

Plant Litter–Soil Enzyme Interactions and Biochemical Index of Soil Fertility in *Jhum* Agroecosystem

Thesis

Submitted in partial fulfillment of the requirements for the award of the
degree of

**Doctor of Philosophy
In
Soil Science and Agricultural Chemistry**

by

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Umiam, Pin : 793103, Meghalaya, India

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DEDICATED
TO
THE *JHUM* FARMERS OF
NORTHEAST INDIA



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I hereby declare that the thesis entitled “**PLANT LITTER–SOIL ENZYME INTERACTIONS AND BIOCHEMICAL INDEX OF SOIL FERTILITY IN *JHUM* AGROECOSYSTEM**” is an authentic record of the work done by me and that no part thereof has been presented for the award of any other degree, diploma, associateship, fellow or any other similar title.

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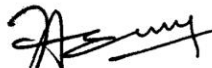
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ABBREVIATIONS

%	Per cent
μ	Micron
μg g ⁻¹	Microgram per gram
μg	Microgram
μL	Micro litre
μm	Micro metre
μM	Micro-molar
³² P	Phosphorus isotope
A	Absorbance
AA	Ash amendment
ADF	Acid detergent fibre
AMY	Amylase activity
ANOVA	Analysis of variance
ASA	Aryl-sulphatase activity
Avl K	Available Potassium
Avl N	Available nitrogen
Avl P	Available phosphorous
C	Carbon
Ca	Calcium
Ca ²⁺	Calcium ion
CaCl ₂	Calcium chloride
CaCO ₃	Calcium carbonate
cfu	Colony forming unit
Chl-a	Chlorophyll-a
Chl-b	Chlorophyll-b
cm	Centimetre
CO ₂	Carbon dioxide
Cu	Copper
DAB	Diaminobenzidine
DAS	Days after sowing
DHA	Dehydrogenase activity
DMRT	Duncan's Multiple Range Test
dw	Dry weight
e.g.	<i>exemplia gratia</i>
EBT	Erichrome black
EC	Electrical Conductivity
EDTA	Ethylene diamine tetra-acetic acid
<i>et al.</i>	<i>et alia</i>
etc	<i>et cetera</i>
FFL	Forest floor litter
g	Gram
GSA	β- glucosidase activity
h	Hour
H ₂ O ₂	Hydrogen peroxide
H ₂ SO ₄	Sulphuric acid
H ₃ PO ₄	Phosphoric acid
ha	Hectare
HCl	Hydrochloric acid

HClO ₄	Perchloric acid
HNO ₃	Nitric acid
IBM	International Business Machines
ICAR	Indian Council of Agricultural Research
<i>In situ</i>	on site
K	Potassium
K ₂ Cr ₂ O ₇	Potassium dichromate
K ₂ SO ₄	Potassium sulphate
KCl	Potassium chloride
kg ha ⁻¹	Kilogram per hectare
kg	Kilo-gram
KMnO ₄	Potassium permanganate
L	Litre
LA	Litter amendment
LP	Lipid peroxidation
m	Metre
M	Molar
mM	Milli mole
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MBP	Microbial biomass phosphorous
MC	Microbial Consortium
MCS	Monte-Carlo's significance test
MDA	Malondialdehyde
meq	milli equivalent
Mg	Magnesium
mg	Milligram
mg/kg	Milligram per kilogram
Mg ²⁺	Magnesium ion
MgCl ₂	Magnesium Chloride
min	Minute
mL	Millilitre
mm	Millimetre
MUB	Modified Universal Buffer
N	Normality
NaOH	Sodium hydroxide
NDF	Neutral detergent fibre
NE	North East
NEH	North Eastern Hill
ng	Nanogram
NH ₄ F	Ammonium fluoride
NH ₄ -N	Ammonium nitrogen
NH ₄ OAC	Ammonium acetate
nm	Nanometer
NO ₃ -N	Nitrate nitrogen
°C	Degree Celsius/ Centigrade
P	Phosphorus
P ₂ O ₅	Phosphorous pentoxide
PHA	Phosphomonoesterases activity
pMN	Potentially mineralizable nitrogen
PNG	<i>p</i> -Nitrophenyl-β-D-glucoside
p-NPP	<i>p</i> -nitrophenyl phosphate
PNS	<i>p</i> -Nitrophenyl sulphate
PRO	Protease activity
qCO ₂	Respiration quotient

<i>r</i>	Correlation coefficient
rpm	Rotation per minute
RL	Root length
RD	Root diameter
RSA	Root surface area
RV	Root volume
ROS	Reactive oxygen species
S	Sulphur
SMB	Soil microbial biomass
SOC	Soil organic carbon
SOM –N	Soil organic matter-nitrogen
SOM	Soil organic matter
sp	Species
SPSS	Statistical Package for the Social Sciences
SQI	Soil quality Index
TBARS	2-thiobarbituric acid- reactive substances
TCA	trichloroacetic acid
TPF	Triphenyl formazan
Tris	Tris (hydroxymethyl) aminomethane
TBA	Thiobarbituric acid
TTC	2,3,5-triphenyl-tetrazolium chloride
v/v	Volume per volume
w/v	Weight per unit volume
wt	Weight
yr	Year
Zn	Zinc

ABSTRACT

This study assessed whether the slash-burn practice (*jhum*) induced disturbance on the above-ground biological inputs (plant and leaf litters) had any influence on the soil biochemical processes in terms of soil enzyme activities and thereby framing up biochemical index of soil fertility. The *jhum* cycles of 5 yr, 10 yr and 15 yr from Mizoram and 5 yr, 10 yr and 20 yr from Nagaland were selected. Litter (adjacent fallow stands/secondary forest) and soil samples (burnt and unburnt cropping phase) were collected from three slopes (upper, middle and lower) from each site and were analyzed for chemical and biochemical properties. Two microcosm experiments were conducted using *jhum* soils (before and after burnt and unburnt from 5 yr and 10 yr fallows) to investigate the effect of different forest floor litter types on stress physiology of *jhum* rice, soil chemical and biochemical processes, and also to compare the effects of litter amendment (LA), microbial consortium (MC), LA+MC, ash amendment (AA) and no input on physiology and growth of *jhum* rice and soil biochemical properties. Forest floor litter (FFL) accumulation significantly increases with the increasing fallow length and accumulation dynamics showed an increasing trend in the order of January > April > August > November. Quality of FFL (N, P, Ca, Mg and Zn contents) varied significantly among fallow lengths with maximum contents in the longer fallows ($P < 0.05$, Kruskal-Wallis H-test). Higher content of Carbohydrate, Cellulose, Hemicellulose, Pectin and Lignin in FFL was in the order of 20yr & 15yr > 10yr > 5yr and effects were significant. Soil chemical and biochemical properties varied significantly between burnt and unburnt or among fallow periods ($P < 0.05$, Kruskal-Wallis test). In microcosm experiment-I, there was significantly positive influence on reducing physiological stress and root growth of *jhum* rice due to burning or longer fallow lengths or types of FFL (5, 10 and 15 yr FFL). The extent of positive influence of FFL addition on rice grain was more pronounced under burning situation. The extent of grain yield enhancement decreased with the increasing complexity of the litter types. However, such influence was nullified under 10 yr burnt situation. In microcosm experiment II, the extent of physiological stress in *jhum* rice was the minimum in LA+MC followed by MC and AA. Application of LA+MC and MC supported better soil enzyme activities (AMY, ASA, DHA, GSA, PHA and PRO) in both 5yr and 10 yr burnt *jhum* soils as compared to other LA and AA alone applied pots. The extent of change of soil biochemical attributes, SOC and Avl P relative to reference site (reserve forest) were more pronounced due to burning as well as fallow lengths. Among soil enzymes, PRO, PHA and DHA were more sensitive to burning. Soil BD seems to be more sensitive to burning than fallow lengths. Higher fallow lengths reflected higher SQI. The differences in SQI among fallow lengths were significant under unburnt situation. In general, SQI values were higher in unburnt compared to their respective burnt situations. In conclusion, burning of biomass releases a higher quantum of plant available nutrients in *jhum* soils momentarily, which can support better crop growth under longer fallow lengths. However, burning negatively impacted the biochemical quality of *jhum* soils. Thus, it indicates that burning gradually decrease the inherent nutrient cycling potentials of *jhum* soils. Application of less complex litter materials along with native microbial consortium as biological inputs can rejuvenate the biochemical and biological activities of *jhum* soils. The SQI index values of different fallow lengths under burnt situation indicated that *jhum* soils seem to attain a new threshold limit of soil quality at approximate 10 yr fallow length, where SQI value was comparable with the SQI values of 15 yr and 20 yr fallows.

Key words: Litter accumulation dynamics, Litter quality, Microbial consortium, Shifting cultivation, Soil quality

Chapter- I

INTRODUCTION

Chapter-1

Introduction

Shifting cultivation (synonym: slash-cum-burn agriculture) exists in ASEANs, Africa and Latin America and is locally known as *jhum*, *Bukma*, *Taungya*, *Kaingin*, *Lading*, *Poddu*, *Suddo Mannu*, *Swidden*, *Milpa* or *Tavya* (Thakuria and Sharma, 2014). It still supports the livelihood of an estimated 300-500 million people in Central Africa, South America, Oceania, and Southeast Asia and is practiced on about 30% of all arable land but providing food to only 8% of the world population indicating wide land to man ratio (Kumar, 2008). So, the soil resources of *jhum* lands could be the potential natural production system of today's world in contributing to the food basket of the ever-increasing population. In North East India, out of 4.0 million hectare of net sown areas, about 1.6 million hectare area is under *jhumming* with very low average productivity. *Jhum* cultivation involves several cultural operations (clearing of forest biomass by slashing, release of nutrients accumulated in vegetation over time by burning of slashed biomass, suppression of weeds, pest and diseases by soil sterilization, etc.) to grow mixed crops on the hill slope for a year or two (cropping phase) followed by abandoning the land as fallow for some years for regeneration of secondary forest vegetation (fallow phase) (Tripathi and Barik, 2003; Thakuria and Sharma, 2014). It is believed that fallowing the land rejuvenate the *jhum* soils and bring back its fertility (Ramakrishnan and Toky, 1981; Silva-Forsberg and Fearnside, 1997). Slashing and burning remained to be the easiest way not only to sanitize the soil, minimizing the weeds and soil pathogens but also to release the locked nutrients within the biomass as ash load which is considered to be more readily available nutrient forms (Juo and Manu, 1996). On contrary, surface soil dwelling organisms have been claimed to be destroyed by these burning operations (Buddle *et al.*, 2006; Malmström *et al.*, 2008, 2009). In order to manage a burnt agriculture land more effectively, one must rely on the detailed knowledge of the fluxes and losses of nutrients incurred during and after burning of the slashed biomass (Raison, 1979). Few contradictory findings on *jhum* cultivation in relation to the study of after-effects of burning on soil physico-chemical and biological attributes have led to certain ambiguities on its advantages or disadvantages (Bruun *et al.*, 2009, Filho *et al.*, 2013, Osman *et al.*, 2013). It has been reported that fire leads to changes in the chemical properties of soil with regard to the changes in quantity and quality of organic matter, soil moisture, availability of nutrients, exchange capacity, and base saturation (Certini, 2005).

Now-a-days, some schools of thought opine that *jhum* practice is environmentally destructive and a faulty land-use practice having low output-input ratio. Earlier, it was reported that the re-growth of secondary forest is restricted due to the shortening of fallow phase within a *jhum* cycle because of ever increasing human population and food demand (Ramakrishnan and Toky, 1981). The stability of *jhum* agro-ecosystem primarily depends upon the length of the fallow phase that allows re-growth of secondary forest. Thus, the varying lengths of the fallow phase directly affect the quantum of secondary forest biomass build-up leading to quantitative differences in subsequent slash load and ash release during burning (Ramakrishnan, 1998). At ecosystem process level, it has been postulated that the above-ground vegetation and below-ground biota communities are related through soil as medium (Bardgett *et al.*, 2008). The biological inputs like litter falls and root exudates of the above-ground vegetations are thought to be the modulators of the diversity and activity of soil biota communities. As feedback mechanism, soil biota also regulates soil processes through their control over decomposition dynamics of organic matter, recycling of nutrients and stabilization of terrestrial ecosystems (Wardle, 2002). Agricultural activities for example, slash and burn operations followed by cropping in forest lands are expected to disturb the linkage between above-ground vegetation and below-ground biota communities. Thus, soil restoration initiatives in the disturbed agroecosystem must consider the philosophy of functional interactions between the above-ground biomass and below-ground biota communities and the impacts of such interactions on soil fertility.

The fallow phase of the *jhum* cycle stands to exist as a living example in understanding the impact of fire on nutrient cycling processes that drives through the interactions of plant community succession and soil biota community shifts. Thus, different degree of relationship may exist in the pattern of forest floor litter accumulation, soil nutrient availability and microbiologically induced biochemical reactions in *jhum* soils depending on the length of the fallow phase. According to Bruun *et al.* (2006), the amount of nutrients accumulated depends primarily on the nutrient content in the biomass, the temperature threshold of respective nutrient elements and the quality of burning. Fire does not only burn out the slashed biomass but also the litter layer, and the uppermost humus layer which is a major part of the resources and habitats for soil organisms (DeBano *et al.*, 1998). Further, the changes in belowground biota community are thought to be tightly linked with the processing of biological pools of soil C, N and P through their control over soil enzyme activities (Harper *et al.*, 2005). But it is still unclear how the pattern of forest floor litter accumulation, soil nutrient availability and enzyme activities with respect to the length of fallow phase varies especially in *jhum* agroecosystem.

The chemical composition of forest floor litter seems to vary greatly depending on the length of the fallow phase (Cornwell *et al.*, 2008). Some types of litters have more easily decomposable labile C while other may have higher concentrations of lignin or recalcitrant C which is not easily decomposable (Gessner *et al.*, 2010). Reintroduction of fire in slash and burn practices is also known for favouring certain plant communities with particular sets of functional traits that drives the soil communities (Pausas *et al.*, 2004). The regenerated plant biomass of the secondary forest that has accumulated over time seems to play key role in restoration of ecological soil functions of *jhum* lands. The relationship between belowground food-web community and nutrient cycling potentials in soils of forest ecosystem was also previously observed in relation to fire induced shifts in functional plant community (Wardle *et al.*, 2004; Kardol and Wardle, 2010). Therefore, it can be hypothesized that the slash-cum-burn induced modifications in the photosynthesis- and consumer-based subsystem within terrestrial ecosystem (Wardle, 2002) can bring about drastic changes on the belowground food-web community and thereby possible alterations in the nutrient cycling potentials of *jhum* soils. Understanding such alterations in nutrient cycling processes in relation to the length of fallow phase is pertinent for formulating sustainable nutrient management practices for enhancing *jhum* productivity.

The biochemical reactions involve in litter decomposition and nutrient cycling processes can be judged by measurement of soil enzymatic activities and availability of soil nutrients. Soil enzymes are sensitive indicators in judging the soil fertility status (Nannipieri *et al.*, 1990). Although there have been extensive studies on assessment of nutrient cycling potentials of various agroecosystems through the activities of soil enzymes (Klose and Tabatabai, 2000; Acosta-Martínez *et al.*, 2007; Makoi and Ndakidemi, 2008; Baldrain *et al.*, 2013; Burns *et al.*, 2013; Kotroczo *et al.*, 2014), little has been known about the status of soil enzyme activities in unique land-use scenario like *jhum* agro-ecosystem. Further, there is lack of understanding on how composition and quality of litter falls under varied length of fallow phases relate to the availability of nutrients and activities of enzymes in *jhum* soils.

The functioning of soil biota and nutrient cycling processes are thought to be intimately interlinked at ecosystem process levels that determine the productivity of an agroecosystem. In one hand, burning of biomass imposes stress on soil biota community and its functioning (Malmström, 2012), while on the other hand burning of biomass enhances nutrient availability in soil (Nye and Greenland, 1960; Fritze *et al.*, 1994; Khanna *et al.*, 1994; Giardina *et al.*, 2000). So, it is difficult to interpret the cumulative stress impact of biomass burning on the system productivity. Therefore, observation on the physiological stress of a *jhum* crop seems to be meaningful in judging the cumulative stress impact of biomass burning according to the length of the fallow phases in *jhum* agroecosystem. Although

remarkable study on the physic-chemical properties of the slash and burn soil was carried out (Thomaz *et al.*, 2014), no observations has yet revealed the consequences of burning on the physiological stresses of the crop plants. Microbial inoculation is also an important strategy in eco-restoration processes of a degraded ecosystem (Harris, 2009). The burning practice is believed to be negatively impacting the microbial functioning in *jhum* soils. The degree of negative influence on microbial functioning may vary according to the length of fallow phases. So, research on the response of microbial inoculation to crop growth and development in *jhum* soils may provide important clue in mitigating stress physiology of *jhum* crops.

The consequences of land use change on soil processes and agroecosystem functioning are many and are of global importance (Vitousek, 1994; Saurette *et al.*, 2008). Both the land use history and those changes in soil management practices have profound influences on the physical, chemical, and biological environments, thereby affecting fertility and productivity of soils (Gonnety *et al.*, 2012; George *et al.*, 2013; Tondoh *et al.*, 2011 and 2013). The assessment of soil properties due to the land-use-induced changes is critical in understanding the agro-ecosystem functioning and sustainable production (Yao *et al.*, 2010). There is a strong need to understand the changes in soil quality due to cultivation in order to manage the sustainability of production systems. Cultivation on slashed and burned secondary forest land under tropical humid climate may rapidly diminish soil quality as the ecologically sensitive components are not able to buffer the induced detrimental effects of *jhum* practices. There is every possibility that the quality of *jhum* soils may be differentially influenced by slashed and burned activities according to the length of the fallow phases. The physico-chemical and biological changes in soils following deforestation and subsequent cultivation of crops in the humid tropics have been reported extensively (Ghuman and Lal, 1991; Juo *et al.*, 1995; San José and Montes, 2001; Koutika *et al.*, 1997; Schroth *et al.*, 2002; Sisti *et al.*, 2004; Tchienkoua and Zech, 2004; Walker and Desanker, 2004). Such studies on the land-use-induced changes on soil quality in *jhum* agro-ecosystems according to the length of the fallow phase have not been studied previously.

Realizing the above discussed facts, findings and priorities, the present study is formulated with the following objectives:

- 1. To determine plant litter accumulation and soil enzyme activities in different *jhum* cycles.**
- 2. To study the effect of plant litter types on soil processes in microcosms of different *jhum* cycles.**

3. To compare the effects of microbial consortium, litter- and ash-amendments on growth and development of *jhum* rice.
4. To develop soil biological quality index of different *jhum* cycles under natural farming situations.

Chapter- II

REVIEW OF LITERATURE

Chapter-2

Review of Literature

“Like the soil, mind is fertilized while it lies fallow, until a new burst of bloom ensues.”

— John Dewey, *Art as Experience*

2.1. Background of *Jhum*

Shifting cultivation is a very primitive form of agriculture, which is believed to have originated in the Neolithic period around 7000 B.C. (Subhramanyam and Sambamurty, 2000). *Jhumming* can be referred to clearing and burning of vegetation, cropping and shifting from one place to another after a year or two. In the past, *jhumming* used to be an appropriate and sustainable land-use practice in diverse socio-economic set ups where the dependent human population was within the carrying capacity of a 10-15 years *jhum* cycle (Ramakrishnan, 1994). *Jhum* cultivation which is also known as swidden cultivation or shifting cultivation or slash-and-burn farming has been depicted to be an age-old method of farming system and considered to be a prevailing subsistence farming practice in the tropical regions across the world (Brady, 1996; Inoue *et al.*, 2010; Comte *et al.*, 2012).

The primary principles of sustainable shifting cultivation are that losses of plant-available nutrients should be coordinated by new supply over the complete rotational cycle, and that all other components of soil quality (e.g., texture and organic matter content that together determine water holding capacity) should be conserved (Grogan *et al.*, 2012). Similar idea was propounded by Lawrence and Schlesinger (2001), which states that the main concern of shifting cultivation was that nutrient removal within the harvested crop as well as nutrient losses due to run-off, leaching and fire volatilisation should not exceed plant-available nutrient inputs from nitrogen fixation plus *in situ* soil biogeochemical transformations from non-available forms.

According to the meta-analysis of Van Vliet *et al.* (2012), it was ascertained that shifting cultivation is being practiced mostly in the mountainous and hilly parts of Latin America, Central Africa and Southeast Asia and happens to be the dominant agricultural system. While in the review published by Li *et al.* (2014), most of the tropical countries of the world including Mexico, Panama, most part of South America,

Central and Southeast Africa, Southeast Asia including India and China extending up to Indonesia and other Polynesian islands are engaged in shifting cultivation. It has also been perceived that the present agricultural system that exists in many parts of Southeast Asia had its inception from the primitive shifting agriculture system which has evolved with time (Meine *et al.*, 2010).

Li *et al.* (2014) has reviewed that studies on shifting cultivation has started in 1930s and traced back the studies in Southeast Asia in 1940s. According to them, 1950-1960 was an era of important works on shifting cultivation with respect to anthropology and other minor studies were carried out in soil science, agronomy and geography while shifting cultivation was studied with relevance to evolution and ecology during the 1970s and 1980s.

It has also been reviewed that in the 1990s, much of the studies on shifting cultivation has stressed on the negative impacts and out shadowed the many other advantages that slash-and-burn had with its existence. With these inferences and conclusions, many alternatives for shifting cultivation had been put forward across the tropical regions of the world (Brady, 1996; Li *et al.*, 2014).

2.2. Global Scenario of *Jhumming*

Pedroso-Júnior *et al.* (2008) have summarized that shifting cultivation has been globally practiced in forests around the world for thousands of years, especially in the tropics, where it provides livelihood for rural populations. Past estimates have indicated that two-third of the world's secondary forest till 1980 were fallow phases caused by shifting cultivation, while a worldwide population of 35 million to 1 billion people depended on shifting agriculture systems for their subsistence (Lanly, 1982).

A study conducted by Sanchez in 1996 has recorded that shifting cultivation was practised by 300 to 500 million farmers worldwide and was responsible for the bulk of rainforest clearing, which totals about 10 million hectare per year.

While compiling the important causes for deforestation, it was reported that shifting cultivation accounted for 70% of total deforestation in Africa, 50% in Asia, and 35% in Tropical America, respectively (Cleuren, 2001).

In eastern Madagascar, shifting cultivation is locally known as *tavy* where farmers grow upland rice after clearing and burning the site and is presently raising wide concern among conservationists, as it threatens the remaining endemic rainforest harbouring a rich biodiversity (Brand and Pfund, 1998).

With respect to the existence of shifting cultivation in the Amazon basin, a study over many years have debated in suggesting that slash-and-burn was an

adaptation of late Holocene immigrating agriculturalists who encountered adverse conditions as they moved into Amazonia (Meggers and Evans, 1957; Meggers, 1971, 1995, 1997). In their opinion, high labour demands associated with felling trees to make gardens, coupled with the low nutrient status of Amazonian soils, had imposed stringent limitations to population growth and livelihoods demanding the frequent relocation of communities. Meanwhile, another school of thought argued that practices of slash-and-burn had originated in the extension of Amazonian house gardens (Lathrap, 1970, 1977; Myers, 1974; Oliver, 2001).

The traditional peasant farmers still practice shifting cultivation along the main channel of the Amazon River, its tributaries and interfluvies (Steininger, 1996; Alves *et al.*, 1997; Tucker *et al.*, 1998).

In the continent of Southeast Mexico, traditional “slash-and-burn” systems are by and large still practiced, and replacing the practice of burning with other alternative especially in and near the protected areas, has become very essential (SEMARNAT, 2001).

In Asia, the majority of the people practicing shifting cultivation belongs to ethnic groups that are generally categorized under the ethnic minority groups, tribal people, hill tribes, or other indigenous peoples (Erni, 2008).

Phongoudome *et al.* (2012) have summarized from findings of others that in Laos, more than 6.5 million ha of forests contributing to 28.2% of the total land area in Laos are affected by shifting cultivation involving about 17% of the human populations.

Prasit (2002) has also highlighted in his paper that shifting cultivation practiced by the Karen people of Chiang Mai, Northern Thailand, is changing due to population pressure and a resulting decrease in the per capita arable land-base. This has resulted in a reduction of the fallow period, which was 10 years or more in the past.

Karmakar *et al.* (2012) has also depicted about the shortened shifting cultivation cycles from more than 20 years before 1960 to a less 2-3 years fallow cycle till 2010 in the Chittagong Hill tracts of Bangladesh due to many anthropogenic interferences like construction of hydro-electric projects yielding to forced immigration of population from low lying areas to higher altitudes, illicit tree fellings, commercial cultivations, etc. Since 2009, the fallow length has been reported to have increased to 10-15 years (Talukder *et al.*, 2013).

Tanaka (2012) reported that in East Asian countries like Borneo, Philippines and Thailand, cropping period in shifting cultivation areas is usually one year and extends from 3 to 5 years in Japan and Yunnan with upland rice as the major crop grown.

It was highlighted that fallow period in *jhum* cycles are being reduced from 20-30 years down to 0-5 years across South East Asia and many other places in the world (Tawnenga *et al.*, 1996; Anonymous, 2009; Schmidt-Vogt *et al.*, 2009).

2.3. Indian scenario of *Jhumming*

The Indian hill farmers slash the vegetation on selected sites during winter months (January-February) in each year, wait for it to dry, and then burn it *in-situ* before planting a variety of annual crops as mixed crops to coincide with monsoon showers (Ramakrishnan and Toky, 1981). The farmers abandon the site after a year or two and leave the land to naturally regenerate so as to recover the vegetation and soil fertility.

Shifting cultivation or *jhum* was a common practice in the tropical forests of southwestern, central, and eastern India. Presently, this practice is pre-dominant in the states of northeastern India, especially in the hill tracts. About 100 tribal communities consisting of more than 620,000 families in the region depend on *jhum* for their livelihood (Ramakrishnan, 1992).

In the past decades, the net decrease in forest cover due to *jhum* in northeast India was estimated to be 387 sq. km between 1989 and 1991, 448 sq. km between 1991 and 1993, and 175 sq. km between 1993 and 1995 (Shankar, 2001). UNDP (2013) has reported about a gradual decline in the length of *jhum* fallow period in Nagaland which has reduced the time for soil fertility restoration and yield ultimately affecting farmers who were once self-sufficient in food grains to produce enough only for a few months of the year. Further, this shortened *jhum* cycle has also been reported to have accelerated soil erosion and disrupted the hydrology of the area.

Tangjang (2009) has depicted that in Tirap district of Arunachal Pradesh, the *jhum* fallow length was reduced from 15-20 years to 8-10 years due to increasing requirement for cultivation of land. It may be noted that Tirap district has the highest population density in Arunachal Pradesh estimated to be 42 persons per sq. km.

According to Chaudhary *et al.* (2012), 75% of the rice growing area in Arunachal Pradesh is contributed by the traditional method of shifting cultivation while few *jhum* areas have maize or ginger or finger millet or chilli as their main crop. The number of tribal families practicing shifting cultivation was estimated to be around 367,000 and the area affected by this practice is 385,400 ha annually (Patiram and Verma, 2001).

2.4. *Jhum* management practices

Mertz *et al.* (2009) defined shifting cultivation in Southeast Asia as “a land use system that employs a natural or improved fallow phase, which is longer than the cultivation phase of annual crops, sufficiently long to be dominated by woody vegetation, and cleared by means of fire”. They further described the shifting cultivation scenario of Southeast Asia to be a cycle of short cropping period of 1–3 years succeeds a long fallow period of about 5–20 years where clearing is done by slashing and burning and those parts of the fallow areas are often planted with useful tree crops either for subsistence or cash income. In East Kalimantan, Indonesia, after clearing and burning the forest cover in these regions, farmers usually plant upland rice for one year only, and then leave the land fallow for more than 20 years (Funakawa *et al.*, 2009). In Thailand, shifting cultivation has been classified into three major groups 1) short-cropping and short-fallow periods, 2) short-cropping and long-fallow periods, and 3) long-cropping and very long fallow periods (Kunstadter *et al.*, 1978).

In Northeast India, every year, village communities slash the vegetation on selected sites during winter, wait for it to dry, and then burn it *in-situ* before planting a variety of annual crops to coincide with the return of the rains (Toky and Ramakrishnan, 1981) (Appendix 1.1. and 1.2.).

Ziegler *et al.* (2009) in their study in Montane Mainland of Southeast Asia has described a rather grim picture due to changes brought about by shifting cultivation where they argued that shifting cultivation, in its original form, generally very benign in their effects on the physical environment. They further described that external forms of intensification or conversion to other land use systems would result in disruption of stream flow, decline in stream water quality, increased erosion and higher risk of mass failures.

In tropical agricultural systems, especially slash-and-burn situations farmers do not apply fertilizer to upland rice but have traditionally relied on fallowing their land to restore soil fertility and to reduce problems from insects and weeds (Nye and Greenland, 1960). Farmers from the Yunnan province of China use to plant economic trees (*Cassia siamea*, *Gmelina arborea*, *Cajanus cajan*, *Alnus nepalensis*, *Pinus armandi*, and *Pinus yunnanensis*) during the cropping phase as a tradition and let them grow during the fallow phase of the shifting cultivation (Xu, 1991; Guo and Padoch, 1995).

The deeply rooted culture of shifting cultivation in northeast India has many intricate sciences to be understood from within. *Jhum* system remains to be a perfect

institute as a repository for local germplasm of paddy, cucumber, millet, bajra, maize, pumpkin, chillies, etc. having high resistance to pest and diseases. It has been a long-known practice of grown alder tree (*Alnus nepalensis*) in *jhum* lands of Nagaland to suffice the need for N (Rathore *et al.*, 2010). The mix cropping pattern of this traditional agroecosystem happens to provide biochemicals within itself and maintaining a natural line of defense against invading insects and pest (Ramakrishnan, 1984). The details of slash and burning methods and way of burning in different parts of the world are presented in Table 2.1.

Table 2.1. Region specific slash and burn practices across the world

Region/ location where <i>jhum</i> is practiced	Synonym of shifting agriculture	Slash and burn practices			
		Month of Slashing	Time of burning	Way of burning	
Thailand & Myanmar Malaysia	Swidden	January-	March-April	Lua	Upper
	Swidden	February		Karen	Lower
	Swidden	May -July	August-September	Iban	Lower
				Kantu	Winward
NEH Region of India South India	<i>Jhum</i>	December-January	February-March	Kenyah	Lower
				Windward and low	
East India	<i>Suddo</i>				
Latin America	<i>Mannu</i>				
Africa	<i>Poddu</i>	March	April-May	Information not available	
	<i>Milpa</i>	December-January	January-February	Information not available	
	<i>Tavya</i>				

2.5. Perception in *jhumming*

Myers (1992) has distinguished between the traditional shifting cultivator and the “shifted cultivator” where shifted cultivators are migrants who have only recently begun practicing slash-and-burn agriculture, and typically practice a form of slash-and-burn that does not account for environmental constraints.

A handful of researchers and development experts are with a view that some slash-and-burn agro-ecosystems are sustainable under conditions of low land use pressure, and that there is a scope to develop the prevailing slash-and-burn agriculture system (Okigbo, 1984; Pimentel and Heichel, 1991).

Brand and Pfund (1998) has highlighted the relative advantages of slash-and-burn technique which included the fact that slashing and burning removes weeds from the topsoil and keeps predators away while ashes produced from burning the biomass serve as an important source of fertilizer (Weischet and Caviedes, 1993).

Arunachalam (2002) have depicted that in Northeast India shifting cultivation (slash-and-burn) is a major agricultural system and foresees that this system would reduces soil fertility in the long run.

While slashing and burning have been the prerequisites for shifting cultivation it has also been quoted to enhance faunal and microbial deterioration, soil erosion and land degradation (Nair, 1993; Marafa and Chau, 1999).

Jhum is the basic foundation of the economic outfit in the ethnic community of Chittagong Hill Tracts region of Bangladesh and the main source of earning and livelihood where *jhumming* and logging of forest woods are their main source of food, shelter, medicine and other products (Talukder *et al.*, 2013).

Rahman *et al.* (2012) has concluded from their research in Eastern Bangladesh that tradition plays a principle role in shifting cultivation and occupies a central position in the culture of shifting cultivators and has already been practiced for generations together. They further quote the inefficacy of integrated modern high-yielding varieties, species or cultivation techniques to promote the cultivation system as it was already embedded closely to the custom and habits of the cultivators.

Styger *et al.* (2009) has cited that allowing cultivated sites to regenerate naturally by fallowing to restore soil fertility has brought about breakdown of agricultural systems worldwide. They elaborated that with the shortening of fallow cycles, tree species were unable to regenerate and were replaced by early generating shrubs and grasses.

Padoch and Pinedo-Vasquez (2010) has proposed that shifting cultivation would be an important component for 'biodiversity-friendly' agriculture in the tropics as many shifting cultivation systems maintain very high levels of biodiversity while providing livelihood for populations in tropical forest areas worldwide.

In Northeast India, the biological diversity of ecosystems are used and conserved by traditional communities through various informal institutions and using traditional ecological knowledge. *Jhum* cultivators are known to manage more than 30 indigenous crops along with other biodiversity (Singh *et al.*, 2009).

Rice (2003) in his study on tropical agro-ecosystem has stated that the present opinion on the detrimental effects of shifting cultivation has to be pondered upon again in the way in which resources are used in slash-and-burn agriculture, as its role in direct deforestation remains much lower than it was predicted and modelled by many past scholars.

2.6. Positive impact

Among the positive impacts of shifting cultivation that can be highlighted from past studies are that there is an increase in soil fertility after conversion, with an increase of P, Ca, and Mg that indicates that the stocks of these macronutrients are not affected (Brinkmann and Nascimento, 1973; Stromgaard, 1986; Andriesse and Schelhaas, 1987; Juo and Manu, 1996; Zarin *et al.*, 1998; Frizano *et al.*, 2003; Oliveira, 2008).

Tripathi and Barik (2003) has highlighted that shifting cultivation helps in conserving the rich cultural diversity that exist among the *jhum* farmers of the north-east region of India consisting of more than 200 tribes, as it is interwoven into their culture and tradition.

The following phase is essential to help restore soil fertility lost during the preceding cropping phase (Liang *et al.*, 2009) and the fallow phase guarantees enough accumulation of nutritional elements into the forest vegetation (Richter *et al.*, 2000).

Zinke *et al.* (1978) in their findings have cited that clearing and burning of vegetation cover cause some of the nutrients stored in plant biomass to be released, making them available for crop use. It has been reported that fire leads to changes in the chemical properties of soil with regard to the quantity and quality of organic matter, soil moisture, availability of nutrients, exchange capacity, and base saturation (Certini, 2005). Burning has been intensively studied and concluded to supply bases and phosphorus via ash input (Leonard *et al.*, 1998; Giardina *et al.*, 2000). N supply is increased by enhanced mineralization after burning (Knoepp and Swank 1993; Tanaka *et al.*, 2001). At a Mexican dry forest site, soil heating during slash burning transformed 35 kg of non-plant- available organic and occluded soil P per ha into plant-available mineral forms (Giardina *et al.*, 2000).

Some soil properties relating to soil acidity improve when soil organic matter (SOM) increases in the late stages of the fallow phase. The litter input may be supplying bases that are obtained via tree roots from further down the soil profile to the surface soil (Funakawa *et al.*, 2006). Although fire decreases the amount of organic matter in the soil, impact on soil structure and bring change in the macro-aggregates (< 0,250 mm), it may also result in an increase of mineral carbon and carbonated matter (Filho *et al.*, 2013). Bruun *et al.* (2009) while analyzing the effects of changes in shifting cultivation on soil carbon and soil quality found out that alternative land use systems show lower levels of carbon storage and reduced soil quality as compared to shifting cultivation and that these findings proved valid too while comparing between short-fallow and long-fallow period.

Filho *et al.* (2013) has described that after slash-and-burn operations all soil moisture is not lost due to the latent heat of vaporization which prevents soil

temperature from exceeding 95°C where water completely vaporizes and ultimately decreases its negative impacts on the physical properties of the soil.

When soil samples were collected 4 weeks after burning under shifting cultivation in Papumpare district of Arunachal Pradesh, Northeast India, it has shown that the bacterial (*B. clausii*, *B. licheniformis*, *B. megaterium*, *B. subtilis*, *B. thuringiensis*, *P. aeruginosa* and *P. stutzeri*) and actinomycetes counts were significantly higher in fired plots which signify a higher rate of recovery as compared to the fallow plots. This indicates that burning operations in *jhum* plots have microbiological benefits as *Bacillus* and *Pseudomonas* species are important in plant growth promotion and bio-control (Pandey *et al.*, 2011).

