IMPACT OF FALLOW PERIODS AND TREATMENTS ON THE PATTERN OF RECOVERY OF SOIL FERTILITY AND PLANT PRODUCTIVITY IN SHIFTING CULTIVATION SITES IN AIZAWL DISTRICT, MIZORAM

THESIS

SUBMITTED IN PARTIAL FULFILMENT FOR THE AWARD OF THE DEGREE

OF

DOCTOR OF PHILOSOPHY IN FORESTRY

BY:

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Dedicated

To

The Jhum Farmers of Northeast India

Particularly the Mizoram Farmers:

Pu Lalsangzuala (3 years fallow site)

Pu C. Lalnunzira (5 years fallow site)

Late Pu Rotlunga (10 years fallow site)

Who provided their lands and extended full heartily cooperation for carrying out this work for three consecutive years during 2013-2015.

DECLARATION

I, **Wapongnungsang,** hereby declare that the subject matter of this thesis entitled, "*Impact of fallow periods and treatments on the pattern of recovery of soil fertility and plant productivity in shifting cultivation sites in Aizawl District, Mizoram*" is the record of work done by me and that the contents of the thesis did not form basis for the award of any previous degree to me or anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This thesis is being submitted to the Mizoram University for the degree of **Doctor of Philosophy** in the Department of Forestry.

Date:______January 2018

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CERTIFICATE

This is to certify that the thesis entitled **"Impact of fallow periods and treatments on the pattern of recovery of soil fertility and plant productivity in shifting cultivation sites in Aizawl District, Mizoram"** submitted by **Wapongnungsang (Ph.D. Regn. No. MZU/ Ph.D./ 576 of 13.05.2013)** in partial fulfillments of the requirement for the award of degree of **Doctor of Philosophy** in Forestry, Mizoram University, Aizawl, embodies the record of original investigations carried by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Doctor of Philosophy (Ph. D) Degree. The thesis or part thereof has not been submitted by him for any degree to this or any other university.

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PREFACE

Mizoram is one of the seven sister states of northeastern India which is located in tropical hilly areas where different tribal populations inhibit. Majority of these tribal populations are involved in shifting agricultural practice for their livelihood through centuries. This agricultural system was adequately productive, economically viable and ecologically efficient due to prolonged fallow period (~20-30 years) in the past. However, in recent years as a result of exponential increase in human population, the length of fallow periods have been considerably reduced to ~<5 years which has led to decrease in soil fertility and crop productivity. This has posed a problem of food security for the majority of the local populations of the region. The main aim is to sustain shifting agriculture practice in this region to overcome with problems food security for the farmers. To achieve the objectives, shifting cultivation sites of different fallow ages (e.g. 3 years, 5 years and 10 years old) have been selected. Various treatments plots have been established as: T_1 ─ soil microbial (*Burkholderia sp., Ceredia sp.*, and *Enterobactor sp*.,) inoculation; T_2 ─ top soil amendment (@ 2 t ha^{-1} from nearby forest) and T_3 ─ litters input (@ 5 t ha^{-1} from nearby forest), and a Control plot (no imput) in Muallungthu area of Mizoram. After the establishment of treatment plots following soil and plant sampling and analyses were made in all treatments in relation to control and fallow lands, for example, a) physico-chemical properties (C, N, P, K, MBC, MBN, enzyme activity) of soils, b) organic matter and nutrient return/release into soil, c) soil nutrients (NO_3^-, NH_4^+, PO_4^{--},) availability and N-mineralization rates, d) plant biomass, productivity, and the amount of C and N associated with plant biomass and productivity, and e) the relationship of plant biomass data with that of soil nutrient availability. The locally available litter material and microbial inoculation from the rhizosphere soil of early regenerating plant have found to considerably affect the productivity and soil fertility and has immense potential to be used for the improvement soil fertility even in the shorter fallow of shifting cultivation and can beneficially be used as an important tools to sustain crop productivity and food security in the region.

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List of Abbreviation and Symbols

%	Percent	mg/kg	Milligram per kilogram
amsl	Above the mean sea level	mm	Millimetre
ANOVA	Analysis of variance	N	Nitrogen
AG	Aboveground biomass	NH_4-N	Ammonium nitrogen
BG	Belowground	NO_3-N	Nitrate nitrogen
BD	Bulk density	°C	Degree Celsius/Centigrade
P_{avail}	Available phosphorus	$p<0.01$	Significant level at 1 percent
C	Carbon	$p<0.05$	Significant level at 5 percent
cm	Centimetre	PHA	Phosphomonoesterases activity
cm^2	Centimetre square	r	Correlation coefficient
CO_2	Carbon dioxide	SE	Standard error
DHA	Dehydrogenase activity	SMB	Soil microbial biomass
dw	Dry weight	SOM	Soil organic matter
e.g.	*Exemplia gratia*	sp	Species
Et.al.	*Et alia* and others	SPSS	Statistical Package for the Social Sciences
etc	*Et cetera*	T_{cont}	Control treatment
FAO	Food and Agricultural Organization	T_{micro+}	Microbial inocula treatment
FSI	Forest Survey of India	T_{soil+}	Soil amendment treatment
FL	Fallow land	$T_{litter+}$	Litter amendment treatment
g	Gram	TOC	Total organic carbon
g cm-3	Gram per centimeter cube	TN	Total nitrogen
GSA	β- glucosidase activity	TRB	Total root biomass
h	Hour	TWB	Total weed biomass
ha	Hectare	TRP	Total rice productivity
HSD	Honest significant difference	TVP	Total vegetable productivity
JAB	Just after burnt	TSF	Time of slashing forest
$K_{exchang}$	Exchangeable Potassium	TCM	Time of crop maturity
kg	Kilogram	TCH	Time of crop harvest
Kg ha^{-1}	Kilogram per hectare	wt	Weight
L	Litre	yr	Year
LA	Litter amendment	µg	Microgram
m	Metre	µg g^{-1}	Microgram per gram
m	Million		
m^2	Metre square		
MBC	Microbial biomass carbon		
MBN	Microbial biomass nitrogen		
mg	Milligram		

