828	<0.001	***

Note: * - significant, ns - not significant, *** - highly significant

Available phosphorus exhibited significant variation only during the pre-monsoon season, likely due to immediate nutrient release following biomass burning. In contrast, available potassium consistently showed highly significant variation across all seasons, reflecting strong effects of ash deposition and nutrient cycling in jhum ecosystems. Total nitrogen did not differ significantly among sites during any season, suggesting relatively stable nitrogen dynamics despite seasonal fluctuations in cultivation practices and rainfall patterns.

The present investigation clearly demonstrates that shifting cultivation practices and fallow duration substantially influence seasonal soil nutrient dynamics in Mizoram. Significant variation in soil pH and available potassium was consistently observed among land-use systems, whereas total nitrogen showed comparatively stable distribution across seasons. Available phosphorus exhibited significant variation only during the pre-monsoon season, likely reflecting the immediate influence of biomass burning and ash incorporation. Undisturbed forest ecosystems consistently maintained better soil quality due to stable nutrient cycling, higher organic matter accumulation, and continuous litter deposition. Active jhum systems showed temporary nutrient enrichment, particularly in phosphorus and potassium, resulting from slash-and-burn activities. In contrast, short fallow systems consistently recorded lower nutrient status, indicating incomplete soil recovery under shortened fallow cycles.

The present study demonstrated that shifting cultivation and fallow duration significantly influence seasonal soil nutrient dynamics in Mizoram. Soil pH remained acidic throughout all seasons, ranging from 5.45 to 6.39, with comparatively higher values consistently observed in the undisturbed forest (UD) system. Significant variation in soil pH was observed during pre-monsoon ($F = 16.326$, $p = 0.0009$) and monsoon seasons ($F = 4.308$, $p = 0.0438$), indicating the influence of land-use practices on soil reaction.

Total nitrogen content ranged from 0.28% to 0.58%, with relatively higher values recorded in Jhum (J) and UD systems. However, nitrogen variation among sites remained statistically non-significant across all seasons. Available phosphorus varied from 4.48 to 15.66, showing significant variation only during the pre-monsoon season ($F = 4.15$, $p = 0.0477$), likely due to temporary nutrient enrichment from ash deposition following slash-and-burn activities.

Available potassium exhibited the highest seasonal variation, ranging from 63.36 to 434.22, and showed highly significant differences among sites during pre-monsoon ($F = 117.388$, $p < 0.001$), monsoon ($F = 111.471$, $p < 0.001$), and post-monsoon seasons ($F = 83.828$, $p < 0.001$). Higher potassium levels in J and UD systems reflected the effects of ash incorporation and efficient nutrient recycling, respectively. Overall, undisturbed forest systems maintained comparatively better soil fertility, whereas short fallow systems consistently recorded lower nutrient status, indicating incomplete soil recovery under shortened fallow cycles.

In conclusion, the present study demonstrated that soil physicochemical properties in shifting cultivation systems of Mizoram are strongly influenced by seasonal variation, soil depth, and fallow duration. Long fallow and undisturbed forest systems showed better nutrient restoration and soil fertility compared to short fallow and active jhum sites. Significant variations in soil pH and nutrient distribution highlight the ecological importance of maintaining adequate fallow periods for sustainable soil recovery. The findings emphasize that longer fallow duration and conservation of secondary vegetation are essential for sustaining agricultural productivity, soil fertility, and ecological stability in shifting cultivation landscapes of Mizoram, Northeast India.

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Author Contributions

Lallawmkima Bochung: Investigation, formal analysis, writing—original draft. S. T. Lalzarzovi: Validation, methodology, writing—reviewing. John Zothanzama:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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