2.7. Negative impact

Studies have indicated about the negative impacts on soil fertility and an increase in the occurrence of erosion (Brand and Pfund, 1998; McDonald *et al.*, 2002).

Due to population pressure the rotation has been reduced to 3–5 years and become unsustainable in the area of the Chittagong Hill Tracts in Bangladesh bordering Northeast India in recent decades (Borggaard *et al.*, 2003). The shortened phase of fallowing would not allow forests to recover sufficiently for regeneration of soil fertility and control of weeds (Rasmussen and Jensen, 1999). The destabilization of the nutrient cycles of the soil/plant systems, based on the increase in the number of slash-and-burn and cultivation cycles, has also been presented as a negative impact (Hölscher *et al.*, 1997; Gafur *et al.*, 2003; Davidson *et al.*, 2007).

Numerous studies reviewed by Filho *et al.* (2013) concluded that burning of slashed vegetation could be the main cause to impact of the conversion of the forest into a cultivatable area where combustion of soil organic carbon takes place. Loss of soil organic carbon has been thus concluded to have a negative impact, mainly on the structure of the soil which assumes to be the main cause of argument to make shifting cultivation unsustainable.

Impacts on the physical properties of the soils because of slash-and-burn has been depicted by other authors that could intensify the resulting leaching process and mainly would result in a decrease in the quantity of organic matter (McDonald *et al.*, 2002; Frizano *et al.*, 2003).

In Northeast India, it has been reported that forests cannot recover if the length of the fallowing phase is shorter than 10 years (Ramakrishnan, 2006). Tripathi and Barik (2003) has also reported that due to shortening of fallow cycles, the secondary forests do not get enough time to regenerate and ultimately gets converted

into degraded wastelands. In another aspect, Robinson (1988) while commenting on the degrading tropical forest has stated that "It is offensive that the products of an indefinite number of genetic changes, accumulated over an immense period of time, should be endangered by a short burst of economic development spurred by short-term necessity". Mamede and Araújo (2008) has also cited about the decrease in the diversity of the seed bank due to the use of fire in the conversion phase of shifting cultivation where this phenomenon could result in a decrease in the biodiversity of these forest ecosystems.

Objective-I: To determine plant litter accumulation and soil enzyme activities in different *jhum* cycles

2.8. Organic inputs in soil

Falling of leaf litters and their decomposition with consequent release of nutrient characterizes major biological pathways for element transfer from vegetation to soils which play important functions in regulating nutrient cycling and maintaining soil fertility in forest and agro-ecosystems (Yang *et al.*, 2003). It has been reported that in forest ecosystems, almost all the above ground biomasses (more than 90% of net aboveground primary production) returns to the forest floor as litter-fall which constitutes the major substrate for plant species and soil decomposers (Swift *et al.*, 1979). The duration of increases in soil organisms depends on the amount and proportions of readily decomposable carbon substrates added and the availability of nutrients, particularly nitrogen (Hartz *et al.*, 2000; Adediran *et al.*, 2003). Among the many organic inputs following slash-and-burn, dead roots from cut vegetation and the above-ground biomass that was not burned contributes to be the main organic sources. The necromass of fine roots was reported to be as much as 15 t ha⁻¹ (Vitousek and Sanford, 1986) as in contrast to only 2.4 t ha⁻¹ after clearing a forest in Costa Rica (Veldkamp, 1994).

In a shifting cultivation scenario, in the first year or two following clearing and burning, inputs are restricted mainly to crop residues only with the exception of few weed biomass. These above-ground inputs contribute only about 30-40% as compared to that of a natural forest system and the level of above-ground inputs were about 3.2 t ha⁻¹ year⁻¹ and below-ground was 1.2 t ha⁻¹ year⁻¹ taking into account the major crops to be as rice, maize and beans (Palm *et al.*, 1996). In Northeast India, after a year or two, the cropped area are fallowed and left to regenerate. Eventually, the organic inputs increase with increase in biomass from the regenerated fallow lands. Toky and Ramakrishnan (1983) has documented that the litterfall increased in the trend of 1.2 t ha⁻¹ in a 1 year old fallow , 4.8 t ha⁻¹ in 5 year old fallow, 7.1 t ha⁻¹ in 10 year old fallow and 9.7 t ha⁻¹ in 20 years old fallow which resembles more or less to that of a mature forest. Similar findings were also reported elsewhere which has usually exceeded a natural forest system (Szott *et al.*, 1991; Ewel, 1996).

Soil organic matter has been regarded as the single most important indicator of soil productivity (Haynes, 2005). Soil organic matter reflects the productivity of shifting agricultural systems because of its role in maintaining soil fertility and soil structure. It was estimated that 8.4 t ha⁻¹ year⁻¹ of above-ground and 5.8 t ha⁻¹ year⁻¹ of below-ground inputs would be required to maintain soil organic matter levels similar to those of humid forests (Young, 1989). Moreover, as most of the nutrients are stored in the organic form (N, P, and S) and held in the mineral form. Microbial activity in the soil also gets stimulated directly by humic substances which provides the provision of carbon substrate, supplementation of nutrients, and enhanced nutrient uptake across cell walls (Valdrighi *et al.*, 1996).

2.9. Jhum fallow phase

The length of the cultivation period varies depending on the region (one to three years), but is always shorter than the fallow period. The fallow period may be natural or managed (secondary forest stand) and allows recovery from the soil degradation resulting from conversion and cultivation. The duration of the fallow period is variable, but it must be long enough for woody vegetation to become dominant (Filho *et al.*, 2013). Mertz (2002) has described that the productivity of the succeeding cropping phase would decline in shifting cultivation although conclusive remarks cannot be perceived in the relationship between length of fallow and crop yields.

2.10. Accumulation in quantity and dynamics

Funakawa *et al.* (2006) studied fallow phase in the shifting cultivation system used by the Karen people in northern Thailand and summarized that the decline in soil organic C during the cropping phase may be compensated by litter input during a fallow phase of 6–7 years. Research conducted in a slash-and-burn situation of Madagascar showed that during the fallow period, the amount of litter increased from 1.2-1.6 t ha⁻¹ yr⁻¹. The litter production increased with age and represented more than 25% of the above-ground phyto-mass after 5 years. Nutrient concentration of litter, similar to the vegetation, showed a great variability, especially for exchangeable cations. No distinct evolution in the nutrient concentration of the litter was found, except for K, which was clearly increasing (Brand and Pfund, 1998). Results from 2 years long litter-fall studies in South-eastern Puerto Rico has recorded that litter-fall averaged 10.4 ($\pm$ 0.6 SE) Mg ha⁻¹y⁻¹ in the first year and 10.6 ($\pm$ 0.5 SE) Mg ha⁻¹y⁻¹ in the second year across 10, 20, 30, 60, 80 years old secondary forest and a primary forest. Total litter-fall varied significantly among ages in the first year. The 10 and 30 year old secondary forests and the primary forests had the lowest litter-falls averaging around 8 Mg ha⁻¹y⁻¹ ($F_{5,12} = 5.39$, $P < 0.01$) whereas, in the second year there were no significant differences among different ages of the forest (Ostertag *et al.*, 2008).

2.10.1. Quality of litter inputs

In a comparative study between natural forest and agro-forestry based management of Sulawesi, Indonesia, it was found that the litter produced by natural forest has different amount and different composition which is based on the structure and the species diversity of the plants which thrive in it (Triadiati *et al.*, 2011). A study conducted on private lands in the Sierra de Cayey in south-eastern Puerto Rico concluded that mixed-leaf litter chemistry differed significantly from root litter chemistry. Leaf litter had a higher percentage of C ($P < 0.0001$), water-soluble compounds ($P < 0.0001$), and tannins ($P < 0.0001$) as compared with root litters. Root litter had significantly more Klason lignin ($P = 0.03$) and acid soluble polysaccharides than leaves ($P < 0.0001$). In addition, roots had significantly higher lignin-to-N ratios ($P < 0.0001$) (Ostertag *et al.*, 2008).

2.10.2. Forest litter quantity and soil enzyme activity relationship

The microbial community undergoes a succession from rapid resource consumers to stable and slow utilizers. Beside the establishment of secondary forest,

this retards leaching of N and enhances N accumulation in forest-like ecosystems. It is noteworthy that during the fallow period, nitrification activity of soil microbes, which was once active in the cropping phase, is apparently suppressed (Funakawa *et al.*, 2006). A study in the wet tropical forest of south-western Costa Rica has also shown that the enzyme activity with respect to C, N and P degradation increased with the amount of organic inputs in the form of leaf litter amendment (Weintraub *et al.*, 2012).

2.10.3. Forest litter quality and soil enzyme activity relationship

It has been observed that the impact of plant species on litter decomposition and nutrient availability depend on the chemical composition of their litterfall, tree species and species groups such as climax and pioneers (Mesquita *et al.*, 1998; van Dam, 2001). The type of organic inputs in the soil also plays an important role in the secretion of various enzymes by the soil microbes. Allison and Vitousek (2005) in their studies have revealed that the production of enzymes by the microbes followed an economic theory where more enzymes were produced in abundance of complex nutrient organic substrate and when the simple nutrient organic sources are scarce.

2.10.4. Impact of fire on litter accumulation

Vegetation response to fire was depicted to be a result of the interaction between severity of the fire and plants characteristics (Duchesne and Hawkes, 2000). However, shortly after fire, vegetation re-growth and the ecosystem functioning are potentially restored (Lloret and Zedler, 2009). In the case of shrub lands, plant species were grouped into three categories, according to their post-disturbance regeneration response: seeders, sprouters, and facultative seeders (Keeley, 1991). Normally, seeders regenerated well after fire, but fewer re-sprouting species sprouted following high intensity fires, since high levels of soil heating damages the tissues. Although sprouters could reproduce from the seed bank, most species only produce a few seeds that were intolerant of heat exposure (Keeley, 1991).

After a rangeland wildfire in Eastern Spain, Cerdà (1998) found that vegetation biomass became zero, but the recovery of plant cover was very rapid during the following years while in another study in South-Eastern Australia, Doerr *et al.* (2006) found rapid vegetation recovery over the following two years after the fire, even under relatively low rainfall. Fire also induces the death of sensitive species to soil heating

(Hart *et al.*, 2005) which in turn, can promote the proliferation and activity of surviving species, reducing competition and facilitating their access to resources. Filho *et al.* (2013) have reviewed that the seed bank is also strongly impacted by fire, where there was reduction of seed density and diversity, mainly of the herbaceous groups and consequently disturbing the ecological succession over time. The emergence of invasive species has been accounted to loss of the diversity and density of seeds due to burning.

2.11. *Jhum* cropping phase

According to Filho *et al.* (2013) shifting cultivation across the world has a relative homogeneity and is more or less the same in relation to the different locations, biomes, and types of soil.

2.11.1. Abundance of crop residues and accumulation dynamics

In South and Southeast Asia, large amounts of crop residue are burned or removed after harvest results in loss of organic matter and nutrients (Nguyen *et al.*, 1994; Smil, 1999). According to Palm *et al.* (1996), in a shifting cultivation scenario of maize, rice, and bean, the crop residues can contribute to about 3.2 t ha⁻¹ year⁻¹ from the above-ground necromass and about 1.2 t ha⁻¹ year⁻¹ from the below-ground roots.

2.11.2. Quality of crop residues

Mandal *et al.* (2007) observed that crop species and cropping systems that may also play an important role in maintaining SOC stock because both quantity and quality of their residues that are returned to the soils vary greatly affecting their turnover or residence time in soil and thus its quality.

2.11.3. Crop residues quality and soil enzyme activity relationship

Acosta-Martínez and her co-workers (2007) have also cited that the activity of β -glucosidase was greater in Oxisols compared to the Inceptisols and Ultisols, and the response was in the increasing order of pasture > forest > agriculture. The activities of acid phosphatase and arylsulfatase activities were also found greater in Oxisols and Ultisols than in Inceptisols, and was in the order of forest = pasture > agriculture land.

2.11.4. Impact of fire on crop residues accumulation

There is lack of scientific database on the impact of fire on the crop residue accumulation during cropping phase in *jhum* cycles.

2.11.5. Impact of fire on soil nutrient accumulation

In a *jhum* agro-ecosystem, burning plays an extremely important role in soil fertility. The nutrients that are released from the biomass and even the parent material during burning may become available for crop uptake, escape via volatilization, leaching or surface runoff, or remain bound in recalcitrant ash complexes (Ramakrishnan, 1992). Researchers have the view that within a shifting cultivation schedule, burning of the forest or fallow biomass results in the release of nutrients that can be utilized by crops planted after the burning process is over (Sanchez, 1976). A short-term increase in soil fertility has also been reported because of the incorporation of Ca, Mg and K from nutrient-rich ash into the cation exchange pool (Nye and Greenland, 1960).

At a Mexican dry forest site, soil heating during slash burning transformed 35 kg of non-plant- available organic and occluded soil P per ha into plant-available mineral forms (Giardina *et al.*, 2000). Sertsu and Sanchez (1978) found that both exchangeable Mg and Ca declined steadily while exchangeable K increased steadily with heating to 600°C. At temperatures above 300°C, soil organic N is lost during the thermal oxidation of organic matter in the form of oxidized N gases and N₂ (Raison, 1979).

2.11.6. Impact of fire on soil microbial activity

While studying on the microbial population of shifting cultivation plots of Northeast India, colony counts of three microbial communities, viz. bacteria, actinomycetes and fungi showed that the bacterial and actinomycetes counts in burnt plots were significantly higher ($P \leq 0.01$ and $P \leq 0.05$, respectively), as compared to those in fallow plots. Fungal counts were also slightly higher, but the differences were not statistically significant indicating that the three groups of microbial communities possess differential tolerance to fire event (Pandey *et al.*, 2011). A recent study conducted on forest fire in central Colorado, reported no significant difference in total microbial biomass between the unburnt and burnt soils. However, the microbial

communities in the burnt sites were structurally different from the unburnt sites (Hamman *et al.*, 2007). In a study conducted during 1979–1980, quantitative reduction in soil microflora was attributed to fire event under slash-and-burn process wherein it was summarized that the effect of fire depends upon the intensity and duration of fire. Another study also reported that the composition of the fungal species was not influenced by burning (Deka and Mishra, 1983). Several studies conducted some years after forest conversion to pastures have documented a decrease in soil microbial activity and nutrient losses associated with the loss of plant cover, severe erosion, and reduction in soil organic matter and microbial biomass (Maass *et al.*, 2002). A study conducted in the coast of Jalisco, México has concluded that forest conversion by means of slash-and-burn followed by cultivation resulted in few immediate changes in the AMF communities, most probably because of the low heat conductivity of the soil and rapid combustion of plant residues (Aguilar-Fernández *et al.*, 2009). A study conducted at two pair sites of Chittagong Hill Tracts in Bangladesh to find out the effects of shifting cultivation on soil fungal and bacterial population has shown that both fungal and bacterial population in surface and subsurface soils were in most cases significantly ($p \leq 0.05$) lower in shifting cultivated land compared to village common forest under study (Miah *et al.*, 2010).

2.12. Relationship between plant litter inputs and soil humus

2.12.1. Impact of fallow length on soil humus

Studies conducted in Southern Cameroon have revealed an important change in soil morphology during the natural fallow re-growth. It was observed that the humus rich A1 organic horizon destroyed during shifting cultivation activities gets recovered at the age of 7 to 9 years during the natural fallow re-growth (Martin *et al.*, 2002). In another slash-and-burn situation of Madagascar, the C concentration decreased generally until the third year of fallow because of the increased decomposition of organic matter under cultivation and low inputs through litter decomposition during the first years of fallow. However, after 5 years of fallow the top soils showed a high C concentration, because of increased contributions from litter (Brand and Pfund, 1998).

2.14.2. Impact of fire on soil humus

The effect of fire on the total SOM content was found to be highly variable and influenced by several factors including fire type (canopy or aboveground, underground

fires), intensity, and slope (González-Pérez *et al.*, 2004). These effects ranged from the almost total destruction of the soil OM to increases that reached 30% in the surface layers as a consequence of external inputs, mainly from dry leaves and partially burnt plant materials in fires affecting the tree canopy (Chandler *et al.*, 1983). Fire does not only burn out the slashed biomass but also the litter layer, and the uppermost humus layer which constitute to be the major part of the resources and habitats for soil organisms (DeBano *et al.*, 1998). However, after a moderate wildfire, an increase of C in soil is usually observed suggesting a substantial incorporation of forest necromass (Rashid, 1987). The soil C:N after burning are usually lower than in the original soils, a phenomenon that has been cited in numerous types of post-fire soils (Almendros *et al.*, 1984; Vega, 1986).

A study conducted in Northeast Indian *jhumming* condition has shown that just after burning, there is a significant reduction in the carbon content ($P = < 0.05$) and the phenomenon was more prominent in 10 and 30 year *jhum* fallow compared to 5 years old fallow. The trend for reduction in carbon continued upto a period of 90 days in 10 and 30 year *jhum* cycle sites and for a period of 30 days only in the site of 5 year cycle. After this period, carbon content in the surface soil showed an increasing trend (Ramakrishnan and Toky, 1981). The decrement in carbon content had been attributed to the effect of dissimilar intensities of fire from unequal amount of slashed biomass of different *jhum* fallows. The transformations exerted by fire on the soil humus fractions (HAs and FAs) have been modelled and studied in detail by Almendros *et al.* (1990) for wildfire-affected soils and simulation laboratory experiments using a mineral soil phase mixed with isolated humic fractions that were submitted to isothermal heating (350°C) at variable time periods. Severe transformation of the original humic materials was observed with a drastic change in solubility properties. In an early stage, half the HA was rapidly transformed into an alkali-insoluble macromolecular material. This insolubility drastically increased during subsequent thermal stages. A similar transformation was also observed for the FA that was first transformed into an acid-insoluble macromolecule (HA-like) and then into an alkali-insoluble substance (humins-like). In addition, after alkaline permanganate oxidation of both humic fractions, a variable amount of black unoxidized residue remained. It displayed, after IR spectroscopy and elementary analysis, those characteristics that would be expected for a BC-like material. A study conducted in Beforona, the central eastern Madagascar has shown that slash-and-burn of a 5-year-old fallow resulted in a decrease of the topsoil carbon concentration by approximately 20% which indicates that fire affected the organic matter in the first few centimetres of topsoil (Brand and Pfund, 1998). During a three year post-fire evolution studies on soil properties in Mediterranean heathland, soil

organic matter content after the fire ($1.1 \pm 0.1\%$) was reduced to 34.6% the pre-fire content ($3.1 \pm 0.2\%$). However, after one year of the burning, organic matter content did not vary significantly, although it increased slightly during the following two years until the end of experiments ($1.5 \pm 0.1\%$, on average) (Granged *et al.*, 2011).

2.13. Soil enzymes

The microbiological and biochemical status of the soil has often been proposed as an early and sensitive indicator of soil ecological stress or restoration processes in both natural and agroecosystems (Dick and Tabatabai, 1993; Dick, 1994). Enzyme activity in the soil environment is considered important to contributing to the overall soil microbial activity and to soil quality (Jordan *et al.*, 1995). Soil enzymes play key biochemical functions in the overall processes of organic matter decomposition and nutrient cycling in the soil system (Dick, 1994). All soils contain diverse group of enzymes that determine soil metabolic processes (McLaren, 1975) which, in turn, depend on its physical, chemical, microbiological and biochemical properties. The activities of soil enzymes have been considered to be the appropriate indicators for studying the soil processes as they are closely related to the biology of the soil, their ease for measurement and its rapid response to the changes in land use practices with high sensitivity to discriminate among different management practices (García-Ruiz *et al.*, 2008). Soil enzyme activities has been described to be used in characterizing abundance and metabolic activity of soil microbes, while kinetic parameters derived from the catalytic reaction of enzyme activities are used to describe catalytic activity, origin, and substrate affinity of the enzymes (Zhang *et al.*, 2009).

Enzyme activity in soil results from the activity of accumulated enzymes and from enzymatic activity of proliferating micro-organisms (Kiss *et al.*, 1975). Sources of accumulated enzymes are primarily microbial cells (Ladd, 1978), while it is also known to originate from plant and animal residues (Tabatabai, 1994). Enzymes accumulated in soil are free enzymes such as exoenzymes released from living cells, endoenzymes released from disintegrated cells and enzymes bound to cell constituents (Kiss *et al.*, 1975). Upon reviewing the use of soil enzyme activity as biological process level indicator for soil health, soil enzyme activities are regarded to be very sensitive to both natural and anthropogenic disturbances, and show a rapid response to the induced modification (Dick, 1997). Reports have indicated that soil enzyme activities can reflect change in soil management and land use and that these changes in soil enzyme activities can be used for predicting soil quality before they are detected by other soil analyses (Ndiaye *et al.*, 2000). Trásar-Cepeda *et al.* (2000) has suggested that the

most relevant methodology in terms of measuring soil quality would be measuring its soil biochemical properties which happen to be environmentally most sensitive with regard to the concept of sustainable development. From inversely proportional relationships between P-availability and phosphatase activity and N-availability and N-acquiring enzyme activities, Sinsabaugh (1994) concluded that measurements of specific enzyme activities can be used as indicators of relative nutrient limitation. Soil extracellular enzymes play a critical role in organic matter decomposition, regulating both carbon (C) storage and the supply of essential nutrients to below- and above-ground communities (Berg, 2000; Burns and Dick, 2002).

2.14. Soil enzymes: types, activity and their functions

Biological functions of decomposition of plant debris and other organic constituent of the soil for available plant nutrients, nutrient cycling and catalysing of several important reactions necessary in the life processes of micro-organisms in soils and the stabilisation of soil structure are being efficiently carried out by certain group of proteins known as enzymes which are secreted from different sources to act upon specific substrates (Dick *et al.*, 1994; Tabatabai, 1994; Gessner *et al.*, 2010). The physical, chemical, microbiological and biochemical status of the soil also determines the activities and nature of such metabolic activities depending on the type of enzymes present. Soil enzymes are essential for catalyzing reactions necessary for organic matter decomposition and their activities are strongly influenced by organic matter content of the soil (Ajwa *et al.*, 1999; Klose and Tabatabai, 2000). Ross (1983) has described amylase to be as a starch hydrolyzing enzyme that is widely distributed in soils and primarily hydrolyzes starch to form reducing sugar which is an energy source for soil microbes (Eivazi and Tabatabai, 1990). Research evidence suggests that several other enzymes are involved in the hydrolysis of starch, but one of most important enzyme would be α -amylase which converts starch like substrates to glucose and/or oligosaccharides and α -amylase, which converts starch to maltose (Thoma *et al.*, 1971).

Arylsulphatases are responsible for the hydrolysis of sulphate esters in the soil (Kertesz and Mirleau, 2004) and are secreted by bacteria into the external environment as a response to sulphur limitation (McGill and Colle, 1981).

β -glucosidase plays an important role in soils because it is involved in catalysing the hydrolysis and biodegradation of various β -glucosides present in plant debris decomposing in the ecosystem (Ajwa and Tabatabai, 1994; Martínez and Tabatabai, 1997). β -glucosidase catalyzes the hydrolytic conversion of cellulose to

glucose and cellulose is quantitatively the most important organic compound and its mineralization and degradation in soil is a major process within the carbon cycle (Sinsabaugh *et al.*, 1991). The activity of β -glucosidase is considered as an indicator for biomass turnover in the soil as it is the driving force in the decomposition of carbohydrates (Deng and Tabatabai, 1996). β -glucosidase is characteristically useful as a soil quality indicator, and may give a reflection of past biological activity, the capacity of soil to stabilise the soil organic matter, and can be used to detect management effect on soils (Bandick and Dick, 1999; Ndiaye *et al.*, 2000). Acosta-Martínez and Tabatabai, (2000) reported that β -glucosidase as sensitive to pH changes and therefore could be used as a good biochemical indicator for measuring ecological changes resulting from soil acidification in situations involving activities of this enzyme. Past reviews have concluded that β -glucosidase is concentrated in organic debris of the soil surface and in the fine soil fraction (< 2 mm) where there is abundance of fungal hyphae (Wick, 1997).

Dehydrogenase enzymes oxidise soil organic matter by transferring protons and electrons from substrates to acceptors. These processes are part of respiration pathways of soil micro-organisms and are closely related to the type of soil and soil air-water conditions (Kandeler, 1996; Glinski and Stepniewski, 1985).

Phosphatases are enzymes responsible for catalysing hydrolysis of esters and anhydrides of phosphoric acid which are essential in P cycles (Schmidt and Lawoski, 1961). Acid phosphatases are produced by plants and soil microorganisms. They are also found in rhizodermal and root cap cells, soil fungi and bacteria, root mucilages and microbial membranes in soil (Fraser *et al.*, 1994). When there is P deficiency in soil, plant roots secrete acid phosphatase to enhance the solubilisation and remobilisation of phosphate to counteract the P-stressed conditions (Kai *et al.*, 2002; Versaw and Harrison, 2002).

Proteases play a significant role in soil in nitrogen mineralization, an important process regulating the amount of plant available nitrogen and plant growth (Ladd and Jackson, 1982). Proteases decompose proteins into smaller membrane-permeable peptides (oligopeptides) and amino acids which microorganisms can assimilate and metabolize to ammonia and carbondioxide. The main mineralization processes of biomass-N involve amino acid formation from protein and ammonification from amino acids (Loll and Bollag, 1983; Hayano, 1996). Soil proteases are considered to reflect the proteolytic potential of a soil and therefore indicate the protein degradation capacity (Loll and Bollag, 1983). Badalucco *et al.* (1996) while studying on the wheat rhizosphere remarked that the protease activity was highest in the root hair zone and

concluded therefore a contribution of root-hair-enzymes to the overall protease activity at the soil-root-interface.

2.15. Impact of fire on the activity of soil enzymes

Temperature strongly affects and controls soil enzyme activities, changing enzyme kinetics and stability, substrate affinity and enzyme production because it can influence the size and activity of microbial biomass (Rao *et al.*, 2014). In a study conducted in savanna type grassland in southern India, following a wildfire it was reported that the activity of soil enzymes, such as, amylase, cellulase, invertase and phosphatase increased in burnt soil as compared to the adjacent unburnt soil (Senthilkumar *et al.*, 1997). Serrasolsas and Khanna (1995) reported a steady decline in phosphatase activity with increasing temperature, and a near complete loss of phosphatase activity in soils heated to 250 °C. Straw burning instead of straw soil incorporation decreased acid but not alkaline phosphomonoesterase activity of the soil (Dick *et al.*, 1988). After prolonged incubation (11 weeks) of wildfire-affected soil under controlled conditions, acid phosphomonoesterase activity did not show signs of recovery probably because the high inorganic P repressed enzyme synthesis by soil microorganisms (Saa *et al.*, 1998).

2.16. Impact of fallow length period on the activity of soil enzymes

Enzyme activities investigated in natural and improved fallows of the semi-arid zone of Senegal showed that β -glucosidase and amylase activities were significantly higher in 21-year-old than in 11-year-old fallows (Badiane *et al.*, 2001).

Objective-II: To study the effect of plant litter types on soil processes in microcosms of different *jhum* cycles

2.17. Soil biota and soil processes

Heterotrophic microbial communities inhabiting soil are cited to mediate key processes that control ecosystem carbon (C) and nitrogen (N) cycling, and represent a potential link between plant diversity and ecosystem function (Zak *et al.*, 2003).

2.18. Various soil processes

Respiration and mineralization are regarded to be the key soil processes carried out by the biggest part of soil microbial community which is highly influenced by changes in temperature, soil moisture and nutrients (Mulder *et al.*, 2003; Franchini *et al.*, 2007). Investigators often measure microbiological activity in soil by determining soil respiration in the absence (basal respiration) or in the presence of specific organic substrates or organic residues (Nannipieri *et al.*, 1990).

2.19. Role of soil biota on soil processes

Past findings have indicated that the complimentary group of microorganisms synergistically work together to recycle debris of plants and microbes and their constituent carbon rich bio-macromolecules, such as cellulose, hemicellulose, pectin, chitin, lignin and tannin (Hedges and Oades, 1997; Gessner *et al.*, 2010). Application of *Azospirillum* and *Azotobacter* in the soil has been reported to increase the yield of rice (Balandreau, 2002). Phosphate solubilizing bacteria when applied in aerobic rice has also shown higher photosynthesis rate and indole acetic acid concentration (Panhwar *et al.*, 2013). The use of microbial consortium in *jhum* fields is also expected in retaining a long term soil fertility status. Microorganisms indeed make up the largest part of the total biomass in the soil (Brookes *et al.*, 1982; Winding *et al.*, 2005) and are key drivers in processes that contribute to the provision of essential ecosystem services, such as respiration, decomposition of organic matter and nitrification and other N-related processes (Barios, 2007).

2.20. Effect of above- and below-ground plant inputs on soil processes

Theoretical analysis in the past decade had predicted that the diversity of organic substrates in detritus would have no effect, or a negative effect, on microbial processes controlling ecosystem-level dynamics and that interactions between the diversity of primary producers (plants) and that of decomposers (microbial communities) are the two key functional groups that form the basis of all ecosystems and have major consequences for agricultural management (Loreau, 2001). Zak *et al.* (2003) has demonstrated that plant diversity impacted ecosystem processes by modifying the composition and function of heterotrophic microbial communities in soil while studying field soils in Minnesota, USA.

2.21. Relationship of fire and soil biota

Jesus *et al.* (2009) in their study has cited that in a slash-and-burn situation, the community structure of soil microbes was visibly altered when crops were introduced but tended to become more similar to the primary forest when the land was allowed to regenerate indicating that the intensity of slash-and-burn agriculture practiced in the studied areas was not sufficient to significantly impact soil bacterial communities. These sites were surrounded by large forest areas, which might have served as an inoculum source for colonization during secondary forest stands.

2.22. Relationship of fallow length period and soil biota

The microbial community undergoes a succession from rapid resource consumers to stable and slow utilizers. Alongside the establishment of secondary forest, this retards further leaching of N and enhances N accumulation in forest-like ecosystems. It is noteworthy that during the fallow period, nitrification activity of soil microbes, which was once active in the cropping phase, is apparently suppressed (Funakawa *et al.*, 2006). In a study on four *jhum* sites in Senapati district of Manipur, Northeast India, it was concluded that soil microbial biomass C, N and P was found to be maximum in protected forest site followed by 7-year old fallow site, 3-year old fallow site and minimum in recently slash and burnt site (Binarani and Yadava, 2010).

A comparative soil metagenomic survey was carried out recently in two different (5 yrs and 20 yrs) fallow phases of *jhum* cycles from Nagaland, India (Thakuria and Sharma, 2014). The aim of the investigation was to study the impact of fallow length (5 and 20 year old) on the composition and functional attributes of the soil biota communities. Findings indicated that soils of 5 year fallow housed approximate 2

times (108 nos.) higher bacterial orders than 51 nos. in 20 year fallow. The higher rank abundance of taxa in 5 year fallow community were Proteobacteria, Acidobacteria, Actinobacteria, Firmicutes, Chloroflexi, Verrucomicrobiota, etc. and in 20 year fallow community were Streptophyta, Chordata, Cyanobacteria, Ascomycota, etc.. The enzyme classes such as Oxidoreductases, Transferases, Lyases, etc. were abundant in 5 year fallow and Tranferases, Ligases, Hydrolases, etc. were abundant in 20 year fallow. Of the predicted proteins, 60.2% and 38.1% were metabolism related in 5 and 20 year fallows, respectively. The relative abundances of genes associated with iron acquisition and P metabolism were lower, while photosynthesis, potassium and secondary metabolisms were higher in 5 year fallow communities compared to 20 year fallow communities. As the most comprehensive metagenomic survey on shifting cultivation cycles, this study demonstrates clearly the role of the regenerated above-ground vegetation in shaping the soil biodiversity and thereby regulation on ecosystem processes and stability.

2.23. Relationship fire and soil processes

In an attempt to review the effect of fire on soil organic matter, González-Pérez *et al.* (2004) has concluded that the effect on soil processes and their intensity influenced by fire are highly variable and no generalized tendencies could be suggested for most of the fire-induced changes in humus composition. According to Sakamoto *et al.* (1993) and Shimamoto *et al.* (1995), the increase in $\text{NH}_4\text{-N}$ can be attributed to a deamination reaction caused by heating. Frequent wild-fires were studied in Var, Southeast France, in the south-eastern part of the mountain range of Les Maures, where it was found out that microbial activities (Basal respiration, Microbial biomass, $q\text{CO}_2$, Alkaline Phosphatase, FDA hydrolase) decreased with increase in wildfire frequency (Guénon and Gros, 2013).

2.24. Relationship of fallow length and soil processes

In a study conducted in eastern Madagascar, it was found that topsoil fertility regeneration started after 4 to 5 years of fallow where during the first 4 years of fallow, the concentration of C and exchangeable cations decreased in the topsoil. From the fourth year onwards, C and cations concentration started to increase, and aluminum toxicity decreased (Brand and Pfund, 1998). Similar topsoil fertility regeneration was noticed by Ramakrishnan (1992) in India.

Objective III: To compare the effects of microbial consortium, litter- and ash-amendments on growth and development of *jhum* rice

2.25. Ash accumulation due to burning of plant biomass

It has been outlined that the nutrients stored in the forest biomass are released both through burning and decomposition and mineralization of plant residues (Andriesse and Schelaas, 1987). It may be noted that the quantities of nutrient elements incorporated the soil after burning depend not only upon the amount of each element in the ash but also the capacity of the soil to retain and store these nutrient elements in forms that are readily available to the plant (Juo and Manu, 1996). In a study conducted in eastern Madagascar, it was found that burning of the slashed biomass provided an estimated $1.4 \text{ t ha}^{-1} \text{ year}^{-1}$ of ashes, which had a 5 to 20 times higher P and cation concentration, a similar N concentration but a lower C concentration than the preceding phytomass (Brand and Pfund, 1998). Similar (K, Ca) or somewhat lower (N, P) concentration were found after burning a 12 to 15-year-old fallow in Sarawak (Andriesse and Schelhaas, 1987).

2.26. Ash as an amendment of nutrient

It is widely accepted that ash addition by burning improves soil acidity and fertilize soils to elevate nutrient content, while only a portion of nutrients accumulated in aboveground biomass are transferred into ash, and only a proportion of those nutrients in the ash are infiltrated into the soils (Tanaka, 2012). The amount and magnitude of change in soil chemical properties are influenced by the chemical composition of the ash and the mineralogy and charge characteristics of the soil (Juo and Manu, 1996). In a study conducted in Southern Cameroon, it was reported that ashes from burned vegetation biomass at the beginning of the cropping period act as lime fertiliser and significantly influence soil chemical properties (Martin *et al.*, 2002). Nutrient data compiled from South and Central America have shown that the element content of ash was significantly correlated with nutrient content of the standing crop where on an average, 3%, 49%, 50% and 57% of total aboveground N, P, Ca and K, respectively, returned to soil in the form of ash. After burning has been completed, a proportion of nutrients transferred to the ash will then be lost due to wind and runoff water (Giardina *et al.*, 2000). A study conducted in ash from the burnt vegetation was found to add

more available Ca, Mg, K, S, Fe, Mn, and Zn to the soil than was removed in runoff sediments, whereas soil C, N, P, and Cu contents decreased (Gafur *et al.*, 2004).

2.27. Role of ash on soil organic matter accumulation

The soil that gets heated during slash-and-burn operations has been claimed to alter the chemical composition of organic matter either through soil desiccation, thermal modification or release of microbial biomass (Fernandez *et al.*, 1997; Giardina *et al.*, 2000). In slash-and-burn agriculture, soil attributes change as a consequence of the deposition of ash from the burned vegetation and increased rates of organic matter decomposition (Juo and Manu, 1996).

2.28. Significance of ash as soil amendment on plant growth and development

Additions of ash often increase soil microbial activity because labile-C in ash is added to soil or mineralization of native soil C is stimulated by changes in pH and additions of nutrients (Giardina *et al.*, 2000). Khanna *et al.* (1994) found that ash additions of 25 Mg/ha increased C respiration rates by 50–100% in acid soils with widely ranging organic matter contents. Stromgaard (1984) found out that plant-available P in ash from a Zambian miombo woodland site (Bray and Kurtz, 1945) contained about 0.8 kg plant-available P per ha.

Objective-IV: To develop soil biological quality index of different *jhum* cycles under natural farming situations

2.29. Soil quality

According to Karlen *et al.* (1997), soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Doran and Safley (1997) defined soil quality as “the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, sustain biological productivity, to promote the quality of air and water environments, and to maintain plant, animal and human health”. Rodale Institute (1991) has identified three essential criteria for soil quality which are productivity, environmental quality and health of living organisms. Doran (2000) further opined that these indicators of soil quality must fulfill few essential criteria which may answer (i) their utility in defining ecosystem processes; (ii) their ability to integrate physical, chemical and biological parameters; and (iii) their sensitivity to management and climatic variations.