List of Weed Abbreviation and Symbols	
Ai	*Ageratum indicum*
Ac	*Ageratum conyzoides*
Ag	*Allardia gabra*
Bp	*Bidens pilosa Linn.*
Ca	*Centella asiatica*
Co	*Chromolaena odorata*
Cs	*Costus speciosus (Koening) Sm.*
Gc	*Gynura crepidioides Benth.*
Kc	*Knoxia corymbosa*
Mc	*Mikania cordata*
Mn	*Melastoma nepalensis*
Oa	*Oxalis corniculata*
Os	*Oxalis stricta.*
Sa	*Spilanthes acemella Murr*
Sd	*Scoparia dulcis*
Ul	*Urena lobata*

CHAPTER 1

INTRODUCTION

1.1. Shifting cultivation in the world

Shifting cultivationis a primitive and traditional practice of agriculture commonly occurring in the moist tropical hilly regions of the world(Inoue *et al.*, 2010; Grogan*et al*., 2012;Das *et al.*, 2014). In this practice of cultivation, farmers slash a piece of forest land, wait it to dry and burn the biomass *in situ*followed by cropping for few years depending on the soil fertility and abandon the land for few years 10-30 years to restore soil fertility through natural regeneration, and moved to other forested area for their cultivation (Tawnenga, 1997; Grogan *et al.*, 2012; Yadav, 2013).Earlier the system was working well because of the long fallows of about ~ 20 years, however, during the course of time the fallow length has considerably decreaseddue to increase in population pressure that has decreased soil fertility and crop productivity and posed a serious concern for food security in many regions (Ramakrishnan, 1992).Thisleads to the formation of secondary forestofdifferent stages of regeneration, contained within a mature forest matrix that helps to sustain them (Martins, 2005).

The Food and Agriculture Organization (FAO) in 1957 described shifting cultivation ‘‘as the greatest obstacle not only to the immediate increase of agricultural production, but also to the conservation of production potential for the future, in the form of soils and forests'' (FAO, 1957). Since then, this practice has widely considered as a primitive and economically inefficient form of agricultural production that increases soil erosion, watershed siltation, and atmospheric CO_2 concentration. This consideration has been central to land management policies in many affected regions of the world (Mertz 2002; Maithani 2005; Anonymous 2009c). The International Tropical Timber Organization (ITTO) estimates that as of 2000, secondary or degraded forests made up 850 M ha, or approximately 60%, of tropical forests worldwide (ITTO, 2002).

Shifting cultivation has been considered to be one of the drivers of tropical deforestation in the 1990s (Bandy *et al.,* 1993; Brady, 1996), andwasresponsible for 10% loss of forested areas in Latin America (Houghton *et al.,* 1991), 30-35% in Amazon region (Serrao *et al.,* 1996), and 50% in Indonesian region (Jong, 1997). In addition to deforestation, there was also a concern that the impact on soils that could compromise forest biodiversity (FAO, 1985; Bandy *et al.,* 1993; Brady, 1996). Further, there are reports that the areas used for shifting cultivation could function as a significant cause of global warming (Fearnside, 2005) by representing significant source of CO_2 emissions into the atmosphere (Brown and Lugo, 1990), which would be difficult to be compensated by secondary forest growth during the fallow. Such negative concerns regarding the environmental sustainability of the shifting cultivation have guided public policies in many tropical countries towards eradicating this agricultural system (Ziegler *et al.,* 2009).

1.2.Shifting cultivation inIndia

Shifting cultivation is widely practiced by tribal people in many states of India, for example, states of northeast India (Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Tripura and Mizoram), Madhya Pradesh, Orissa, Andhra Pradesh and Kerala. It is locally known as *Jhum* in northeast India, *punamkrishi* in Kerala, *podu* in Andhra Pradesh and Orissa, *bewar, mashan, penda* and *beera* in different parts of Madhya Pradesh. Approximately 2 M ha of forested land is slashed and the biomassof tree and shrubs are burnt *in situ*every year, and then abandoned when the fertility decreases. Paddy, buck wheat, maize, millets, tobacco, some vegetables and banana are grown on the burnt over clearings and the products shared jointly by the clan. Rice is the major crop grown in shifting cultivation dominated landscape in northeast India.

1.3.Shifting cultivation (*Jhuming*) in Northeast region

Northeast India consists of 8 sister states with a total geographical area of 26.2 M ha which is about 8% of the country's total area supports about 47.9 M populations (2014). Rainfall occurs from May to November in the region. This region consistsone of highest rainfall area (Cherrapunji and Mawsynram) of the world which received total annual rainfall of 11,465 and11,873 mm. In general, the total annual rainfall varies from 2,000-4,000 mm in different part of the northeast India. About 90% of the rural population of the state depends on agriculture for their livelihood. Among the workers of the region, 60.1% are cultivators, 9.3% are agricultural labourer while

7.3% are connected with livestock, forestry, fishery and other allied activities (Das*et al.,* 2011).Out of 4.0 M ha of net sown areas, about 1.6 M ha area is under *jhumming*with very low average productivity. *Jhum* cultivation involves several cultural operations 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 (Thakuria and Sharma, 2014). It is observed that during the land abandonment fallow lands rejuvenate the levelofsoil 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 provide more readily available soil nutrients (Juo and Manu, 1996).

1.4. Shifting cultivation in Mizoram

Mizoram is one of the seven sister states of northeastern India,located in tropical hilly areas dominated by tribal populations involved in shifting agricultural practice for their livelihood through centuries. During shifting cultivation, farmers slash the piece of forest land and burn the dry mass *in situ* followed by sowing seeds of desired crops manually without tilling the soil (Tawnenga, 1996; Grogan *et al.,* 2012; Yadav, 2013), and continues cropping for 1-2 years depending on the soil condition and abandon the land for few years to restore soil fertility (Tripathi *et al.,* 2017). Decreased fallow length in recent years due to increased population density has created problems food security for the small farmers and environmental degradation in the region. Mizoram's topography makes it unusual relative to many other areas in the Tropics where shifting cultivation is practiced. At least 70% of the state's total plan metricland area (2 M ha) is sloped at angles steeper than 33^o (Anonymous, 2009c). Approximately half of all households in Mizoram are engaged in shifting cultivation (Anonymous, 2009c), primarily in relatively undeveloped remote villages (Singh *et al.,* 2010). Remote sensing based estimates of the total area burned each year by farmers and wildfires ranges from 40,000-110,000 ha (Tawnenga *et al.,* 1996; Anonymous, 2009b, c).

