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Impact of secondary forest fallow period on soil microbial biomass carbon and enzyme activity dynamics under shifting cultivation in North Eastern Hill region, India

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ABSTRACT

Length of the secondary forest fallow period has often played an important role in affecting the soil fertility status for first year cultivation of crops in shifting cultivation system. However, information regarding the soils after the first year cultivation is limited. The objective of the study was to assess the effect of different shifting cultivation fallow period on the dynamics of soil health status during the first and second year. Results suggest that increase in the fallow period significantly ($p < 0.05$) decreased the bulk density (BD), while increasing the soil organic carbon (SOC), soil nutrients, MBC and enzyme activities. While the SOC decreases between 6.1 and 31.3% due to cultivation compared to the soil condition before burning during the first year, MBC decreases between 33.61 and 60.9%. The SOC was recovered at the end of second year, while the MBC increases sharply during the second year. Enzyme activities in general decreased after burning and increased gradually during the second year. PCA results indicated that length of fallow period > 10 year maintains one cluster where fallow period including 10 and below maintains another cluster during the first and second year. Results therefore suggest that MBC, MBC:SOC and soil enzyme activities played as an indicator of soil health and maintaining secondary forest fallow period > 10 years was better in conserving soil health for first and second year under shifting cultivation.

1. Introduction

Shifting cultivation involves burning of slashed native vegetation, followed by cultivation of crops. Shifting cultivation has been practiced as an indigenous subsistence farming in the hilly tracts of Latin America, Central Africa and Southeast Asia for ages (Inoue et al., 2010; van Vliet et al., 2012). Although the negative impact due to unabated deforestation, soil erosion and ecosystem degradation has been associated with it (Saha et al., 2007), but in many cases may be overestimated (Ziegler et al., 2009). Nevertheless, it still dominates the tropical agricultural system (van Vliet et al., 2012). In India, shifting cultivation is concentrated in the north east hill (NEH) regions with an estimated 1.47 million hectares of land being involved (Yadav, 2013) where the system of practice varies greatly among tribal communities. Ram and Singh, 1993 reported the loss of 702.9 kg of organic carbon (OC), 63.5 kg of phosphorus (P) and 5.9 kg of potassium (K) ha^{-1} from steep slopes (44–53%) of NEH region due to shifting cultivation. Finding technological alternatives and improvement remains a frontal challenge in steep slopes of NEH regions like Mizoram (Grogan et al., 2012). In order to take up the challenge, plantation of oil palm, rubber, arecanut has been introduced after the first year cultivation of slash and burn by the state government thereby slowly reducing the area under shifting cultivation system.

Information on shifting cultivation in relation to chemical and physical soil properties with length of the fallow period, before and after burning during the first year were reported from NE India region (Ramakrishnan and Toky, 1981; Arunachalam, 2002; Sarkar et al., 2015). Available reports indicated that the length of the fallow period often played a crucial role in conserving soil organic carbon (SOC) and soil available nutrients (Ramakrishnan and Toky, 1981; Sarkar et al., 2015). While the availability of nutrient P, K, calcium (Ca) and magnesium (Mg) increased after burning, SOC content decreased due to burning. Tawnenga et al., 1997 observed a decline in soil fertility from first year to second year cultivation for 6 and 20 year forest fallows in Mizoram. Although, soil nutrient constitutes the foundation for plant growth, high level microbial activity is widely accepted for

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maintenance of soil health. Soil enzyme activities such as phosphatase, β-glucosidase, arylsulphatase and dehydrogenase were often used as indicators of soil quality due by burning and anthropogenic disturbances (Ajwa et al., 1999; Boerner et al., 2005). Furthermore, soil enzymes play a crucial role in organic matter (OM) decomposition and nutrient cycling and thus have a direct link with microbial biomass carbon (Yao et al., 2006). In the process of SOC turnover, soil microbial biomass carbon (MBC) acts as a sensitive component (Marinari et al., 2006), rapidly responds to soil management and disturbance than native SOC (Shao et al., 2015).

The evaluation of second year shifting cultivation on soil fertility status by Tawnenga et al., 1997 involved cultivation of paddy during the second year where soil disturbances due to cultivation reduced the soil fertility. With the lack of available information on the second year soil health where plantation crops are grown, it was necessary to evaluate the fallow after the first year cultivation through dynamics of MBC and soil enzyme activities. We hypothesize that the length of fallow period has a strong positive influence on the soil health status of the second year after the first year cultivation. The objectives of this research work was to: 1) evaluate the effect of different length of secondary forest fallow periods on the dynamics of SOC, MBC and potential enzyme activities of the first and second year. 2) elucidate the relationship between SOC, MBC and enzyme activities as a potential indicator of soil health under shifting cultivation.

2. Materials and methods

2.1. Site description and selection

The study was conducted at Bilkhawthlir and Thingdawl blocks of Kolasib district, Mizoram, North eastern India. The area falls under sub-tropical, humid to per humid climate and the present soil was formed from parent rock of sandstone, siltstone and shale of Bhuban formation (Miocene). The soils from this region are moderately shallow to moderately deep (80 to 120 cm) mostly dark yellowish brown to yellowish brown (Fine, Typic Haplahumults). Detailed information regarding the study sites and weather conditions are displayed (Table 1; Fig. 1). Shifting cultivation in Mizoram consists of cultivation of local landraces of upland paddy (*Oryza sativa*) during the first year as sole crop or as an intercrop with maize (*Zea mays*), cowpea (*Vigna sinensis*), sesame (*Sesamum indicaum*), chilli (*Capsicum spp*), pumpkin (*Cucurbita peto*), brinjal (*Solanum melongena*), etc. without external application of pesticides and chemical fertilizers. Site selection was done through questioning the farmers who would currently undergo the operation at the site and farmers who had operated the site before. The forest vegetation was slashed during December, 2013 and January, 2014 and burned during the month of March, 2014 before the onset of monsoon. Cleaning and one weeding was done before sowing after which paddy was sown during the month of May. Three weeding was done during rice growth period.