2.30. Significance of biological soil quality

The biochemical properties of soil have been used widely to evaluate soil quality, both individually and combined in simple indexes and in more complex ones, which stresses the fact that the scientific community recognizes their potential value (Gil-Sotres *et al.*, 2005). Specific enzymatic activities have been used to compare and discuss values of enzymatic activities in soils with different organic matter contents (Barriuso *et al.*, 1988) and could be considered as simple indexes of soil quality. It has been reported that the changes in soil properties, particularly in the activities of soil microbes are brought about by high levels of microbial activity are fundamental in maintaining soil quality (Garcia *et al.*, 2002). The selected indicators must satisfy a series of requisites: (a) sensitivity to the presence of the greatest possible number of degrading agents; (b) consistency in the direction of the change undergone in response to a given contaminant; and (c) ability to reflect the different levels of degradation (Elliott, 1994). In accordance with Dalal (1998) a good indicator should measure one or more functions of the soil; be sufficiently sensitive to reflect changes due to

disturbance, restoration or management; provide reference, critical or threshold values; be easily interpretable; and be easy and inexpensive to obtain. While working with biological soil health, Ghoshal (2004) proved that different biological indicators contributed differently towards explaining biological soil health for different cropping systems.

2.31. Soil quality indices and their critical limits

Masto *et al.* (2007) has highlighted that the success and usefulness of a soil quality index mainly depends on setting the appropriate critical limits for individual soil properties. With regard to the selection of properties for use as indicators, Doran and Parkin (1996) consider a 'minimum data set' for use in soil quality evaluation, which includes physical (texture, rooting depth, infiltration rate, bulk density, water retention capacity), chemical (pH, total C, electrical conductivity, nutrient level) and biological properties (C and N microbial biomass, potentially mineralizable N, soil respiration). An index was constructed by Andrews and Carroll (2001) that integrated the physical, chemical, and biological attributes of the soil to evaluate its functional capacity including the concepts of soil ecology. They further described that the selection of attributes that are appropriate to be included in a soil quality index (SQI) should take into consideration the functions of the soil as well as the objectives of agricultural use. Mineralizable N is regarded as a measure of readily decomposed organic N, and as a measure of biological activity (Hill *et al.*, 2004). Mandal (2005) identified a few master variables (Available P, Microbial biomass C, organic C, Alkaline phosphatase, organic C, mineralizable N and mean weight diameter) and their relative contributions towards soil quality index (> 25%, 15-25% and <15%) calculated for different cropping systems and soil types (Typic Haplustept, Eutrochrept and Aeris Haplaquept). Amacher *et al.* (2007) has evolved a soil quality index (SQI) that reflects the forest soil health integrating 19 measured physical and chemical properties of forest soils into a single number that serves as the soil's "vital sign" of overall soil quality. The physical and physico-chemical parameters were regarded to be of little use as they alter only when the soil undergo a really drastic change (Filip, 2002). On the contrary, biological and biochemical parameters are sensitive to the slight modifications that the soil can undergo in the presence of any degrading agent (Klein *et al.*, 1985; Nannipieri *et al.*, 1990; Yakovchenko *et al.*, 1996). Amongst the general parameters, the microbial biomass C is considered to be the most reliable (41% of authors) followed by dehydrogenase activity (28%) and N mineralization capacity (16%). Phosphatase (28%), β -glucosidase (16%) and urease (11%) activities are the most frequently used

among the specific biochemical parameters and, appropriately, represent the P, C and N cycles.

Sharma *et al.* (2008), in a long term study conducted in rainfed Alfisol, on integrated nutrient management under reduced and conventional tillage in sorghum–mungbean system, reported that irrespective of conventional and reduced tillage, the sole organic treatments out-performed in aggrading the soil quality to the extent of 31.8% over control whereas, the conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2%, and the sole inorganic treatment could aggrade only to the extent of 18.2% over unamended control. In an effort to use the kinetics of soil enzyme activity as an index of soil quality in Jharkhand, India, it was found that forest soil support increased microbial activity and biomass due to higher organic matter content, and consequently exhibited higher maximum reaction velocity ($V_{\max}$) when compared with fresh mine spoil. Besides, lower K_m value in forest soil as compared to other soil types explained the strong enzyme-substrate affinity of different soil enzymes in forest soil (Kujur and Kumarpatel, 2014).

Microbial biomass represents the living component of the organic matter of soil, excluding animals and plant roots. Although microbial biomass usually makes up less than 5% of soil organic matter (Dalal, 1998), it carries out many critical functions in the soil ecosystem, among which the following could be pointed out: it is both a source and sink for nutrients, it participates in the C, N, P and S transformations, it plays an active role in the degradation of xenobiotic organic compounds and in the immobilization of heavy metals, it participates in the formation of soil structure, etc. (Nannipieri *et al.*, 2002).

The dehydrogenase activity of the soil is considered to be an indicator of the microbial redox system and of the oxidative activities of the soil (Trevors, 1984). It has been noted that ploughing can both increase and decrease dehydrogenase activity (Bergstrom *et al.*, 1998, 2000) while addition of organic fertilizers, landfill effluents and industrial waste generally increases dehydrogenase activity (Bardgett *et al.*, 1995; Pascual *et al.*, 1999; Langer and Gunther, 2001). Dehydrogenase activity has also been used to evaluate the degree of recovery of degraded soils, being considered as a good indicator, even in soils that have been contaminated by petroleum spillage (Margesin *et al.*, 2000).

Acid phosphomonoesterase activity has been the most frequently used for estimating changes in soil quality due to either management or the presence of contaminants. It is a good index of the quality and quantity of organic matter in the soil (Jordan *et al.*, 1995; Mullen *et al.*, 1998; Bergstrom *et al.*, 2000) and can be very high

in arable soils as long as the levels of organic matter in the soil are maintained (Dick *et al.*, 1994).

With regard to the enzymes involved in the carbon cycle, β -glucosidase has been the most widely used in the evaluation of soil quality in soils subjected to different management procedures. β -glucosidase activity was significantly lower in arable soils than in woodland and meadow soils (Bandick and Dick, 1999; Saviozzi *et al.*, 2001). The high degree of variability of enzyme activities could be, however, a limitation to their use as indicators of soil quality because contradictory results in different studies might result. Therefore, the reliability of enzyme activity measurements as indicators of changes in soil quality is severely related to the possibility of comparing information from different laboratories (Cardoso *et al.*, 2013).

Individual soil microbiological and bio-chemical properties are not useful measures of soil quality because they vary both seasonally and spatially (Nannipieri, 1994). It was suggested that the indices required to assess soil quality must be simple, accurate and rapid which compose of a minimum data set which reflects important soil microbiological and biochemical processes and methods used to measure these properties should be (Doran and Parkin, 1994; Trasar-Cepeda *et al.*, 1998). Soil organic matter has been considered an important indicator of soil quality because it is a nutrient sink and source, enhances soil physical and chemical properties, and promotes biological activity (Doran and Parkin, 1994; Gregorich *et al.*, 1994). In recent studies, soil organic matter has been considered as an important indicator of soil quality due to its association with different soil chemical, physical and biological processes, and soil biochemical properties, such as microbial biomass, microbial respiration, chitinase and acid phosphatase activities (Silveira *et al.*, 2009). Mohanty *et al.* (2007) recorded that soil quality in rice-wheat cropping system is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the two crops and observed that Soil Quality Index (SQI) values of 0.84 to 0.92, 0.88 to 0.93 and 0.86 to 0.92 were found optimum for rice, wheat and the combined system (rice+wheat), respectively. While studying an alfisol of Eastern India, the extent of percent contribution of the key indicators towards soil quality index (SQI) were found out to be as: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA- Zn (25.3%), DTPA- Cu (8.6%), hydraulic conductivity (6.1%) and mean weight diameter (2.9%) (Sharma and Mandal, 2009). Chaudhury *et al.* (2005) in a study of identifying several biological, chemical, and physical indicators of soil quality concluded that the highest SQI was found in 100% NPK+FYM treatment followed by 100% NPK, 100% NP, 100% N, and control treatment, respectively.

Masto *et al.* (2007) quantified the effects of 10 fertilizer and farm yard manure (FYM) treatments applied for 31 years to a rotation that included maize, pearl millet, wheat and cowpea on an Inceptisol in India. A soil quality index (SQI) based on six soil functions was derived for each treatment using bulk density, water retention, pH, electrical conductivity (EC), plant-available nutrients, soil organic matter (SOM), microbial biomass, soil enzymes and crop yield. Soil quality index ratings ranged from 0.552 (unfertilized control) to 0.838 for the combined NPK fertilizer plus manure treatment. Soil quality indices have been used to compare tillage practices, organic and conventional vegetable production systems, litter management practices, and spatially large regions Plains, Hills, and several other practices (Andrews *et al.*, 2003). These varied uses suggest that Soil quality indices may be applicable not only to different soil types but also to multiple regions and management systems.

2.32. Research gap and future research directions

In conclusion, a review of the current state of knowledge suggests that an array of inherent ecological factors as well as anthropogenic interference seem to play defining roles in nutrient cycling processes and functioning of *jhum* soils. An in-depth understanding on the relationship among ecological factors, anthropogenic disturbances and soil processes needs further confirmations in light of the length of the fallow phase. The following research gaps are identified based on the literatures reviewed:

- How do the pattern of forest floor litter accumulation and their quality according to the length of the fallow phases relate to the nutrient status and biochemical attributes of *jhum* soils?
- To what extent burning practice can modify / alter soil enzyme activities and microbial biomass C, N and P ratio that are indicative of the state of C, N, P and S cycling in *jhum* soils.
- There is lack of scientific data that can support the interpretation of the cumulative stress impact of biomass burning on the stress physiology of *jhum* crops.
- There is a need to develop the quantitative soil quality index of *jhum* land relative to the undisturbed adjacent reserve forest land in order to judge the favourable length of the fallow phase within a *jhum* cycle.

Chapter- III

MATERIAL AND METHODS

Chapter-3

Materials and Methods

Objective–I: To determine plant litter accumulation and soil enzyme activities in different *jhum* cycles

3.1. Location

Keeping in view the severity of *jhum* cultivation across North East India, Mizoram and Nagaland were selected as representative hill states to suit best the *jhumming* scenarios of the region. The tribal communities of these study areas are still practicing shifting cultivation at large scale. Based on the prevalence of *jhum* cycles in these states, three identified *jhum* fallow lengths viz. 5 years, 10 years and 20 years at Changki, Mokokchung district of Nagaland and 5 years, 10 years and 15 years at Muallungthu, Aizawl district of Mizoram (MF) were selected. Geographical location of these study sites are presented in Table 3.1.

Table 3.1. Geographic location and other attributes of study areas

<i>Jhum</i> practicing state	Age of the Fallow phase (year)	Area (ha)	Latitude	Longitude	Aspect	Altitude (m)
Nagaland	5	2	26°24.101' N	94°22.499' E	S - SE	670 -692
Nagaland	10	2	26°24.179' N	94°22.513' E	S - SE	727-733
Nagaland	20	2	26°24.149' N	94°22.491' E	S - SE	714-722
Mizoram	5	2	23°36.279' N	92°42.909' E	N-NE	841 -857
Mizoram	10	2	23°36.305' N	92°43.873' E	N - NS	838- 891
Mizoram	15	2	23°35.768' N	92°42.991' E	S - SE	792- 820

3.2. Climate and Soil

Mokokchung district of Nagaland experiences warm tropical climate in the areas bordering Assam. The areas bordering Assam viz. Longtho, New Chungtia, Merakiong, Longnak and Changki valley experience hot-humid weather during summer seasons with average temperature of 24°C particularly during the month of May to September

and the climate is moderately cold during the winter months. Nevertheless, the weather is pleasant during the summer months. The area under study also experiences similar type of climate (Table 3.2).

Maximum and minimum temperature in Changki ranges from 19.9°C to 29.1°C and 6.8°C to 21.3°C, respectively. Out of total annual rainfall (1455.3 mm), about 79 % occurred during June to September and relative humidity ranges between 60.1 to 81% during most of the periods with the exception of few dry months.

Table 3.2. Weather parameters of Changki village, Nagaland during 2014

Month	Maximum temperature (°C)	Minimum temperature (°C)	Average mean temperature (°C)	Relative humidity (%)	Rainfall (mm)
January	19.9	6.8	13.35	62.8	19.1
February	22.1	7.5	14.80	62.0	21.7
March	25.0	9.5	17.25	60.7	33.6
April	29.1	14.5	21.80	61.5	41.3
May	28.8	17.2	23.00	61.9	67.7
June	28.6	20.4	24.50	67.3	174.7
July	28.2	21.1	24.65	76.0	407.1
August	27.4	21.3	24.35	81.0	326.8
September	27.6	20.7	24.15	74.7	311.7
October	26.7	17.5	22.10	60.1	49.4
November	24.2	13.0	18.60	43.1	2.2
December	20.7	9.9	15.30	36.3	0.0

Source: Soil and water conservation department, Government of Nagaland

Aizawl district of Mizoram also experiences warm humid tropical climate. Muallungthu and its adjoining places like Falkawn, Tachhip and Aibawk falls on the southern part of Aizawl district which experiences hot-humid weather during the summer months with an average temperature of 25°C during May to August. Winter months usually remains cold with moderate summer months. The area under study also experiences similar climatic conditions (Table 3.3).

Maximum and minimum temperature in Muallungthu ranges from 20.8°C to 31.6°C and 7.1°C to 20.2°C, respectively. Out of total annual rainfall (2115 mm), about 81 % occurs during May to August and relative humidity ranges between 60.7 to 80.9% during most of the periods.

Soils of Mokokchung district falls under red soil group and the dominant soil order is Inceptisol. Soils are mostly light to medium texture (sandy loam and clay loam) with depth ranging from deep to very deep. Soils of more than 80% of the geographical area are acidic (pH below 5.5).

Table 3.3. Weather parameters of Muallungthu village, Mizoram during 2014

Month	Maximum temperature (°C)	Minimum temperature (°C)	Average mean temperature (°C)	Relative humidity (%)	Rainfall (mm)
January	20.80	7.10	13.95	61.60	0.00
February	26.50	9.60	18.05	60.70	18.70
March	29.60	11.10	20.35	62.20	85.50
April	30.40	14.30	22.35	65.40	118.90
May	29.80	18.30	24.05	65.80	570.20
June	31.60	18.50	25.05	71.10	349.50
July	30.00	20.10	25.05	80.90	411.90
August	30.70	20.20	25.45	79.50	348.30
September	30.90	19.90	25.40	76.10	123.70
October	29.20	18.70	23.95	69.80	76.80
November	27.20	12.50	19.85	62.40	0.00
December	22.50	7.90	15.20	61.90	12.40

Source: Department of Agriculture (Research & Education), Government of Mizoram

Soils of Aizawl district falls under red soil group and the dominant soil order is Inceptisols followed by entisols and ultisols. Soils are mostly light to medium texture (sandy loam and clay loam) with depth ranging from deep to very deep. Soils of more than 90% of the geographical area are acidic (pH below 5.4).

3.3. Sampling procedures

The area (approximate 2 ha) under each of the identified fallow phases (secondary forest stand) was divided into two equal halves along the slope direction. One part of the secondary forest stand was kept undisturbed (no slash and burn operations) and hereafter referred to as adjacent unburnt site. The other half of the secondary forest stand was subjected to slashed and burned operations involving the expertise of the local farmers and hereafter referred to as burnt site/field. This procedure was followed in order to make the comparative study on the effect of slash and burning operations on soil physico-chemical and biochemical properties under different fallow lengths.

3.3.1. Litter sampling

Litter samples were collected using quadrat (1 sq m area) from 5 random spots of each of the adjacent unburnt sites in the identified *jhum* fallow lengths

(Sampling was done at every three months interval (sampling months were February, May, August and November) during 2014. These samples were carefully packed, air dried and weighed. Dried litter samples were grinded using a Willey Mill (Secor make, India) and passed through 0.5 mm sieve. One-fourth part of each of the ground litter sample was kept separately for analysing the elemental and biochemical compositions. The remaining three-fourth part of each ground litter sample was stored separately for use as litter amendment in the microcosm experiments conducted under the objectives II and III.



Fig. 3.1. Depiction of litter sampling using quadrat in secondary forest stands (fallow phase) of identified *Jhum* cycles of Mizoram and Nagaland.

3.3.2. Soil sampling and processing

Soil cores from surface layer (0 to 15 cm depth) were collected using 2.5 cm diameter core sampler from both adjacent unburnt site and burnt site at same time point to maintain uniformity in sampling time. Soil samples were collected within 12 h of completion of the burn operation (Appendix1.3.). Within each site, area are demarcated based on natural slope boundary i.e. summit, shoulder and backslope (Fig. 3.2). Five random grids (each grid size was 25 m²) were considered along the direction of each of the natural slope boundary. Soil samples from five random spots within each grid were collected and mixed them all to make one composite per grid. Thus, five composite soil samples were obtained along each natural slope boundary (Fig. 3.3). Finally, each

composite soil sample of summit, shoulder and backslope along the direction of slope gradient were mixed together to get overall five composite soil samples for each site (Fig. 3.3). In doing so, the possible influence of slope gradient on soil attributes was confounded. Since, the present investigation aimed to study the effect of burning and the length of the fallow phases on soil physico-chemical and biological attributes. These composite soil samples were subjected to laboratory analysis for physico-chemical and biochemical properties.

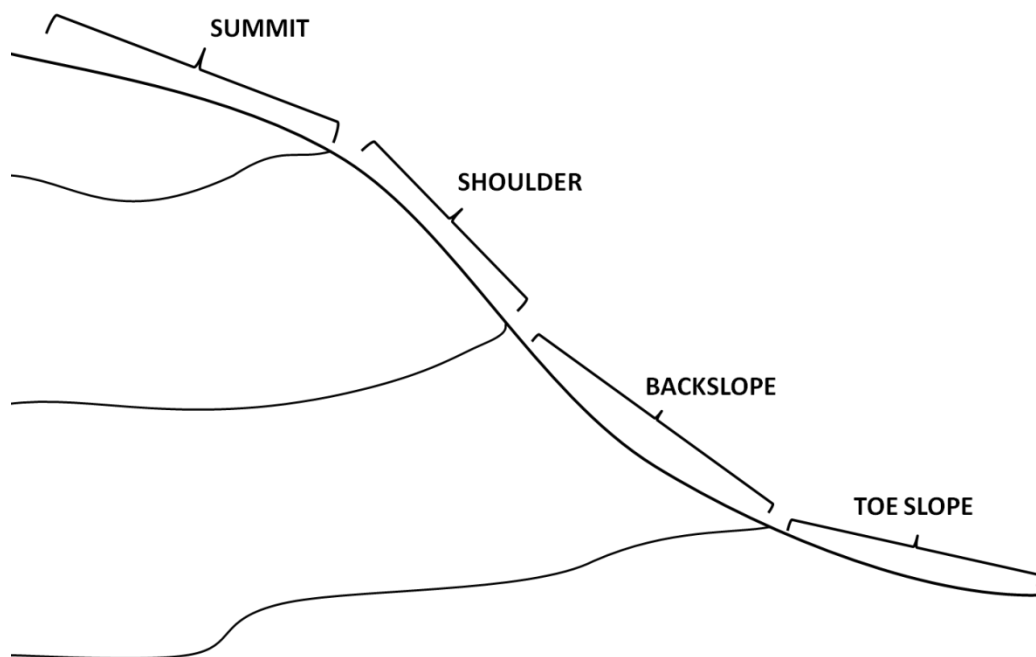


Fig 3.2. A generalized illustration of natural slope boundary on *jhum* lands.

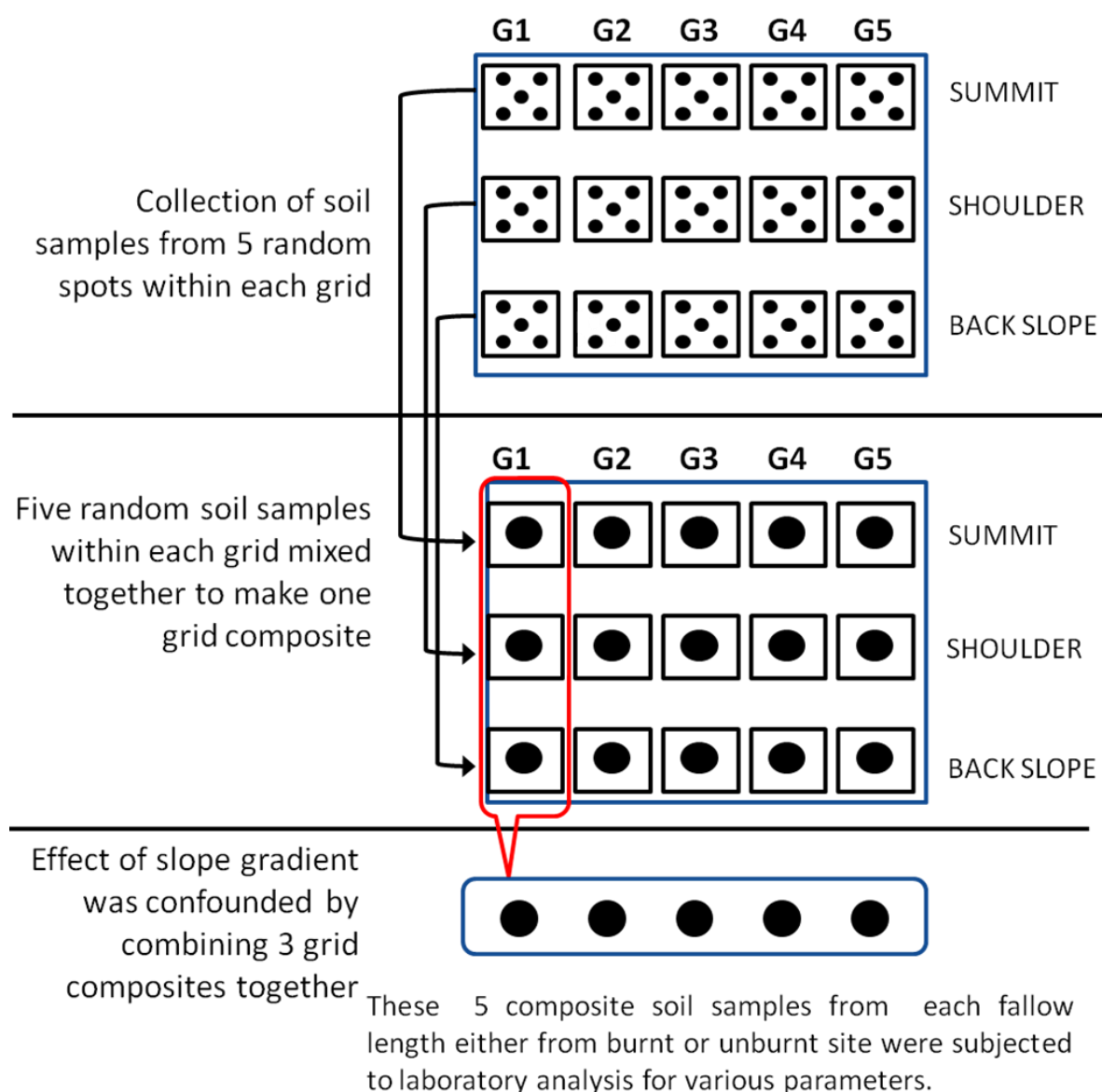


Fig 3.3. Pictorial depiction of soil sampling strategy in burnt and unburnt fields of different fallow phases under *jhum* cycles of Nagaland and Mizoram.

Each composite soil sample was divided into two equal halves and one part was stored at 4°C immediately after collection and used later for biochemical and microbiological analyses. Just before analysis, soil samples were incubated at 28±1°C for overnight and then passed through 1 mm sieve. All visible organic debris and fine root segments were removed and then soil samples were ready for biochemical and microbiological analyses. The other part of the soil sample was air dried and passed through 1 mm sieve, stored at room condition and used later for chemical analysis.

3.4. Soil physico-chemical properties

3.4.1. Bulk density (BD)

Bulk density of the soil was determined by Keen-Rackzowski box method as described by Baruah and Barthakur (1997).

3.4.2. pH

Soil samples were analyzed for pH (1:2.5 soil/water suspension) using a standard pH meter (Mettler Toledo, Switzerland).

3.4.3. Electrical conductivity (EC)

Soil samples were analyzed for electrical conductivity (1:5 soil/water suspension) using a standard conductivity meter (Mettler Toledo, Switzerland).

3.4.4. Soil Organic Carbon (SOC)

Finely grinded (<0.1 mm) air dried soil was used to determine SOC by following the potassium dichromate wet oxidation method described by Walkley (1947). Soil sample (0.5 g) was mixed with 10 mL of 1N $K_2Cr_2O_7$ and 20 ml of conc. H_2SO_4 in a 500 mL conical flask and kept for 30 minutes. After oxidation, 200 mL distilled water and 5 mL H_3PO_4 was added to the flask. The residual $K_2Cr_2O_7$ was titrated with freshly prepared 0.5 N ferrous ammonium sulphate in presence of diphenylamine indicator. SOC content in soil was expressed in $g\ 100g^{-1}$ soil (%).

3.4.5. Soil Available Nitrogen (Avl N)

Fresh soil (0.5 g) sieved through 1 mm sieve was used for determination of available nitrogen by alkaline permanganate oxidation method as described by Subbiah and Asija (1956). Soil sample was taken in a distillation tube and to this 40 mL of 0.32% $KMnO_4$ and 40 mL of 2.5% NaOH were added and distilled for 6 min in an automated distillation chamber (Classic DX, Pelican Equipment, Chennai). Ammonia generated during distillation was collected in 2% boric acid containing few drops of mixed indicator (Composition of mixed indicator: 0.1 g bromocresol green with 0.07 g of Methyl red and dissolved this mixture in 100 mL ethanol) in a conical flask and finally

amount of boric acid used for absorption of ammonia was determined by titrating with standard 0.02 N H₂SO₄. Available nitrogen was expressed in kg ha⁻¹.

3.4.6. Soil Available Phosphorus (Avl P)

Available phosphorus in soil was determined by following the stannous chloride blue colour method (Bray and Kurtz, 1945; Page *et al.*, 1982). Finely grinded air dried soil (0.5 g) was extracted with 50 mL of 0.03N NH₄F in 0.025N HCl for 5 min in a reciprocating shaker. After shaking, the soil suspension was filtered through Whatmann No. 42. A 5 mL volume of filtrate was taken for developing blue colour by adding 5 mL of Dickman Bray's reagent and 1 mL stannous chloride. Finally, intensity of blue colour was measured at 660 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA) and concentration of P was obtained from the standard curve. Available phosphorus was expressed as kg ha⁻¹.

3.4.7. Soil Available Potassium (Avl K)

Soil available potassium was determined by following the ammonium acetate method described by Hanway and Heidel, (1952). An aliquot (25 mL) of neutral normal ammonium acetate was added to 5 g finely grinded air dried soil sample and shook for 5 min in a shaker. After shaking, the soil suspension was filtered through Whatman No.1 and the concentration was measured using a flame photometer.

3.4.8. Exchangeable Calcium and Magnesium

Exchangeable fraction of Ca and Mg in soil was extracted using 1N ammonium acetate (NH₄OAC) and then the suspension was filtered through Whatman filter paper No. 42. The concentration of Ca and Mg in the filtrate was determined by compleximetric titration using ethylenediaminetetraacetic acid in presence of erichrome black (EBT) and calcon for Ca+Mg and Ca, respectively (Lanyan and Heald, 1982). Exchangeable Ca and Mg were expressed as meq per 100 g soil.

3.5. Soil biochemical properties

3.5.1. Amylase Activity (AMY)

Amylase (EC 3.2.1.1) activity was assayed according to the procedure described by Deng and Tabatabai (1994) and MacIlvain (1921). Moist sieved (1 mm) soil was mixed with citrate buffer (pH 4.0), 2.5 M starch as substrate and incubated at 37°C for 2 h. After incubation, the samples were centrifuged at 15,000 rpm at 4°C for 3 min. The supernatant was then assayed for the amount of glucose by Nelson's (1944) and Somogyi method (1952) and intensity of blue colour developed in the solution was measured at 620 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). The concentration of glucose in the filtrate was determined against a standard curve prepared by using standard glucose solution. Amylase enzyme activity was expressed as $\mu\text{g glucose g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.2. Arylsulphatase Activity (ASA)

Arylsulphatase (EC 3.1.6.1) was measured following the principle described by Tabatabai and Bremner, (1970) which was based on determination of *p*-nitrophenol released after incubation of soil with *p*-nitrophenyl sulphate (PNP). Moist sieved (1 mm) soil was added with 0.25 mL toluene, 4 mL 0.5 M acetate buffer (pH 5.8) solution, 25 mM 1 mL *p*-nitrophenyl sulphate and incubated at 37°C for 1 h. After incubation, 1 mL of 0.5 M CaCl_2 and 4 mL 0.5M NaOH were added to the soil suspension and filtered using Whatman No. 42 filter paper. Intensity of yellow colour was measured in the filtrate at 400 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). The concentration of *p*-nitrophenol in the filtrate was determined against a standard curve prepared by using *p*-nitrophenol standard solution. Arylsulphatase enzyme activity was expressed as $\mu\text{g (PNP) g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.3. β -glucosidase Activity (GSA)

β -glucosidase (EC 3.2.1.21) was determined following the assay outlined by Tabatabai (1982) and Eivazi and Tabatabai (1988). Moist sieved (1 mm) soil was added with 0.25 mL toluene, 4 mL MUB (Modified Universal Buffer, pH 6.0) solution, 1 mL *p*-nitrophenyl- β -D-glucoside (PNG) and incubated at 37°C for 1 h. After incubation, 1 mL of 0.5 M CaCl_2 and 4 mL 0.1M THAM buffer, pH 12.0 were added to the soil suspension and filtered using Whatman No. 2v folded paper. Intensity of yellow colour

was measured in the filtrate at 400 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). The concentration of *p*-nitrophenol in the filtrate was determined against a standard curve prepared by using *p*-nitrophenol standard solution. β -glucosidase enzyme activity was expressed as $\mu\text{g (PNP) g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.4. Dehydrogenase Activity (DHA)

Dehydrogenase (EC 1.1.1.X) was determined in air dried soil samples as per the method described by Casida *et al.* (1964). Soil sample (10 g) was mixed with 0.1g CaCO_3 and then, the mixture was divided into three parts (each part weighed 3 g) and transferred to three screw cap test tubes. To each test tube 0.5 mL of 1% 2,3,5-triphenyl-tetrazolium chloride (TTC) and 1.25 mL of distilled water were added and mixed thoroughly by gentle tapering and incubated it at 37°C for 24 h. After 24 h incubation, the soil suspension was filtered through glass funnel fitted with absorbent cotton. Methanol was added to extract the soil suspension until the cotton plug's colour became white and the final volume was made up to 50 mL. Intensity of reddish colour was measured by using microtiter plate reader at a wavelength of 485 nm (Multiskan, Thermo Scientific, USA). The concentration of triphenyl formazan (TPF) in the supernatant was determined against a standard graph prepared using known concentrations of TPF. DHA was expressed as $\mu\text{g (TPF) g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.5. Phosphomonoesterase Activity (PHA)

Fresh sieved (1 mm) soil samples were used for phosphomonoesterase (EC 3.1.3.2) determination following the protocol described by Tabatabai and Bremner (1969). Soil sample (1 g) was taken in an Erlenmeyer flask and to this 4 mL of MUB (Modified Universal Buffer, pH 6.5), 0.25 mL of toluene and 1 mL of *p*-NPP (*p*-nitrophenyl phosphate) were added and incubate at 37°C for 1 h. After incubation, 1 mL of 0.5 M CaCl_2 and 4 mL 0.5M NaOH were added to the soil suspension and filtered using funnel fitted with cotton plug. Intensity of yellow colour was measured in the filtrate at 400 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). The concentration of *p*-nitrophenol in the filtrate was determined against a standard curve prepared by using *p*-nitrophenol standard solution. phosphomonoesterase enzyme activity was expressed as $\mu\text{g (PNP) g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.6. Protease Activity (PRO)

Protease (EC 3.4.2.21-24) enzyme activity was determined based on the method described by Ladd and Butler (1972). Moist sieved (1 mm) soil was added with 5 mL 2% sodium caseinate, 5 mL 0.5 M Tris buffer (pH 8.1) and incubated at 50°C for 2 h in shaking water bath. After incubation, 5 mL of 15% trichloroacetic acid was added and centrifuged at 12,000 rpm for 10 min. 5 mL of the clear supernatant was mixed with 7.5 mL alkaline reagent (1 M NaOH + anhydrous Na₂CO₃) and incubated for 15 min at room temperature. 5 mL of 33% Folin-Ciocalteu reagent was added to the solution and filtered through filter paper (Whatman No.42). After exactly 1h, the intensity of the filtrate was measured at 700 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). The concentration of tyrosine in the filtrate was determined against a standard curve prepared by using tyrosine standard solution. Protease enzyme activity was expressed as $\mu\text{g tyrosine g}^{-1} (\text{dw}) \text{ soil h}^{-1}$.

3.5.7. Microbial Biomass Carbon (MBC)

Freshly collected soil samples were used for MBC determination by the procedure chloroform-fumigation-extraction method (Brookes and Joergensen, 2006). First the root debris and all the visible organic residues were removed from the sample. Each soil sample was divided into two sub samples (each sub sample weight was 25 g). Each sub sample was taken in 50 mL beaker. One sub-sample was fumigated for 24 h with chloroform vapour in a desiccator and the other sub-sample kept in a desiccator as check without fumigation for 24 h. After incubation for 24 h, the residual chloroform in the fumigated sample was removed by releasing the pressure maintaining valve. To each sub-sample 100 mL 0.5 M K₂SO₄ (1:4 ratio) was added and the samples were shaken for 30 min at 200 rpm in an orbital shaker (Rotek LES, Pelican Equipment, Chennai). Then, soil suspensions were filtered through a Whatman No. 42 filter paper and 10 mL of the supernatants were used for determination of C by wet oxidation method similar to that described for determination of SOC in the section 3.4.4. The difference in C content between fumigated and non-fumigated sub-samples was determined and then, MBC was calculated using a conversion factor, $K_{\text{EC}} = 0.38$ (Vance *et al.*, 1987; Wu *et al.*, 1990; Dilly and Munch, 1998). MBC content was expressed in $\mu\text{g g}^{-1} (\text{dw}) \text{ soil}$.

3.5.8. Microbial Biomass Nitrogen (MBN)

MBN was determined in freshly collected soil sample using the chloroform-fumigation-extraction method (Brookes and Joergensen, 2006). The supernatants obtained from fumigation and non-fumigation samples for the determination of MBC were also used for determination of N content. 10 mL of the aliquot was taken in a digestion tube where 10 mL conc. H_2SO_4 and 2.0 g digestion mixture were added and then the suspension was digested in an aluminium heating block (KEL Plus, Pelican Equipment, India) at 360°C for 2 h. After digestion, N content was determined in the samples by following the regular Kjeldahl method similar to the procedure described for Avl N determination in the section 3.4.5. The difference in N content between fumigated and non-fumigated sub-samples was determined and then, MBN was calculated by using the conversion factor, $K_{\text{EN}} = 0.45$ (Gijsman *et al.*, 1997; Jenkinson, 1988; Ross and Tate, 1993). MBN was expressed as $\mu\text{g g}^{-1}$ (dw) soil.

3.5.9. Microbial Biomass Phosphorus (MBP)

MBP was determined in freshly collected soil sample using the chloroform-fumigation-extraction method (Brookes and Joergensen, 2006). The supernatants obtained from fumigation and non-fumigation samples for the determination of MBC were also used for determination of inorganic P content. Inorganic P content in 10 mL portion of the supernatant of each of the fumigated and non-fumigated samples was determined using Bray's-I method by following the similar procedure used for Avl P determination in the section 3.4.6. The difference in inorganic P content between fumigated and non-fumigated sub-samples was determined and then, MBP was calculated by using the conversion factor, $K_{\text{EP}} = 0.40$ (Brookes *et al.*, 1982; Gijsman *et al.*, 1997). MBP was expressed as $\mu\text{g g}^{-1}$ (dw) soil.

3.6. Elemental and biochemical composition of litters

3.6.1. Nitrogen

Total N concentration in litter sample was determined as per the procedure described by Bremner and Mulvaney (1982). In brief, 0.5 g finely ground litter sample was put in the digestion tube and added 6 mL of conc. H_2SO_4 followed by 1 g digestion mixture. After digestion at about 350°C for 3 h, the content was cooled and distilled for 6 min in an automated distillation chamber (Classic DX, Pelican Equipment, Chennai).