Fire is an integral part of the Mizo culture. It clears the land, temporarily nourishes the soil, and restricts weeds, plant pests and pathogens. The mizo term for February ('Ramtuk Thla') literally means the 'time for preparing the land for burning'.Slash and burn agricultural practices are common and widespread in Mizoram resulting in a landscape dominated by mixed species bamboo forests in various stages of post-fire succession. Mature sub-tropical wet hill and tropical wet evergreen forests that are the natural climax vegetation in the higher and lower altitudes of this region, respectively, (Champion and Seth, 1968) cover just 20% of the land area (Singh *et al.,* 2010).

Cropping on *jhum* lands in Mizoram is predominantly practiced for one year. The second year cropping is scarce, and if done, it is only on old *jhum*fallows (Tawnenga *et al.,* 1996). Even in other parts of north-eastern India, the land is often abandoned after first year of cropping, and second year cropping is sometimes practiced with plantations of banana and pineapple (Kushwaha and Ramakrishnan, 1987). Typical shifting cultivation crops include upland rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), maize (*Zea mays*), chillies (*Capsicum annuum*), eggplant or ‘brinjal’ (*Solanum melongena*), lady’s fingers/okra (*Abelmoschus esculentus*), squash (*Sechium edule*), pineapple (*Ananas comosus*), Cassava (*Manihot esculentum*) and herbs such as Mustard (*Brassica juncea*). In addition, ginger (*Zingiber officinalis*) and turmeric (*Curcuma longa*) are frequently planted in recently burned sites because they grow well on steep slopes which considered ashigh value crops that store and transport well (Grogan *et al.*, 2012).

In 2010, Government of Mizoram has initiated a New Land Use Policy with an aim to wean away of the *Jhum* by providing small monetary support to *Jhumias* to create productive assets in each family through livelihood activities like promotion of agri-horticultural, plantation crops, animal husbandry, fishery and micro enterprises, and to convert the *jhum* area under the rain forest. However, the scheme was limited to few farmers and hence majority of them continue to *Jhuming*. Being organic state resource intensive agriculture i.e. the excessive use of chemical fertilizer will be a major concern of the public and the Government in this region as they may contaminate the water through leaching and runoff losses of nutrients due to steep slopes. This present research demonstrates low cost locally available soil amendments like microbial inoculums, top soiland litter from the nearby same age forest. The basic idea behind the amendment was to recover soil microbial growth hampered due to burning that may lead to improve the soil fertility and crop productivity.

1.5. Weeds in shifting cultivation

In general, the weed has serious concern for the crop productivity over the world. Globally, annual rice yield loss of 10-35% was reported by weed completion (Karim *et al.*, 2004**;** Rabbani *et al.*, 2011). Losses caused by weeds varied from one location to another location depending on the predominant weed flora and management parctices adapted by farmers. The weed infestation adversely affects the crop as experienced by yield reduction, if weeds are not manageged during growing period (Azmi *et al.*, 2007). Weed infestation is more severe in rain-fed than in the irrigated croplands (Hyvonen and Salonen, 2002). Invasive species have been considered as the second largest threat to biodiversity globally after habitat destruction (Gurevitch and Padilla, 2004).

The crops and weeds compete for light, water and nutrients. Weeds commonly absorb added nutrients more rapidly than crops and so competing for nutrients, light, space and moisture throughout the growing season (Hayat, 2004; Hussain *et al.*, 2008). Weed succession and distribution patterns in rice fields are dynamic in nature. The composition of weed flora may differ depending on location (Begum *et al.*, 2008; Uddin *et al.*, 2010) and cropping systems (Uddin *et al.*, 2010). Thorough survey has been recommended for the proper management of weed problems and target oriented research programs in rice field (Boldt *et al.*, 1998). Weedicides are very common in the intensive agriculture to avoid the problems of weeds.

The distribution and nature of the weeds of the hilly area could be different due to factors associated with soil pH and nutrients. In the state of Mizoram,age old slash and burn agriculture ("*jhum*") is still the chief agronomic activity of the tribal people, except terrace cultivation in small area that was introduced about two decades ago to enhance yield and check soil erosion in this hilly region. The *Jhum* field is heavily infested by a large variety of weed species favored by climatic conditions. Since Mizoram being an organic state, therefore, weedicides are generally not used in this region and considered as second factors which affect soil fertility and crop productivity. The information on the up to date presence, composition, abundance, importance and ranking of weed species is needed to formulate appropriate weed management strategies to produce optimum yields of rice (Begum *et al.,* 2005) in the shifting cultivation sites of Mizoram.

1.6. Soil fertility in shifting cultivation

1.6.1. Organic matter production and decomposition

Litter production and decomposition are key processes regulate nutrient recycling in ecosystems and influences net ecosystem carbon (C) storage, and areimportant in the formation of soil humus (Hobbie *et al.,* 2000; Lalnunzira and Tripathi, 2018). Litter decomposition can be affected by many environmental factors including the physical environment (e.g. temperature, moisture, and soil pH), nutrients availability and activities of decomposers in the soil (Chapin *et al.,* 2002). On the other hand, litter quantity can alter micro-climate, number and dynamics of decomposer organisms and nutrient availability in forest floor and mineral soil (Sayer *et al.,* 2006). It has been reported that global climate changes due to rising atmospheric CO_2 concentration and temperature can increase net primary production (NPP) and consequently litter production in forest ecosystems (Hickler *et al.,* 2004). In contrast, litter inputs are also likely decreased due to extensive deforestation and cultivation (Holmes *et al.*, 2006). Therefore, evaluating the effects of these changes in litter inputs on litter decomposition is crucial for our understanding of ecosystem nutrient supplies and future global C cycle through forest degradation. Such information would be more important in regenerating ecosystems following disturbance to understand the potential role land use change on C and N dynamics.