Secondary forest fallows facing southward slopes were selected chronologically to represent young and old fallow namely - 23, 21, 14, 10, 6, 3 and 1 year represented as F_{23}, F_{21}, F_{14}, F_{10}, F_6, F_3 and F_1 respectively. For example, after cultivation, the site has been kept uncultivated and left for forest regeneration for 23 years (F_{23}) and so on. One year fallow represent site where paddy was cultivated after 14 years of forest fallow during May to October 2013 and the site was again cultivated for second year during 2014 after cleaning the leftover paddy straw but without burning. We included T_1 in order to check the soil variability as affected by cultivation without burning. In all the selected forest fallow sites, farmer's cultivated upland paddy (*Trai*, a local paddy landrace) till maturity with their own traditional cultivation practice as described above.

2.2. Soil sampling and processing

In the first year, surface soil samples (0–10 cm) were collected with soil core during January 2014 from all the sites, just before the vegetation was slashed (T_1). Second sampling was carried out in the month of May (T_2) 45 days after burning to represent the soil condition during the sowing time for paddy and third sampling during the month of October immediately after final harvest (T_3). In the second year, similar soil samples were collected during February (T_4), July (T_5) and November (T_6). Three plots ($10 \times 10\ m^2$) were demarcated from each site to represent the entire slope and soil samples were collected homogenously from each plot (6 points per plot to make a composite sample) representing three replications per site. Field moist soil samples were sieved to pass through 2 mm size and preserved at 4 °C for the determination of soil moisture, MBC and soil enzymatic activities. The other part of the soil was air dried to determine initial soil properties and passed through a 0.5 mm sieve for SOC determination.

2.3. Soil analysis

Gravimetric water content of the soil was determined and BD by core method. Soil pH was measured at soil: water suspension of 1:2.5 (pH meter; WPH-10, Wensar, India). Determination of SOC was carried out by $K_2Cr_2O_7$ wet oxidation method (Walkley and Black, 1934). Available N was determined by $KMnO_4$ oxidation method (Subbiah and Asija, 1956); total N by kjeldahl digestion (Distyl-EM, Pelicans, India) method (Jackson, 1973). Available P was extracted by Bray no 1 reagent, total P by digestion with $HClO_3$ and finally determined by ascorbic acid method (Kuo, 1996). Determination of NH_4OAc extractable K was done using flame photometer (ESICO-1382, India).

Table 1
Important characteristics of the experimental site.

Code	Altitude (m msl)	Slope (°)	Location	Major vegetation	Soil texture
F_{23}	834	18	24 23.855 N 92 44.925 E	*Dendrocalamus longispathus, Melocanna baccifera, Tectona grandis*	CL
F_{21}	861	24	24 22.072 N 92 44.065 E	*Dendrocalamus longispathus, Melocanna baccifera*	CL
F_{14}	1122	18	24 21.135 N 92 43.465 E	*Dendrocalamus longispathus, Schima wallichii, Artocarpus chaplasha.*	CL
F_{10}	836	17	24 11.222 N 92 40.193 E	*Melocanna baccifera, Dendrocalamus longispathus, Ficus racemosa, Baccaurea ramiflora.*	SC
F_6	1040	16	24 11.175 N 92 40.219 E	*Saccharum arundinaceum, Melocanna baccifera, Imperata cylindrica*	SC
F_3	1980	18	24 12.651 N 92 40.420 E	*Imperata cylindrica, Saccharum arundinaceum*	CL
F_1	855	16	24 21.772 N 92 44.746 E	*Oryza sativa*	CL

Cl: Clay loam; SC: Sandy clay.

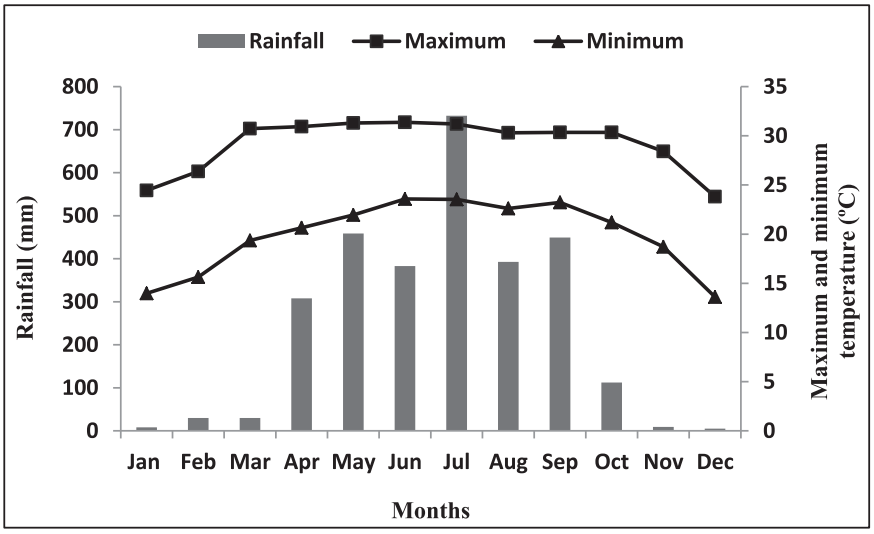

Fig. 1. Mean monthly weather parameters during 2014–2015 of the region.