Ammonia generated during distillation was collected in 2% boric acid containing few drops of mixed indicator (Composition of mixed indicator: 0.1 g bromocresol green with 0.07 g of Methyl red and dissolved this mixture in 100 mL ethanol) in a conical flask and finally amount of boric acid used for absorption of ammonia was determined by titrating with standard 0.02N H₂SO₄. Nitrogen was expressed in percentage (%).

3.6.2. Phosphorus

Total P concentration in litter sample was determined by the vanadomolybdophosphoric yellow colour method (Jackson, 1973). Fine grinded samples were digested with di-acid mixture (HNO₃ and HClO₄) at a ratio of 5:2. After digestion, the residue was mixed with distilled water and filtered through Whatman No. 42 and volume made up. 30 mL of the aliquot was taken and mixed with 10 mL vanadate-molybdate solution and diluted to 50 mL with distilled water. After 10 min, the absorbance was read at 420 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA). Phosphorus was expressed in percentage (%).

3.6.3. Potassium, Calcium, Magnesium and Zinc

The litter sample digestion was performed by wet oxidation method (di-acid digestion) for analysis of total K, secondary and micronutrients as per the procedure described by Jackson (1973). The di-acid digestion used was HNO₃ and HClO₄ (3:1 ratio). In brief, 0.5 g litter sample was initially pre-digested with HNO₃ for 6-8 h. 10 mL of HNO₃ and 2-3 mL HClO₄ were then added and the samples were placed in digestion block at about 300°C till the contents become colourless. The residue was mixed with distilled water and filtered through Whatman No. 42 filter paper and volume made up to 100 mL. The clear filtrate was subsequently used for determination of K by flame photometry and Ca, Mg and Zn by atomic absorption spectrophotometry principles. The concentrations of elements were expressed in percentage (%).

3.7. Biochemical composition of litter

3.7.1. Total carbohydrate

Total carbohydrate was determined by Anthrone method (Sadasivam and Manickam, 2008), where carbohydrates were first hydrolysed into simple sugars using dilute hydrochloric acid. In hot acidic medium glucose is dehydrated to hydroxymethyl

furfural. The yielded compound forms a green coloured product when mixed with anthrone and the absorption was read at 630 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA).

3.7.2. Cellulose

Cellulose determination was performed as per the procedure described by (Sadasivam and Manickam, 2008). In brief, cellulose was acetolysed with acetic/nitric reagent forming acetylated cellodextrins which gets dissolved and hydrolyzed to form glucose molecules on treatment with 67% sulphuric acid. The glucose molecule thus formed is dehydrated to form hydroxymethyl furfural which forms a green coloured product with anthrone and the colour intensity was read at 630 nm using microtiter plate reader (Multiskan, Thermo Scientific, USA).

3.7.3. Hemicellulose

Hemicellulose was estimated following the principle described by (Sadasivam and Manickam, 2008). Hemicellulose was estimated by subtracting the amount of Acid detergent fibre (ADF) from Neutral detergent fibre (NDF). Powdered samples were refluxed with a mixture of Neutral detergent solution (disodium ethylenediamine tetraacetate + sodium borate decahydrate + sodium lauryl sulphate + 2-ethoxy ethanol and disodium hydrogen phosphate), decahydronaphthalene and sodium sulphite for 60 min. After suction filtration, the residue was washed with hot water and acetone; dried in crucible at 100°C for 8 h. The content was then weighed. ADF was determined by refluxing the sample materials with acid detergent solution which removed the water-solubles and materials other than the fibrous component. Acid detergent solution (Cetyl trimethyl ammonium bromide + 1 N H₂SO₄) was added with sample material, boiled and filtered in sintered glass crucibles. The residue was then washed with acetone, dried at 100°C for overnight and weighed after cooling in desiccator.

3.7.4. Pectin

Pectin was estimated gravimetrically following the procedure outlined by (Sadasivam and Manickam, 2008). Blended litter sample was boiled consecutively with 0.01 N, 0.05 N and 0.3 N HCl and suction filtered. The filtrates were collected after each boiling, pooled up and volume made up. Known amount of the filtrate was taken

and neutralized with 1 N NaOH and allowed to stand overnight. Acetic acid and CaCl_2 was then added and boiled briefly after which it was filtered through pre-weighed Whatman No. 1 filter paper. The filter paper was dried at 100°C along with the residue, cooled and weighed. Pectin was expressed as per cent yield of calcium pectate.

3.8. Statistical analysis

All statistical analyses were performed using SPSS v.21 (IBM Corp. Released 2012). The different fallow lengths of either unburnt or burnt condition within a study site (Nagaland or Mizoram) were analyzed for differences among mean ranks in terms of each of the parameters (litter accumulation, elemental composition of litter, biochemical composition of litter, and individual soil attribute), by performing non-parametric Kruskal-Wallis H-test incorporating 10000 randomization and Monte Carlo significance test at 95% level of confidence).

Objective–II: To study the effect of plant litter types on soil processes in microcosms of different *jhum* cycles

3.9. Location of microcosm experiment

To study the effects of plant litter types on soil processes under burnt and unburnt conditions of different fallow lengths, a microcosm experiment under poly house was carried out at the Experimental Farm of the College of Post Graduate Studies, Umiam, Meghalaya. The study area is located at 91°54.643" E, 25°40.929" N latitude and 950 m above mean sea level. The maximum and minimum temperature in the study site ranges from 20.9°C to 28.3°C and 4.4°C to 19.1°C, respectively. Out of total annual rainfall (2190 mm), about 76% occurs during May to September. The relative humidity ranges between 50.91 to 83.87% during most of the periods.

Table 3.4. Weather parameters of Umiam, Meghalaya during 2014

Month	Maximum temperature (°C)	Minimum temperature (°C)	Average mean temperature (°C)	Relative humidity (%)	Rainfall (mm)
January	20.9	4.7	12.80	69.17	0.0
February	21.2	5.6	13.40	66.27	11.0
March	22.5	8.1	15.30	66.23	54.0
April	26.8	12.7	19.75	50.91	72.0
May	24.9	15.5	20.20	74.47	230.0
June	23.5	19.1	21.30	88.87	419.0
July	28.3	15.9	22.10	75.83	322.0
August	27.6	14.8	21.20	86.14	551.0
September	26.0	14.1	20.05	88.09	430.0
October	26.4	10.3	18.35	76.70	95.0
November	25.5	8.0	16.75	71.70	2.0
December	23.7	4.4	14.05	70.90	4.0

Source: mosdac.gov.in

3.10. Soils and litter materials for microcosm experiment

The bulk quantities of soils from plough layer were collected from the same 5 years and 10 years old fallow phases under both burnt and unburnt situations identified under objective-I. These four categories of bulk soils (burnt and unburnt from 5 and 10 years old fallows) were collected at the time of soil samplings for objective-I and carried to the experimental farm, where soils were passed through sieve of 2 mm openings to remove stones, stubbles and larger root fragments. These soils were used for filling the pots those arranged as per the experimental layout presented in Figure 3.4 and

Appendix 1.7. To impose litter treatments in the microcosm experiment, the forest floor litter collected from 5, 10, and 15 years fallows under objective-I were used (see section 3.3.1.). The basic characteristics of soils of four different categories used in the microcosm experiment are presented in Table 3.5.

Table 3.5. Basic characteristics of soils used in the microcosm experiment

Fallow	Situation	pH (1:2.5 soil: water)	SOC (%)	Avl N (kg ha ⁻¹)	Avl P (P ₂ O ₅ kg ha ⁻¹)	Avl K (kg ha ⁻¹)
5 years	Unburnt	4.63±0.07	1.46±0.41	263±25	6.83±2.07	226±62
	Burnt	4.98±0.06	1.76±0.49	272±29	7.02±2.19	239±69
10 years	Unburnt	4.88±0.05	1.22±0.52	222±31	7.88±1.52	257±58
	Burnt	5.12±0.07	1.42±0.56	281±37	8.06±1.67	259±62

Values represent means ± SD. Each mean are the average of 5 composite soil samples

3.11. Treatment details of the microcosm experiment

According to the four categories of soils, pots were arranged as per the layout shown in Figure 3.4 and Appendix 1.8. Each pot was filled with 6.0 kg soil and the bulk density of pot soil was maintained by volume basis to mimic the BD values of field soil. Within each category of soil four treatments were imposed: (1) no litter addition, (2) litter from 5 years fallow, (3) litters from 10 years fallow and (4) litters from 20 years fallow. Each treatment comprised of four replicated pots. Pot soils belonged to litter treatments of 5, 10 and 15 years old fallows received 11.84 g, 20.70 g and 23.34 g of litter material per pot, respectively. The quantities of litters added in pot soils of different treatments were calculated based on the values of forest floor litter accumulation on area basis obtained for 5 years, 10 years and 15 years old fallows (secondary forest stands) of Mizoram. The added ground litter was mixed with surface soil of the pot. Soil moisture in pot was constantly maintained at field capacity throughout the experimental period.

Khawlian buh, a common *jhum* rice cultivar predominantly grown in *jhum* fields of Mizoram was selected as test rice crop. The sowing time of seeds (15th April, 2014) in pots was matched with the sowing time of *jhum* rice in farmers' fields (Fig. 3.5).

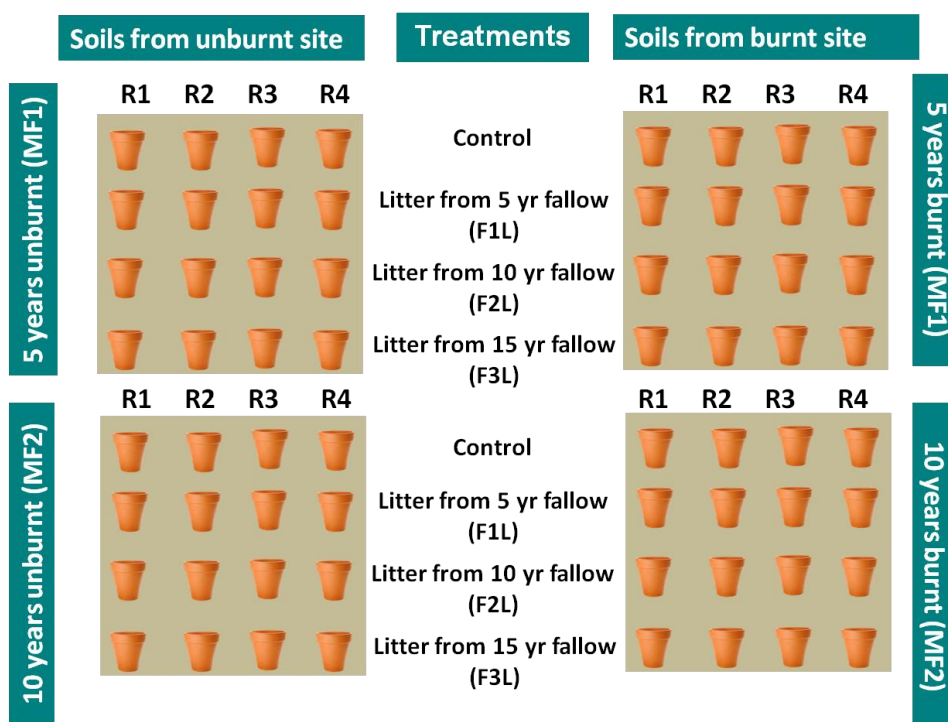


Fig 3.4. Layout of the microcosm experiment using *jhum* field soils collected from burnt and unburnt sites of 5 and 10 years old fallow phases of Mizoram. The layout was designed to study the interaction effects of 3 factors viz. burning, fallow length and litter types on soil process level indicators and stress physiology of *jhum* rice.



Fig. 3.5. A microcosm experiment illustrating the interactive effects of burning, fallow length and litter types on growth of *jhum* rice (*Khawlian buh*), Kharif season, 2014.

3.12. Soil parameters

3.12.1. Soil sampling

Soil cores (0 to 10 cm depth) were collected from each pot using a core sampler of 2.5 cm diameter at 90 days after sowing (DAS) of *jhum* rice and packed in sterile polythene bags. In the laboratory, each soil sample was divided into two parts: one half was air dried and sieved for analysis of chemical properties and the other half was stored at 4°C for analysis of biochemical properties.

3.12.2. Soil chemical and biochemical properties

Soil chemical properties viz. pH, EC, SOC, Avl N, Avl P, Avl K, Exchangeable Ca and Mg and biochemical properties viz. AMY, ASA, DHA, GSA, PHA, PRO, MBC, MBN and MBP were determined similar to the previously described procedures in the sections 3.4 and 3.5, respectively under objective-I.

3.12.3. Potentially mineralizable nitrogen (pMN)

Static anaerobic incubation procedure was used to determine pMN in freshly collected soil samples. Each soil sample was divided into 2 sub-samples. From one sub-sample, 16 g portion of soil was taken in test tube and 40 mL distilled water was added. Trapped air was removed by lightly tapping the tubes and then, the mouth is closed using screw caps. Soils were incubated at 35°C for 7 days. The other sub sample is added with same amount of distilled water but is kept as such without incubation. The inorganic $\text{NH}_4\text{-N}$ produced during 7 days incubation under anaerobic situation was extracted using 40 mL of 4M KCl solution by shaking the sample for 1 h and then filtered through Whatman No. 42 filter paper. 10 mL of the aliquot taken in digestion tube and 0.5 g of devarda's alloy is added into the tube. Mineralized N content was determined in the samples by following the regular Kjeldahl method similar to procedure described for Avl N determination in section 3.4.5 under objective-I. The mineralisable N during 7 days incubation was calculated by the difference between incubated and non-incubated samples (Page *et al.*, 1982; Franzleubbers *et al.*, 2000; Tirol-Padre *et al.*, 2007). pMN is expressed in $\mu\text{g g}^{-1}$ (dw) soil.

3.12.4. Soil respiration

Soil respiration in terms of CO₂ evolution was measured based on the principles of absorption of infrared photons by CO₂ using environmental gas monitoring system (EGM 4, PP Systems, USA) and the values were expressed in ppm.

3.13. Plant physiological parameters

During the active growth stage of rice plant, root growth parameters viz. root length (RL), root surface area (RSA), root volume (RV), and root diameter (RD), and plant physiological stress indicators viz. leaf pigmentation (Chlorophyll-a, -b and carotenoid content), reactive oxygen species (ROS) activity, lipid peroxidation activity and cell membrane stability, and plant growth parameters viz. dry biomass yield and root to shoot ratio were determined. These parameters were sampled and observed between 30 to 45 DAS.

3.13.1. Root parameters

Out of 3 rice plants maintained in each pot, one rice plant was uprooted carefully with minimum disturbances so that roots remain intact. The uprooted roots were placed on a sieve and carefully washed under running tap and after cleaning excess water was soaked with tissue paper. Each root system was scanned and the image was processed with Rhizoscan® software for determination of RL, RSA, RV and RD.

3.13.2. Leaf pigmentation

Chlorophyll and carotenoid pigments concentration in flag leaf were determined by the procedure described by Mackinney (1941) and Davies (1976), In brief, 80% acetone was used to extract the leaf pigments. A sub sample extract of 1000 µL was taken and absorbance was recorded at 480, 645 and 663 nm. The absorbances (A) recorded were fitted into a formula as described below in order to calculate the pigment concentration expressed in mg g⁻¹.

$$\text{Chlorophyll } a = 12.72 \times A_{663} - 2.58 \times A_{645}$$

$$\text{Chlorophyll } b = 22.87 \times A_{645} - 4.67 \times A_{663}$$

Chlorophyll $a+b = 8.05 \times A_{663} + 20.29 \times A_{645}$

Carotenoids = $A_{480} + 0.114 \times A_{663} - 0.638 \times A_{645}$

3.13.3. Lipid peroxidation (LP)

The level of lipid peroxidation was measured as the 2-thiobarbituric acid-reactive substances (TBARS), mainly malondialdehyde (MDA), following the method of Yagi (1998). The fully opened 3rd leaf blade was collected and homogenized in 2mL of 0.1% (w/v) trichloroacetic acid (TCA). The mixture was centrifuged at 6700 *g* for 5 minutes after which the supernatant was mixed with a solution of 4% (w/v) TCA and 0.5% (w/v) TBA. Absorbance of the solution was measured at 532 nm and 600 nm for correcting non specific turbidity. MDA concentration was calculated using its molar extinction coefficient ($\epsilon = 155\text{mM}^{-1}\text{cm}^{-1}$).

3.13.4. Cell membrane stability

The fully opened 3rd leaf fragments were soaked in 50 ml double distilled water for 24 h. In this solution, cell membrane stability was determined as a function of electrical conductivity measured before (EC_i) and after 24 h of rehydration (EC_f). Electrolyte leakage was expressed as $(\text{EC}_f - \text{EC}_i) / (\text{EC}_i) \times 100$. Individual plants were also harvested at 45 DAS and dried in oven.

3.13.5. Root-Shoot ratio

The dry biomass of the shoot and root were measured and root-shoot ratio was calculated.

3.13.6. Grain weight

Grain weight was calculated from individual rice plant at physiological maturity and weight expressed in g plant^{-1} .

3.14. Statistical analysis

The data were analyzed with a two-way or three-way analysis of variance (ANOVA) using litter types, *jhum* fallow lengths and burning as factors to study the interaction effects of these factors on soil process level indicators i.e. soil chemical and biochemical attributes and physiological stress indicators of rice plants. The differences in treatments were tested with Duncan's multiple range test (DMRT) at 95% confidence limit.

Objective–III: To compare the effects of microbial consortium, litter- and ash-amendments on growth and development of *Jhum* rice

3.15. Experimental setup

To achieve the above objective, a microcosm experiment was set up as per the experimental layout indicated in Fig 3.6 and Appendix 1.10. In this experiment, bulk soils from burnt sites of 5 and 10 years fallow lengths were collected and used for filling pots. The processing of soils, quantity taken per pot, pot soil bulk density and moisture content were adjusted following procedures similar to those described for the microcosm experiment carried out under objective-II. Within each group of pot experiment, treatments imposed were: (1) control, (2) litter amendment (LA), (3) microbial consortium (MC), (4) MC+LA, and (5) ash amendment from burnt biomass (Fig.3.6). The litter amendment was chosen based on the best performing litter type from the result of the microcosm experiment under objective-II. The amount of ash applied in the pots of 5 years and 10 years burnt groups was calculated based on the amount of ash generated from the burnt biomass of the respective fallow phase. A suitable local *jhum* rice cultivar (Bhalum-1) was sown in pots (5 seeds per pot). Experiment was continued till the harvest of rice crop.

Rhizospheric and endophytic bacteria of *Thysanolaena maxima*, an early successional plants from slashed and burnt field of Changki, Nagaland were used to formulate microbial consortium. Isolates were screened for acidity and heat tolerance ability and multifaceted plant growth promoting properties viz. ability of pectinase, cellulase, and IAA production, nitrogen fixation; phosphate solubilization [P in $\text{Ca}_3(\text{PO}_4)_2$, AlPO_4 , FePO_4 and phytate amended media]. Based on the results of the PGP attributes of early colonizers, 5 best strains were selected on basis of their maximum scores achieved for multifaceted PGP properties (Appendix 1.10) and were used to formulate microbial consortium. The strains used in the microbial consortium were PDA EN1 (*Konokasia oryzae*), TSA EN1 (not identified), R2A RH 13 (*Klebsiella pneumoniae*), R2A EN3 (not identified) and R2A RH7 (not identified). Finely grinded dry compost (passed through 1 mm sieve) was used as carrier material. A 130 mL volume broth of each strain (total broth volume 650 mL for five strains) was added to 1 kg sterile compost and mixed aseptically. Then the mixture was packed and sealed aseptically and stored in cool dry place. The cfu counts of each gram of compost was 1.25×10^8 up to 3 months from the date of manufacture.

3.16. Soil parameters

3.16.1. Soil sampling

Soil cores were collected from each pot with a core sampler (2.5 cm diameter) up to 15 cm depth and packed in sterile polythene bags. In the laboratory, the samples were divided into two parts: one half part of sample was subjected to air drying and passed through sieve having 1 mm opening. Such processed soil samples were used for analyzing chemical properties and the other half was stored at 4°C for biochemical analyses.

3.16.2. Soil chemical and biochemical analyses

Soil chemical and biochemical properties were also determined under objective III.

3.17. Statistical analysis

The data were analyzed with a two-way analysis of variance (ANOVA) using *jhum* fallow lengths and treatments as factors in order to study the interaction effects of these factors on soil process level indicators i.e. soil chemical and biochemical attributes and physiological stress indicators of rice plants. The differences in treatments were tested with Duncan's multiple range test (DMRT) at 95% confidence limit.

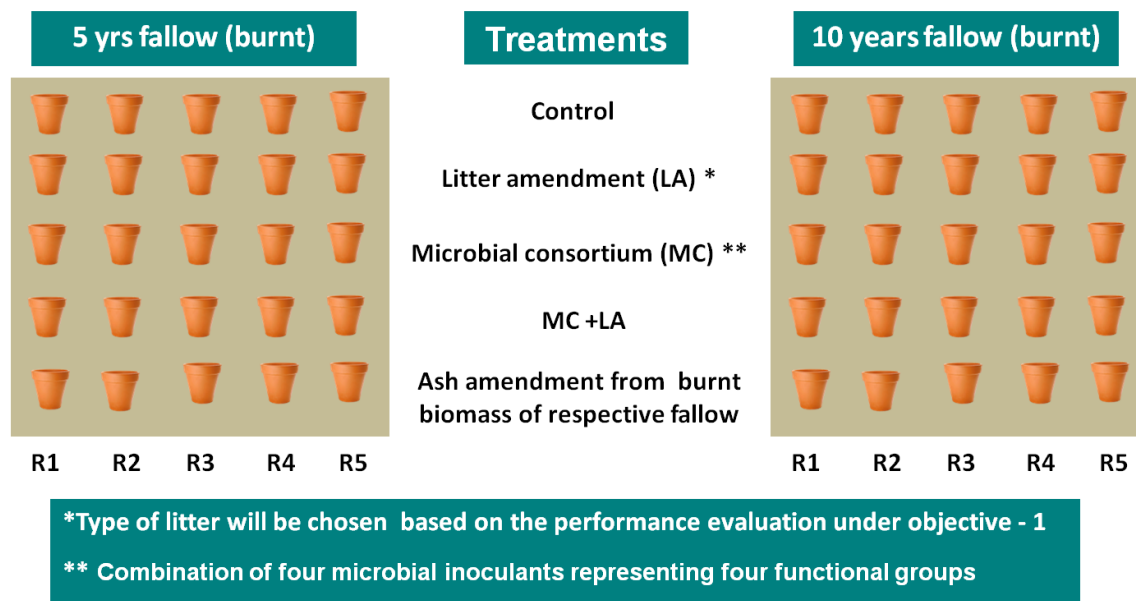


Fig 3.6. Layout of the microcosm experiment using *jhum* field soils collected from burnt sites of 5 and 10 years old fallow phases of Mizoram. The layout was designed to study the interaction effects of 2 factors viz. fallow length and treatments on soil process level indicators and stress physiology of *jhum* rice.

Objective–IV: To develop soil biological quality index of different *jhum* cycles under natural farming situations

3.18. Methodology

Soil analytical data for an array for chemical and biochemical parameters generated for 5 years, 10 years, 15 years and 20 years *jhum* cycles through objective-I were used as early indicators of soil biological quality. The star diagram (AMOEBA method) was used to present all indicator values scaled against a reference site (adjacent reserved/or primary forest) as proposed by Mäder *et al.* (2002). The indexed indicator values used to construct AMOEBA was further condensed into a Soil Biological Quality Index (SQI), using the average factorial deviation from the reference value (Ten Brink *et al.*, 1991). The index was calculated as follows:

$$SQI = 10^{\log m - \frac{\sum_{i=1}^n |\log m - \log n_i|}{n}}$$

where, m is the reference indexed values (each value set to 100%) from reserved forest soil, and n is the measured value as a percentage of the reference.

Chapter- IV

RESULTS

Chapter-4

Results

The findings of the research works under different objectives are presented in this chapter in the following experimental headings:

- Characterisation of forest floor litters (FFL) of *jhum* fallow phases.
- Comparative physico-chemical and biochemical properties of burnt and unburnt soils of *jhum* fallow phases.
- Microcosm experiment-I:
 - a) Impact of FFLs amendment on soil process indicators under burnt and unburnt situations of fallow phases.
 - b) Impact of FFLs amendment on *jhum* rice physiology under burnt and unburnt situations of fallow phases.
- Microcosm experiment-II:
 - a) Impact of addition of FFL, microbial consortium and ash amendments on soil processes.
 - b) Impact of addition of FFL, microbial consortium and ash amendments on stress physiology of *jhum* rice.
- Impact of burning and length of fallow phase on *jhum* soil quality.

4.1. Characterisation of forest floor litters (FFL) of *jhum* fallow phases

4.1.1. Litter accumulation

The data on season-wise accumulation of FFLs in different fallow length phases of Nagaland and Mizoram are presented in Fig. 4.1. The longer fallow length phase produced significant higher quantity of FFLs compared to that produced in the shorter fallow length. The trend of accumulation of FFLs in different fallow phases was in the increasing order of NF3 ($1750 \text{ g m}^{-2} \text{ yr}^{-1}$) > NF2 ($1127 \text{ g m}^{-2} \text{ yr}^{-1}$) > NF1 ($807 \text{ g m}^{-2} \text{ yr}^{-1}$) in Nagaland and MF3 ($736 \text{ g m}^{-2} \text{ yr}^{-1}$) > MF2 ($562 \text{ g m}^{-2} \text{ yr}^{-1}$) > MF1 ($366 \text{ g m}^{-2} \text{ yr}^{-1}$) in Mizoram (Fig. 4.1.; Appendix 1.5). The quantity of accumulated FFLs varied significantly between seasons and the trend of accumulation was in the increasing order of January > April > August > November in both Mizoram and Nagaland (Fig. 4.1.; Appendix 1.5).

4.1.2. Elemental composition of FFLs

The data on elemental composition of FFLs of different fallow phases are presented in Table 4.1 and 4.2. The N content of FFLs increased with the increasing length of the fallow phase in both Nagaland and Mizoram (Table 4.1 and 4.2). The differences of N content of FFLs among fallow periods were significant within each season {Monte-Carlo's significance (MCS) at $P<0.05$ }. The N content of FFLs ranged from 1.09% to 1.88% in Mizoram and from 1.20% to 2.03% in Nagaland.

Though the content of P in FFLs marginally increased with the increasing length of the fallow phase, the differences in P content of FFLs among the fallow phases were not significant (MCS at $P<0.05$). The P content of FFLs ranged from 0.16% to 0.24% in both Mizoram and Nagaland (Table 4.1 and 4.2).

The significant higher values of K content in FFLs was observed in longer fallow phase as compared to that in shorter fallow phase (Table 4.1 and 4.2; MCS at $P<0.05$). The K content of FFLs ranged from 0.74% to 1.22% in both Mizoram and Nagaland.

The contents of Ca, Mg and Zn in FFLs were significantly higher in longer fallow phase compared to that in shorter fallow phase (Table 4.1 and 4.2; MCS at $P<0.05$). The concentration of Ca, Mg and Zn varied in the range from 63.1 to 70.6 ppm, 7.1 to 8.8 ppm and 28.5 to 37.3 ppm, respectively in Mizoram site and from 37.3 to 54.3 ppm, 6.5 to 8.1 ppm and 16.3 to 19.6 ppm, respectively in Nagaland.

4.1.3. Biochemical properties of FFLs

Biochemical compositions {carbohydrate, cellulose, hemicelluloses, pectin (% Ca pectate) and lignin} of FFLs from different fallow phases (secondary forest stands) of Mizoram and Nagaland are presented in Table 4.3 and 4.4. The FFLs of longer fallow lengths contained significant higher amount of carbohydrate than that of shorter fallow lengths (MCS at $P<0.05$) in all the sampling months except for November in Mizoram. Cellulose content in FFLs also found increase with the increasing length of the fallow phase (Table 4.3 and 4.4) and the differences were statistically significant (MCS at $P<0.05$).

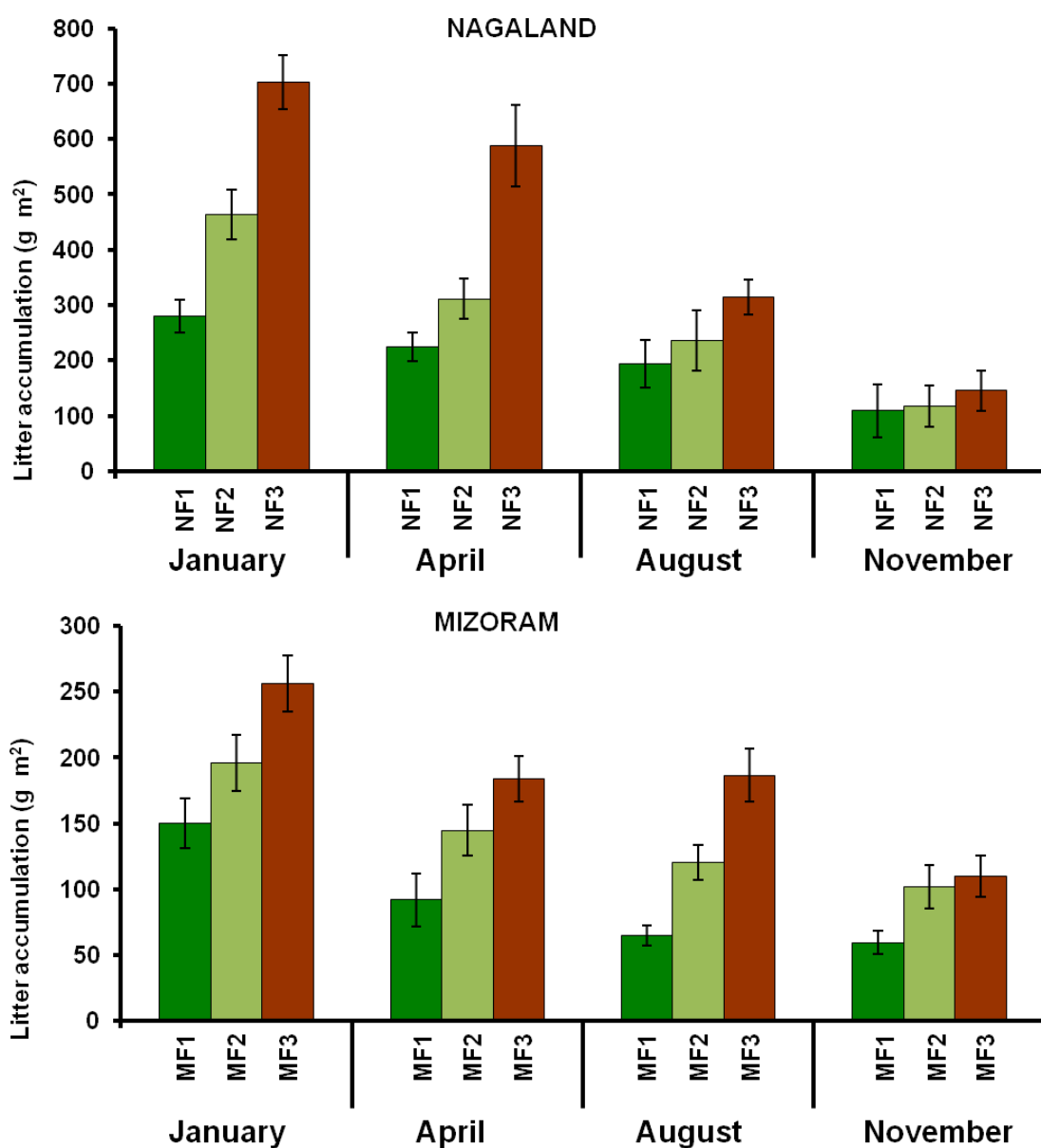


Fig 4.1. Accumulation of forest floor litters in fallow phases (secondary forest stands) of different *Jhum* cycles in Nagaland and Mizoram. Bar attached to each column indicates standard error mean.

Table 4.1. Elemental composition of forest floor litters (FFLs) of different fallow phases collected at four sampling months in Mizoram

Months	Fallow	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Zinc	
		%	rank	%	rank	%	rank	ppm	rank	ppm	rank	ppm	rank
January	F1	1.42	4.5	0.16	5.5	0.74	3.1	49.4	3.0	7.27	3.0	27.4	5.4
	F2	1.45	6.5	0.19	9.2	0.87	7.9	74.7	8.0	9.49	9.6	27.8	6.0
	F3	1.74	13.0	0.18	9.3	1.13	13.0	87.7	13.0	9.58	11.4	40.4	12.6
	Mean	1.54±0.15		0.17±0.02		0.92±0.18		70.6±16.5		8.78±1.13		31.9±7.9	
Monte Carlos significance test		0.001		0.318		0.000		0.000		0.001		0.008	
April	F1	1.09	3.0	0.19	5.4	0.93	4.0	59.6	3.0	6.04	5.5	22.9	3.8
	F2	1.41	8.0	0.21	8.0	1.14	12.6	68.6	9.3	6.04	5.5	24.9	7.2
	F3	1.78	13.0	0.23	10.6	1.00	7.4	70.6	11.7	10.99	13	37.6	13.0
	Mean	1.43±0.29		0.21±0.02		1.02±0.1		66.3±5.2		7.69±2.42		28.5±6.8	
Monte Carlos significance test		0.000		0.189		0.003		0.001		0.002		0.000	
August	F1	1.17	3.0	0.19	8.5	0.81	4.1	52.8	3.0	4.61	3.0	27.3	3.0
	F2	1.36	8.0	0.19	8.2	0.95	8.7	60.3	8.0	6.85	8.0	36.1	10.2
	F3	1.88	13.0	0.19	7.3	1.07	11.2	76.2	13.0	9.81	13.0	37.2	10.8
	Mean	1.47±0.31		0.19±0.02		0.94±0.16		63.1±10.1		7.09±2.25		33.5±5.2	
Monte Carlos significance test		0.000		0.911		0.003		0.000		0.000		0.003	
November	F1	1.14	3.0	0.20	8.0	0.94	7.2	52.8	3.0	6.66	3.0	33.6	3.4
	F2	1.35	8.0	0.21	7.9	1.00	8	66.3	8.0	8.15	8.0	38.4	9.6
	F3	1.70	13.0	0.21	8.1	1.03	8.8	74.2	13.0	9.27	13.0	40.0	11.0
	Mean	1.39±0.24		0.21±0.04		0.99±0.17		64.5±9.2		8.03±1.14		37.3±3.5	
Monte Carlos significance test		0.000		0.999		0.870		0.000		0.000		0.010	

Each value is the mean of five composite soil samples ± standard deviation.

Within each sampling time, differences between fallows in terms of above parameters were determined by non-parametric Kruskal–Wallis H test (10000 randomization) incorporating Monte-Carlo significance at 95% confidence limit.

Table 4.2. Elemental composition of forest floor litters (FFLs) of different fallow phases collected at four sampling months in Nagaland

Months	Fallow	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Zinc	
		%	rank	%	rank	%	rank	ppm	rank	ppm	rank	ppm	rank
January	F1	1.20	3.0	0.15	4.6	1.00	5.0	41.3	3.0	5.51	3.0	13.1	4.8
	F2	1.44	8.1	0.17	7.2	1.11	9.1	51.5	8.0	5.74	9.8	15.9	8.0
	F3	1.64	12.9	0.20	12.2	1.15	9.9	70.2	13.0	6.14	11.2	19.9	11.2
	Mean	1.43±0.		0.17±0.0		1.09±0.1		54.3±12.65		6.50±0.94		16.3±5.09	
	Monte Carlos significance	0.000		0.009		0.179		0.000		0.002		0.068	
April	F1	1.20	3.0	0.20	6.6	1.03	4.7	40.7	3.8	6.02	3.0	15.3	3.8
	F2	1.72	8.0	0.22	7.9	1.13	8.7	42.9	7.2	7.51	8.0	20.6	9.2
	F3	2.03	12.9	0.24	9.5	1.22	10.6	70.3	13.0	10.77	13.0	21.0	11.0
	Mean	1.65±0.3		0.22±0.0		1.13±0.1		51.3±13.9		8.10±2.07		19.0±4.34	
	Monte Carlos significance	0.000		0.620		0.098		0.000		0.000		0.018	
August	F1	1.23	3.7	0.17	4.4	1.01	7.3	30.7	4.4	4.56	3.0	19.2	8.2
	F2	1.35	7.3	0.19	7.9	1.02	6.9	34.9	6.6	6.54	8.6	19.4	7.7
	F3	1.83	13.0	0.22	11.7	1.11	9.8	46.2	13.0	8.51	12.4	19.5	8.1
	Mean	1.47±0.2		0.19±0.0		1.05±0.1		37.3±7.98		6.54±1.96		19.3±2.44	
	Monte Carlos significance	0.000		0.025		0.571		0.001		0.000		0.988	
November	F1	1.60	3.0	0.17	4.4	0.81	6.3	37.0	3.0	6.61	3.0	18.5	7.2
	F2	1.85	9.5	0.20	9.9	0.89	7.9	56.0	8.0	8.29	8.4	19.6	7.6
	F3	1.91	11.5	0.20	9.7	0.94	9.8	67.5	13.0	9.52	12.6	20.7	9.2
	Mean	1.79±0.1		0.19±0.0		0.88±0.1		53.5±13.3		8.14±1.34		19.6±4.05	
	Monte Carlos significance	0.001		0.084		0.491		0.000		0.000		0.782	

Each value is the mean of five composite soil samples ± standard deviation.