Shifting cultivation, a primitive form of agriculture practice, has been carried out extensive areas in moist tropical forest areas of the World (ITTO, 2002). These forests have been reported as the storehouse of biodiversity, C and nutrients and regulate many ecosystems services useful for the humanity. Shifting cultivation has led to modify the natural forest ecosystem into various land uses, for example, secondary forests, plantations and agroforestry systems. Land-use changes associated with agricultural abandonment may affect aboveground and belowground litter dynamics (Yang *et al.,* 2010) due to changes in abiotic environments. Litter decomposition and their influencing factors had been widely studied in various ecosystems worldwide (Silver and Miya, 2001). Studies have measured the above- and belowground litter production and decomposition in relation to vegetation succession following agricultural abandonment (Ostertag *et al.,* 2008) and forest disturbance (Yang *et al.,* 2010; Lalnunzira and Tripathi, 2018).

Roots have been reported to significantly affect the functioning of forest in different parts of the world and they have been reported to increase during forest development up to 100 years following disturbances (Yuan and Chen, 2010). Roots are central components in competitive equilibrium between crops and spontaneous re-growth (de Kroon *et al.*, 2012), and in carbon-dynamics (Pan *et al.*, 2011). Fine roots contribute significantly to the biogeochemical cycling in forest ecosystems (Kardol and Wardle, 2010) because of their high growth and turnover rates. The rate of organic matter addition and nutrient release to the soil is considerably affected with the changes in land uses a result of changes in abiotic (i.e. soil temperature, moisture and nutrients) (Fukuzawa *et al.*, 2010) and biotic factors like floristic composition (Singh *et al.*, 2014) which are important source of variation for fine-root production in successional forest ecosystems. However, the knowledge about the fine root growth dynamics is highly scarce largely due to methodological problems associated with root-quantification.

Frequent slash and burn of aboveground vegetation and shortening fallow periods can favor plant survival strategies in terms of maintenance of significant and well protected underground carbohydrate and nutrient reserves (Clarke *et al.*, 2013). This may lead to increase belowground biomass particularly fine roots in relation to aboveground biomass (Devagiri *et al.*, 2013). Fine roots may contribute more C than aboveground parts to soil organic matter accumulation due to their higher inputs and faster decay rates (Bharbhuiya *et al.*, 2012; Finer *et al.*, 2011). Available research on fine roots in slash and burn fallows and disturbed tropical forest up to 1 m depth showed shallow distribution of fine roots with majority concentrated in upper 10 cm (Jaoa *et al.,* 2015; Tilak *et al*.,2012). Recently, Lalnunzira and Tripathi (2018) have reported that changes in the litter production and decomposition play significant role in the development of ecosystem attributes during secondary succession following stone mining activities in moist tropical forest areas of Mizoram. Such studies may be useful in managing forest fallows and crop productivity of *jhum* field in Mizoram.

1.6.2.Soil organic matter and nutrients

Soil organic matter and nutrients are important factors for maintaining ecosystem productivity and contribute to the quality of environment, and support healthy development of plants and animals (Maly *et al.,* 2002). Microbial parameters are early indicators of soil quality changes because they can respond to modified soil conditions sooner than physical and chemical properties (Tscherko and Kandeler, 1999). In the context of nitrogen turnover, soil quality is significantly affected by two parameters, namely N-mineralization and nitrification (Maly *et al.,* 2002). Nitrification is a process sensitive to soil disturbances, because it is controlled by a narrow range of chemolithotrophic micro-organisms (Sparling, 1997). The dynamics of N mineralization and nitrification in the soil cannot be properly understood without repeated estimation during the year because their seasonal pattern is impossible to predict using only a single determination in the beginning of the vegetation period (Franzluebbers *et al.,* 1995).

In general, N mineralization changes periodically during the annual cycle. N_{min}has been reportedto increase late in the spring during maximum root and after harvest in the late summer and in the autumn when organic residues start to enter the soil (Maly *et al.,* 2002). Minimum values were observed at the summer period as a result of a water shortage (Gill *et al.*, 1995; Rohde, 1996).On the contrary, Campbell *et al.* (1999b) revealed no distinct trends in N_{min} in the course of the vegetation period. It seems that $N_{min}$is rather dependent on the soil cultivation method over several successive years and the accumulation method of an easily mineralizable substrate than on an instantaneous input of N fertilizers (Hassink, 1992; Gill *et al.,* 1995). Enzymatic methods offer a suitable tool for soil quality monitoring (Dick, 1992). Urease is one of the frequently used enzymes whose activity is related to N_{min}(Kandeler and Eder, 1993; Kandeler *et al.,* 1999). On the contrary, Ruppel and Makswitat (1999) found no relationship between this two parameters and no impact of N fertilizers on the activity of the above enzymes.

The rate of supply of available-N generated byN_{min}involves the microbial conversion of more complex organic-N into simpler available mineral-N(NH_4-N^++NO_3-N). Nitrification involves the transformation of NH_4-N^+ into NO-N-3 carried out by two different physiological groups of chemoautotrophic bacteria (Singh *et al.,* 2007). The rates of soil N_{min} and nitrification governs the availability of mineral-N for plant growth and also indicate the ability of soil to retain N, especially after disturbances (Haynes, 1986). The releae of mineral N in soil depeneds on mineralization of organic N either from native soil or through decaying litter as a result of complex interactions between microbial population and their enzymatic activities.