Microbial biomass carbon content of the soil was determined by chloroform fumigation method (Vance et al., 1987). 20 g fresh soil was subjected to fumigation and extracted (fumigated and unfumigated) with 80 ml of 0.5 M K_2SO_4 for 30 min. The suspension was filtered with Whatman No. 42 paper and used for determination of C by $K_2Cr_2O_7$ wet-oxidation method. The difference was determined and MBC was calculated by a conversion factor of $K_{EC} = 0.38$. Acid phosphatase (ACP) and alkaline phosphatase enzyme activity (ALK) was determined after Tabatabai and Bremmer (1969) with modified universal buffer (MUB, pH 6.5 and 11.0) using *p*-nitrophenyl phosphate disodium salt (0.025 M) as a substrate. Determination of β-glucosidase enzyme activity (GLY) was carried out after Eivazi and Tabatabai (1988), with MUB buffer (pH 6.0) using *p*-nitrophenyl-β-D-glucopyranoside (0.025 M) as substrate and the arylsulphatase activity (ARY) after Tabatabai and Bremner (1970) with sodium acetate buffer using *p*-nitrophenyl-sulphate (0.025 M) substrate. The enzyme activities were determined in terms of *p*-nitrophenol (PNP) produced after 1 h of incubation and expressed as μg PNP g^{-1} (dw) soil h^{-1}. Soil dehydrogenase activity (DHY) was estimated by the method given by Casida et al. (1964) and expressed as μg TPF g^{-1} (dw) soil h^{-1}. Measurement of all the above mentioned enzymatic activity was performed by UV-VIS spectrophotometer (Specord 200 plus, Analytikjena, Germany).

2.4. Data analysis

All results were reported as means ± standard error. Two-way ANOVA with fallow period and sampling time as factors was performed. One-way ANOVA was employed for the soil parameters to check the sampling time variability within and between the length of fallow period followed by Duncan's test ($p < 0.05$) to compare the means. Principal component analysis (PCA) was carried out to provide information about the degree of fallow period influence on the studied soil parameters for the first and second year. All statistical analysis was carried out by SAS. v. 9.3 software (SAS Institute).

3. Results

3.1. Initial soil characteristics

The soils under different fallow periods were clay loam texture except for F_{10} and F_6 which were sandy clay (Table 1). The length of fallow period had profound effect on the BD (Table 2). F_1 exerted the highest bulk density (1.24 g m^{-3}) and the lowest by F_{21} (1.03 g m^{-3}). Lengthening of forest fallow period significantly increased the available N from 144 mg kg^{-1} (F_3) to 237 mg kg^{-1} (F_{23}). The total N and total P were significantly influenced by lengthening of forest fallow period and varied between 1.4 g kg^{-1} (F_3) to 2.4 g kg^{-1} (F_{21}) and 353 mg kg^{-1} (F_6) to 423 mg kg^{-1} (F_{21}) respectively. No consistent trend was observed for available P (2.3 mg kg^{-1}; F_6 to 4.3 mg kg^{-1}; F_3) and K (131 mg kg^{-1} for F_1 to 209 mg kg^{-1} for F_{14}; Table 2).

3.2. Dynamics of soil pH, SOC, MBC and MBC:SOC

Results showed the significant impact of fallow period (F) and sampling time (T) on soil pH, SOC, MBC and MBC:SOC (Table 3). Further, the dynamics of the soil parameters studied at different sampling time were checked within and between lengths of the fallow period (Table 4). Soils of the experimental site were acidic with pH value ranging between 5.04 and 5.3 (Fig. 2). Soil pH in general increased from T_1 (5.15) to T_2 (5.24). Further, soil pH decreased slightly as cultivation progressed till the second year (Fig. 2). The SOC content significantly increased with the length of fallow period ranging between 19.1 mg g^{-1} to 30.22 mg g^{-1} following $F_{21} > F_{23} > F_{14} > F_6 > F_3 > F_1 > F_{10}$ ($p < 0.05$). SOC significantly decreased due to burning (T_1 to T_2) between 10% (F_3) to 22.31% (F_{21}; $p < 0.05$), while there was no significant change for F_1 (20.23 to 20.92 mg g^{-1}). SOC decreased gradually as cultivation proceeds (T_3) compared to T_1 from F_1 (6.1%) to F_{21} (31.3%; Fig. 2); then recovered during the end of second year (T_6). The soil MBC and MBC:SOC from older fallows (F_{21}, F_{23}, F_{14}) were significantly higher than younger fallows (F_{10}, F_6, F_3, F_1) with values ranging between 491 and 992.8 mg kg^{-1} MBC and 2.43 to 3.6% MBC:SOC respectively ($p < 0.05$). MBC significantly decreased till the end of crop harvest stage (T_3) where, the decrement due to burning (T_2) varied between 16.8% (F_{10}) to 39.3% (F_{21}) and further to harvesting stage of paddy (T_3) between 33.61% (F_1) to 60.9% (F_{21}). MBC:SOC significantly decreased due to burning (T_2) between 6.03% (F_{10}) to 28.99% (F_{23}; $p < 0.05$) and further decrease to harvesting stage where the decrement up to the harvesting stage (T_3) was between F_1 (29.05%) to F_{14} (47.1%). The MBC and MBC:SOC values increased significantly during the second year from T_4 reaching a value varying from 537.6 mg kg^{-1} to 1042 mg kg^{-1} and 3.5 to 5.3% during T_6 respectively ($p < 0.05$; Fig. 2).

3.3. Dynamics of soil enzyme activities

The length of the F and T had a significant influence on soil enzyme activities (ACP, ALK, ARY, GLY and DHY; Table 3; Table 4). The longer

Table 2
Initial soil characteristics of different fallow period.