Within each sampling time, differences between fallows in terms of above parameters were determined by non-parametric Kruskal–Wallis H test (10000 randomization) incorporating Monte-Carlo significance at 95% confidence limit.

Table 4.3. Biochemical composition of forest floor litters (FFLs) of different fallow phases collected at four sampling months in Mizoram

Months	Fallow	Carbohydrate		Cellulose		Hemicellulose		Pectin		Lignin	
		$\mu\text{g g}^{-1}$	rank	$\mu\text{g g}^{-1}$	rank	$\mu\text{g g}^{-1}$	rank	% Ca-pectate	rank	$\mu\text{g g}^{-1}$	rank
January	F1	206	4.0	173	3.4	0.06	4.8	28.3	3.0	0.64	5.8
	F2	213	8.2	188	10.0	0.08	6.3	34.2	9.0	0.64	5.5
	F3	221	11.8	191	10.6	0.14	12.9	40.1	12.0	0.71	12.7
	Mean	213±9.26		184±11		0.09±0.09		34.2±6.04		0.66±0.0	
Monte Carlos significance test			0.012		0.010		0.003		0.001		0.007
April	F1	191	3.0	140	3.4	0.04	3.0	21.6	3.0	0.58	3.2
	F2	240	8.4	165	7.8	0.06	5.8	28.6	8.0	0.72	9.8
	F3	277	12.6	190	12.8	0.18	15.2	35.2	13.0	0.75	11.0
	Mean	236±40.4		165±24		0.09±0.03		28.5±6.1		0.68±0.0	
Monte Carlos significance test			0.000		0.000		0.002		0.000		0.004
August	F1	211	4.4	157	3.0	0.06	3.6	26.4	4.0	0.61	3.0
	F2	223	7.4	190	9.8	0.08	9.0	28.3	7.0	0.67	10.0
	F3	256	12.2	196	11.2	0.16	11.4	33.6	13.0	0.68	11.0
	Mean	230±28.3		181±20		0.10±0.01		29.4±3.69		0.65±0.0	
Monte Carlos significance test			0.012		0.002		0.010		0.001		0.003
November	F1	223	7.8	173	4.4	0.04	5.2	30.7	3.0	0.64	4.4
	F2	226	7.2	184	9.8	0.09	6.0	40.8	10.2	0.66	6.6
	F3	229	9.0	184	9.8	0.18	12.8	42.3	10.8	0.79	13.0
	Mean	226±10		180±7		0.10±0.06		37.9±5.9		0.7±0.07	
Monte Carlos significance test			0.834		0.082		0.005		0.003		0.001

Each value is the mean of five composite soil samples $\pm$ standard deviation.

Within each sampling time, differences between fallows in terms of above parameters were determined by non-parametric Kruskal–Wallis H test (10000 randomization) incorporating Monte-Carlo significance at 95% confidence limit.

Table 4.4. Biochemical composition of forest floor litters (FFLs) of different fallow phases collected at four sampling months in Nagaland

Months	Fallow	Carbohydrate		Cellulose		Hemicellulose		Pectin		Lignin	
		$\mu\text{g g}^{-1}$	rank	$\mu\text{g g}^{-1}$	rank	$\mu\text{g g}^{-1}$	rank	% Ca-pectate	rank	$\mu\text{g g}^{-1}$	rank
January	F1	187	3.8	184	3.2	0.02	3.0	28.6	4.0	0.62	3.4
	F2	209	7.4	207	9.4	0.04	9.0	34.1	7.0	0.70	8.9
	F3	239	12.8	215	11.4	0.05	12.0	52.2	13.0	0.73	11.7
	Mean	211±24.5		202±16.5		0.04±0.0		38.3±11.		0.69±0.0	
Monte Carlos significance test			0.000		0.003		0.000		0.000		0.004
April	F1	249	5.2	154	3.2	0.04	5.6	23.7	3.0	0.59	5.4
	F2	251	5.8	169	7.8	0.04	7.2	36.5	9.3	0.60	6.2
	F3	327	13.0	214	13.0	0.05	11.2	40.0	11.7	0.66	12.4
	Mean	276±42.3		179±28.29		0.04±0.0		33.4±7.7		0.62±0.0	
Monte Carlos significance test			0.002		0.000		0.121		0.000		0.014
August	F1	122	3.0	144	4.6	0.04	7.2	30.7	4.2	0.71	4.1
	F2	194	10.2	166	8.2	0.05	8.6	34.2	9.4	0.73	8.5
	F3	197	10.8	192	11.2	0.06	8.2	35.4	10.4	0.76	11.4
	Mean	171±37.9		167±31.6		0.05±0.0		33.4±3.2		0.74±0.0	
Monte Carlos significance test			0.002		0.060		0.899		0.057		0.022
November	F1	143	3.0	144	5.6	0.02	3.0	24.8	3.0	0.61	5.0
	F2	202	8.0	148	6.0	0.03	8.0	34.2	8.8	0.62	7.0
	F3	272	13.0	176	12.4	0.06	13.0	40.3	12.2	0.67	12.0
	Mean	206±56.9		156±20.0		0.04±0.0		33.1±7.5		0.63±0.0	
Monte Carlos significance test			0.000		0.018		0.000		0.000		0.031

Each value is the mean of five composite soil samples ± standard deviation.

Within each sampling time, differences between fallows in terms of above parameters were determined by non-parametric Kruskal–Wallis H test (10000 randomization) incorporating Monte-Carlo significance at 95% confidence limit.

In general, the content of cellulose in FFLs of Mizoram site was found lesser (ranged from 140 $\mu\text{g g}^{-1}$ to 196 $\mu\text{g g}^{-1}$) compared to that (from 144 $\mu\text{g g}^{-1}$ to 215 $\mu\text{g g}^{-1}$) in Nagaland site.

In case of hemicellulose contents of FFLs, there was an increasing trend in the order of NF3>NF2>NF1 in Nagaland and MF3>MF2>MF1 in Mizoram (Table 4.3 and 4.4). The differences of hemicelluloses contents in FFLs among fallow phases were significant at each sampling month (MCS at $P<0.05$). In Mizoram, hemicellulose content generally ranged from 0.04 to 0.18 $\mu\text{g g}^{-1}$; while in Nagaland, it was varied from 0.02 to 0.06 $\mu\text{g g}^{-1}$.

The content of pectin in FFLs was found to increase with the increasing length of the fallow phase and the differences in pectin content among fallow lengths were significantly different (Table 4.3 and 4.4; MSC at $P<0.05$). In general, the pectin content in FFLs ranged from 21.6 % to 52.2 % Ca-pectate.

The content of lignin in FFLs was found to increase with the increasing length of the fallow phase and the differences in lignin content among fallow lengths were significantly different (Table 4.3 and 4.4; MSC at $P<0.05$). In general, lignin content in FFLs ranged from 0.58 to 0.79 $\mu\text{g g}^{-1}$ in Mizoram and 0.59 to 0.76 $\mu\text{g g}^{-1}$ in Nagaland.

4.2. Comparative physico-chemical and biochemical properties of burnt and unburnt soils of *jhum* fallow phases

4.2.1. Physico-chemical properties of soil

Physico-chemical properties (BD, pH, EC, SOC, Avl N, Avl P and Avl K) of soils under burnt and unburnt conditions of different fallow length phases are presented in Table 4.5 and Appendix 1.4. Values of BD, pH, EC, Avl P and Avl K in soils under burnt sites were found higher relative to their values in unburnt sites irrespective of fallow lengths in both Nagaland and Mizoram (Appendix 1.4). On the other hand the contents of SOC and Avl N under burnt sites were found lesser relative to their values in unburnt sites (Appendix 1.4).

The length of fallow period showed a distinct influence on soil BD, pH, EC, SOC, Avl N, Avl P and Avl K (Table 4.5). Except BD, values of all above soil properties were found significantly higher in the longer fallow phase compared to that in shorter fallow phase and the higher values were in the order of F3 > F2 > F1 (Table 4.5; MSC at $P<0.05$). Soil BD decreased with increasing the length of the fallow phase (Table 4.5).

Table 4.5. Influence of burning and length of fallow phase on physico-chemical attributes of *jhum* soils in Mizoram and Nagaland

		BD Mg m ⁻³ (Rank)	pH 1:2.5 soil: water (Rank)	EC μS s ⁻¹ (Rank)	SOC % (Rank)	Avl N kg ha ⁻¹ (Rank)	Avl P kg ha ⁻¹ (Rank)	Avl K kg ha ⁻¹ (Rank)	
NAGALAND	UNBURNT	5 yr fallow	1.60 (24.67)	4.01 (15.88)	36.1 (17.58)	1.70 (8.13)	275 (11.42)	6.75 (17.38)	190 (14.08)
		10 yr fallow	1.59 (23.54)	4.16 (17.04)	37.6 (18.33)	2.75 (21.75)	306 (21.13)	6.77 (18.83)	207 (20.67)
		20 yr fallow	1.56 (7.29)	4.25 (22.58)	40.1 (19.58)	2.85 (25.63)	328 (22.96)	7.26 (19.29)	208 (20.75)
		Mean±SD	1.58±0.02	4.15±0.23	37.9±11	2.43±0.86	303±56	6.93±1.55	201±31
		Significance	0.000	0.255	0.901	0.000	0.013	0.898	0.210
	BURNT	5 yr fallow	1.62 (28.46)	4.28 (11.63)	47.1 (15.04)	1.63 (9.96)	251 (10.88)	6.82 (13.17)	182 (11.38)
		10 yr fallow	1.60 (20.42)	4.53 (17.33)	49.2 (16.75)	1.88 (18.96)	278 (21.29)	7.42 (19.46)	240 (20.46)
		20 yr fallow	1.57 (6.63)	4.68 (26.54)	54.0 (23.71)	2.16 (26.58)	288 (23.33)	7.89 (22.88)	270 (23.67)
		Mean±SD	1.60±0.02	4.50±0.27	50.1±8.8	1.89±0.34	272±30	7.37±1.28	231±70
		Significance	0.000	0.001	0.101	0.000	0.005	0.068	0.009
MIZORAM	UNBURNT	5 yr fallow	1.59 (30.50)	4.63 (6.50)	30.6 (12.88)	1.46 (11.88)	263 (15.21)	6.83 (17.58)	226 (15.63)
		10 yr fallow	1.55 (18.5)	4.98 (18.5)	35.8 (20.92)	1.76 (17.88)	272 (17.63)	7.02 (18.00)	239 (17.58)
		15 yr fallow	1.44 (6.50)	5.20 (30.50)	35.8 (21.71)	2.14 (25.75)	281 (22.67)	7.14 (19.92)	268 (22.29)
		Mean±SD	1.53±0.07	4.94±0.24	34.1±10	1.79±0.49	272±29	7.00±2.19	244±69
		Significance	0.000	0.000	0.072	0.003	0.200	0.857	0.279
	BURNT	5 yr fallow	1.61 (29.42)	4.88 (6.58)	30.7 (9.79)	1.22 (7.83)	222 (6.50)	7.88 (16.46)	257 (17.17)
		10 yr fallow	1.57 (19.58)	5.12 (18.58)	38.8 (21.21)	1.42 (19.21)	281 (23.50)	8.06 (16.63)	259 (18.25)
		15 yr fallow	1.45 (6.50)	5.36 (30.33)	40.6 (24.50)	1.82 (28.46)	293 (25.50)	9.32 (22.42)	272 (20.08)
		Mean±SD	1.54±0.07	5.12±0.21	36.7±7.6	1.48±0.56	265±39	8.42±1.67	263±62
		Significance	0.000	0.000	0.001	0.000	0.000	0.287	0.803

Each value represents the mean of five composite soil samples and values within parentheses represent ranks.

Within fallow length, differences between fallows in terms of above parameters were determined by non-parametric Kruskal–Wallis H test (10000 randomization) incorporating Monte-Carlo significance at 95% confidence limit.

4.2.2. Biochemical properties of soil

The activity of soil enzymes (AMY, GSA, DHA, ASA, PHA and PRO) and MBC, MBN and MBP in different fallow phases were strongly influenced by burning activity (Table 4.6 to 4.9; Fig. 4.2; Appendix 1.6.).

The activities of DHA, GSA, PRO and PHA in burnt soils were decreased, whereas ASA activity increased relative to unburnt soils in each fallow phase (Fig. 4.2). In unburnt fallow phases of Mizoram, the activities of AMY, GSA, DHA, ASA, PHA and PRO were significantly higher in longer fallow phase compared to that in short fallow length (Table 4.6; MSC at $P<0.05$) and the higher enzyme activity was in the order of $F3 > F2 > F1$ (Fig. 4.2). The activities of these enzymes in unburnt fallow phases of Nagaland also showed the similar trend with that in unburnt fallow phases of Mizoram (Table 4.8; MSC at $P<0.05$).

In burnt fallow phases of Mizoram, the activities of DHA, ASA, PHA and PRO were significantly higher in longer fallow phase compared to that in short fallow phase (Table 4.7; MSC at $P<0.05$) and the higher enzyme activity was in the order of $F3 > F2 > F1$ (Fig. 4.2). The activities of these enzymes in burnt fallow phases of Nagaland also showed the similar trend with that in burnt fallow phases of Mizoram (Table 4.9; MSC at $P<0.05$). Whereas, the activities of AMY and GSA were significantly lower in longer fallow phase compared to that in short fallow phase (Table 4.7; MSC at $P<0.05$) and the higher enzyme activity was in the order of $F1 > F2 > F3$ (Fig. 4.2). The activities of these enzymes in burnt fallow phases of Nagaland also showed the similar trend with that in burnt fallow phases of Mizoram (Table 4.9; MSC at $P<0.05$).

Microbial biomass in soils was found to be negatively impacted by the burning activity in each fallow phase (Table 4.6 to 4.9; Fig.4.3). In both unburnt and burnt situations, MBC, MBN and MBP were significantly higher in longer fallow phase compared to that in short fallow phase (Table 4.6 to 4.9; MSC at $P<0.05$) and the higher values of MBC, MBN and MBP was in the order of $F3 > F2 > F1$ (Fig. 4.3). Besides, the C:N:P within microbial biomass was found to vary with the length of fallow phase and also with burning activities (Fig. 4.3). The longer fallow phase supported narrower C:N:P within microbial biomass, whereas wider C:N:P was observed in shorter fallow phase. The narrower C:N:P within microbial biomass was in the order of $F3 > F2 > F1$ (Fig. 4.3).

Table: 4.6. Influence of the length of fallow phase on biochemical properties of unburnt soils in Mizoram

UNBURNT	SLOPE	AMY	GSA	DHA	ASA	PHA	PRO	MBC	MBN	MBP	
		$\mu\text{g glu g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g pNP g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g TPF g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g pNP g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g pNP g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g tyr g}^{-1}$ soil h^{-1} (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	
	Upper slope	MF1	4.52 (4.50)	162 (3.00)	1.64 (2.50)	124 (2.50)	1044 (2.50)	1.78 (3.50)	1907 (3.00)	186 (2.50)	37.4 (2.50)
		MF2	5.03 (4.50)	191 (6.00)	3.17 (6.50)	161 (6.50)	1455 (6.50)	2.17 (5.50)	2214 (8.75)	225 (7.75)	45.2 (7.75)
		MF3	10.32 (10.50)	269 (10.50)	6.47 (10.50)	203 (10.50)	2778 (10.50)	6.43 (10.50)	2190 (7.75)	232 (9.25)	46.6 (9.25)
		Mean	6.62±2.92	207±48.9	3.76±2.14	163.0±35.0	1759±783	3.46±2.29	2103±199	215±25.4	43.1±5.1
	Monte Carlo's Significance test		0.017	0.001	0.000	0.000	0.000	0.006	0.045	0.008	0.008
	Middle slope	MF1	8.26 (4.00)	161 (3.25)	1.81 (5.00)	126 (2.50)	1004 (2.50)	1.41 (2.50)	1952 (3.50)	191 (2.50)	38.3 (2.50)
		MF2	8.49 (5.00)	193 (7.00)	1.89 (6.50)	162 (6.50)	1856 (9.75)	4.33 (6.50)	2021 (5.50)	206 (6.50)	41.2 (6.50)
		MF3	11.82 (10.50)	209 (9.25)	2.13 (8.00)	208 (10.50)	1677 (7.25)	6.72 (10.50)	2314 (10.50)	246 (10.50)	49.2 (10.50)
		Mean	9.52±2.33	188±29.5	1.94±0.40	166±35.42	1512±402	4.16±2.41	2096±196	214±32.8	42.9±6.55
	Monte Carlo's Significance test		0.009	0.054	0.562	0.000	0.002	0.000	0.004	0.000	0.000
	Lower slope	MF1	4.23 (2.50)	105 (3.00)	2.27 (5.25)	131 (4.50)	1072 (2.50)	3.72 (5.75)	1866 (2.50)	183 (2.50)	36.6 (2.50)
		MF2	8.47 (6.50)	127 (6.75)	2.79 (6.75)	134 (6.25)	2270 (9.25)	3.98 (7.25)	2294 (8.00)	234 (7.75)	46.8 (7.75)
		MF3	13.89 (10.50)	147 (9.75)	2.90 (7.50)	141 (8.75)	2105 (7.75)	3.86 (6.50)	2358 (9.00)	250 (9.25)	50.2 (9.25)
		Mean	8.87±4.17	126±22.1	2.66±0.95	135±8.35	1816±582	3.85±0.41	2173±259	222±32.8	44.5±6.56
	Monte Carlo's Significance test		0.000	0.019	0.705	0.276	0.007	0.866	0.012	0.007	0.007

Table: 4.7. Influence of the length of fallow phase on biochemical properties of burnt soils in Mizoram

BURNT	SLOPE	AMY	GSA	DHA	ASA	PHA	PRO	MBC	MBN	MBP	
		$\mu\text{g glu g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g TPF g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g tyr g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	
	Upper slope	MF1	13.65 (8.50)	262 (10.50)	1.16 (3.00)	163 (4.75)	641 (3.00)	1.17 (3.75)	1862 (3.50)	179 (3.00)	35.8 (3.00)
		MF2	13.61 (8.50)	195 (5.50)	1.47 (6.00)	189 (5.25)	822 (6.25)	1.61 (7.25)	1968 (6.25)	196 (6.00)	39.4 (6.00)
		MF3	5.25 (2.50)	183 (3.50)	1.95 (10.50)	204 (9.50)	993 (10.25)	1.95 (8.50)	2245 (9.75)	244 (10.50)	48.8 (10.50)
		Mean	10.83±4.27	213±38.6	1.53±0.39	185±29.3	819±180	1.58±0.60	2025±248	206±34.6	41.3±6.92
		Monte Carlo's Significance test	0.015	0.005	0.001	0.134	0.003	0.167	0.038	0.001	0.001
	Middle slope	MF1	13.52 (10.50)	191 (9.50)	1.12 (4.88)	164 (4.75)	484 (3.75)	1.25 (3.75)	1837 (3.25)	176 (2.75)	35.3 (2.75)
		MF2	8.59 (4.75)	166 (7.50)	1.30 (6.88)	191 (4.75)	537 (5.25)	1.74 (5.25)	2037 (7.25)	203 (6.75)	40.7 (6.75)
		MF3	7.43 (4.25)	106 (2.50)	1.45 (7.75)	207 (10.00)	876 (10.50)	3.53 (10.50)	2121 (9.00)	230 (10.00)	46.1 (10.00)
		Mean	9.84±3.05	154±41.3	1.29±0.42	187±30.3	633±196	2.17±1.22	1998±187	203±27.1	40.7±5.42
		Monte Carlo's Significance test	0.014	0.004	0.546	0.050	0.007	0.007	0.058	0.003	0.003
	Lower slope	MF1	13.15 (10.50)	157 (9.00)	1.07 (4.00)	106 (2.50)	435 (2.50)	1.65 (2.50)	1904 (4.88)	183 (3.75)	36.6 (3.75)
		MF2	6.65 (4.75)	146 (8.00)	1.52 (6.25)	183 (7.50)	725 (8.25)	2.76 (7.75)	1960 (7.75)	196 (6.00)	39.2 (6.00)
		MF3	5.74 (4.25)	77 (2.50)	1.88 (9.25)	193 (9.50)	731 (8.75)	3.04 (9.25)	2056 (6.88)	223 (9.75)	44.7 (9.75)
		Mean	8.51±3.63	127±39.3	1.49±0.53	161±41.2	630±159	2.49±0.70	1973±184	200±25.3	40.2±5.07
		Monte Carlo's Significance test	0.011	0.009	0.121	0.003	0.011	0.005	0.550	0.051	0.051

Table: 4.8. Influence of the length of fallow phase on biochemical properties of unburnt soils in Nagaland

UNBURNT	SLOPE		AMY $\mu\text{g glu g}^{-1}$ soil h ⁻¹ (Rank)	GSA $\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	DHA $\mu\text{g TPF g}^{-1}$ soil h ⁻¹ (Rank)	ASA $\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	PHA $\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	PRO $\mu\text{g tyr g}^{-1}$ soil h ⁻¹ (Rank)	MBC $\mu\text{g g}^{-1}$ (Rank)	MBN $\mu\text{g g}^{-1}$ (Rank)	MBP $\mu\text{g g}^{-1}$ (Rank)
	Upper slope	NF1	10.65 (2.50)	100 (2.50)	1.99 (2.75)	125 (2.50)	884 (2.50)	1.36 (2.50)	2639 (7.25)	258 (5.00)	51.7 (5.00)
		NF2	15.88 (6.50)	171 (6.50)	2.75 (6.25)	192 (6.50)	1337 (6.50)	1.64 (6.50)	2486 (2.50)	253 (4.00)	50.7 (4.00)
		NF3	19.58 (10.50)	185 (10.50)	6.25 (10.50)	220 (10.50)	1908 (10.50)	2.07 (10.50)	2823 (9.75)	300 (10.50)	60.1 (10.50)
		Mean	15.37±4.04	152±38.9	5.55±4.80	179±42.2	1377±456	1.69±0.33	2649±177	270±25.0	54.2±5.01
		Monte Carlo's Significance test	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.010	0.010
	Middle slope	NF1	14.09 (2.75)	110 (2.50)	1.34 (2.75)	125 (2.50)	832 (2.50)	3.28 (2.50)	2433 (4.00)	238 (3.50)	47.7 (3.50)
		NF2	17.93 (6.25)	132.5 (6.50)	2.40 (6.50)	191 (6.50)	1047 (6.50)	4.53 (6.50)	2499 (5.50)	255 (5.50)	51.0 (5.50)
		NF3	24.22 (10.50)	165 (10.50)	4.38 (10.25)	205 (10.50)	1750 (10.50)	6.65 (10.50)	2674 (10.00)	284 (10.50)	56.9 (10.50)
		Mean	18.75±4.86	136±24.3	2.71±1.51	173±37.4	1210±429	4.82±1.48	2535±166	259±23.6	51.9±4.71
		Monte Carlo's Significance test	0.000	0.000	0.001	0.000	0.000	0.000	0.040	0.004	0.004
	Lower slope	NF1	13.03 (2.50)	108 (2.50)	1.62 (5.25)	145 (2.50)	832 (2.50)	3.00 (4.75)	2465 (3.88)	241 (3.25)	48.3 (3.25)
		NF2	17.55 (7.50)	118 (6.50)	1.97 (7.75)	181 (6.50)	1045 (6.50)	3.45 (7.00)	2582 (6.63)	263 (5.75)	52.7 (5.75)
		NF3	18.43 (9.50)	162 (10.50)	2.05 (8.50)	226 (10.50)	1743 (10.50)	3.58 (7.75)	2625 (9.00)	279 (10.50)	55.9 (10.50)
		Mean	16.34±2.67	129±24.3	2.88±1.77	184±35.5	1207±421	3.34±0.67	2557±110	261±19.8	52.3±3.95
		Monte Carlo's Significance test	0.005	0.000	0.003	0.000	0.000	0.512	0.140	0.003	0.003

Table: 4.9. Influence of the length of fallow phase on biochemical properties of burnt soils in Nagaland

BURNT	SLOPE	AMY	GSA	DHA	ASA	PHA	PRO	MBC	MBN	MBP	
		$\mu\text{g glu g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g TPF g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g pNP g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g tyr g}^{-1}$ soil h ⁻¹ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	$\mu\text{g g}^{-1}$ (Rank)	
	Upper slope	NF1	18.26 (10.00)	147 (8.00)	0.96 (2.50)	113 (3.00)	744 (2.50)	2.11 (4.00)	1837 (2.50)	176 (2.50)	35.3 (2.50)
		NF2	17.35 (7.00)	137 (5.75)	1.75 (6.50)	125 (7.50)	1079 (9.00)	2.11 (5.00)	2117 (6.50)	211 (6.50)	42.3 (6.50)
		NF3	15.39 (2.50)	107 (4.25)	6.64 (10.50)	131 (9.00)	1061 (8.00)	3.04 (10.50)	2408 (10.50)	261 (10.50)	52.3 (10.50)
		Mean	17.00±1.39	140±16.0	3.12±2.64	123±9.77	961±176	2.42±0.72	2121±269	216±38.2	43.3±7.65
		Monte Carlo's Significance test	0.001	0.649	0.000	0.042	0.013	0.013	0.000	0.000	0.000
	Middle slope	NF1	20.55 (10.50)	117 (10.50)	1.05 (3.50)	115 (4.00)	847 (2.75)	2.54 (3.00)	1872 (2.75)	180 (2.50)	36.0 (2.50)
		NF2	14.97 (6.50)	96.3 (6.25)	1.25 (5.50)	122 (6.50)	979 (8.00)	3.30 (7.00)	2123 (6.25)	212 (6.50)	42.5 (6.50)
		NF3	12.85 (2.50)	85.2 (2.75)	7.13 (10.50)	127 (9.00)	987 (8.75)	3.72 (9.50)	2453 (10.50)	266 (10.50)	53.3 (10.50)
		Mean	16.12±3.68	99.8±15.5	3.14±2.96	121±7.54	937±91.3	3.19±0.71	2149±265	219±38.4	43.9±7.68
		Monte Carlo's Significance test	0.000	0.000	0.005	0.153	0.027	0.026	0.000	0.000	0.000
	Lower slope	NF1	16.47 (10.50)	118 (9.75)	1.03 (5.00)	111 (3.25)	764 (3.50)	2.95 (3.75)	2376 (7.50)	228.5 (5.75)	45.7 (5.75)
		NF2	11.70 (5.00)	105 (7.25)	1.05 (4.00)	120 (5.75)	834 (5.50)	3.16 (7.00)	2098 (3.00)	209.8 (3.25)	42.0 (3.25)
		NF3	11.55 (4.00)	68.4 (2.50)	5.26 (10.50)	144 (10.50)	1241 (10.50)	3.53 (8.75)	2490 (9.00)	270.7 (10.50)	54.1 (10.50)
		Mean	13.24±2.51	97.4±24.0	2.45±2.21	124±16.2	946±234	3.21±0.39	2322±227	236.3±30.3	47.3±6.06
		Monte Carlo's Significance test	0.011	0.003	0.010	0.003	0.005	0.146	0.041	0.003	0.003

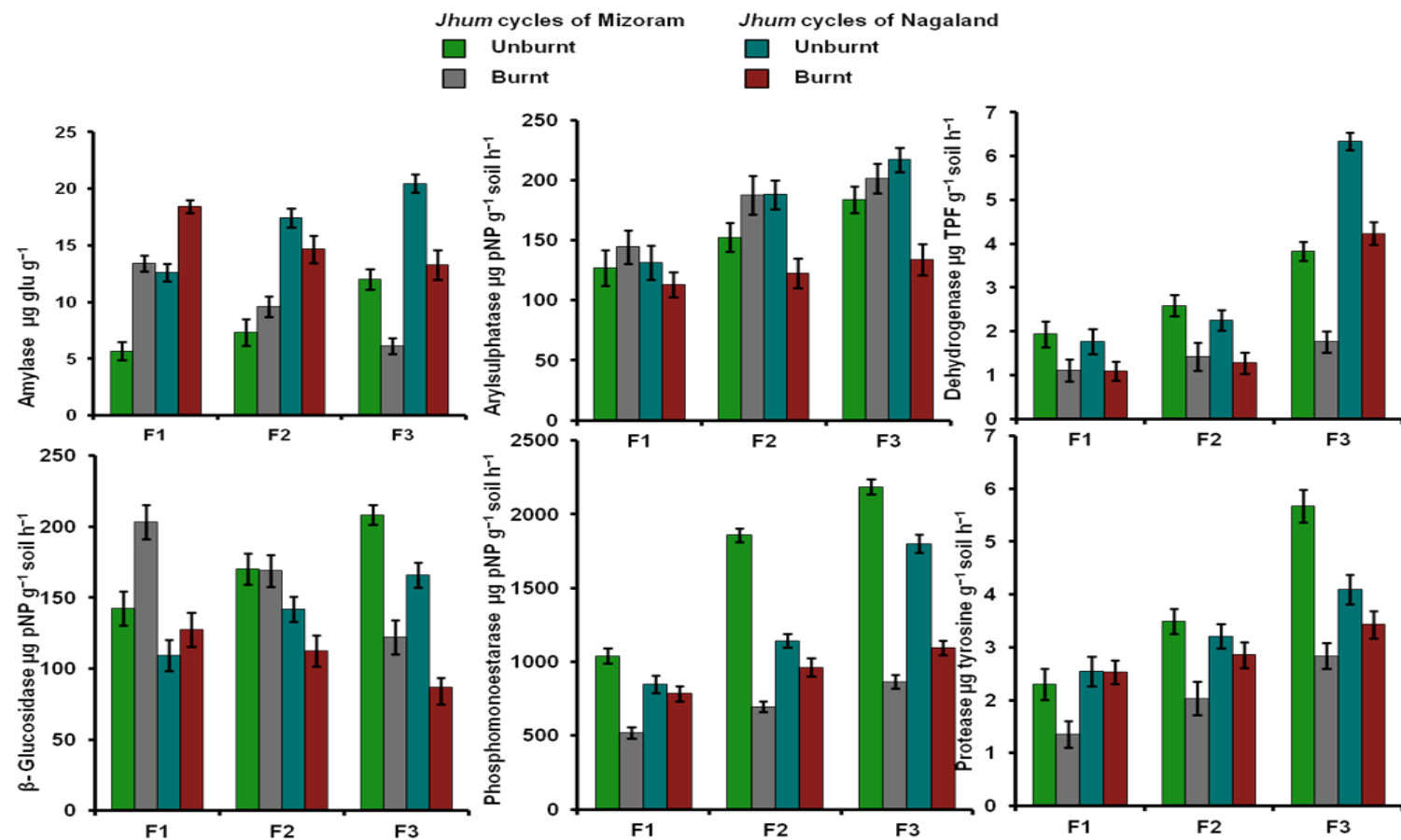


Fig 4.2. Soil enzyme activities as influenced by burning and the length of fallow phases in *jhum* cycles of Mizoram and Nagaland. F1 – 5 years fallow, F2 – 10 years fallow and F3 – 15 years fallow for Mizoram and 20 years fallow for Nagaland.

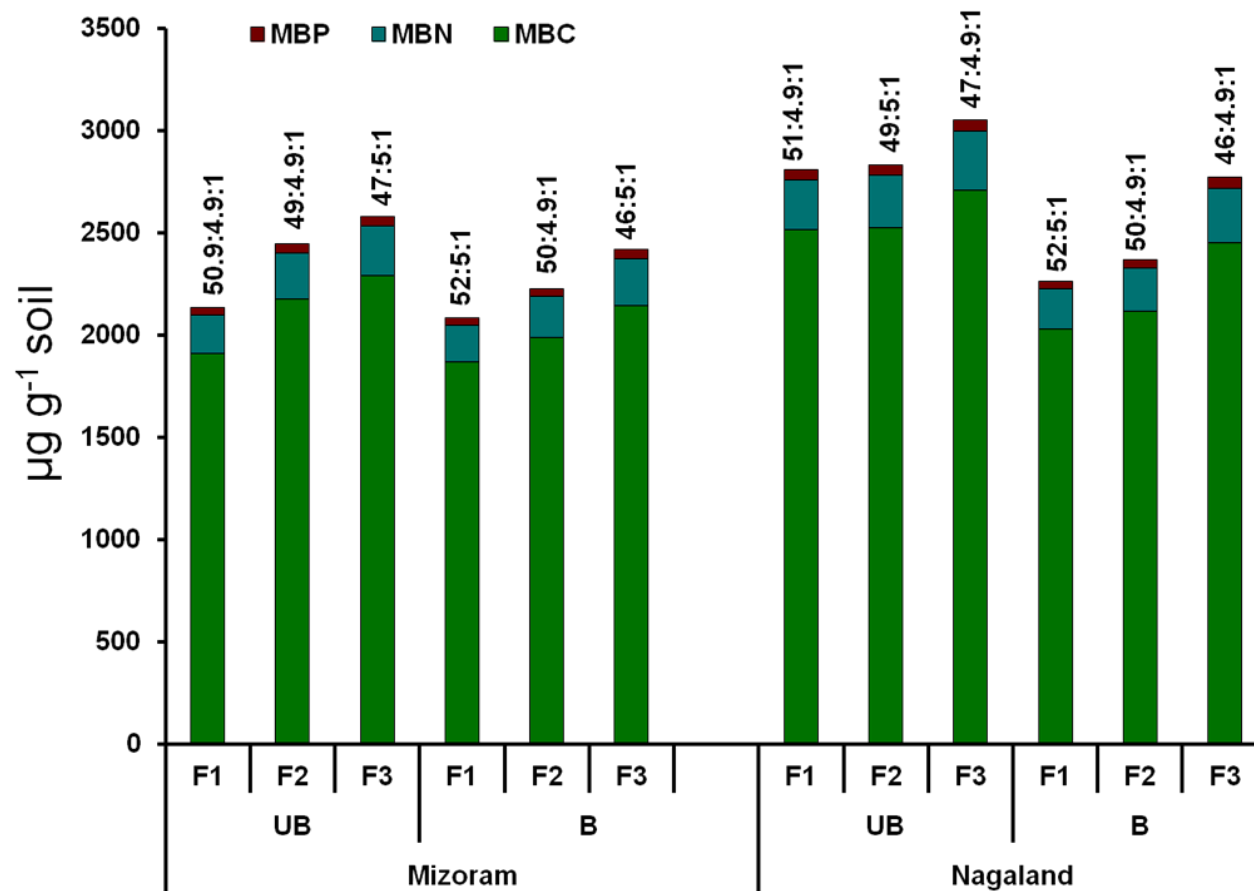


Fig 4.3. The carbon:nitrogen:phosphorus within microbial as influenced by burning and the length fallow phase in *jhum* cycles of Mizoram and Nagaland. F1 – 5 years fallow, F2 – 10 years fallow and F3 – 15 years fallow for Mizoram and 20 years fallow for Nagaland.

4.3. Microcosm experiment-I:

4.3.1. Impact of FFLs amendment on soil process indicators under burnt and unburnt situations of fallow phases

Soil collected from burnt and unburnt sites of two different *jhum* cycles of Mizoram viz. 5 years cycle (MF1) and 10 years cycle (MF2) were amended with ground FFLs from MF1, MF2 and MF3 fallow phases and a *jhum* rice cultivar *Khawlian buh* was grown in these microcosms. The changes in soil physico-chemical and biochemical properties and physiological stress indicators in rice plants were studied and data are presented in Table 4.10 to 4.12, and Fig.4.4.

The differences in soil pH, Avl K and Exch.Mg were non-significant between burnt and unburnt soils (Table 4.10). Whereas, the differences in EC, SOC, Avl N, Avl P and Exch.Ca were significant between burnt and unburnt soils (Table 4.10). The effect of the length of fallow phase on pH, EC, Avl N, Avl P, Avl K and Exch.Mg were significant, while on SOC and Exch.Ca were non-significant (Table 4.10). The addition of FFLs of different fallow phases had significant influence on all soil attributes.