The enzymatic activity is mainly microbial in origin, being derived from intracellular, cell-associated or free enzymes in the soil. Enzyme activity maintains a unique balance of chemical, physical and biological components in maintaining soil health. Soil health is indicators of all these components and is essential for land ecosystems to remain intact or to recover from forest disturbances such as climate change, drought, pest infestation and human exploitation (Elliott *et al.*, 1994). Soil enzymes are playing an important role in maintaining soil ecology, physico-chemical properties and soil health. Enzymes play key role on biochemical functioning in the overall process of organic matter decomposition in the soil system (Sinsabaugh *et al.,* 1991), and are important in catalyzing several vital reactions necessary for the life processes of micro-organisms in soils (Dick *et al.,* 1994, 1997).

The major factors that limit N_{min} are environmental parameters like temperature, SM, pH, soil OM, quality and quantity and soil type (Banerjee *et al.,* 1999; Owen *et al.*, 2003). De Neve *et al.* (2003) also reported that soil moisture play an important factor controlling $N_{min}$and nitrification at sites. Fluctuations in environmental conditions (temperature, moisture and aeration) affect $N_{min}$and nitrification by altering microbial population size (Jha *et al.,* 1996a). Vegetation also affects $N_{min}$and nitrification through both litter quality and quantity (Berg and Staff, 1981). Vitousek *et al.* (1982) investigated the potential N_{min}, nitrification and immobilization in a range of ecosystems and concluded that N-poor sites produced refractory organic nitrogen compounds and produced litter with high C: N ratio. This suggest that litter quality (as reflected by dominant vegetation) and quantity may be important factors controlling N_{min} and possibly nitrification during ecosystems development following disturbance. Therefore, N_{min} is very crucial in determining soil fertility of the site and significantly affected by land use change particularly ecosystem development following shifting cultivation and can be easily manipulated by management interventions to increase crop productivity.

Decreasing soil fertility and crop productivity in the northeastern region, particularly, Mizoram has become a matter of concern for the Government and people. Therefore, this study aims to improve the efficiency of shifting cultivation sites by using ecological principles (e.g. soil organic matter, soil water, soil fauna, nutrient synchrony and integration of biological processes) of soil fertility management. On the above basis, viable options to sustainable shifting cultivation includes: establishment of agro-forestry with anti-erosional and nitrogen fixing plants, microbial inoculants, soil development to ensure moisture conservation and nutrient synchronization with that of crop nutrient demand. Realizing the above discussed facts, findings and priorities, the present study is formulated with the following major objectives:

- To determine physico-chemical properties (C, N, P, K, MBC, MBN, enzyme activity) of soils in different shifting cultivation sites and their treatments.
- To determine the magnitude of organic matter and nutrient release into soil in different sites and to assess the level of soil nutrients (NO_3^-, NH_4^+, PO_4^{--},) availability and N-mineralization rates in all sites and treatments.

- To estimate plant biomass and productivity in different shifting cultivation sites and their treatments and to relate the plant biomass data with that of soil nutrient availability.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Studies on shifting cultivation in the world

Shifting cultivation is an old age agriculture system which is carried out by small scale societies of rural populations in tropical moist forests over the world (Dove and Kammen, 1997; Altieri, 1999; Bellwood, 2005) and is based on the traditional way of managing ecological processes of forest ecosystems for food production (Long and Zhou, 2001; Vadez *et al.,* 2004; Pedroso-Junior *et al.,* 2008, 2009). The practice of shifting cultivation has been band to forested areas of the tropics for centuries because the population exploitation has made this practice impossible in Europe (Boserup, 1989; Worster, 2003). It is estimated that current ~350 million to 1 billion people around the world depend on shifting agriculture for their subsistence (IFAD *et al.,* 2001; Sanchez *et al.,* 2005). Shifting cultivation appears to be sustainable under specific conditions of low demographic densities and the use of low input technologies (Johnson *et al.,* 2001; Pedroso-Junior, 2008, 2009). However, the rapid and important climatic and economic-political transformations that have occurred in recent decades (Pedroso-Junior *et al.,* 2008, 2009; Van Vliet *et al.,* 2012) have produced a growing concern about the sustainability of shifting cultivations (Bruun *et al.*, 2009) and the food security of subsistence farmers (Adams *et al.*, 2005).

Sustainability of shifting cultivation has long been associated with the conservation of tropical forest ecosystems (Pedroso-Junior *et al.*, 2008, 2009). During the 1950s, the Food and Agriculture Organization of the United Nations (FAO, 1957) requested that governments, research centers, and public and private associations to invest in the modernization of agricultural practices and disregarded those associated with shifting cultivation. According to FAO, shifting cultivation represented a backward and inadequate system for the conservation of the tropical forest ecosystems (Mertz *et al.*, 2009). However, a few decades later, studies of shifting cultivation showed that these practices displayed a certain economic and environmental rationality (Fox, 2000; Mertz, 2002). The impact of new studies was to support the hypothesis that the shifting cultivation system techniques have traditional characteristics and those they consequently exhibit ecological sustainability (Kleinman *etal.*, 1995; Pedroso-Junior *et al.*, 2008, 2009).

Reviewing studies on shifting cultivation, Li et al (2014) concluded that the important work on shifting cultivation with respect to anthropology and other minor studies on soil science, agronomy and geography was conducted during 1930-1960 while the studies on evolution and ecology were conducted during 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 of the shifting cultivation. 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).

Shifting cultivation systems and their impacts on soil and vegetation have been widely studied over the world by the various groups of researchers (Giardina *et al.*, 2000; Lawrence and Forster, 2002; Mertz *et al.*, 2009). The current intensification of studies on the tropic was mainly related to problems linked with the global warming (Lal *et al.*, 1995; Kauffman *et al.*, 2009) and increase forestation in rainforest areas (Fearnside, 2005). Past estimates have indicated that two-third of the world's secondary forest till 1980 were under different fallow phases caused by shifting cultivation carried out over the past three centuries mainly in forested areas of the tropics.

A study conducted by Sanchez (1996) reported that shifting cultivation was practiced by millions of farmers worldwide was responsible for the bulk clearing of rainforest totaling about 10 million hectare every 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 Latin America, respectively (Cleuren, 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).