Fallow (Year)	Bulk density (g m^{-3})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Total N (g kg^{-1})	Total P (mg kg^{-1})
F_{23}	1.07 ± 0.03^{cd}	237 ± 3^{a}	2.70 ± 0.12^{b}	157 ± 2^{b}	2.1 ± 0.15^{b}	412 ± 9^{ab}
F_{21}	1.03 ± 0.01^{d}	230 ± 4^{a}	3.0 ± 0.31^{b}	150 ± 1^{b}	2.4 ± 0.09^{a}	423 ± 10^{a}
F_{14}	1.06 ± 0.02^{cd}	226 ± 4^{a}	2.1 ± 0.13^{b}	209 ± 2^{a}	2.0 ± 0.06^{b}	406 ± 10^{abc}
F_{10}	1.08 ± 0.01^{bc}	163 ± 6^{bc}	3.2 ± 0.55^{b}	198 ± 5^{a}	1.7 ± 0.06^{c}	388 ± 8^{bc}
F_{6}	1.13 ± 0.01^{b}	176 ± 10^{b}	2.3 ± 0.07^{b}	164 ± 7^{b}	1.6 ± 0.03^{cd}	353 ± 10^{d}
F_{3}	1.20 ± 0.02^{a}	144 ± 6^{c}	4.3 ± 0.61^{a}	158 ± 9^{b}	1.4 ± 0.03^{d}	375 ± ^{cd}
F_{1}	1.24 ± 0.01^{a}	147 ± 4^{c}	2.8 ± 0.08^{b}	131 ± 4^{c}	1.6 ± 0.06^{cd}	381 ± 14^{bcd}

Means followed by ± numbers represent standard error (SE). F_{23}: 23 year fallow; F_{21}: 21 year fallow; F_{14}: 14 year fallow; F_{10}: 10 year fallow; F_{6}: 6 year fallow; F_{3}: 3 year fallow; F_{1}: 1 year fallow. Different letters along the column are significantly different ($p < 0.05$) according to Duncan's test.

Table 3
Statistical results (F value) of two-way ANOVA for individual soil parameters.

	Fallow (F)	Time (T)	FxT
pH	16.91***	6.59***	1.01
SOC (mg g^{-1})	130.39***	74.81***	2.78***
MBC (mg kg^{-1})	188.63***	426.10***	11.23***
MBC:SOC (%)	30.71***	196.33***	3.13***
ACP (μg pNP g^{-1} h^{-1})	131.65***	52.77***	3.9***
ALK (μg pNP g^{-1} h^{-1})	80.94***	103.09***	6.80***
DHY (μg TPF g^{-1} h^{-1})	79.34***	304.67***	17.81***
ARY (μg pNP g^{-1} h^{-1})	108.19***	33.15***	2.47***
GLY (μg pNP g^{-1} h^{-1})	87.06***	61.90***	4.36***

SOC: Soil organic carbon; MBC: Microbial biomass carbon; ACP: Acid phosphatase enzyme; ALK: Alkaline phosphatase enzyme; DHY: Dehydrogenase enzyme; ARY: Arylsulphatase enzyme; GLU: β-glucosidase enzyme; * p-level < 0.05; ** p-level < 0.01; ***p-level < 0.001.

fallow period (F_{23}, F_{21} and F_{14}) significantly harbours more soil enzyme activities than the younger fallow periods (F_{10}, F_{6}, F_{3} and F_{1}; Fig. 3). ACP significantly decreased from T_1 (493.82 μg pNP g^{-1} h^{-1}; F_3 to 783.01 μg pNP g^{-1} h^{-1}; F_{23}) to T_2 by 10% (F_{23}) to 23.7% (F_{21}) while no significant change was observed for F_1 ($p < 0.05$). ACP increased as cultivation proceeds up to T_6 varying between F_3 (588.81 μg pNP g^{-1} h^{-1}) to F_{23} (844.04 μg pNP g^{-1} h^{-1}; Fig. 3). Similarly, ALK decreased significantly from T_1 (143.27 μg pNP g^{-1} h^{-1}; F_{10} to 186.57 μg pNP g^{-1} h^{-1}; F_{21}) to T_2 by 7.7% (F_{14}) to 22.23% (F_3), decrease further to T_4 and increased up to T_6 (105.93 μg pNP g^{-1} h^{-1}; F_6 to 154.24 μg pNP g^{-1} h^{-1}; F_{23}; Fig. 3). A rapid decline in the DHY activity from T_1 (6.46 μg TPF g^{-1} h^{-1}; F_3 to 16.56 μg TPF g^{-1} h^{-1}; F_{21}) to T_2 was observed ranging between 49.3% (F_3) to 67.8% (F_{10}; $p < 0.05$). DHY remained stable from T_2 to T_5 and increased during T_6 (3.67 μg TPF g^{-1} h^{-1}; F_6 to 5.47 μg TPF g^{-1} h^{-1}; F_{21}; $p < 0.05$). The percent decrease in ARY activity from T_1 to T_2 varied between 10% (F_{21}) to 21% (F_3); increased gradually thereafter and maintained a significant higher value during T_6 (239.21 μg pNP g^{-1} h^{-1}; F_3 to 309.97 μg pNP g^{-1} h^{-1}; F_{21}; $p < 0.05$). Similarly, GLY decreased significantly between 8.4% (F_{14}) to 23% (F_3; $p < 0.05$) from T_1 to T_2, decrease further and increased during T_6 (70.25 μg pNP g^{-1} h^{-1}; F_1 to 111.62 μg pNP g^{-1} h^{-1}; F_{23}; Fig. 3).

3.4. Relationship between the soil parameters

The spatial variability in terms of the different soil attributes within the fallow period during the first and second years was presented in Fig. 4 respectively. In both years principal component analysis (PCA) generated two distinct clusters where F_1, F_3, F_6 and F_{10} formed a cluster and F_{14}, F_{21} and F_{23} formed another cluster. Correlation matrix analysis of soil properties revealed that SOC positively influenced the MBC. As a result, all the soil enzyme activities (ACP, ALK, ARY, GLY and DHY) were significant and positively correlated with SOC and MBC (Table 5). PCA verified the first two components accounted for 90.62% of the total variance into variables (PC1: 75.11%, PC2: 15.51%) during the first year (Table 6). PC1 showed positive loadings on all the soil parameters except the pH, and PC2 had negative loadings on SOC, ALK and DHY. Similarly, results of the second year in PCA had two components accounting for 88.02% of the total variance into variables (PC1: 74.97%, PC2: 13.05%).