Interaction effects of burning and fallow phase was found to be significant for EC, SOC, Avl N, Avl P, Avl K, Exch.Ca and Exch.Mg, but non-significant for pH (CD at 5%; Table 4.10). The interactive effect between burning and treatment (addition of FFLs) or between fallow phase and treatment were found significant for pH, SOC, Avl P, Avl K and Exch.Ca, but non-significant for EC, Avl N and Exch.Mg. The interaction among burning, fallow phase and treatment had also shown significant influence on pH, SOC, Avl N, Avl P, Avl K, and Exch.Ca; whereas such interactive effect was non-significant for EC and Exch.Mg (CD at 5%; Table 4.10).

Table 4.10. Effect of forest floor litter amendment of different fallow phases on the physico-chemical properties of burnt and unburnt soils of 5 years and 10 years *jhum* cycles in microcosm experiment

Situation	Fallow	Treatments	pH (1:2.5 soil:water)	EC ($\mu\text{S cm}^{-1}$)	SOC (%)	Avl N (kg ha^{-1})	Avl P (kg ha^{-1})	Avl K (kg ha^{-1})	Exch.Ca (meq/100g)	Exch.Mg (meq/ 100g)
UNBURNT	MF1	Control	5.16b	30.00a	2.35c	332a	11.49a	255b	0.80c	0.96c
		F1L	5.25a	24.00b	2.55b	307a	9.47b	265b	1.51bc	1.04b
		F2L	5.29a	22.50b	2.64b	276b	8.38b	323a	1.80b	1.23ab
		F3L	5.32a	20.00b	2.82a	270b	6.57c	362a	3.76a	1.26a
	MF2	Control	5.25c	40.00a	2.41b	408a	19.76a	317c	2.64c	1.21c
		F1L	5.37b	37.00ab	2.79ab	351b	18.94a	342b	2.65c	1.46b
		F2L	5.37b	36.00ab	2.85a	339c	11.70b	366ab	4.14b	1.63a
		F3L	5.49a	33.00b	2.88a	326d	10.02c	387a	4.59a	1.64a
Mean (Unburnt)		5.31b	30.3b	2.66a	326b	12.04b	327b	2.74b	1.30b	
BURNT	MF1	Control	5.32b	53.50a	2.31c	426a	11.73c	395b	2.26c	1.49d
		F1L	5.39ab	47.50a	2.46b	383ab	12.73bc	414ab	3.31b	1.90c
		F2L	5.41ab	47.50a	2.58a	345b	14.98b	420ab	3.39b	2.14b
		F3L	5.45a	42.50b	2.59a	332b	15.94a	497a	3.76a	2.46a
	MF2	Control	5.35b	50.00a	2.21c	477a	12.83c	431c	4.31b	2.54b
		F1L	5.43ab	48.50a	2.30b	420b	13.59b	443bc	4.55ab	2.70ab
		F2L	5.46a	48.50a	2.34b	351c	15.56ab	452b	4.65ab	2.76ab
		F3L	5.46a	42.50b	2.46a	339c	16.50a	484a	4.70a	2.94a
Mean (Burnt)		5.41a	47.6a	2.41b	384a	14.23a	442a	3.87a	2.37a	
CD at 5%	Burning (B)		0.02	2.44	0.21	13.38	0.65	53.42	0.18	0.16
	Fallow (F)		0.02	2.44	NS	13.38	0.65	53.42	0.18	0.16
	Litter types(LT)		0.03	3.45	0.21	18.92	0.92	75.55	0.26	0.23
	BxF		NS	3.45	0.18	18.92	0.92	75.55	0.26	0.23
	BxLT		0.04	NS	0.20	NS	1.30	106.84	0.37	NS
	FxLT		0.04	NS	0.16	NS	1.30	106.84	0.37	NS
	BxFxLT		0.06	NS	0.14	37.83	1.84	151.10	0.52	NS
	Mean (Fallow MF1)		5.32b	35.9b	2.54a	334b	11.41b	366b	2.57b	1.56b
Mean (Fallow MF2)		5.40a	41.9a	2.53a	376a	14.86a	403a	4.03a	2.11a	
Control – no litter input, F1L- litter from 5 years fallow, F2L- litter from 10 years fallow and F3L – litter from 15 years fallow										

In microcosm experiment, the activity of AMY was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from longer fallow phase have also exhibited higher amylase activity than that of shorter fallow phase (Table 4.11). In general, higher AMY activity was in the order of $F3L > F2L > F1L > \text{control}$ and the differences in AMY activity between litter amended soils were significant (DMRT at $P < 0.05$). The activity of AMY was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

The activity of ASA was found significantly lower in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from longer fallow phase supported higher ASA activity than that of shorter fallow phase (Table 4.11). Higher ASA activity was in the order of $F3L > F2L > F1L > \text{control}$ and the differences in ASA activity between litter amended soils were significant (DMRT at $P < 0.05$). The activity of ASA was found to be significantly altered due to the interaction effect of burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%). However, interactive effect of burning x fallow phase was non-significant in terms of ASA activity.

There was no significant effect of burning on the activity of DHA in litter amended soil (Table 4.11; DMRT at $P > 0.05$). Litter amended soils from longer fallow phase supported higher DHA activity than that of shorter fallow phase (Table 4.11). Though higher DHA activity was in the order of $F3L > F2L > F1L > \text{control}$ and the differences in DHA activity between litter amended soils were non-significant (DMRT at $P > 0.05$). The activity of DHA was found to be significantly altered due to the interaction effect of burning x fallow phase, but interactive effect of burning x litter types, fallow phase x litter type and burning x fallow phase x litter type were non-significant (3 factorial CRD and CD at 5%).

The activity of GSA was found significantly lower in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from longer fallow phase supported higher GSA activity than that of shorter fallow phase (Table 4.11). Higher GSA activity was in the order of $F3L > F2L > F1L > \text{control}$ and the differences in GSA activity between litter amended soils were significant (DMRT at $P < 0.05$). The activity of GSA was found to be significantly altered due to the interaction effect of burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%). However, interactive effect of burning x fallow phase was non-significant in terms of GSA activity.

The activity of PHA was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from shorter fallow phase have also exhibited higher PHA activity than that of longer fallow phase (Table 4.11). In general, higher PHA activity was in the order of F3L > F2L > F1L > control and the differences in PHA activity between litter amended soils were significant (DMRT at $P < 0.05$). The activity of PHA was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

The activity of PRO was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). There was no significant effect of the length of fallow phase on the activity of PRO in litter amended soils (Table 4.11; DMRT at $P > 0.05$). Though higher PRO activity was in the order of F3L > F2L > F1L > control, the differences in PRO activity between litter amended soils were non-significant (DMRT at $P > 0.05$). The activity of PRO was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

Values of MBC, MBN and MBP were found significantly higher in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from longer fallow phase have also exhibited higher values of MBC, MBN and MBP than that of shorter fallow phase (Table 4.11). Higher values of MBC, MBN and MBP were in the order of F3L > F2L > F1L > control and the differences between litter amended soils in terms of MBC, MBN and MBP were significant (DMRT at $P < 0.05$). Values of MBC, MBN and MBP were found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

The amount of pMN was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.11; DMRT at $P < 0.05$). Soils from shorter fallow phase have also exhibited higher pMN than that of longer fallow phase (Table 4.11). Higher pMN was in the order of F3L > F2L > F1L > control and the differences in pMN between litter amended soils were significant (DMRT at $P < 0.05$). The amount of pMN was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

Soil respiration (in terms of CO₂ evolution in ppm) didn't vary significantly between burnt and unburnt situations or the length of fallow phase (Table 4.11; DMRT

at $P > 0.05$). Soil respiration varied significantly due to addition of different litter types and the higher values of soil respiration was in the order of $F3L > F2L > F1L > \text{control}$ (DMRT at $P < 0.05$). Soil respiration was found to be significantly altered due to the interaction effect of burning x litter types, but the interactive effect of burning x fallow phase, fallow phase x litter type and burning x fallow phase x litter type were non-significant (3 factorial CRD and CD at 5%).

Table 4.11. Effect of forest floor litter amendment of different fallow phases on the biochemical properties of burnt and unburnt soils of 5 years and 10 years *jhum* cycles in microcosm experiment

Situation	Fallow	Treatment	AMY ($\mu\text{g glu g}^{-1}$ soil h^{-1})	ASA ($\mu\text{g pNP g}^{-1}$ soil h^{-1})	DHA ($\mu\text{g TPF g}^{-1}$ soil 24h^{-1})	GSA ($\mu\text{g pNP g}^{-1}$ soil h^{-1})	PHA ($\mu\text{g pNP g}^{-1}$ soil h^{-1})	PRO ($\mu\text{g tyr g}^{-1}$ soil h^{-1})	MBC ($\mu\text{ g}^{-1}$)	MBN ($\mu\text{ g}^{-1}$)	MBP ($\mu\text{ g}^{-1}$)	pMN ($\mu\text{ g}^{-1}$)	Soil respiration (CO_2 in ppm)
UNBURNT	MF1	Control	8.39c	8.04d	1.62b	115c	918d	2.09c	2079c	212c	42.41c	44.55c	483b
		F1L	11.24b	10.95c	2.21a	125b	1255c	2.84bc	2207b	225b	45.04b	48.79b	492b
		F2L	11.93b	12.26b	2.25a	136a	1341b	3.18b	2509a	256a	51.21a	57.17a	512b
		F3L	16.44a	15.17a	2.51a	141a	1532a	5.06a	2515a	257a	51.32a	58.80a	567a
	MF2	Control	8.68d	13.25c	3.42b	178c	816c	2.79b	2204d	234d	46.89d	56.47b	503b
		F1L	10.94c	16.03b	3.56ab	210b	1430b	2.80b	2302c	245c	48.97c	73.14a	516b
		F2L	12.56b	16.70b	3.64a	241a	1513a	4.37a	2453b	261b	52.19b	75.55a	525ab
		F3L	14.71a	18.52a	3.87a	248a	1535a	5.04a	2504a	266a	53.27a	76.07a	559a
Mean (Unburnt)		12.36a	13.87b	2.89a	174b	1293a	3.52a	2347a	245a	48.91a	61.32a	520a	
BURNT	MF1	Control	8.01b	9.54d	1.90b	125c	957c	1.45c	1594d	159d	31.88d	41.20b	486b
		F1L	9.08b	11.59c	2.31ab	147b	1054b	2.25bc	1722c	172c	34.43c	47.90c	516ab
		F2L	11.50a	13.45b	2.86ab	155a	1144a	2.84b	1958b	196b	39.17b	48.44a	523ab
		F3L	11.68a	15.22a	3.20a	162a	1166a	4.23a	1925a	193a	38.50a	49.54c	539a
	MF2	Control	9.48c	13.86c	2.90b	177c	458c	1.33c	1744d	190d	37.91d	24.97c	499b
		F1L	10.59b	14.84c	2.97b	233b	926b	1.82bc	1965c	214c	42.72c	32.43b	520ab
		F2L	10.76b	16.99b	3.08ab	281a	956b	1.91b	2051b	223b	44.59b	34.10ab	528ab
		F3L	13.25a	19.72a	3.25a	283a	1103a	3.23a	2229a	242a	48.44a	35.70a	562a
Mean (Burnt)		10.54b	14.40a	2.81a	195a	971b	2.38b	1899b	199b	39.71b	39.29b	522a	
CD at 5%	Burning (B)		0.55	0.36	NS	3.14	21.6	0.29	10.2	1.1	0.2	1.17	NS
	Fallow (F)		NS	0.36	0.30	3.14	21.6	NS	10.2	1.1	0.2	1.17	13.4
	Litter types (LT)		0.78	0.51	NS	4.45	30.6	NS	14.5	1.5	0.3	1.66	18.9
	BxF		0.78	NS	0.42	NS	30.6	0.41	14.5	1.5	0.3	1.66	NS
	BxLT		1.11	0.73	NS	6.29	43.3	0.58	20.5	2.1	0.4	2.34	26.7
	FxLT		1.11	0.73	NS	6.29	43.3	0.58	20.5	2.1	0.4	2.34	NS
	BxFxLT		1.57	1.03	NS	8.89	61.2	0.82	29.0	3.0	0.6	3.31	NS
	Mean (Fallow MF1)		11.41a	12.03b	2.36b	138b	1171a	2.99a	2064b	209b	41.75b	49.55b	515b
Mean (Fallow MF2)		11.37a	16.24a	3.34a	231a	1092b	2.91a	2182a	234a	46.87a	51.05a	527a	
Control – no litter input, F1L- litter from 5 years fallow, F2L- litter from 10 years fallow and F3L – litter from 15 years fallow													

4.3.2. Impact of FFLs amendment on *jhum* rice physiology under burnt and unburnt situations of fallow phases

Physiological stress indicators viz. lipid peroxidation (in terms of MDA production), membrane stability (in terms of % electrolyte leakage), leaf pigmentation (Chl-a, Chl-b, and carotenoids), root morphology (surface area, average diameter, total length and volume), root:shoot and grain weight were determined and data are presented in Table 4.12 and Fig.4.4.

Accumulation of MDA in leaf was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.12; DMRT at $P < 0.05$). Plants grown in soils from shorter fallow phase exhibited higher MDA accumulation in leaf than that of longer fallow phase (Table 4.12). Higher MDA accumulation was in the order of control > F1L > F2L > F3L and the differences in MDA accumulation were significant (DMRT at $P < 0.05$). The accumulation of MDA in leaf was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%).

The per cent electrolyte leakage in leaf was found significantly higher in unburnt situation compared to that of burnt situation (Table 4.12; DMRT at $P < 0.05$). Plants grown in soils from longer fallow phase exhibited lower per cent electrolyte leakage in leaf than that of shorter fallow phase (Table 4.12). More per cent electrolyte leakage in leaf was in the order of control > F1L > F2L > F3L and the differences in per cent electrolyte leakage were significant (DMRT at $P < 0.05$). The per cent electrolyte leakage in leaf was found to be significantly altered due to the interaction effect of burning x fallow phase, fallow phase x litter type and burning x fallow phase x litter types, but the effect of burning x litter types was non-significant (3 factorial CRD and CD at 5%).

There was no significant interaction effect of burning, fallow phase and litter types on the content of Chl-a in leaves of rice (Table 4.12; DMRT at $P > 0.05$). However, the content of Chl-b in leaf was found significantly higher in burnt situation compared to that of unburnt situation (Table 4.12; DMRT at $P < 0.05$). Plants grown in soils from longer fallow phase exhibited higher Chl-b content in leaf than that of shorter fallow phase (Table 4.12). Higher content of Chl-b in leaf was in the order of F3L > F2L > F1L > control and the differences in Chl-b content were significant (DMRT at $P < 0.05$). The content of Chl-b in leaf was found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%). The content of carotenoids in leaf was found significantly higher in unburnt situation

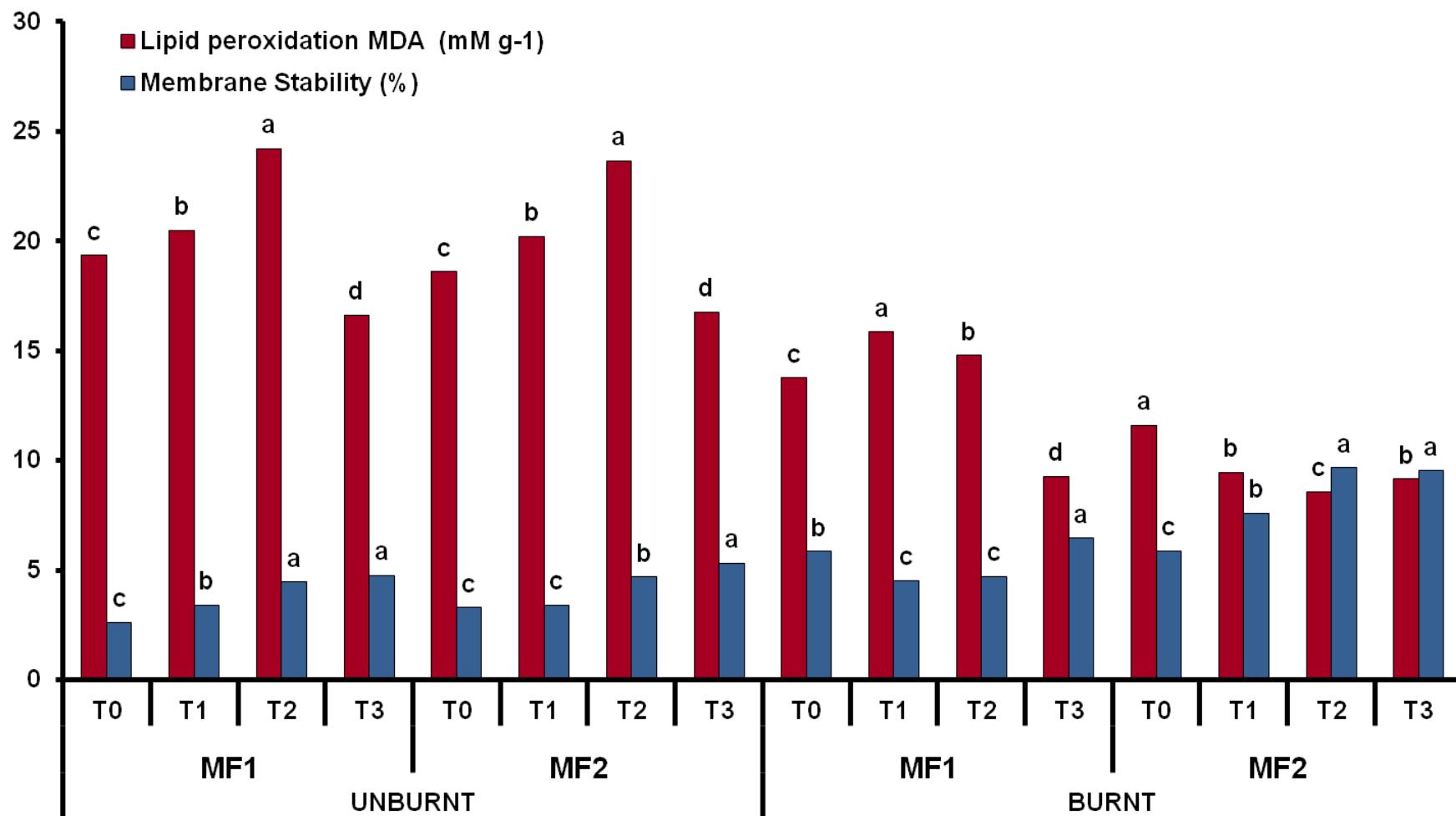
compared to that of burnt situation (Table 4.12; DMRT at $P < 0.05$). Plants grown in soils from longer fallow phase exhibited higher content of carotenoids in leaf than that of shorter fallow phase (Table 4.12). Higher carotenoids content in leaf was in the order of control > F1L > F2L > F3L and the differences in carotenoids content were significant (DMRT at $P < 0.05$). The carotenoids content in leaf was found to be significantly altered due to the interaction effect of fallow phase x litter type and burning x fallow phase x litter types, but the effect of burning x fallow phase and burning x litter types were non-significant (3 factorial CRD and CD at 5%).

Values of RSA, RL, RV and root:shoot were found significantly higher in unburnt situation compared to that of burnt situation (Table 4.12; DMRT at $P < 0.05$). Plants grown in soils from shorter fallow phase exhibited higher values of RSA, RL, RV and root:shoot than that of longer fallow phase (Table 4.12). Higher values of RSA were in the order of F3L > F2L > F1L > control and the differences in RSA were significant (DMRT at $P < 0.05$). Higher values of RL, RV and root:shoot were in the order of control > F1L > F2L > F3L and their differences were significant (DMRT at $P < 0.05$). Values of RSA, RL, RV and root:shoot were found to be significantly altered due to the interaction effect of burning x fallow phase, burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%). There was no significant interaction effect of burning and fallow phase on RD of rice (Table 4.12; DMRT at $P > 0.05$). Higher values of RD were in the order of F3L > F2L > F1L > control and the differences in RD were significant (DMRT at $P < 0.05$). Values of RD were found to be significantly altered due to the interaction effect of fallow phase x litter types, but the interaction effects of burning x fallow phase, burning x litter type and burning x fallow phase x litter types were non-significant (3 factorial CRD and CD at 5%).

Grain yield per plant was found significantly lower in unburnt situation compared to that of burnt situation (Table 4.12; DMRT at $P < 0.05$). Soils from longer fallow phase supported higher grain yield per plant than that of shorter fallow phase (Table 4.12). Higher grain yield per plant was in the order of F3L > F2L > F1L > control and the differences in grain yield between litter amended soils were significant (DMRT at $P < 0.05$). Grain yield per plant was found to be significantly altered due to the interaction effect of burning x litter types, fallow phase x litter type and burning x fallow phase x litter types (3 factorial CRD and CD at 5%). However, the interactive effect of burning x fallow phase was non-significant in terms of grain yield per plant.

Table 4.12. Effect of forest floor litter amendment of different fallow phases on *jhum* rice physiology in burnt and unburnt soils of 5 years and 10 years *jhum* cycles in microcosm experiment

Experiment	Situation	Fallows	Treatments	LEAF				ROOT					Grain yield (g/ plant)	
				Lipid peroxidation (mM MDA g ⁻¹)	Membrane Stability (%)	Chl-a (mg g ⁻¹)	Chl-b (mg g ⁻¹)	Carotenoid (mg g ⁻¹)	RSA (cm ²)	RD (mm)	RL (m)	RV (cm ³)		Root: shoot
UNBURNT		MF1	Control	24.19a	9.67a	1.40a	0.58b	0.09a	130d	0.50a	69.85a	180.93a	0.75a	2.74c
			F1L	20.48b	9.52a	1.41a	0.62a	0.09a	319c	0.57a	55.43b	126.79b	0.40b	2.74c
			F2L	19.34c	7.58b	1.51a	0.63a	0.09ab	362b	0.58a	55.28b	122.52c	0.34c	3.53b
			F3L	16.63d	5.86c	1.52a	0.63a	0.08b	415a	0.63a	27.50c	105.59d	0.32c	5.78a
		MF2	Control	23.66a	6.45a	1.47a	0.68b	0.11a	219b	0.55b	42.28a	69.20a	0.30a	4.19c
			F1L	20.20b	5.84b	1.54a	0.69b	0.09b	232b	0.59ab	36.94b	60.64b	0.27ab	6.72b
			F2L	18.59c	4.71bc	1.56a	0.71ab	0.09b	234b	0.65ab	36.48c	53.57c	0.23b	7.14ab
			F3L	16.76d	4.51c	1.61a	0.76a	0.09b	268a	0.73a	36.21c	51.97c	0.18c	7.36a
		Mean (Unburnt)	19.98a	6.77a	1.50a	0.66b	0.09a	272a	0.60a	45.00a	96.40a	0.35a	5.03b	
	BURNT		MF1	Control	15.86a	5.30a	1.58a	0.73b	0.08a	158d	0.44c	41.47a	52.42a	0.29a
F1L				14.79b	4.69b	1.59a	0.75ab	0.07a	183c	0.54b	32.01b	23.14b	0.21b	6.44c
F2L				13.76c	3.40c	1.61a	0.82a	0.07a	193b	0.55b	27.46c	15.49c	0.21b	7.77b
F3L				9.26d	3.29c	1.62a	0.85a	0.07a	233a	0.82a	25.55c	15.21c	0.19b	8.46a
MF2			Control	11.58a	4.74a	1.59a	0.84c	0.09a	152c	0.39c	37.90a	25.23a	0.19a	8.02c
			F1L	9.45b	4.46a	1.60a	0.90bc	0.09ab	175c	0.57b	30.41b	20.18b	0.18a	8.69bc
			F2L	9.15b	3.42b	1.64a	0.97b	0.08bc	236b	0.60b	25.29c	18.45c	0.16ab	9.54b
			F3L	8.56c	2.61c	1.65a	1.29a	0.07c	297a	0.71a	23.16d	12.92d	0.13b	11.21a
		Mean (Burnt)	11.55b	3.99b	1.61a	0.89a	0.08b	203b	0.58a	30.41b	22.88b	0.20b	8.15a	
CD at 5%			Burning (B)	0.20	0.17	NS	0.03	0.00	7.47	NS	0.78	0.70	0.02	0.23
		Fallow (F)	0.20	0.17	NS	0.03	0.00	7.47	NS	0.78	0.70	0.02	0.23	
		Litter types (T)	0.28	0.24	NS	0.04	0.01	10.57	0.07	1.10	1.00	0.03	0.33	
		BxF	0.28	0.24	NS	0.04	NS	10.57	NS	1.10	1.00	0.03	NS	
		BxLT	0.40	NS	NS	0.06	NS	14.95	NS	1.56	1.41	0.04	0.47	
		FxLT	0.40	0.34	NS	0.06	0.01	14.95	0.10	1.56	1.41	0.04	0.47	
		BxFxLT	0.56	0.48	NS	0.09	0.01	21.14	NS	2.20	1.99	0.06	0.66	
		Mean (Fallow 5Y)	16.79a	5.98a	1.53a	0.70b	0.08b	249a	0.58a	41.82a	80.26a	0.34a	5.31b	
	Mean (Fallow 10Y)	14.74b	4.59b	1.58a	0.86a	0.09a	227b	0.60a	33.58b	39.02b	0.21b	7.86a		
Control – no litter input, F1L- litter from 5 years fallow, F2L- litter from 10 years fallow and F3L – litter from 15 years fallow														



4.4. Physiological stress indicators viz. lipid peroxidation (in terms of MDA production), membrane stability (in terms of % electrolyte leakage), in leaves of *jhum* rice as affected by different FFL amendments.

Fig

4.4. Microcosm experiment-II:

4.4.1. Impact of addition of FFL, microbial consortium and ash amendments on soil processes

A microcosm experiment was conducted using soils from burnt sites of 5 years (MF1) and 10 years (MF2) *jhum* fallows and an upland rice variety (Bhalum-1) was grown in order to study the effects of input treatments viz. litter amendment (LA), microbial consortium (MC), LA+MC, and ash amendment (AA).

Soil pH and EC was significantly higher in longer fallow phase compared to that in shorter fallow phase (Table 4.13). Soil pH and EC was significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher soil pH values were in the order of AA > LA+MC > MC > LA > control. In case of soil EC, higher values were in the order of AA > MC, LA > LA+MC > control. The interactive effect of fallow phase x input treatments was non-significant on soil pH (DMRT at $P > 0.05$), but significant in case of EC (DMRT at $P < 0.05$).

Soil Avl N and SOC were significantly higher in shorter fallow phase than that of longer fallow phase (Table 4.13). Soil Avl N and SOC contents were significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher SOC contents were in the order of LA+MC, LA > MC > AA, control. In case of soil Avl N, higher contents were in the order of control, AA > MC > LA, LA+MC. The interactive effect of fallow phase x input treatments was non-significant on SOC content (DMRT at $P > 0.05$), but significant in case of soil Avl N (DMRT at $P < 0.05$).

Soil Avl P, Avl K and Exch. Mg contents were significantly higher in longer fallow phase than that of shorter fallow phase (Table 4.13). There was no significant difference between fallow phase in terms of Exch.Ca content. The content of Avl P, Avl K, Exch.Ca and Exch.Mg in soils were significantly altered by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher Avl P, Avl K, Exch.Ca and Exch.Mg contents were in the order of AA > LA+MC > MC > LA > control. The interactive effect of fallow phase x input treatments was significant on Avl P, Avl K, Exch.Ca and Exch.Mg contents (DMRT at $P < 0.05$).

The activities of AMY, ASA and PRO were significantly higher in longer fallow phase compared to that in shorter fallow phase (Table 4.14). The activities of AMY, ASA and PRO were significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). In general, higher activities of AMY, ASA and PRO were in the order of LA, LA+MC > MC > AA > control. The interactive effect of

fallow phase x input treatments was significant on AMY, ASA and PRO activities (DMRT at $P < 0.05$).

The length of fallow phase as well as interactive effect of fallow phase x input treatments had no significant effect on the activities of DHA and GSA (Table 4.14; DMRT at $P < 0.05$). However, the activities of DHA and GSA were significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). In general, higher activities of DHA and GSA were in the order of LA+MC, LA > MC > AA > control.

The activity of PHA was significantly higher in shorter fallow phase compared to that in longer fallow phase (Table 4.14). The activity of PHA was significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher PHA activity was in the order of LA > LA+MC > MC > control > AA. The interactive effect of fallow phase x input treatments was significant on PHA activity (DMRT at $P < 0.05$).

Table 4.13. Effect of litter amendment, microbial consortium and ash amendment on physico-chemical properties of burnt soils belonging to 5 years and 10 years fallow phases under microcosm experiment

Fallow	Treatments	pH (1:2.5 soil: water)	EC ($\mu\text{S cm}^{-1}$)	SOC (%)	Avl N (kg ha^{-1})	Avl P (kg ha^{-1})	Avl K (kg ha^{-1})	Exch. Ca (meq/ 100 g)	Exch. Mg (meq/ 100 g)
MF1 (burnt)	Control	5.16b	30.00c	2.28c	451a	8.96c	363c	1.90d	0.34d
	LA	5.28a	38.60ab	2.68a	384b	9.24bc	375c	2.65c	0.37c
	MC	5.26a	38.60ab	2.34b	429c	9.14bc	389b	2.72c	0.40b
	LA+MC	5.27a	36.60b	2.65a	394c	10.96ab	392b	3.13b	0.41b
	AA	5.30a	44.60a	2.29c	439b	11.14a	440a	3.68a	0.44a
	Mean (MF1)	5.25b	37.7b	2.45a	419a	9.89b	392b	3.68a	0.39b
MF2 (burnt)	Control	5.24c	33.40d	2.09c	406a	11.97d	350d	2.35d	0.57c
	LA	5.34b	47.40b	2.38a	346b	13.11c	373c	3.86c	0.58c
	MC	5.36b	47.60b	2.22b	399a	14.21b	412b	3.97bc	0.63b
	LA+MC	5.35b	42.60bc	2.34a	365b	14.56ab	418b	4.00b	0.64b
	AA	5.42a	53.80a	2.10c	396a	15.22a	481a	4.16a	0.68a
	Mean (MF2)	5.34a	45.0a	2.23b	382b	13.81a	407a	3.67a	0.62a
CD at 5%	<i>Fallow (F)</i>	0.04	2.12	0.28	17.53	1.45	7.43	NS	0.01
	<i>Treatment(T)</i>	0.06	3.35	0.44	27.72	2.29	11.75	0.09	0.01
	<i>FxT</i>	NS	4.73	NS	39.20	3.23	16.61	0.12	0.02

4.4.2. Impact of addition of FFL, microbial consortium and ash amendments on stress physiology of *jhum* rice

Accumulation of MDA and per cent electrolyte leakage in leaf was significantly higher in shorter fallow phase compared to that in longer fallow phase (Table 4.15). Accumulation of MDA and per cent electrolyte leakage in leaf was significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher MDA accumulation in leaf was in the order of control > AA, MC > LA+MC, LA. In case of per cent electrolyte leakage higher values were in the order of control > LA > MC > LA+MC, AA. The interactive effect of fallow phase x input treatments was significant on MDA accumulation and per cent electrolyte leakage (DMRT at $P < 0.05$). The content of Chl-a and Chl-b in leaf was significantly higher in longer fallow phase compared to that in shorter fallow phase (Table 4.15). Content of Chl-a and Chl-b in leaf was significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher content of Chl-a and Chl-b in leaf was in the order of LA+MC > AA > MC, LA > control. The interactive effect of fallow phase x input treatments was significant on Chl-a and Chl-b contents (DMRT at $P < 0.05$). The length of fallow phase as well as interactive effect of fallow phase x input treatments had no significant effect on the content of carotenoid in leaf (Table 4.15; DMRT at $P < 0.05$). However, the content of carotenoid was significantly influenced by the application of input treatments i.e. LA, MC and AA (DMRT at $P < 0.05$). Higher carotenoid content in leaf was in the order of control > MC, LA > LA+MC > AA.

Table 4.14. Effect of litter amendment, microbial consortium and ash amendment on biochemical properties of burnt soils belonging to 5 years and 10 years fallow phases under microcosm experiment

Fallow	Treatments	AMY ($\mu\text{g glu g}^{-1} \text{ soil h}^{-1}$)	ASA ($\mu\text{g pNP g}^{-1} \text{ soil h}^{-1}$)	DHA ($\mu\text{g TPF g}^{-1} \text{ soil 24h}^{-1}$)	GSA ($\mu\text{g pNP g}^{-1} \text{ soil h}^{-1}$)	PHA ($\mu\text{g pNP g}^{-1} \text{ soil h}^{-1}$)	PRO ($\mu\text{g tyr g}^{-1} \text{ soil h}^{-1}$)
MF1 (burnt)	Control	9.73d	23.37c	2.75d	117c	384c	1.26c
	LA	14.28a	37.05a	3.07cd	149ab	476a	1.83a
	MC	12.76b	31.77b	3.66ab	136b	414b	1.63b
	LA+MC	14.07a	38.32a	3.97a	155a	462ab	1.92a
	AA	11.84c	24.25c	3.35bc	128bc	320d	1.34c
	Mean (MF1)	12.54b	30.95b	3.36a	137a	411a	1.60b
MF2 (burnt)	Control	11.31e	32.63c	3.05c	115c	325a	1.29b
	LA	18.89a	44.36a	3.45b	148ab	439a	2.03a
	MC	13.10c	38.56b	3.64b	137b	426a	2.16a
	LA+MC	16.18b	49.08a	4.07a	167a	437a	2.27a
	AA	12.46d	34.94bc	3.21bc	117c	302b	1.45b
	Mean (MF2)	14.39a	39.91a	3.48a	137a	386b	1.84a
CD at 5%	Fallow (F)	0.20	1.95	NS	NS	26.24	0.09
	Treatment(T)	0.32	3.09	0.25	13.65	41.48	0.14
	FxT	0.45	4.37	NS	NS	58.67	0.20

Table 4.15. Effect of litter amendment, microbial consortium and ash amendment on *jhum* rice physiology in burnt soils belonging to 5 years and 10 years fallow phases under microcosm experiment

Fallow	Treatments	Lipid peroxidation (mM MDA g⁻¹)	Membrane Stability (%)	Chl-a (mg g⁻¹)	Chl- b (mg g⁻¹)	Carotenoid (mg g⁻¹)
MF1 (burnt)	Control	16.49a	17.13a	1.11c	0.56d	0.19a
	LA	11.94c	12.30b	1.47ab	0.62c	0.16ab
	MC	13.18b	10.45c	1.39b	0.62c	0.16ab
	LA+MC	11.93c	9.14d	1.63a	0.91a	0.13b
	AA	13.80b	9.36d	1.60a	0.77b	0.08c
	Mean (5Y)	13.47a	11.68a	1.44b	0.70b	0.14a
MF2 (burnt)	Control	13.80a	0.97a	1.47b	0.67d	0.18a
	LA	10.48c	0.85a	1.71a	0.75c	0.15ab
	MC	11.79b	7.63b	1.73a	0.83ab	0.14ab
	LA+MC	10.00c	6.62c	1.87a	0.99a	0.13b
	AA	11.60b	6.17c	1.78a	0.86bc	0.10b
	Mean (10Y)	11.53b	8.45b	1.71a	0.82a	0.14a
CD at 5%	Fallow (F)	0.53	0.45	0.03	0.01	NS
	Treatment(T)	0.84	0.71	0.05	0.02	0.01
	FxT	1.19	1.00	0.07	0.03	NS

4.5. Impact of burning and length of fallow phase on *jhum* soil quality

Soil analytical data (chemical and biochemical parameters) generated from objective-I was used as early indicators of soil biological quality. From the AMOEBA diagram plotted with normalized soil quality indicator parameters, observations recorded are presented as below –

4.5.1. Burning and fallow length induced changes in soil attributes relative to adjacent reserve forest

The per cent variations of soil quality indicator parameters under burnt and unburnt situations scaled to 100% of the values detected in the adjacent reserve forest are depicted as AMOEBA Fig 4.5. and 4.6. Out of 16 indicator parameters considered, it was found that except BD, values of all the parameters decreased to varying extent below the 100% scaled values of the reserve forest site. The extent of decrease in SOC content and activity of DHA, PHA and PRO were the maximum in burnt sites compared to unburnt sites. The activity of AMY and ASA depleted to a greater extent in unburnt site compared to burnt site. The extent of increase in EC and Avl P on burnt site was more than the unburnt site. The change in BD in both burnt and unburnt site was more than the 100% scaled values of the reserve forest site. The change in content of Avl N, MBC, MBN, MBP, GSA and pH did not vary to a great extent between the burnt and unburnt sites.