In Japan, burning in a traditional shifting cultivation system had three timings for burning, spring, summer, and autumn (Tachibana, 1995). A fire was ignited at an upper slope, which then slowly moved downward. Unburned or charred fuels were subsequently piled up together and reburned. Many different phrases were used to express this burning method (Sasaki, 1972), for example, "*honemade yaku*" (burn to the core (*hone* = bone) and "*soko made yaku*" (burn down to the bottom). Among the groups practicing shifting cultivation in northern Thailand and Myanmar, the Karen and Lua' people practiced shifting cultivation with short cropping and long fallow periods (Kunstadter, 1978). The time form slashing and cutting was traditionally January to February and that for burning was March to April (the end of dry season).

In Bangladesh, Shifting cultivation, locally known as '*jhum*' is the predominant farming system in Chittagong Hill Tracts (CHTs), which in the past has been well adapted to the lives and livelihood of tribal people with little adverse effect on the ecology of the region. Increasing population pressure coupled with a shortage of suitable uplands reduced the shifting cycle from 15-20 years in 1900 to 3-5 years in the 1990s in the absence of regulations to prevent deforestation, soil erosion, biodiversity loss and environmental degradation (Gain, 1998). 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, Phillipinesand 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 further 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). 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).

According to a study, about 40% of the land surface of the earth was converted into croplands and permanent pastures by early 1990s (WRI, 1996). More than 6% area under tropical forests was converted into shifting cultivation between 1980 and 1990. On the basis of data given in FAO and other sources, it is estimated that each year approximately 1.9-3.6 x 10^6 ha land of primary close forests, 3.4- 40 x 10^6 ha land of secondary close forests, and 6.9-21.9 x 10^6 ha land of secondary open forests are being lost due to shifting cultivation (Detwiler and Hall, 1988). So far, about 2.7 million ha land has been affected and each year about 0.45 ha land falls under shifting cultivation.

The adverse effects of shifting cultivation on the environment are well established scientific facts. Biologist, foresters and conservationists have noticed the effects of shifting cultivation on biodiversity in the tropical forests (Raman, 2000). FAO (1957) reveals that shifting cultivation was identified long time ago as a threat to tropical forests. Many scholars believe that shifting cultivation effects are very destructive (Lal and Prajapathi, 1990; Tiwari, 1991; Dwivedi, 1993). These conclusions are based on the scientific data and experiments conducted world-wide (FAO, 1984; Tawnenga *et al.*, 1997). Air pollution due to lashing and burning, loss of fauna and flora and other ecological implications are very common in the areas where shifting cultivation is practiced.

2.2. Studies on shifting cultivation(*Jhumming*) in India

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 6, 20,000 families in the region depend on *jhum*for their livelihood (Ramakrishnan, 1992). 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 recover the vegetation and soil fertility.

In northeastern region, shifting cultivation is prevalent in the region on 0.88 million hectares of land with an annual cropping in 387 thousands hectares of land. With the perception of considering the *jhuming* a form of agriculture which is detrimental to the natural forest ecosystem, soil and environment, the efforts are being made to wean away of the shifting cultivation. But the efforts are not successful as the practice of shifting cultivation is linked to socio-economic condition of the people and prevalence of complex land tenure system. Over the ages, tribal farmers developed some potential indigenous farming systems in the region using their ingenuity and skill. These techniques and systems have sustainable agriculture base and are practiced sincecenturies (Das*et al*., 2011).

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 3, 67,000 and the area affected by this practice is 3, 85, 400 ha annually (Patiram and Verma, 2001).

In shifting cultivation farmers do not apply fertilizer to upland rice but traditionally relied on fallowing their land to restore soil fertility and to reduce problems from insects and weeds (Nye and Greenland, 1960).

The deeply rooted culture of shifting cultivation in northeast India has many intricate sciences to be understood from *Jhum* system that remains to be a perfect institute as a repository for local germplasm of paddy, cucumber, millet, bajra, maize, pumpkin, chilliesetc with high resistance to pest and diseases. In the Nagaland, it has been a long-known practice of carryout *Jhuming* with alder tree (*Alnus nepalensis*) plantation to provide N for the crops (Rathore *et al*., 2010). The mix cropping pattern of this traditional agro-ecosystem happens to provide bio-chemicals within itself and maintaining a natural line of defense against invading insects and pest (Ramakrishnan, 1984).

Bordoloi (1976) analysed the importance of soil conservation and fertility of soil. He observed that *jhum* cultivation should not be discouraged without giving any alternative. He suggested encouraging algal growth in *jhum* field. Jain *et al.* (1976) analysed the process of shifting cultivation and the influence of *jhuming* on evolution of flora and vegetation in Meghalaya and Arunachal Pradesh. Authors did not propose any methods of stopping this age old practice abruptly but rather suggested methods of improvement in shifting cultivation to preserve vegetation and flora of the region.

Plants require light, water and nutrients for growth and reproduction. Crop productivity is strongly influenced by nutrient availability in soil and the nutrient supply rate (e.g. N-mineralization) is a crucial process of nutrient dynamics (Binkely and Votousek, 1989). Conversion of natural forest to cultivated land generally leads to a reduction of the organic carbon stock (Davidson and Ackerman, 1993; Murty *et al.,* 2002). This reduction is mainly due to (1) reduced litter inputs (2) higher top soil temperatures that leads to higher decomposition rates and (3) soil disturbance that increases decomposition due to increased aeration and destruction of physiochemical protection mechanism (Schlesinger and Andrews, 2000; Tinker *et al*., 1999). Soil is regarded as a nutrient pool of micro and macro-nutrients. Tree increase the soil nutrients content under its canopy (Verinumbe, 1991). The soil under the trees was slightly richer in terms of organic matter content, Mg and K than the soil from the adjacent trees in the sites with fewer trees (Kater *et al.*, 1992).

Mishra and Ramakrishnan(1983) have studied the effect of shifting cultivation on soil fertility at high elevation of Meghalaya using 15, 10 and 5 years shifting cultivation cycle and terrace system. Goel *et al.* (1968) reported effect of degree and length of slope and soil type on plant nutrient losses in run-off. Borthakur *et al.* (1983) have reported the effect of burning on some soil properties. The study was conducted at burn hat in North- eastern states. Singh and Ramakrishnan (1982) observed that shifting cultivators comprise of 82 per cent of the rural main workers and few urban main workers also involved in shifting cultivation.