Table 4
One-way ANOVA results for exploring significance of sampling time soil variability within and between lengths of the fallow period.

	pH F	SOC F	MBC F	MBC:SOC F	ACP F	ALK F	DHY F	ARY F	GLY F
Within fallows									
F_{23}	1.17NS	18.64***	105.68***	73.8***	10.14***	8.94**	109.45***	9.93***	22.86***
F_{21}	1.70NS	31.61***	117.49***	46.2***	16.02***	12.44***	107.50***	2.21NS	28.33***
F_{14}	16.93***	10.18***	119.60***	58.45***	11.17***	20.94***	48.42***	5.32**	16.19***
F_{10}	1.23NS	5.7**	56.25***	25.62***	5.72**	14.49***	57.05***	9.19***	9.94***
F_{6}	2.49NS	5.74**	42.55***	17.64***	10.57***	9.63***	25.10***	5.62**	6.13**
F_{3}	2.69NS	25.71***	33.27***	13.29***	7.41**	10.56***	11.10***	4.65*	2.36NS
F_{1}	0.56NS	2.22NS	19.35***	23.38***	8.15**	1.61NS	7.79**	12.82***	2.44NS
Between fallows									
T_1	14.85***	51.83***	86.27***	10.48***	27.92***	27.22***	77.57***	24.52***	36.29***
T_2	5.75**	19.11***	20.00***	7.64***	21.05***	18.24***	30.52***	17.81***	35.24***
T_3	9.25***	18.20***	3.48NS	1.02NS	36.37***	27.56***	15.18***	29.41***	11.55***
T_4	3.43*	25.29***	17.71***	4.06*	20.99***	5.41**	1.28NS	22.83***	5.71**
T_5	1.24NS	17.18***	66.83***	6.16**	19.19***	12.75***	2.68NS	14.53***	6.32**
T_6	2.47NS	18.96***	67.52***	20.55***	21.18***	14.79***	14.29***	11.06***	15.97***

F_{23}: 23 year fallow; F_{21}: 21 year fallow; F_{14}: 14 year fallow; F_{10}: 10 year fallow; F_{6}: 6 year fallow; F_{3}: 3 year fallow; F_{1}: 1 year fallow; T_1: Before burning, 2014; T_2: 45 days after burning, 2014; T_3: Harvesting, 2014; T_4: February 2015; T_5: July 2015; T_6: November 2015; SOC: Soil organic carbon; MBC: Microbial biomass carbon; ACP: Acid phosphatase enzyme; ALK: Alkaline phosphatase enzyme; DHY: Dehydrogenase enzyme; ARY: Arylsulphatase enzyme; GLU: β-glucosidase enzyme; * p-level < 0.05; ** p-level < 0.01; ***p-level < 0.001.

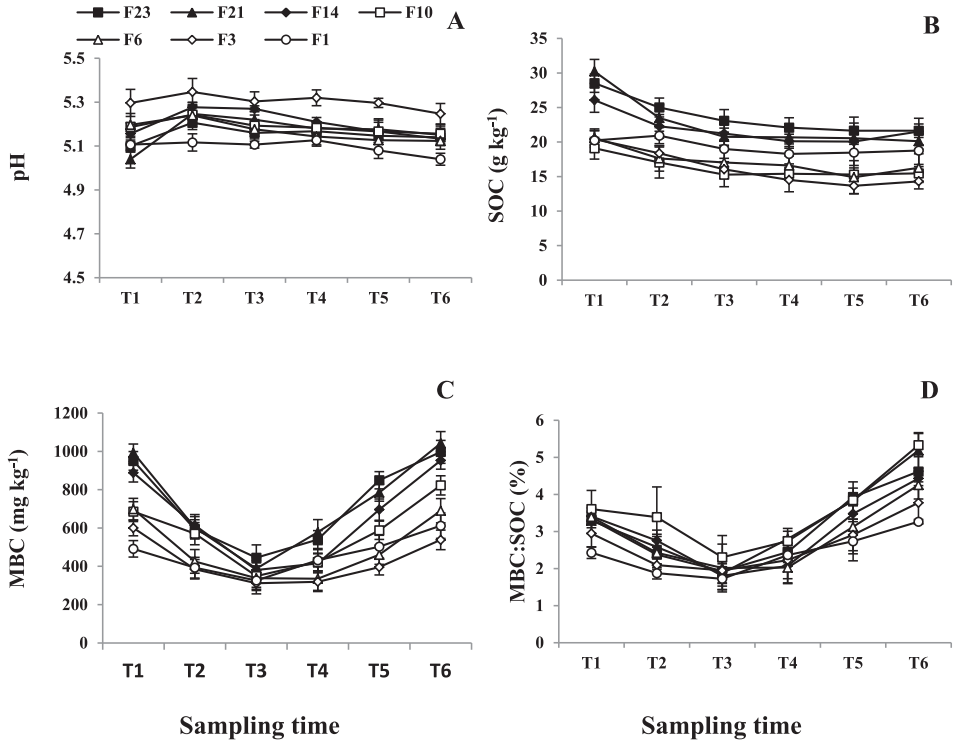

Fig. 2. Dynamics of soil pH (A), Organic carbon (B), MBC (C) MBC:SOC (D) at different sampling time as affected by different fallow period.F_{23}: 23 year fallow; F_{21}: 21 year fallow; F_{14}: 14 year fallow; F_{10}: 10 year fallow; F_6: 6 year fallow; F_3: 3 year fallow; F_1: 1 year fallow; T_1: Before burning, 2014; T_2: 45 days after burning, 2014; T_3: Harvesting, 2014; T_4: February, 2015; T_5: July, 2015; T_6: November, 2015.

4. Discussion

The significant decrease in BD from F_1 (1.24 g m^{-3}) to F_{21} (1.03 g m^{-3}) was due to the higher accumulation of soil OM with the longer length of fallow period (Jia et al., 2005; Sarkar et al., 2015). Lengthening of secondary forest fallow period up to 23 years (F_{23}) enhanced soil nutrient availability in terms of available N, total N and total P in the soil (Ramakrishnan and Kushwaha, 2001). The significant rise in SOC (Tables 3, 4) was evident with the increase in fallow period length due to the increase accumulation of OM (Sarkar et al., 2015). Thus, SOC acted as a storehouse and regulator of soil nutrient availability under variable fallow period in our study.