The impact of the length of the fallow phase on per cent variation of 16 soil quality indicator parameters either within burnt or unburnt situation was compared against the 100% scaled values of the adjacent reserve forest site and the data are presented as AMOEBA Fig 4.7. and 4.8 for Mizoram and Nagaland respectively. Values of all indicator parameters of fallow phase soils were within the 100% scaled values of the reference site except BD under unburnt situation and BD, pH and EC under burnt situation. The extent of changes in the activity of AMY, DHA, ASA, PHA and PRO were the maximum in F2 in both burnt and unburnt situations. The maximum extent of change in Avl N, SOC, EC, PHA, PRO, MBC, MBN and MBP was observed in F1 fallow followed by F2 and the least change in F3 with reference to the 100% scaled value of the reserve forest site. The extent of deviation of the per cent change in values of soil quality indicator parameters from the 100% scaled values of the reserve forest site was in the order of $F1 > F2 > F3$. The differences in such deviations among the three fallows were wider under unburnt situation and narrower under burnt situation.

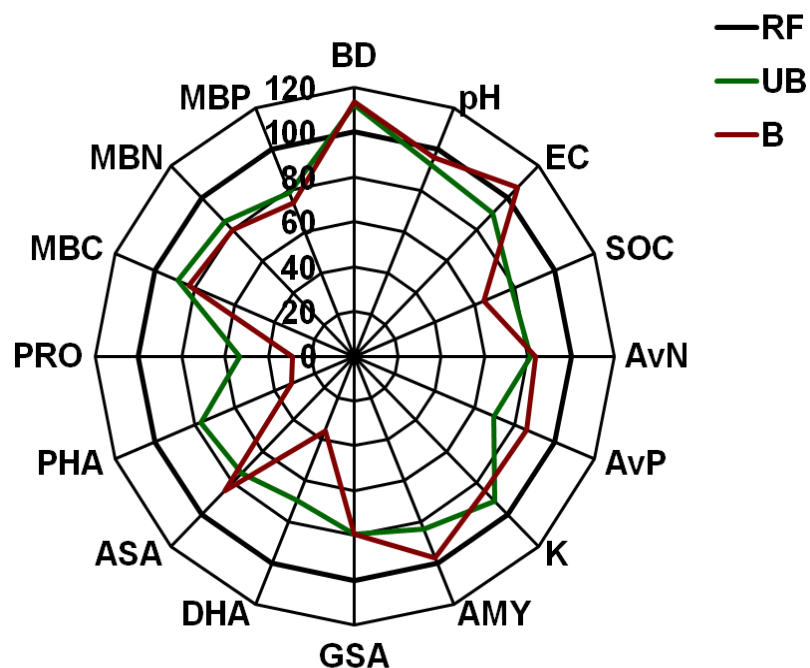


Fig 4.5. AMOEBA diagram showing percentage variation in soil indicator parameters at burnt (B) and unburnt (UB) sites scaled to 100% of the values detected in the adjacent reserve forest site (RF) of **Mizoram**.

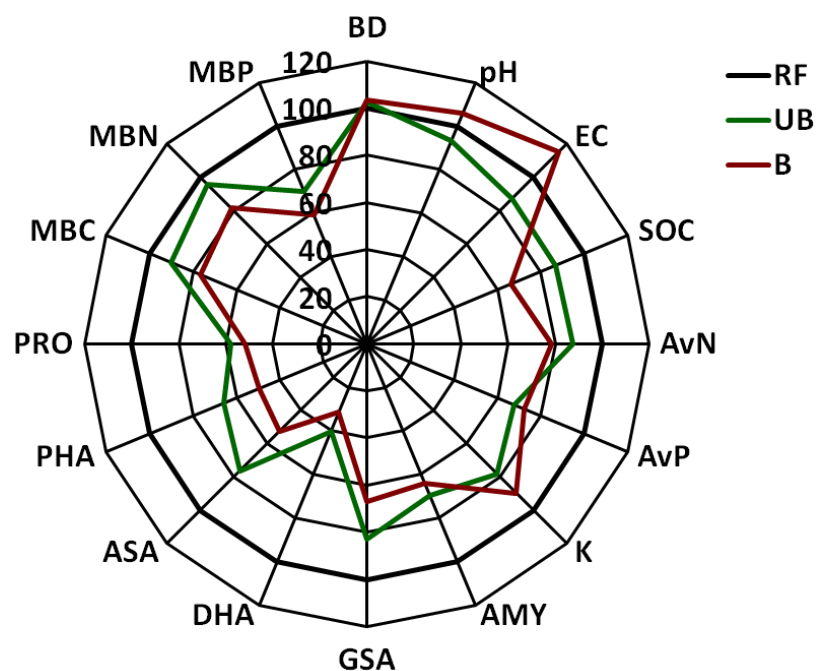


Fig 4.6. AMOEBA diagram showing percentage variation in soil indicator parameters at burnt (B) and unburnt (UB) sites scaled to 100% of the values detected in the adjacent reserve forest site (RF) of **Nagaland**.

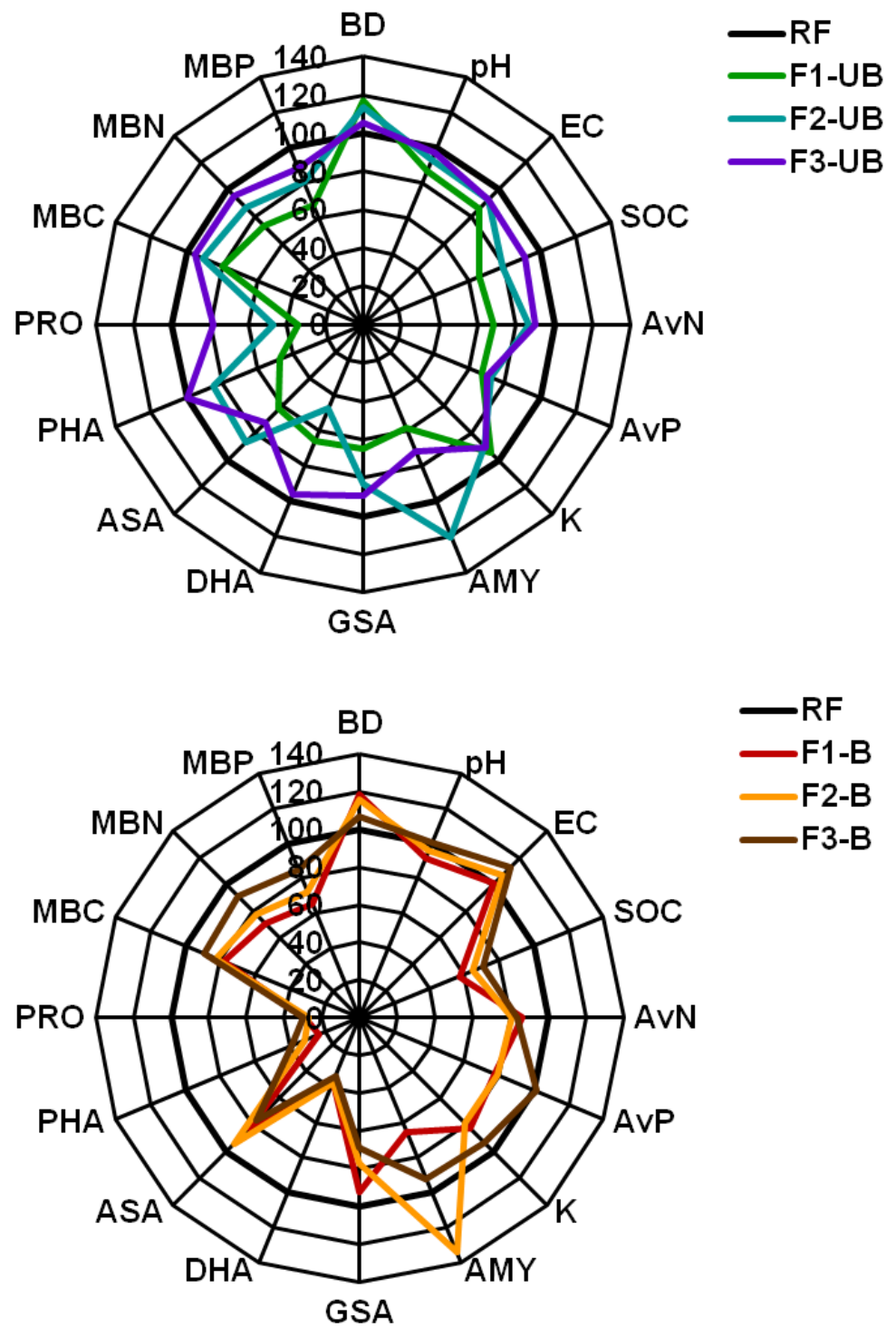


Fig. 4.7. AMOEBA diagram shows the percentage variation in soil indicator parameters at different fallow periods (F1 – 5 yr, F2 – 10 yr and F3 – 15 yr) under burnt (B) and unburnt (UB) sites scaled to 100% of the values detected in the adjacent reserve forest site (RF) of **Mizoram**.

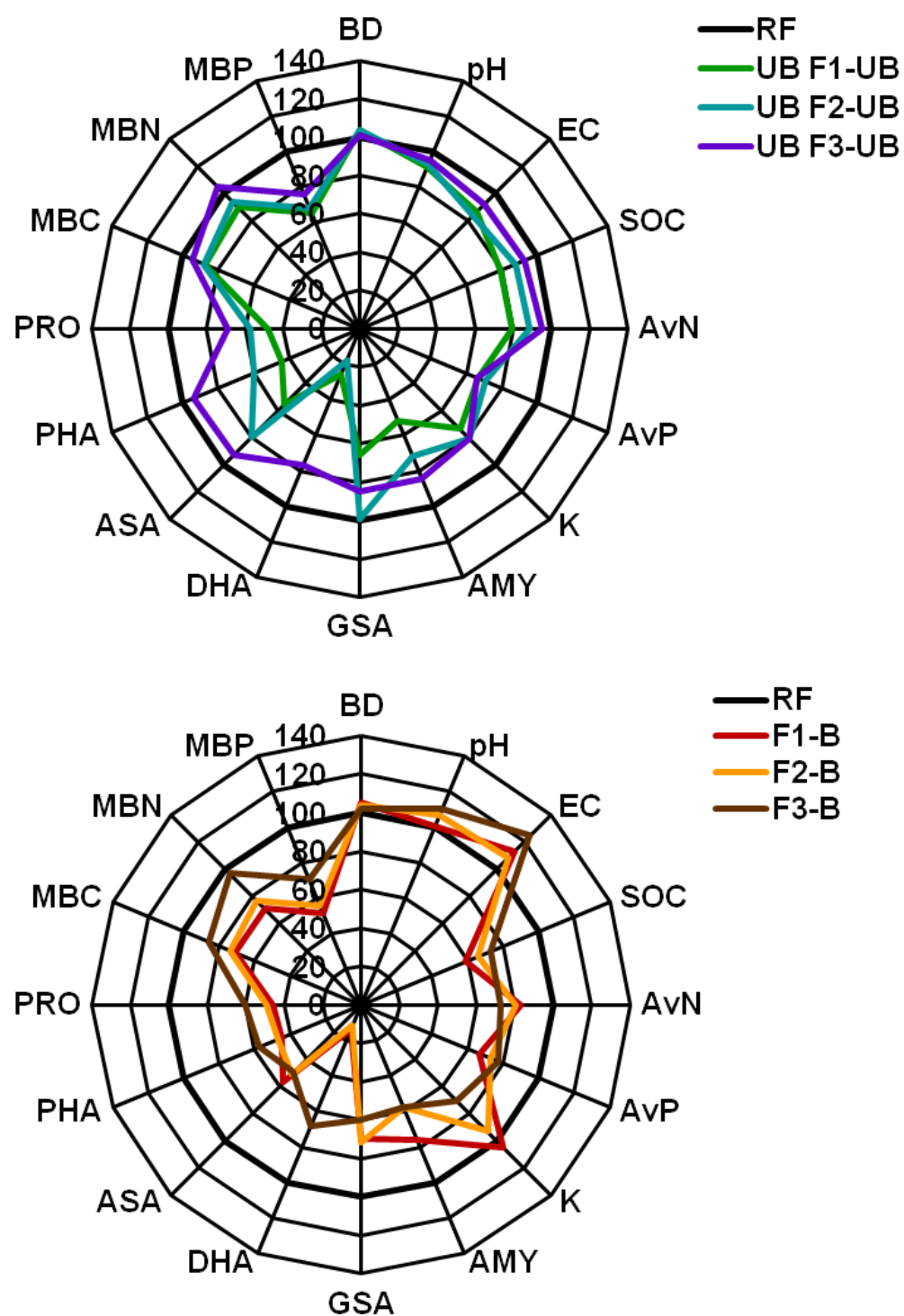


Fig. 4.8. AMOEBA diagram shows the percentage variation in soil indicator parameters at different fallow periods (F1 – 5 yr, F2 – 10 yr and F3 – 20 yr) under burnt (B) and unburnt (UB) sites scaled to 100% of the values detected in the adjacent reserve forest site (RF) of Nagaland.

4.5.2. Soil Quality index (SQI)

The indicator values used for constructing AMOEBA diagram were used to generating histograms by averaging the factorial deviation from the reference value (adjacent reserve forest). It was observed that the soil quality indices of unburnt situations were higher than that of burnt situations in both Mizoram and Nagaland (Fig. 4.9). In unburnt condition, the SQI values of F1, F2 and F3 were significantly different from each other in both Mizoram and Nagaland. In Mizoram, the values obtained were 68.14, 82.38 and 88.41 in F1, F2 and F3 respectively while in Nagaland, the values were 66.61, 73.33 and 86.77 in F1, F2 and F3 respectively. However, in the case of burnt situation, the SQI values of F1 have differed from F2 and F3 but in between F2 and F3, the difference was non-significant (Fig. 4.9). In burnt situation of Mizoram, the values were 68.85, 72.37 and 74.47 for F1, F2 and F3 respectively while in Nagaland, the values were 64.58, 67.26 and 72.15 for F1, F2 and F3 respectively.

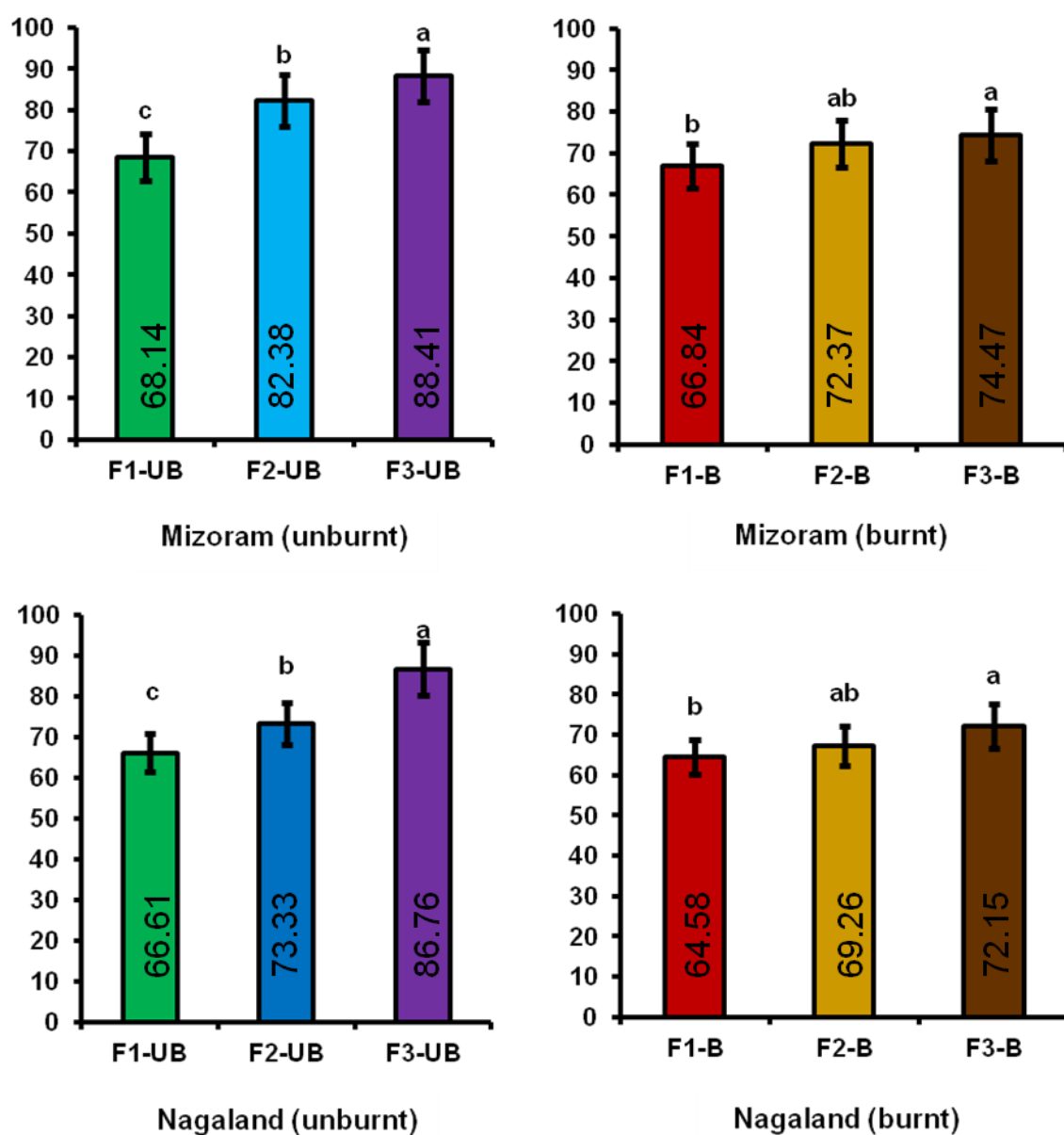


Fig. 4.9. Fallow period-wise Soil Quality Index (SQI) determined using the average factorial deviation from the values of soil indicator parameters of different fallow periods relative to reserve forest sites.

Chapter- V

DISCUSSIONS

Chapter-5

Discussions

The fallow phases of varying ages of *jhum* cycles stand to exist as a living example for scientific exploration in understanding the impact of fire on nutrient cycling processes that drives through the interactions of plant community succession and soil biota community shifts. The regenerated plant biomass of the secondary forest stand (fallow phase) that has accumulated over time seems to play key role in restoration of ecological soil functions of *jhum* lands. It is expected that the varying degree of relationships in the pattern of accumulation of forest floor litters, the release of locked nutrients within biomass and microbiologically induced biochemical reactions in *jhum* soils upon burning may exist depending on the length of the fallow phase. Besides, it is still unclear whether the composition and quality of litter falls of different fallow phases are related to the availability of nutrients and activities of enzymes in *jhum* soils. There is still lack of scientific evidences on understanding such relationship especially in *jhum* agroecosystem. An understanding of the impact of fallow length phases on the nutrient cycling potentials in *jhum* soils is pertinent for formulating sustainable nutrient management practices for enhancing *jhum* productivity.

Fire-induced alterations on soil reaction and nutrient availability, soil biota community and above-ground and below-ground linkages may contribute to abiotic and biotic stresses in *jhum* crop production during cropping phases. However, it is difficult to determine/interpret such cumulative stresses during cropping phase of a *jhum* cycle. In an attempt to evaluate such cumulative stresses associated with *jhum* crop production system belong to varying length of fallow phases, the observation on the physiological stresses of a *jhum* crop is considered to be meaningful. Moreover, microbial inoculation is also an important strategy in eco-restoration processes of any degraded ecosystem. The burning practice is believed to be negatively impacting the microbial functioning in *jhum* soils. The degree of negative influence of burning on microbial functioning may vary according to the length of fallow phases. Thus, the study on the response of microbial inoculation to crop growth and development in *jhum* soils may provide an important clue in mitigating physiological stresses of *jhum* crops. Another aspect of sustaining *jhum* agroecosystem is the management of *jhum* soil quality. Cultivation on slashed and burned secondary forest land under tropical humid climate may rapidly diminish soil quality as the ecologically sensitive components may not be able to buffer the induced detrimental effects of *jhum*

practices. There is every possibility that the quality of *jhum* soils may be differentially influenced by slashed and burned activities according to the length of the fallow phases. The land-use-induced changes on soil quality in *jhum* agro-ecosystems according to the length of the fallow phase have not been studied previously.

In light of the above discussed points, it is essential to glean scientific facts on how inherent ecological factors as well as anthropogenic disturbances of *jhum* cycles play defining roles in nutrient cycling processes and functioning of *jhum* soils. So, the objectives of the present study were four folds: (1) determined plant litter accumulation and soil enzyme activities in different *jhum* cycles, (2) studied the effect of plant litter types on soil processes in microcosms of different *jhum* cycles, (3) compared the effects of microbial consortium, litter- and ash-amendments on growth and development of *jhum* rice, and (4) developed soil quality index of different *jhum* cycles under natural farming situations. The experimental findings of above four objectives are discussed hereunder as follows:

5.1 Characterisation of forest floor litters (FFLs) of *jhum* fallow phases

The distinctive scenario of Northeast India depicts a diversified forest ecosystem that yields immense variety of forest floor litters and upon which variants of *jhum* activities take place. The intimacy of these *jhum* farmers to this fragile ecosystem would rightly be portrayed only when the quanta of litter loads released are well understood during the fallow phases of *jhumming*. Considerable variation in the total amount of accumulated biomass were reported across the world wherein 4 years fallow length can lead to biomass accumulation of 56.1 t ha⁻¹ in the tropical area of south-west Côte d'Ivoire (Van Reuler and Janssen, 1993), 6.2 kg m⁻¹ in 8 years fallow period (Thomaz *et al.* 2014) while in a 10 years fallow period it ranges from 48 to 160 t ha⁻¹ (Juo and Manu, 1996) and in 20 years it was reported to be 117.4 t ha⁻¹ (Van Reuler and Janssen, 1993). All these findings directed towards a positive relation with the present observation of litter accumulation with respect to length of fallow period. In the present study, the quantity of accumulated FFLs increased with the increasing length of the fallow phase. The annual accumulation pattern of litters from Mizoram and Nagaland during the study period showed a similar trend with the previous observation in Northeast India where a total litterfall of 547.7 g m⁻² yr⁻¹ was recorded in oak dominated forest of Manipur (Pandey *et al.*, 2007). Seasonal variation in the rate of litter accumulation was in concurrence with Pandey *et al.* (2007) who cited that the litter fall was distinctively seasonal and two-third amount of total annual litter fall was accumulated during December to March. Scherer-Lorenzen *et al.* (2007) observed that litter

production usually increases with the onset of dry season and gradually declines till the wet season approaches.

The nutrients content of FFLs of *jhum* fallow phases from Mizoram and Nagaland reflected the successional pattern of secondary forest stand with different types of aboveground biomass that inhabits within. Different types of litter get accumulated in course of time depending on the length of fallow phase. The type of litters differed significantly as the secondary forest type changes in succession. Thus, species diversity in the secondary forest has been a main factor causing differences in nutrient contents (Rai and Proctor, 1986; Kavvadias *et al.*, 2001; Lawrence and Foster, 2002; Sariyildiz and Anderson, 2005, AESL, 2015).

It is evident that shorter fallow length phases harbour smaller shrubs and lower plants. Their efficiency in converting light energy to carbohydrates would be very less as compared to a thickly foliated, matured secondary forest (Chapin *et al.*, 2002). It is also a known fact that there is a faster growth rate of plant species in the younger fallow phase while competing among each other to thrive luxuriantly. In such situation, carbohydrate concentrations in plants are least when rapid growth of the plant species occurs (Chapin, 1991), thus linking a possible cause for lower carbohydrate content in shorter fallow phase which then gradually increased with time in longer fallow length. Cellulose being the most abundant chemical constituent of leaf litter happens to constitute for a major biochemical pool of C cycling in soil. The age and type of biomass in the different fallow phases can also be a reason for variation in the cellulose content of the forest floor litters (Coûteaux *et al.*, 2002). The content of cellulose of FFLs was found higher in longer fallow phase as compared to that in shorter fallow phase in *jhum* cycles of Mizoram and Nagaland. Higher cellulose content in most of the fallow site could also be seen because of many bamboo species which was earlier reported by Li, (2004). Cellulose content in softwoods is also usually less (33-42%) as compared to 38-51% in hardwoods (Sjöström, 1993). A close relation exist between the cellulose and hemicellulose in leaf litters where their content ratio remained invariably constant (Sariyildiz and Anderson, 2005). The content of hemicellulose in the leaf litter of *jhum* fallow is also therefore expected to vary according to the cellulose content of these litter samples. In this study the contents of cellulose and hemicelluloses in FFLs showed a significantly positive correlations ($r = 0.69^{**}$ at $n-2=58$). The lignin contents in FFLs of 15 years and 20 years fallow phase of Mizoram and Nagaland, respectively were also higher compared to that in shorter fallow phase (5 and 10 years), which may be due to the presence of bigger lignified tree species in older fallow phase. Forest floor litters of such longer fallow consisted of not only tender leafy parts but harder twigs and fallen debris of tree trunks. Higher lignin content of leaf litters are therefore expected in older fallows which have more matured plant and tree species as reported by Pettersen (1984). The gradual

increase in the pectin content of FFLs with the increasing length of the fallow phases in both Mizoram and Nagaland could be explained by the accumulation of pectic substances during the secondary regrowth of the biomass in course of time as highlighted by Yavitt and Williams (2015).

5.2 Comparative physico-chemical and biochemical properties of burnt and unburnt soils of *jhum* fallow phases

The burning event as well as the length of the fallow phase caused variations in the physico-chemical attributes of *jhum* soils. Past findings have revealed differing evidences on nutrient availability status in different fallow phases (Giardina *et al.*, 2000; Kavvadias *et al.*, 2001). The role of organic matter cannot be ignored as it consequentially affected different physico-chemical attributes of the soil. Burning activities have reduced the organic matter content from the secondary forests which were found to reduce the bulk density (Alegre and Cassel 1996; Granged *et al.* 2011; Biswas *et al.*, 2012). Soil BD has also decreased with increasing age of secondary forest and which could probably due to the accumulation of organic matter (Gupta *et al.*, 2010). Similar observation of decreasing BD with increase in age of secondary forest was reported by Jia *et al.* (2005). Rise in pH after burning was more prominent in acidic soils than in alkaline soils and was reported to be contributed by loss of OH, oxide formation and release of alkaline cations like Ca, Mg, and K (Certini, 2005). Increasing pH with increasing length of fallow phase as well as increase of pH with burning activity were reported in recent years (Dikici and Yilmaz, 2006; Terefe *et al.*, 2008; Granged *et al.*, 2011; Kulmala *et al.*, 2014). Our results also corroborated these past findings. Results from this study also indicated that EC of the soil has increased immediately after burning. Similar increment in EC was previously observed by Terefe *et al.* (2008) and Granged *et al.* (2011) when the soil was exposed to beyond 150°C. It was reported that the soil temperature raises up to 242°C± 10°C during burning of slashed biomass in *Jhum* fallows of NE India (Thakuria, 2015).

Decrease in SOC content after burning has been vividly described in the past (Nye and Greenland, 1960; Fernandez *et al.*, 1997). Alteration in SOC content can be accounted for higher topsoil temperature (242°C± 10°C) during burning that causes burning of FFLs leading to limited incorporation of litter materials in burnt plots (Tinker *et al.*, 1996). Findings indicated that the content of SOC increased with the increase in the length of fallow phase and the differences in SOC contents among fallow phases were significant. Tinker *et al.* (1996) reported that during the fallow phase of shifting cultivation, the carbon status increased with the length of forest succession and that after a sufficient longer period, the site could nearly regain its original status. At temperatures above 300°C, soil organic N is

lost during the thermal oxidation of organic matter in the form of oxidized N gases and N₂ (Raison, 1979). The content of NO₃-N has a declining trend after burning (Ramakrishnan and Toky, 1981). In this study, soil Avl N content decreased with the increasing length of the fallow periods. Past findings indicated that burning activity decrease the content of soil Avl N, but as the fallow length increases available N tends to increase gradually (Neff *et al.*, 2005; Xue *et al.*, 2014). Depletion of N from the topsoil can also be attributed to leaching loss caused by heavy monsoon rainfall and absorption by fast sprouting weed species (Wallbrink *et al.*, 2005), which is a common phenomenon in *jhum* fields across Northeast India. Loss of nitrogen at temperature as high as 100°C was reported by DeBano *et al.* (1979), which in the case of conventional *jhumming* usually exceed this threshold temperature. Increase in the content of Avl P after burning is a common phenomenon in *jhum* scenarios across Northeast India. Recently, Adeyolanu *et al.* (2014) has also cited an increase of Avl P while studying a slash and burn situation in tropical rainforest of Nigeria. The increase in Avl P can be attributed to the incorporation of P from the slashed biomass in the form of ash as indicated by Raison *et al.* (1985). Ramakrishnan and Toky (1981) reported increase in P and K concentrations after burning as well as an increasing trend with increase in fallow length and summarized the phenomenon to be controlled by quantum of slashed and burned biomass of the above-ground plant species. Neff *et al.* (2005) have however reported about a mild shift in the K content after burning.

Senthilkumar *et al.* (1997) described about the greater amylase activity after burning of natural grassland from Southern India and that fire had greater impact on amylase than other enzyme activities studied (cellulase, invertase and phosphatase). The increased amylase activity in shorter fallow phases of Mizoram and Nagaland could be due to the highly diverse soil microbiota community. Recently, Thakuria and Sharma (2014) reported approximate 2 time higher prokaryotic diversity in 5 yrs fallow phase than that of 20 yrs fallow phase in Nagaland based on the whole metagenomic survey. This might be supported by diversified aboveground plant species in early succession stages, which is closely related to the findings of Anjaneyulu *et al.* (2011). The different rates of sulphur immobilization at different fallow length as well as the difference caused by burning could be a reason for change in ASA activity and similar result was also reported by Vong *et al.* (2003). Other reasons that could be attributed for change in ASA activity are change in pH (Acosta-Martínez and Tabatabai, 2000) and the types and amount of organic matter content (Sarathchandra and Perrott, 1981). Ajwa *et al.* (1999) reported on the decrease of DHA after burning which was similar with the present finding. Wolińska and Stępniewska (2012) in their studies also opined that as DHA has close linkage with the dynamics of microbial activity and therefore would get reduced after burning where oxidoreductive microbial population is low. Decrease in GSA activity was reported to decline for over a month after

burning (Ajwa *et al.*, 1999). López-Poma and Bautista (2014) reported a decline in GSA activity for over a year after burning. In another observation at Southern Ohio, USA, the activity of GSA has decreased with the increase in frequency of fire while comparing with unburnt plots of oak-hickory forest (Boerner and Brinkman, 2003). The finding of the experiment was also in synchrony with these above mentioned findings. The activity of PHA in unburnt soils may have been less due to the increase in deficiency of P-stressed conditions. The increase in PHA activity in longer fallows can also be attributed to the load of enzymes secreted from the root zones of the standing biomass which was also depicted by Mudge *et al.* (2002). López-Poma and Bautista (2014) in their studies on the effect of fire to enzymes in Eastern Spain have found that the activity of acid phosphatase continued to decrease for over a year after burning. Ajwa *et al.* (1999) has also reported on the decrease of PHA after burning. Boerner *et al.* (2000) has also described that burning has reduced the acid phosphatase activity. The activity of phosphatase enzyme is involved in P-cycling and has also been reported to be governed by soil microclimate, SOC and the availability of P in the soil (Hamman *et al.* 2008). However, Oseni *et al.* (2009) did not find any change in the proteolytic activity while comparing unburnt and recently burnt plots of teak plantations in Nigeria. Yuan and Yue (2012) found that the activity of protease has peaked up linearly in a plantation forest in a succession pattern of 3 years>7 years>13 years>21 years> 28 years. Malcheva *et al.* (2015) also mentioned that the activity of PRO is reduced at higher temperature, which in our case is brought about by high intensity burning of biomass. The increase in PRO activity with increasing fallow length could be attributed to the accumulation of non cellulosic glucose in higher succession tree species which may have been lesser in composition in shrubs and taller grass species of shorter fallows. Similar proteolytic activity has been depicted by Adamczyk *et al.* (2014). Srilakshmi *et al.* (2012) while comparing littered forest soil with adjacent non-forest soil had the opinion that increase in PRO activity could be due to the availability of casein based substrates in the litter biomass, the prevailing low pH and abundance of proteolytic microbes in the soil.

Reduction in MBC and MBN caused by the after effect of burning was reported elsewhere (Prieto-Fernández *et al.*, 1998; Ajwa *et al.*, 1999; Swallow *et al.*, 2009; Liu *et al.*, 2010). Jia *et al.* (2005) reported that MBC and MBN increased gradually from the first year to the seventeenth year of secondary forest succession. Past findings indicated that many of the soil decomposer community would get reduced or totally die because of the burning effect (DeBano *et al.*, 1998; Malmström, 2012). The remaining species that may have survived would also be suppressed because of the sudden change in the environment like change in pH, temperature and the low soil moisture content (Zelles, 1997) which are outcome of the burning activities. Reduction in microbial activity may also be attributed to the loss of SOC and N after burning operations (Choromanska and DeLuca, 2002).

The disturbed *jhum* agroecosystem due to inevitable slash and burning practices gradually rejuvenate towards a stabilized state during fallow phases as the microbial community replenish the pools of C, N and P. Microbial biomass –C, -N and –P can act as a potential indicator of ecosystem aberration. Thus the stability of this fragile agroecosystem can be reflected by the microbial biomass C:N:P because it acts as labile sink in replenishing pools of C, N and P. The wider C:N:P usually depicts an N-deficient ecosystem as in the case observed in shorter fallow phase. Whereas, the narrower C:N:P was observed in the longer fallow phases indicating a progressive change towards N-sufficient condition. Establishment of diversified above-ground species (woody plants, epiphytes, bryophytes, lichens, moss, etc.) in older secondary forest stand is also a recognizable occurrence indicating about a more stabilized N-rich ecosystem. In general, an ideal agroecosystem maintains an average microbial biomass C:N:P ratio of ~50:6:1 (Smith and Paul, 1990) and the microbial biomass C:N:P in *jhum* agroecosystem found to range from 46:4.9:1 to 52:5:1.

5.3. Microcosm experiment-I: Impact of FFLs amendment on soil process indicators under burnt and unburnt situations of fallow phases

The microcosm experiment was conducted using soils from burnt and unburnt situations of 5 and 10 years fallow phases in order to mimic the actual field situations under controlled environment. This microcosm experiment was performed to study the impact of FFLs addition on soil processes.

The addition of FFLs of different fallow phases as amendment slightly increased pH in pot soils relative to the pH values in soils of field conditions (unamended control pot soil). In Bangladesh, Sarkar *et al.* (2010) also reported the increase in soil pH under the potted condition where ground leaf litters of different tree species were added as amendment in an experiment under red amaranth cultivation. The increase in pH after leaf litter incorporation was recently demonstrated by Ma *et al.* (2014) in Maryland, USA. However, the types of FFLs added as amendment either in burnt or unburnt soils didn't cause notable changes in soil pH.

Although the individual as well as interaction effects of burning and length of fallow phase was clearly visible on EC of *jhum* soils, the effect of FFLs additions on EC couldn't be ruled out, which was evident from the results of the microcosm experiment. The reduction in EC of pot soils was prominent while comparing the values of EC between control and FFLs amended soils. Such observations of reduction in EC of soils after leaf litter amendment was demonstrated in forest soils of Iran after addition of Iron wood leaf litters (Parsakhoo and Jalilvand, 2009).

Increase in the content of SOC in FFLs amended soils compared to unamended control soil can probably be asserted to the addition of comparable amounts of FFLs. Such increase in SOC from 1.22% to 2.53% after application of leaf litters were also observed in Bangladesh (Sarkar *et al.*, 2010). Augmentation in the content of SOC through leaf litter addition and decomposition was demonstrated recently in Italy where litters from secondary forest successions increased the SOC of abandoned agricultural land from 1.5% to 1.9% in the top soil layer and from 1.4% to 1.7% up to a depth of 15 cm (Novara *et al.*, 2015). Issac and Nair (2002) also confirmed that increase in SOC due to addition of addition of jack leaf litter. Interestingly, the types of FFLs differentially impacted the SOC content in amended soils. The increase in SOC content was significantly higher in 15 yrs FFLs amended soil. The lignin content of FFLs from 15 & 20 yrs fallow phase was more as compared to FFLs of shorter fallow phase i.e. 5 and 10 years fallow phase and this may be the cause for lesser decomposition leading to more accumulation of SOC in amended soils.