In Mizoram, shifting cultivation is the main source of livelihood for the poor rural people. Maithani (2005a) reported that shifting cultivation is widely practiced in the state, and is the main occupation and source of economy for the rural population. The data regarding the number of families involved in shifting cultivation are not accurate. According to a study carried out by Maithani (2005b), there were about 58,000 families (approx. 25% population) involved in shifting cultivation. The other study says that there were 50,000 families involved in shifting cultivation. Similarly, about 1500 government employees were indirectly engaged in its practices as their secondary activity. During 1980's onwards the area under shifting cultivation was considerably decreased. It was mainly due to the major efforts of the state government to encourage settled cultivation. The efforts were also comprised to increase food production through settled cultivation and through launching of a new land use policy (NLUP).

Studies differ in terms of economic productivity of shifting cultivation as some observed it is productive and vice versa. The economic productivity of shifting cultivation may be assessed though assessing the number of people supported by it. It is relevant to say that shifting cultivation is productive as its practices have been quite productive in many areas supporting relatively large populations (Thrupp *et al.,* 1997). In Mizoram, according to the Agriculture Department Report (2009-2010), more than 20% population is engaged directly and indirectly in shifting cultivation. It is the major source of livelihoods for them. Shifting cultivation helps to conserve the rich cultural diversity as *Jhum* is interwoven into the culture and tradition of more than 200 tribal races, inhabited in the north-east region (Tripathi *etal.*, 2003a). Shifting cultivation, in its traditional form, contributes to conservation of agro-biodiversity. It represents an effective form of land use. It utilizes space optimally. About 60 varieties of crops are cultivated in a given time and space.

During the past decades, the fallow period of shifting cultivation was substantially long, and therefore, it was sustainable (Luoga, 2000a). However, due to increased population pressure, high demand of cereals and growth of urban markets for forest products, fallow period for shifting cultivation has been significantly reduced (<3 years) from 20-25 years (Luoga, 2000b and Mwampamba, 2009). A Study from the Agro-Economic Research Centre of the Northeast India has compared per ha yields of shifting cultivation that varied between 8 quintals ha^{-1} in Mizoram and 12 quintals ha^{-1} in Assam. Other study says per ha yield of paddy varied from 17.7- 19.59 quintals ha^{-1} for the other crops in 2004-05 (Sati *et al.*, 2014).

Deforestation caused by shifting cultivation is often viewed as one of the most important environmental problems of Southeast Asia (FAO, 1995). In Mizoram, the studies on ecological impact of shifting cultivation have also been carried out by Tawnenga (1990); Tawnenga and Tripathi (1996); Tawnenga *et al.* (1997). Clearing forests for shifting cultivation can contribute to climate change, biodiversity loss, reduced timber supply, flooding, siltation, soil degradation and change of forest vegetation from primary to secondary and eventually to grassland (Holden, 2001). Clearing of forests and burning them for shifting cultivation are the main reason of deforestation (Monela and Abdallah, 2007; Zahabu, 2008). The loss of vegetation cover increases the incidence of soil erosion. Mostly in the hilly areas, soils are the most susceptible to erosion (Shoaib *et al.*, 1998).

In Mizoram, 1.5% of total area is being affected by shifting cultivation, annually (Maithani, 2005b) that costs about Rs. 1 billion forest resources loss (Lalkhana, 1985). A report from the Ministry of Environment and Forest (1997) shows that 1700 sq km area was gained from shifting cultivation mainly comprises of scrubby vegetation. This growth also helped in checking soil erosion from the hilly slopes. Forest clearance alternating with long fallow period's mimics natural, small-scale high-intensity disturbances in forests and may be a sustainable form of land use (Andrade and Rubio-Torgler, 1990). It may enhance biodiversity in the landscape by creating new habitats (Gadgil and Guha, 1992; Kricher and David, 1992). Mizoram state noticed 1.4% increase in forested land from 1991 to 2011. In 1991, the total forested area of Mizoram was 18853 km^2 which increased to 19117 km^2 in 2011. Mean while, forested land area decreased in many neighboring states such as Nagaland (7%) and Manipur (3.4%).

Energy and economic efficiencies were evaluated on young (6 years) and old (20 years) *jhum* fields in Mizoram, North-east, India during second year of cropping, and were compared with those in the first year. The result indicated that traditional jhum cultivation is labor intensive and energy efficient, producing almost 15-20 times of energy invested (Tawnenga *et al.,* 1997). Cropping on *jhum* fallows in north-eastern India is predominantly done for one year. The results revealed that the crop productivity (total dry matter production) and economic yield (rice grain production) decline with shorter *Jhum* cycle.

The recent strong trend towards shorter fallow periods has led to widespread concern about declines in soil fertility, crop yields, and food security. Analysis suggests that the most promising options for improving shifting cultivation are nutrient and water supplementation, optimizing crop choice, extending the site use period, enhancing the fallow recovery rate, and controlling the burns and their environmental impacts. It conclude that intelligent and careful use of commercial fertilizer in combination with organic matter additions is likely to be an important feature of many of the solutions to the problem of shortening fallow periods in shifting cultivation on steep slopes (Grogan*et al.,* 2012). Arunachalam (2003) worked on Ecosystem Restoration of microbial C and N during successional gradients in

Jhum Fallows in Northeast India. The study suggests that the successional dynamics of microbial C and N are linked to other properties like soil organic matter and total nitrogen contents in the soil during community development following land abandonment after shifting cultivation.