The increase in soil pH (0.83% to 3.94%) after 45 days of burning plant biomass was attributed to the release of alkaline cations from ashes originated from the burnt plant biomass (Dikici and Yilmaz, 2006). Granged et al. (2011) observed an increase in soil pH from 6.2 to 7.5 immediately after burning and then decreased to 7.1 one year after burning. After exposure of soil to burning, accelerated soil erosion process greatly reduced the SOC content by 10 to 22.3% immediately within 45 days after burning (Hatten et al., 2005; Choudhury et al., 2015). Our experimental soils were collected 45 days after burning (T_2) to relate the soil condition during the sowing time of paddy in the shifting cultivation systems of Mizoram representing soil due to burning and an exposure to erosion. The fallow sites with more SOC content (F_{23}, F_{21} and F_{14}) were more susceptible to burning loss although maintained higher SOC up to second year. This may be attributed to higher temperature during burning due to the accumulation of more biomass in the longer fallow period (Ramakrishnan and Toky, 1981; Tawnenga et al., 1997). The SOC decreased by 17 to 31.3% during the first year paddy cultivation (Ramakrishnan and Toky, 1981). This was the first indication of an immediate degradation of these forest soils after converting from secondary forest to slash and burn cultivation. The decrease in SOC content from T_1 (January) to T_3 (harvesting) for F_1 was only 6.1% suggesting that the absence of burning reduced the SOC loss. Our results indicated that the SOC content after first year cultivation remained stable from T_5 to T_6 stage approximately one and a half year after burning (Ramakrishnan and Toky, 1981). The recovery of SOC during the second year fallow soil could be due to proliferate vegetative biomass inputs associated with high rainfall (> 2500 mm $year^{-1}$) where herbaceous vegetation bloomed and flushed as the monsoon arrived. Lengthening of fallow period increased MBC in the surface soil layer due to greater accumulation of roots and forest litters (Arunachalam et al., 1996). An ecosystem with higher OM input normally tends to have higher microbial biomass due to rhizodeposition (Shao et al., 2015) thus, contributing to greater recovery of soil fertility status (Sarmiento and Bottner, 2002). Positive correlation ($r = 525$; $p < 0.001$, Table 5) between SOC and MBC indicated that soils under shifting cultivation have not attended equilibrium and C availability was not a limiting factor (Garcia et al., 2005; Zhang et al., 2011). Burning decreased MBC due to temperature change that ultimately modified the soil physical and chemical environment (Palese et al., 2004; Liu et al., 2010). Our results suggested that litter and fine root production from weeds and herbaceous plants due to the absence of cultivation during the second year increased the accumulation of MBC. The MBC:SOC ratio was affected by length of the fallow period before burning (2.43 to 3.6%) that was in harmony with the previous report of 2–4.3% change in NE Indian soils (Arunachalam and Pandey, 2003). The contribution of MBC to SOC increased up to 5% during the second year suggesting that MBC acts as an important indicator in ecosystem recovery and a sensitive index for SOC variation (Garcia et al., 2005).

The strong positive relationship ($p < 0.001$, Table 5) between MBC and SOC with all the studied enzyme activities implied that the dynamics of SOC, MBC and soil enzymes are closely linked in the surface soil layers that was exposed during shifting cultivation practice (Fig. 3). The increased OM content of the soil provides the energy source for microbes thereby increase the soil enzyme activity (Wallenius et al., 2011). SOC contribution from root mass might also be one of the major influential factors towards the increased microbial activity (Ajwa et al., 1999). Burning destroyed the hydrological