Likewise, addition of FFLs showed differential effect on the availability of soil N. The content of Avl N decreased in FFLs amended soils compared to unamended control soil and the extent of decrease of soil Avl N content increases with the increasing complexity of the FFLs i.e. complexity of FFLs increases with the increasing fallow length. It is well established that addition of leaf litters activates the resident soil microbial community and trigger the decomposition process. With the more complex FFLs the rate of immobilization of soil Avl N also more and this may be the probable cause of decreasing trend of soil Avl N in FFLs amended pot soil.

Findings of this study clearly indicated that soil Avl P content was significantly altered in both unburnt and burnt situations. There was significant increase in Avl P content in FFLs amended soils under burnt situation whereas significant decrease under unburnt situation. Such variable response of soil Avl P to FFLs additions might be due to net P immobilization under unburnt situation and net P mineralisation under burnt situation. Sarkar *et al.* (2010) also noticed that soil Avl P content invariably changes to increase with the incorporation of different types of litters.

Higher content of Avl K in FFLs amended soils of both burnt and unburnt situations was also evident and could be correlated with the potassium contents in the FFLs. Parsakhoo and Jalilvand (2009) also observed higher Avl K content due to addition of iron wood leaf litters in forest soils of Iran. Sarkar *et al.* (2010) has highlighted about such increase in potassium content in leaf litter amended soils as compared to untreated ones. Two to three times increment in potassium content after addition of pine needle litters was also reported elsewhere in Canada (Nevzat *et al.*, 2003).

The interactive effect of burning and length of fallow phase enhanced the Ca and Mg content in FFLs amended soils relative to unamended soils. The increase in

contents of Ca and Mg after burning and concomitant increase with the increasing fallow length corroborates the findings of Talukder *et al.* (2013) and Gafur *et al.* (2004) in same *jhumming* scenarios of Chittagong hill tracts of Bangladesh. It may be comprehended that the amount of ash produced from the burnt biomass of different fallows had effects on the change of magnesium content in the soils after burning which was earlier depicted by Kim *et al.* (1999) during their studies on short term effect of fire on pine forest stands of Korea.

The increase in the activity of AMY with increase in fallow length was in accordance with the findings of Haripal and Sahoo (2013) who reported an increase in AMY activity while studying impact of conversion of forest land to agricultural lands of Odisha, India in a chronosequence of 2 year, 4 year, 6 year, 11 year and 15 year. The types of litter incorporated in the soil also had variable impact on the AMY activity and similar observations were reported in Eastern India too (Mukhopadhyay *et al.*, 2014). The general trend of increasing SOC with the increase in fallow length (Aguilera *et al.*, 2013) could give a possible answer for the increase in AMY activities. These free extracellular enzymes increases their activity with the increase in SOC content (Miller and Dick, 1995). Therefore increase in AMY is also expected in 10 years old fallow as compared to 5 years old fallow.

The present finding reflects not only an increase in the activity of ASA in FFLs amended soil relative to unamended soils under both burnt and unburnt situations but also an increase in ASA activity with the amendment of FFLs of longer fallow length. The activity of ASA has also been correlated with the amount of microbial biomass (Klose and Tabatabai, 1999) and it is observed that longer fallow has more ASA activity which is expected because of the greater amount of litter accumulation. Positive correlation between aryl-sulphatase and SOC has also been described by Deng and Tabatabai (1997). As such ASA activity has increased in longer fallow period than that of shorter fallow period.

DHA activity was found to increase after FFLs amendment in a microcosm experiment conducted by Li *et al.* (2014) in Southern China. Similar results were also obtained from the present investigation where FFLs of longer fallow length supported higher activity of DHA. These results corroborate the findings of Haripal and Sahoo (2013) who reported an increase in DHA activity while studying impact of conversion of forest land to agricultural lands of Odisha, India in a chronosequence of 2 year, 4 year, 6 year, 11 year and 15 year.

The results from the microcosm experiment of Li *et al.* (2014) in Southern China indicated that the activity of GSA increased with the addition of leaf litter. Increment in GSA activity was observed in the present study too where different types of litter had differential effects. The action of fire has increased the activity of GSA in the soils of the microcosm experiment. However, Eivazi and Bayan (1996) found that the GSA activity did not change in oak-hickory forest of Missouri after periodic and annual burning. Activities of

GSA is also known to increase with the increase in SOC as was described by Miller and Dick (1995) and such increase in SOC could be brought about by the incorporation of forest floor litters in the soil. Evidently, increase in GSA was prominently visible in FFLs amended soils.

There was decrease in the activity of PHA after burning which was similar to the experiment conducted in oak-hickory forest of Missouri (Eivazi and Bayan, 1996) where burning has reduced the PHA activity. Burning would have increased the available P content in soil and activities of PHA getting reduced as was previously described by (Baldwin *et al.*, 2001) where P stress condition evokes the terrestrial plant to signal PHA enzymes from the roots.

The activity of PRO has been correlated with the amount of moisture content in the soil (Dilly and Munch, 1996). It is expected that burning would extensively reduce the soil moisture content. Under such situation of moisture stress, the PRO activity is also expected to be reduced. Protease activity is known to take part partly in the soil as humo-carbohydrate complex of forests and grasslands (Nannipieri *et al.*, 1980) and such activities were evidently found in the present experiment too with respect to fallow length and litter types incorporated.

The interactive effect of burning and length of fallow phase enhanced the MBC, MBN and MBP in FFLs amended soils relative to unamended soils. The increase in contents of MBC, MBN and MBP after burning and concomitant increase with FFLs of increasing fallow length corroborates the findings of previous studies (Chen *et al.*, 2006; Jiang *et al.*, 2009; Li *et al.*, 2014). Li *et al.* (2014) conducted a microcosm experiment in Southern China with four types of leaf litter amendments on soils and showed difference in MBC which gradually got narrower as the period of amendment increases and these values were higher than controlled conditions. MBN and MBP had followed similar pattern which could also be attributed to the amount and type of biomass content in forest floor detritus. The increase in MBN was also observed in secondary vegetation succession in semiarid abandoned lands of Loess Plateau of China (Jiang *et al.*, 2009). The dependence of MBC, MBN and MBP on soil organic matter in the soil was shown earlier by Chen *et al.* (2006). Increase in the amount of MBC, MBN and MBP with the types and amount of litter incorporated could also be correlated with the SOM contributed by these leaf litters and the microbes working on it.

The reduction in pMN in the burnt soils of the pot experiment may be explained by a previous finding which has also indicated about reduction in pMN after wildfire in pine forest of Oregon state, USA (Choromanska and DeLuca, 2001). The observation that litter addition enhances the pMN in the pot soils holds true with the findings put forwarded by Wang *et al.* (2014) who studied the leaf litter addition in sub tropical soils of Hunan province of China.

Li *et al.* (2014) found that the soil respiration in terms of CO₂ evolution in soils treated with different leaf litters in Southern China remained more or less same at the initial time scale of observation. Similar results were found in the experiment at different litter treated soils.

5.4. Microcosm experiment-I: Impact of FFLs amendment on *jhum* rice physiology under burnt and unburnt situations of fallow lengths

The physiological traits that have been imposed by the types of fallow periods as well as by the differences in burnt and unburnt situations have varying effects. Short term availability on nutrients brought about by burning of biomass seems to modify the physiological characteristics of the rice plant under study. It has been a well known established fact that under adequate moisture and nutrient supply, plants do not need to modify their belowground appendages in order to scavenge for food. Under limited supply of essential nutrients, plants undergo immense modifications in the root zone hampering the vegetative as well as reproductive growth (López-Bucio *et al.*, 2003).

The addition of FFLs amendment produced varying effect on *jhum* rice physiology depending on burnt and unburnt situations. *Jhum* rice exhibited better adaptive fitness against stresses due to FFLs amendment in burnt soils as compared to unburnt soils. This was evident from the results of lower MDA, higher membrane stability (expressed in terms of % electrolyte leakage), higher contents of chl-b and lower carotenoid content in rice plants grown under FFLs amended soils as compared to that in unamended soils.

Root morphological characteristics greatly affect the acquisition of nutrients from the soil by plants (Sattelmacher *et al.*, 1993). Primary root growth has been known to increase with the increase in the availability of phosphorus (López-Bucio *et al.*, 2003). Phosphorus deficiency has also been depicted to change the root morphology by formation of root hairs (Gahoonia and Nielsen, 1998) and growth of secondary hair roots (Sun and Zhang, 2000). Ma *et al.*, (2001) has also shown that there is increase in root hair elongation as well as increase in root hair density up to five times in P-deficient condition. High NO₃ concentration has also been seen to reduce the lateral root elongation throughout the root system of *Arabidopsis*. SO₄²⁻-deprived roots of *Arabidopsis* has also been depicted to exhibit branched root system (Kutz *et al.*, 2002). Such morphological changes viz. RL, RSA, RD and RV evident in the experimental findings reflects that certain nutrients like phosphorus affects the root morphology which increases with burning of slashed biomass as well as the length of fallow period too.

Past findings have indicated that chlorophyll-a and chlorophyll-b are vulnerable to dehydration (Farooq *et al.*, 2009).

Abiotic stress in the rice plant expressed as the amount of melondialdehyde accumulation has greater impacts on shorter fallows as well as in unburnt conditions. Possible reasons that could be related to such phenomenon would be the physical characteristics of the soil. Shorter fallow length soils would accumulate less organic matter as compared to longer fallow length (Ramakrishnan and Toky, 1981). Organic matter tends to increase the water holding capacity of the soil leaving more pore spaces for water molecules to be retained (Brady, N.C., 1990). Jia *et al.* (2005) has found a decreasing bulk density (1.44 g cm^{-3} in one-year secondary forest to 1.16 g cm^{-3} in seventeen-year secondary forest) with increasing age of secondary forest. Moreover, differences in the intensity of burning and the time of combustion as stated by Neary (1999) at different fallows due to the amount of biomass accumulated could have alterations in bulk density at different fallows (Pantami *et al.*, 2010). Moisture content in the soil in such situation would possibly vary showing stressed conditions according to the length of fallow period and burning situations.

Fallow length and the effect of burning had shown positive impact on the grain yield. Although different treatments had shown different results, longer fallow period has encouraged higher yield in general. Comparable positive correlations between fallow length and yield have also been reviewed earlier (Silva-Forsberg and Fearnside, 1997; Brunn *et al.*, 2006).

5.5. Microcosm experiment-II: Impact of addition of FFLs, microbial consortium and ash amendments on soil processes

The effects of litter amendment (LA), microbial consortium (MC), LA+MC, and ash amendment (AA) in 5 years and 10 years burnt soils on soil chemical, biochemical and rice stress physiology were studied under microcosm experiment. Findings clearly indicated the positive response of application of LA, MC and ash amendment in improving the chemical and biological properties of burnt soils and reducing stress impacts on rice physiology. Further, such positive responses were more prominent in 10 years burnt soils compared to that in 5 years burnt soils. Among these inputs, the highest positive influence was exhibited by AA application in terms of chemical properties, by LA+MC application in terms of biochemical properties and rice stress physiology. The positive impacts of LA on soil physic-chemical and biochemical properties were discussed thoroughly in previous section for Microcosm Experiment 1. The positive impacts of MC in improving nutrient cycling processes of burnt soils are: (i) IAA production, (ii) P solubilisation, (iii) pectinase and cellulose activities, and (iv) N_2 -fixation. Besides, the members of the MC are native to *jhum* soils and are well adapted to burnt soil condition as evident from their ability to heat

tolerance and acidity tolerance. Thus, application of this MC could provide adaptive benefit to rice plants against environmental stresses associated with *jhum* soils (Thakuria, 2015). The effect of ash amendment was incredibly higher in changing the pH which is supported by the findings of Arunachalam (2002) who also found increase in pH after burning which can be attributed to the ash load incorporated due to burning. Increase of Avl P content in ash amended soils could be due to its effect in augmenting the availability of phosphorus as reported by Joachim and Kandiah (1948). Former studies have also seen that about 27 kg ha⁻¹ phosphorus can be provided by the ash from 10 year forest fallow (Nye and Greenland, 1960). As observed earlier by Chidumayo (1987), results from the experiment showed that the concentration of potassium and exchangeable cations has been increased to a great extent by ash application.

5.6. Microcosm experiment-II: Impact of addition of FFLs, microbial consortium and ash amendments on stress physiology of *jhum* rice

Allelopathy is an eminent phenomenon that can take place in FLL amended soil. Studies in plant physiology have pointed out the effect of these litter amendment on certain crops which includes rice too (Jadhav and Gaynar, 1995; Djanaguiraman *et al.*, 2005). Physiological effects such as retardation in plumule and radical growth, inhibition in shoot length, reduction in contents of chlorophyll, etc. can take place in such environment. Such interference can be expected in *jhum* soils amended with FFLs undergoing rapid biochemical transformations leading to release of allelochemicals. Recent researches have confirmed that leaf litter contributes to be the major driver in bacterial community composition (Pfeiffer *et al.*, 2013). The effectiveness of microbial inoculation in the soil through microbial consortium could greatly depend on the type of FFLs amended. The above inter-linkage between the forest floor detritus and the microbial strains inoculated could well explain the results obtained from the experiments.

5.7. Impact of burning and the length of fallow phase on *jhum* soil quality

Altogether 16 soil attributes *viz.* BD, pH, EC, SOC, AvIN, AvIP, K, AMY, GSA, DHA, ASA, PHA, PRO, MBC, MBN and MBP were used as indicators of soil quality to compare the effect of either burning or lengths of fallow phase on overall quality index of *jhum* soils relative to adjacent reserve forest site. The effects of burning on per cent change in BD, EC, SOC, AvIP, AMY, DHA, PHA and PRO were more prominent in *jhum* cycles of Mizoram and Nagaland. Likewise, each of the 16 soil attributes responded differently according to the length of fallow phases. In a recent study, Wanshiong *et al.* (2013) reported

the notable response of soil quality indicators in relation to the influence of hill slope on biological pools of C, N and P in acidic alfisols of citrus orchard of North East India. Results on overall changes in soil quality indicated the higher SQI values (68%, 82% and 88% for F1, F2 and F3, respectively) under unburnt situations as compared to that (66%, 72%, and 74% for F1, F2 and F3, respectively) under burnt situation. Similar trend in SQI values were also found in case of Nagaland site. These findings clearly indicated that the rate of degradation of soil quality is more aggressive under burnt situation as compared to that in unburnt situation. With respect to the impact of length of fallow phases on *jhum* soil quality, the higher SQI values were in the order of $F3 > F2 > F1$ under both burnt and unburnt situations. Interestingly, the SQI values of three fallow phases were significantly different from each other under unburnt situation. Whereas under burnt situation, the SQI value of F1 fallow phase was significantly different from the SQI values of F2 and F3 fallow phases and the values of the later two were non-significant. The deviation in SQI values of fallow phases under unburnt condition relative to their adjacent reserve forest between F1 and F2 was 14% and F2 and F3 was 4% in unburnt situation. Similarly, in burnt condition the difference in SQI values between F1 and F2 was 6% and F2 and F3 was 2% only. These findings signify the fact that the combined impacts of burning and length of fallow phase lead to deterioration of soil quality in 5 year fallow length to a greater extent and eventually, this degree of deterioration gradually diminishes as the age of the fallow length increases (10 and 15/20 years). Soon after the cultivated land is abandoned, aggradation processes initiate and the rate of aggradation occurring at faster rates at the initial stage of forest succession. With the progress of secondary forest succession, the rate of aggradation processes slow down and reach a new state of equilibrium. After reaching the new state of equilibrium, the aggradation process nearly reach a plateau and allowing further aggradation process through secondary forest succession does not bring significant changes in soil quality. The finding shows a symptomatic stabilized equilibrium from 10 years fallow length onward although it does not attain the original state of equilibrium as observed from reference reserve forest. This trend in the aggradation process would prove useful in determining the maturity of secondary forest stands at which *jhum* cycles can be reverted.

Chapter- VI

SUMMARY AND CONCLUSION

Chapter –6

Summary and Conclusions

Understanding the importance of relationship among quantity and quality of biological inputs both above-ground and below-ground and the associated soil nutrient cycling processes has become one of ecology's primary goals in order to effectively maintain and sustain the functioning of an ecosystem especially agroecosystems which are under intense perturbations. *Jhum* agroecosystem is the unique blending of forest ecology and agroecology in the sense that the fallow phase represents the secondary forest succession and rejuvenation of soils while the cropping phase represents the primitive forms of agricultural practices involving slashing and burning of above-ground forest biomass and breaking the functional linkages with the below-ground counterparts. As such above-ground and below-ground linkages in *jhum* agroecosystem can be powerful mutual drivers, with both positive and negative impacts. Thus the impact assessment of *jhum* practices on soil biochemical processes as a reflection of the functioning of soil biota community and how the above-ground biological inputs like accumulated forest floor litters during fallow phase control over the functioning of soil biochemical processes were studied in this investigation.

Three *jhum* fallow phases from each of Nagaland and Mizoram were considered in this investigation. The accumulated forest floor litters (FFLs) in different fallow phases were quantified and characterized for the elemental and biochemical compositions. The effects of burning on soil physico-chemical and biochemical properties of *jhum* soils were assessed. Further, a set of four microcosm experiments was carried out using soils from burnt and unburnt situations of 5 and 10 years fallow phases of Mizoram to mimic *jhum* field situations under controlled environment and *jhum* rice was grown as test crop. The aim of this microcosm experiment was to assess the interactive effects of burning, length of fallow phase and type of litters (imposed treatments by adding litters from 5, 10 and 15 years fallow phases) on soil enzymes as indicators of nutrient cycling processes and the stress physiology of *jhum* rice as indicator of overall stresses of the production system. In another set of microcosm experiment, the effects of addition of litter amendment (LA), microbial consortium (MC) and ash amendment (AA) on the biochemical processes of burnt soils of 5 and 10 year fallow phases were studied. The effect of addition of LA, MC and AA on the physiological stresses of *jhum* rice were determined for understanding the potential roles of these inputs in ameliorating the overall stresses of the *jhum* soil. In order to surmise the overall impacts of burning and length of the fallow phases on the quality of *jhum* soils, a set

of soil quality indicator parameters were analysed for different fallow phases both under burnt and unburnt field conditions in Mizoram and Nagaland and the values of these quality parameters were compared against the values obtained from the adjacent reserve forest site (considered as reference site). The soil quality indicator values of reference site were scaled to 100% and the values of different fallow phases were compared for deviations relative to this 100% scaled values. Finally, the soil quality indices for each of the fallow phases both under burnt and unburnt situations were developed and compared.

The major findings under different objectives are summarized below:

The quantity of forest floor litter (FFL) accumulated in fallow phases increased significantly with the increasing length of fallow phase. Accumulation dynamics of FFLs showed an increasing trend in the order of the sampling months *i.e.* January > April > August > November. Chemical properties *viz.* N, P, Ca, Mg and Zn contents in FFLs varied significantly among fallow phases indicating maximum concentrations of these elements in the longer fallow phase. Results from biochemical composition of FFLs reflected that FFLs of longer fallow phase contain higher amounts of carbohydrate, cellulose, hemicellulose, lignin and pectin than that of shorter fallow phase.

Results of field survey revealed that the length of the fallow phase and associated burning practice had significant influence on soil BD and other soil chemical properties like pH, EC, SOC, Avl N, Avl P and Avl K. Soil BD and the length of the fallow phase maintained an inverse relationship and on the other hand all other soil chemical properties showed a positive relationship with the length of the fallow phase. However, the burning practice imposed a negative influence on the positive relationship of the length of fallow phase with SOC content and Avl N. Results of microcosm experiment-I revealed that the litter amendment had positive influence on soil properties and the addition of litter can retard the negative impact of burning on soil properties to a great extent. Interaction effects of burning and fallow phase were positive for EC, SOC, Avl N, Avl P, Avl K, Exch.Ca and Exch.Mg indicating the greater extent of benefits to soil properties upon burning biomass from longer fallow phase. These findings clearly stated that instead of frequent burning of biomass of shorter fallow phase, the less frequent burning of biomass of longer fallow phase is more beneficial in terms of improving physico-chemical properties including SOC status of *jhum* soils.

The findings of the field survey revealed that the length of the fallow phase and associated burning practice had significant influence on soil biochemical properties. The length of fallow phase maintained a significant positive relationship with the activity of GSA, DHA, ASA, PHA and PRO under both burnt and unburnt situations. However, the burning practice imposed a retarding influence on the positive relationship of the length of fallow phase and the activities of soil enzymes except AMY. Only for AMY, the relationship

between the activity of AMY and the length of phase was positive under unburnt situation and the relationship was negative under burnt situation. Results of microcosm experiment-I indicated that amendment of forest floor litters on fallow phase soils exerts strong effects on the activity of soil enzymes. For example, the activity of AMY, PHA and PRO reduced, the activity of ASA and GSA enhanced and the non-significant influence on the activity of DHA when compared between forest floor litters amended burnt and unburnt soils. The activity of AMY, DHA, PHA and PRO were significantly altered due to the interaction effect of burning x fallow phase. The activity of AMY, ASA, GSA, PHA and PRO were significantly influenced by the interaction effect of either burning x litter types or fallow phase x litter type. So, amendment of burnt and unburnt soils with the fallow phase dependent forest floor litters differing in elemental and biochemical compositions can not only alter the soil enzyme activities but also indicated a possible shift in the nutrient cycling processes. The negative response of MBC, MBN and MBP towards burning practice could be altered by amending the burnt soils with forest floor litters. This finding can be supported from the field survey data on microbial biomass that the longer fallow phase soil supports narrower C:N:P within microbial biomass and the shorter fallow phase soil supports wider C:N:P within microbial biomass.

Values of physiological stress indicators *viz.* lipid peroxidation, membrane integrity, Chl-a and -b, carotenoids in leaves and morphology of roots of *jhum* rice obtained from microcosm experiment-I hinted that burning of slashed biomass reduces stress in *jhum* rice plants significantly compared to that in unburnt soils. Moreover, forest floor litter amendment in both burnt and unburnt soils could reduced physiological stress in *jhum* rice significantly compared to unamended soils. The lesser degree of physiology stresser in *jhum* rice plant under litter amended soils burnt soils might be due to the higher availability of soil nutrients coupled with better state of biochemical activities in litter amended soils were the responsible factors.

Findings of the microcosm experiment-II revealed that LA, MC and AA could play critical roles in burnt soils in terms of their modifying effects on soil nutrient availability and nutrient supplying capacity. Amendment of LA along with MC could produce synergistic effects on nutrient cycling processes.

Values of SQI were greater in unburnt fallow phases than that in burnt fallow phases indicating a detrimental effect of burning on soil biochemical processes. SQI values were higher in longer fallow phase compared to that in shorter fallow phase indicating a supporting of longer fallow phase on the build up of overall soil quality.

In conclusion, this study clearly demonstrated that longer fallow phase supports not only higher quantity of accumulated forest floor litters but also maintain higher

soil nutrient availability and better state of C, N and P cyclings. Interaction effects of burning and fallow phase were positive for EC, SOC, Avl N, Avl P, Avl K, Exch.Ca and Exch.Mg indicating the greater extent of benefits to soil properties upon burning of biomass in the longer fallow phase. The process of biomass slashing and burning exerts negative impacts on the accumulation of forest floor litters and inherent capacity for cycling of C, N and P in soils. The positive influences of amending burnt soils with forest floor litters on soil nutrient availability and biochemical processes implied that maintaining the input flow of forest floor litters by allowing longer fallow phase could be a possible way of compensating the detrimental effects of burning. These findings clearly stated that instead of slashed biomass burning at frequent intervals, the less frequent burning in longer fallow phase is more beneficial in terms of improving physico-chemical and biochemical properties of *jhum* soils. It is conclusive that longer fallow phase with burning activities supports better crop growth with minimum physiological stresses to the plant. Judicious use of leaf litters along with native microbial strains as biological inputs can rejuvenate the biochemical and biological activities of *jhum* soils. The SQI values of different fallow lengths under burnt situation indicated that *jhum* soils seems to attain a new threshold limit of soil quality at an approximate 10 year fallow length, where SQI value was comparable with the SQI values of 15 year and 20 year fallows. It is believed that the findings of this investigation will help bringing together naturalists and agriculturalists to arrive at a compromise on the long pending debate whether to continue or stop *jhuming* by taking appropriate decision of maintaining a threshold length of fallow phase with slash and burn activities for achieving higher *jhum* productivity as well as ecosystem sustainability.

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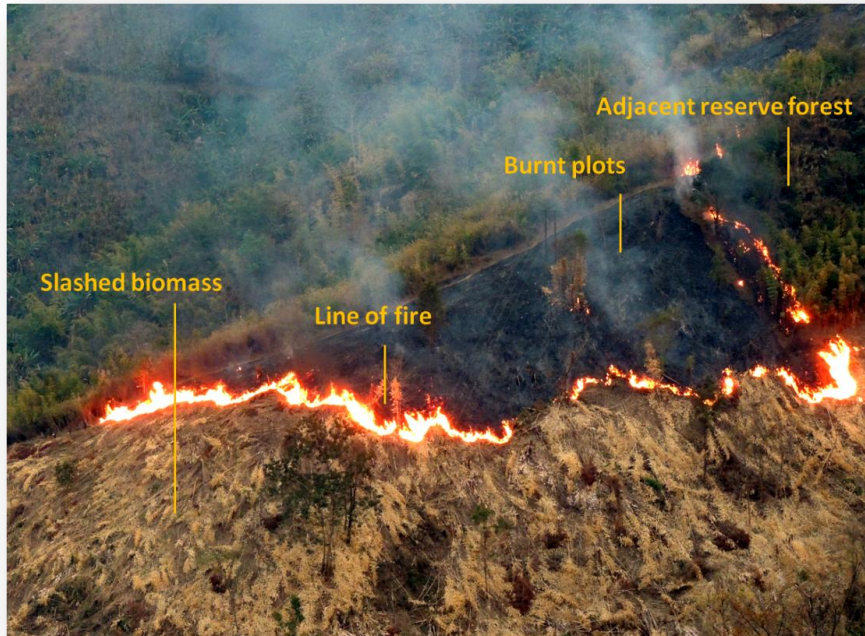
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APPENDICES

APPENDICES

Appendix 1.1 Characteristic slash and burn practice of Northeast India depicting burning process on dry slashed biomass



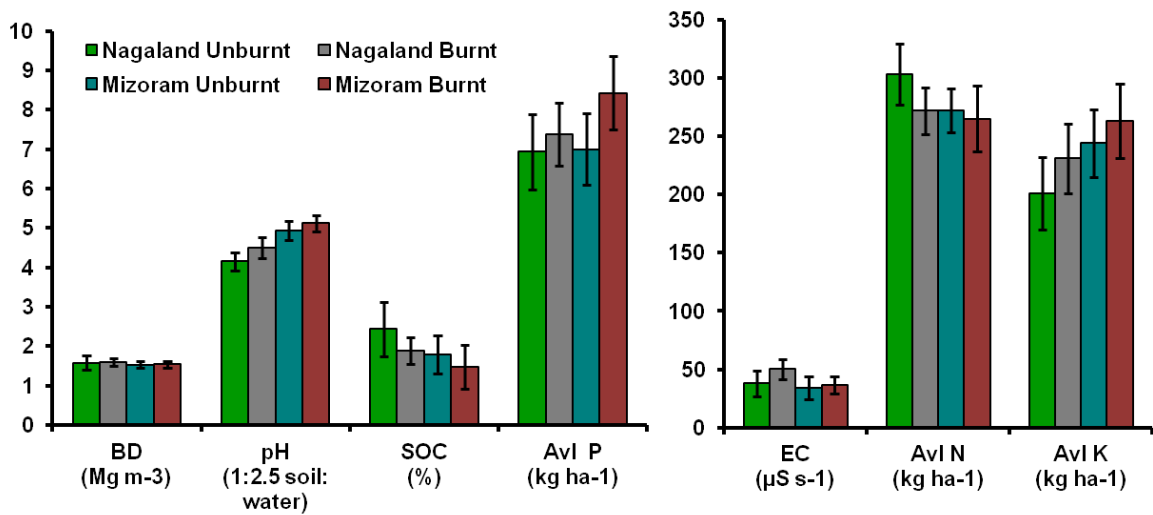
Appendix 1.2 Typical *jhum* field of Northeast India during cropping phase



Appendix 1.3 Soil sampling in burnt and unburnt sites of Mizoram and Nagaland



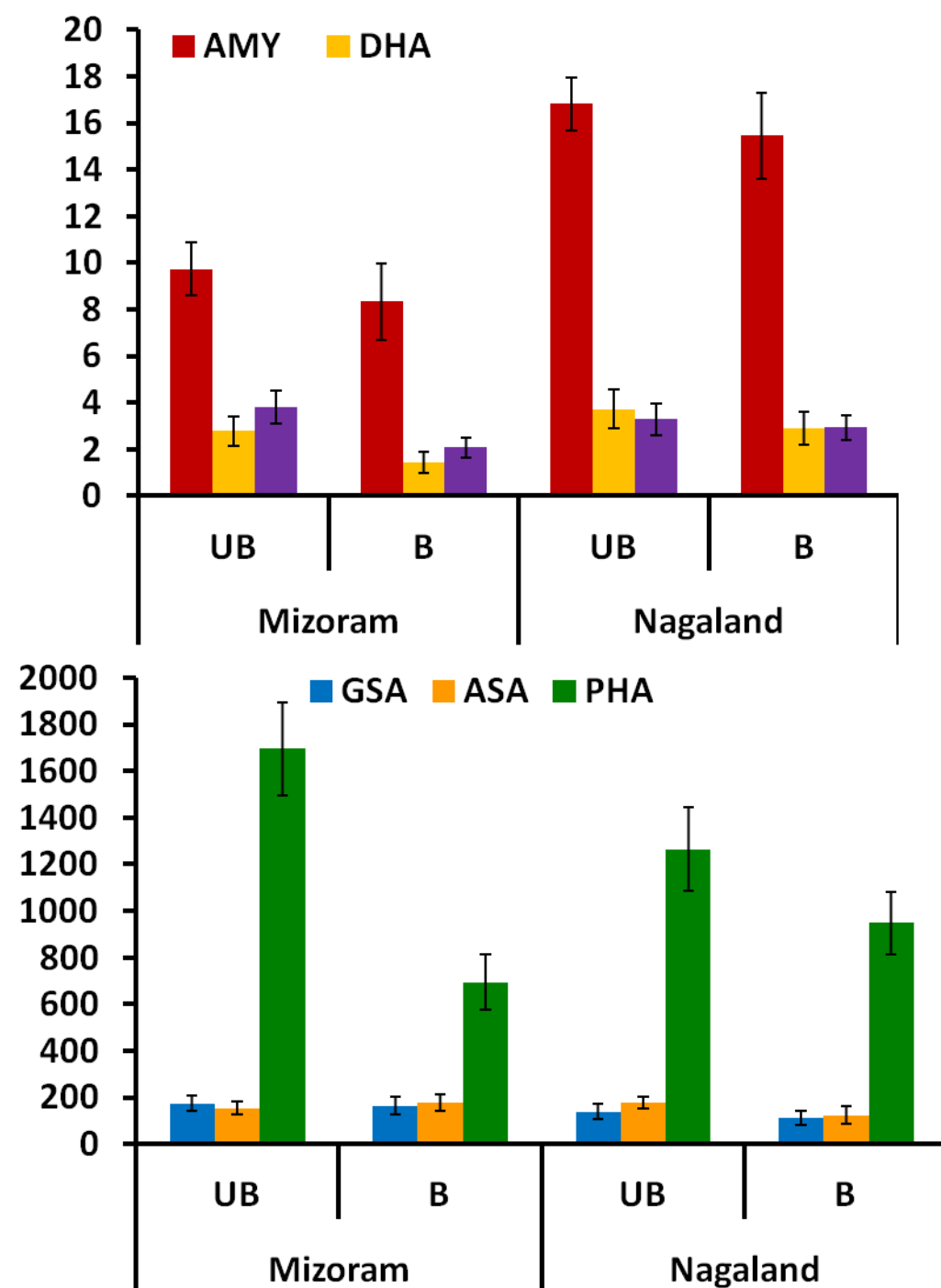
Appendix 1.4. Comparative physico- chemical attributes of *jhum* soils before and after burning in Mizoram and Nagaland



Appendix 1.5 Forest floor litter accumulation of Mizoram and Nagaland at different collection months

Months	Fallow	Total litter accumulation			
		$\text{g m}^{-2} \text{ yr}^{-1}$	rank	$\text{g m}^{-2} \text{ yr}^{-1}$	rank
		MIZORAM		NAGALAND	
January	F1	150	4.6	280	3.8
	F2	196	8.8	463	8.0
	F3	256	10.6	702	12.0
	Mean	201±87.0		482±225	
Monte Carlos significance test			0.089		0.004
April	F1	92.0	3.2	224	3.2
	F2	144.6	8.2	311	7.8
	F3	183.8	12.6	588	13.0
	Mean	140.1±44.2		374±167	
Monte Carlos significance test			0.000		0.000
August	F1	64.8	3.0	194	5.2
	F2	120.0	8.0	236	6.6
	F3	186.4	13.0	314	12.2
	Mean	123±51.9		248±80.1	
Monte Carlos significance test			0.000		0.021
November	F1	59.4	3.0	109	5.3
	F2	101.8	9.8	117	8.1
	F3	110.0	11.2	146	10.6
	Mean	90.4±27.6		123±35	
Monte Carlos significance test			0.002		0.176

Appendix 1.6. Effect of burning on soil enzyme activities in different fallow phases of Mizoram and Nagaland



Appendix 1.7. Characteristic physical appearance of soils used for microcosm experiments collected from *jhum* sites of Mizoram



Appendix 1.8. Illustration of microcosm experiment of rice (Objective-II) at different growth stages



Appendix 1.9 Glimpse of microcosm experiment on *jhum* rice (Bhalum-I) with different treatments imposed

5 years burnt



10 years burnt



Control LA MC LA+MC AA

- LA - Litter amendment {FFLs from *jhum* fallow phase (secondary forest)}
- MC - Microbial consortium (Collected from Microbial Ecology laboratory, SNRM, CPGS, Umiam)
- LA+MC- Mixture of litter amendment and microbial consortium
- AA - Ash amendment (calculated based on ash generated per meter square in field condition)

Appendix 1.10. Identity and multifaceted plant growth promoting properties of bacterial strains (obtained early succession plant species, *Thysanolaena maxima*) used to formulate microbial consortium for application in *Jhum* crops

Strain name	Identity of strain based on the nearest organism (%homology of 16S rRNA sequence)	Pectinase activity Zone dia. in Pectin+NA (mm)	Cellulase activity Zone dia. in CMC agar (mm)	N-fixation in nfb broth	IAA-like substances ($\mu\text{g ml}^{-1}$)	Phosphorus solubilization ($\mu\text{g P}_i\text{ml}^{-1}\text{h}^{-1}$)	Heat tolerance ability ($^{\circ}\text{C}$)	Acidity tolerance ability (pH)
PDA EN1	<i>Konokasia oryzae</i>	1	0	+ Score: 4	0	$\text{Ca}_3(\text{PO}_4)_2$: 62 NaPhy : 172 FePO_4 : 32	60°	3.0
TSA EN1	Not identified	0	4	+ Score: 2	212	NaPhytate: 178	60°	3.0
R2A RH 13	<i>Klebsiella pneumoniae</i>	0	0	+ Score: 3	285	NaPhytate : 84	45°	3.0
R2A EN3	Not identified	0	3	+ Score: 2	0	$\text{Ca}_3(\text{PO}_4)_2$: 195 NaPhytate : 169 Fe_3PO_4 : 15	60°	3.0
R2A RH7	Not identified	0	0	+ Score: 4	61	NaPhytate : 92 AlPO_4 : 4.1	60°	3.0

VITA

Henry Saplalrinliana s/o K.H. Hmingthanga was born in 15th November, 1976 at Kohima, Nagaland. He passed his HSLC in Ist division in the year 1992 under Nagaland Board of School Education and Pre-University (Science) in 2nd division from Kohima Science College, Jotsoma under Nagaland University in the year 1995. He persued his B.Sc (Agriculture) in the same year at School of Agricultural Sciences and Rural Development, Medziphema, Nagaland University and passed in the year 2000 in 2nd division. He further continued his M.Sc (Agriculture) in Soil Science and Agricultural Chemistry from the same institute and completed in 2003 in 2nd division. He served the Department of Horticulture, Government of Mizoram as Project Assistant, Technology Mission, from 2003-04. Later in 2004, he joined as Project Scientist in Mizoram State Remote Sensing Centre, Planning Department, Government of Mizoram. He joined Godrej Agrovet Ltd. India as Development Officer from 2005-08 and served in different places of Mizoram and Andhra Pradesh. Presently, he is appointed as Scientist (Soil Science) at Krishi Vigyan Kendra, Mamit district, Mizoram.



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