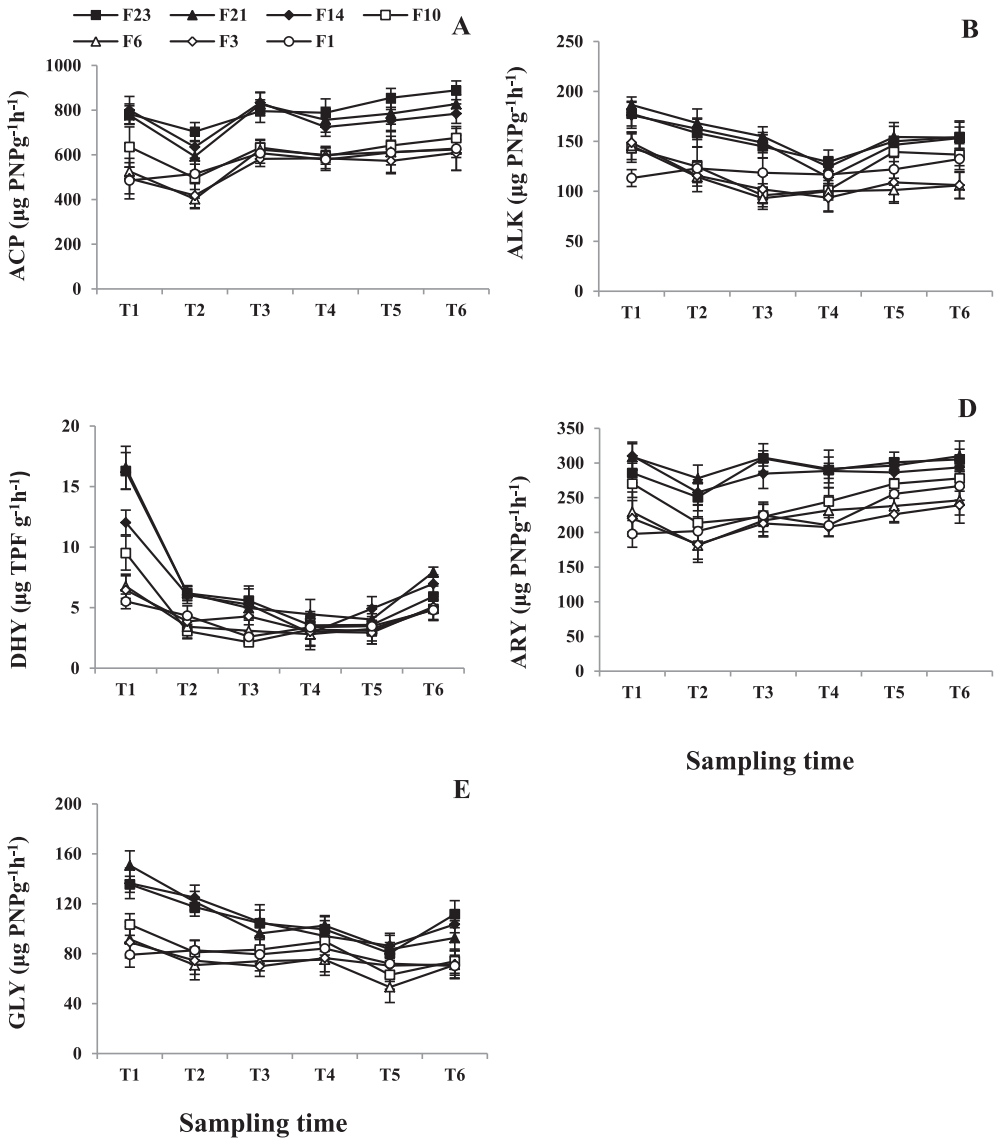

Fig. 3. Dynamics of Acid phosphatase (A) and Alkaline phosphatase (B) Dehydrogenase enzyme (C), Arylsulphatase (D) and β-glucosidase (E) enzyme activity at different sampling time as affected by different fallow period.F_{23}: 23 year fallow; F_{21}: 21 year fallow; F_{14}: 14 year fallow; F_{10}: 10 year fallow; F_6: 6 year fallow; F_3: 3 year fallow; F_1: 1 year fallow; T_1: Before burning, 2014; T_2: 45 days after burning, 2014; T_3: Harvesting, 2014; T_4: February, 2015; T_5: July, 2015; T_6: November, 2015.

enzymes; thereby reduced the soil enzyme (Boerner et al., 2005). The depressed soil enzyme activity was attributed to the overall reduction in labile OC and higher electrical conductivity from ash (Palese et al., 2004). This was a clear indication that fire changes the quality and quantity of substrates for microbes. Phosphatase (ACP and ALK) are a broad group of enzymes which catalyzes ester hydrolysis. The average available P content of the soil before burning was 2.9 mg kg^{-1}, 5.23 mg kg^{-1} after burning and 3.8 mg kg^{-1} at harvesting. Therefore, the increase in ACP secretion from T_2 (after burning) to T_3 (harvesting) was due to enhancement of P solubilization (Versaw and Harrison, 2002). Nutrient stress (P and sulphur) might have increased the secretion of phosphatase and arylsulphatase to cope up with the ecological demand from T_2 to T_6. ALK decreased up to harvesting stage (T_3) and increased similar to the trend of MBC indicating that ALK is of microbial origin (Basu et al., 2011). DHY enzyme is an intracellular enzyme often used as microbial activity indicator and GLY enzyme catalyzed hydrolysis of various β-glycosides present in OM decomposition to produce inorganic compounds (Makoi and Ndakidemi, 2008). Both DHY and GLY activity patterns resembled close with OC indicating that associated changes in these enzymes activities acted as a reflection of a change in substrate availability for microbes (Saha et al., 2011; Gispert et al., 2013).

Principal component (PC1) revealed the importance of SOC and MBC in the maintenance of soil enzyme activities (Fig. 4). PC2 remarked the dominancy of MBC on determining the MBC:SOC ratio as an indicator to the observed variability in MBC for both the first and second year. The PCA scatter diagrams further allowed a better comprehension on the importance of fallow length in maintaining OC, soil MBC and enzyme activities. Two different groups were separated where F_1, F_3, F_6, F_{10} constituting one group and F_{14}, F_{21}, F_{23} another group suggesting that fallow above 10 years maintained better soil health during the first year and second year of our study, irrespective of the soil sampling date. Therefore, maintenance of > 10 year forest fallow was essential for soil fertility recovery, system stability and SOC build up in the acid soils of NE India (Ramakrishnan and Kushwaha, 2001; Sarkar et al., 2015).

5. Conclusion

Length of forest fallow period played an important role in conserving the soil health promoting the soil MBC and enzyme activities for longer fallow period. The soil MBC and enzyme activities decreased

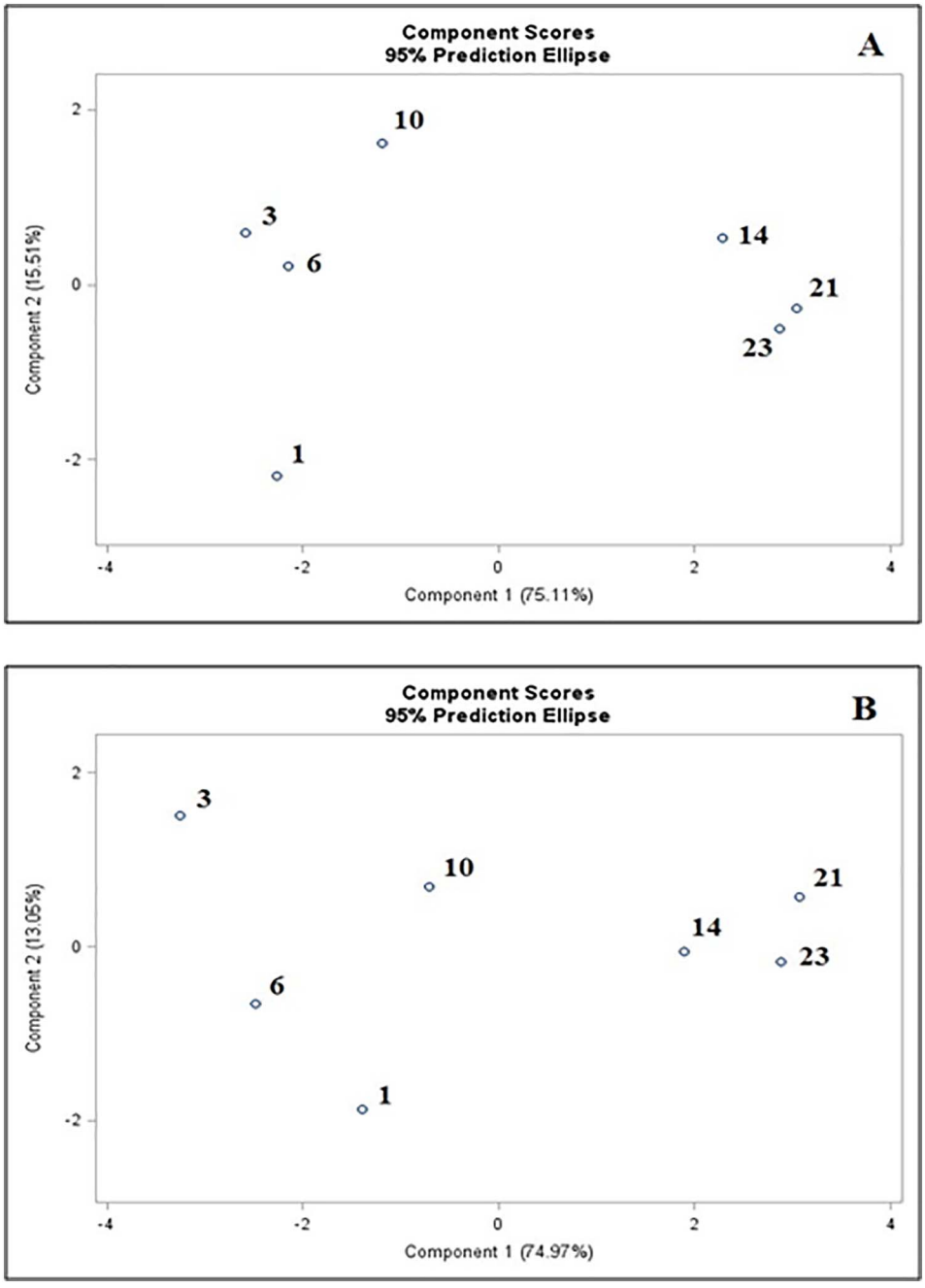

Fig. 4. Scatter diagram showing the effect of different fallow periods on the studied soil parameters irrespective of sampling dates during (A) first year and (B) second year.23: 23 year fallow (F_{23}); 21: 21 year fallow (F_{21}); 14: 14 year fallow (F_{14}); 10: 10 year fallow (F_{10}); 6: 6 year fallow (F_6); 3: 3 year fallow (F3); 1: 1 year fallow (F_1).

Table 5
Correlation matrix of all analyzed soil parameters.

	pH	SOC	MBC	MBC:SOC	ACP	ALK	DHY	ARY
SOC	− 0.246**	1						
MBC	− 0.338***	0.525***	1					
MBC:SOC	− 0.239**	NS	0.821***	1				
ACP	− 0.284**	0.465***	0.519***	0.303**	1			
ALK	NS	0.783***	0.696***	0.322***	0.494***	1		
DHY	− 0.217*	0.733***	0.659***	0.283**	0.326***	0.685***	1	
ARY	− 0.233**	0.497***	0.613***	0.412***	0.840***	0.626***	0.427***	1
GLY	NS	0.806***	0.482***	NS	0. 458***	0.724***	0.746***	521***

SOC: Soil organic carbon; MBC: Microbial biomass carbon; MBC:SOC: Microbial quotient; ACP: Acid phosphatase enzyme; ALK: Alkaline phosphatase enzyme; DHY: Dehydrogenase enzyme; ARY: Arylsulphatase enzyme; GLU: β-glucosidase enzyme; * p-level < 0.05; ** p-level < 0.01; *** p-level < 0.001.

Table 6
Principle component scores of first year and second year.

Soil parameters	First year		Second year	
	PC 1	PC 2	PC 1	PC 2
pH	− 0.095	0.595	− 0.087	0.844
SOC (mg g^{-1})	0.354	− 0.296	0.350	− 0.313
MBC (mg kg^{-1})	0.371	0.185	0.379	0.035
MBC:SOC (%)	0.101	0.720	0.252	0.404
ACP (μg pNP g^{-1} h^{-1})	0.379	0.008	0.369	0.053
ALK (μg pNP g^{-1} h^{-1})	0.377	− 0.022	0.372	− 0.070
DHY (μg TPF g^{-1} h^{-1})	0.376	− 0.017	0.330	0.096
ARY (μg pNP g^{-1} h^{-1})	0.381	0.065	0.382	0.032
GLY (μg pNP g^{-1} h^{-1})	0.382	0.020	0.366	0.082

SOC: Soil organic carbon; MBC: Microbial biomass carbon; MBC:SOC: Microbial quotient; ACP: Acid phosphatase enzyme; ALK: Alkaline phosphatase enzyme; DHY: Dehydrogenase enzyme; ARY: Arylsulphatase enzyme; GLU: β-glucosidase enzyme.

after burning and cultivation due to disturbances with a significant increase during the second year. Soil conservation measures may decrease the SOC loss through erosion during the cultivation in these steep slopes of Mizoram, North East India. A fallow period > 10 years proves to conserve better soil health during the first and second year. We recommended the further evaluation including suitable legumes as an intercrop in the degraded shifting cultivated fallows for the buildup of soil health. Information on soil MBC and enzyme activities could be used as an effective indicator of soil health for soils under shifting cultivation.

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