CHAPTER 3

MATERIAL AND METHODS

3.1. Description of the study sites

3.1.1. Location

Mizoram lies in the north east of India, and its southern part sandwiched between Bangladesh and Myanmar. The state is situated between 21.56 to 24.31 degrees north latitude and 92.16 to 93.26 degrees east longitude, extending over a land area of 21,087 km^2. The Tropic of Cancer passes by the capital city, Aizawl. The length of the state from north to south is 277 km and breadth from east to west it is 121 km. Its major length in the west borders the Chittgong Hill Tracts of Bangladesh, spanning 318 km in the east and south, its border with the Chin Hills and Northern Arakans of Myanmar extends to about 404 km on the Indian side. Mizoram shares boundaries with the states of Assam (123 km), Manipur (95 km) and Tripura (66 km).

3.1.2. Geography and natural resources

The mountain ranges in Mizoram run from north to south. The ranges in the west are characterised by steep and precipitous while those in the east are largely gentle. The average height of the hills in the west is 1000 m, gradually rising to 1,300 m in the east. There are several mountains peaks of medium height. The highest peak in Mizoram is Phawngpui (Blue Mountain) located in the southern part of the State with an altitude of 2,157 m.

Mizoram is interspersed with numerous rivers and streams. The important rivers in the northern part of the state, flowing northwards, are the Barak (Tuiruang) and its tributaries, the Tlawng (Dhaleshwari), the Tuirial (Sonai) and the Tuivai. The Tuivawl, tributaries of the Tuivai, is another important river in the area. The Barak, the Daleshwariin particular had been the main entry and exit routes for Mizoram through the ages. Much of the potential of the rivers and water resources in Mizoram remains largely unexploited. The utilization of the hydro- potential for generation of energy, for example, in whatever form, large scale, mini or micro, is fully fractional. There has been a little improvement in the supply of drinking water but it requires rational and systematic approach to maintain the proper supply of water.

There are three plains in the state scattered over the mainly hilly terrain. The plains have layers of rich alluvial soil. The largest of these plains is the Champhai which is situated near the Myanmar border about 150 km east of Aizawl. Another plain area is at Vanlaiphai about 90 km away of the southeast of Aizawl, which is aproximately 10 km long and ¾ km wide. The third such area is at Thenzawl which is about 100 km south of Aizawl. These plains have been put mainly to paddy cultivation. In addition, there are several small level grounds besides some of the rivers, which have been developed for wet rice cultivation.

The common rocks found in Mizoram are sandstone, shale; silt stone, clay stoneand slates. The rock system is weak and unstable, prone to seismic influence.

Soils vary from sandy loam and clayey loam to clay, generally mature but leached owing to steep gradient and heavy rainfall. The soils are porous with poor water holding capacity, deficient in potash, phosphorus, nitrogen and even humus. The pH shows acidic to neutral reaction due to excessive leaching (Environment & Forest Department Report, 2003).

During Second World War time, forest produce like timber and bamboo are floated down the river from the interior of the hills to the plains of Cachar in Assam. On the other hand, food, consumer goods and merchandise are brought to the place by boats from the Assam plains to the hills of Mizoram. The bank and the Tuivai constitute the borderline between Manipur and Mizoram and the two territories have through the centuries shared the facilities provided by these rivers. Now the roads are good means of transportation for carrying out goods from one place to the other.

According to the report (2003) of the Department of Environment and Forest, 83% of the total area of the state (21,087 km^2) is covered by forests. However, due to the traditional practice of shifting cultivation called "*Jhuming",*uncontrolled fire, unregulated felling and arbitrary allotment of land to individuals, two-third of the area is reported to have partly depleted and degraded.

The different types of land cover in Mizoram as estimated by Landsat Imagery are shown below: (source: Department of Environment and Forest).

Table 3.1.2. Different Types of Land Cover in Mizoram

	Type of Land Cover	**Area (in sq. km)**
1	Closed forest	4,190
2	Closed forest affected by shifting cultivation	13,520
3	Forest degraded by shifting cultivation	2,600
4	Non-forest	640
5	Water bodies	140
	Total	21,090

3.1.3 Location and history of study sites

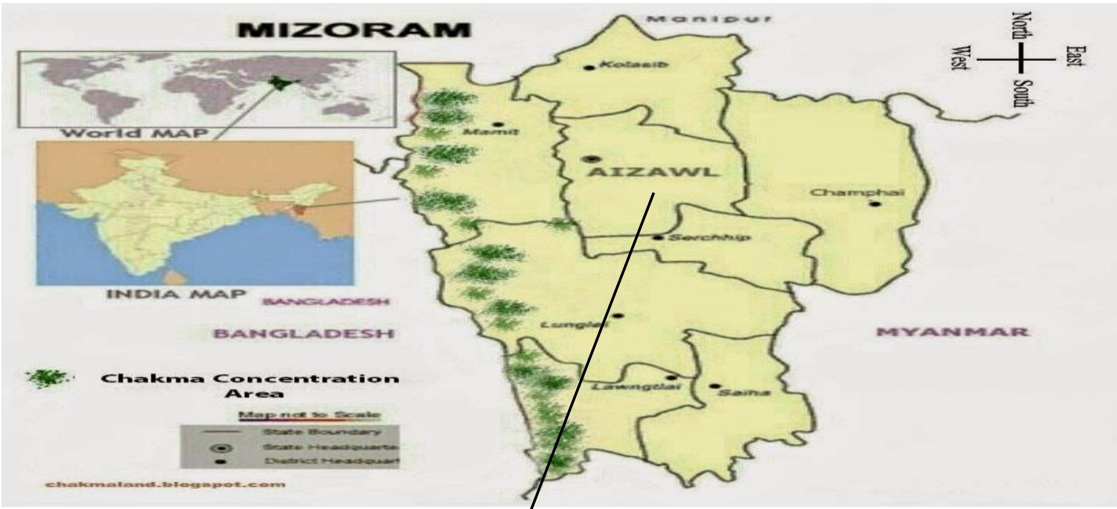
Muallungthu is a village panchayat located in the Aizawl district of Mizoram state, India. The latitude 23°61′09″061 and longitude 92°71′88″944 is the geo co-ordinateof the Muallungthu. The other nearest state capital from Muallungthu is Agartala (149.7 km) and the other surrounding state capitals are Imphal (180.4 km), Shillong (234.1 km) and Dispur (292.0 km).

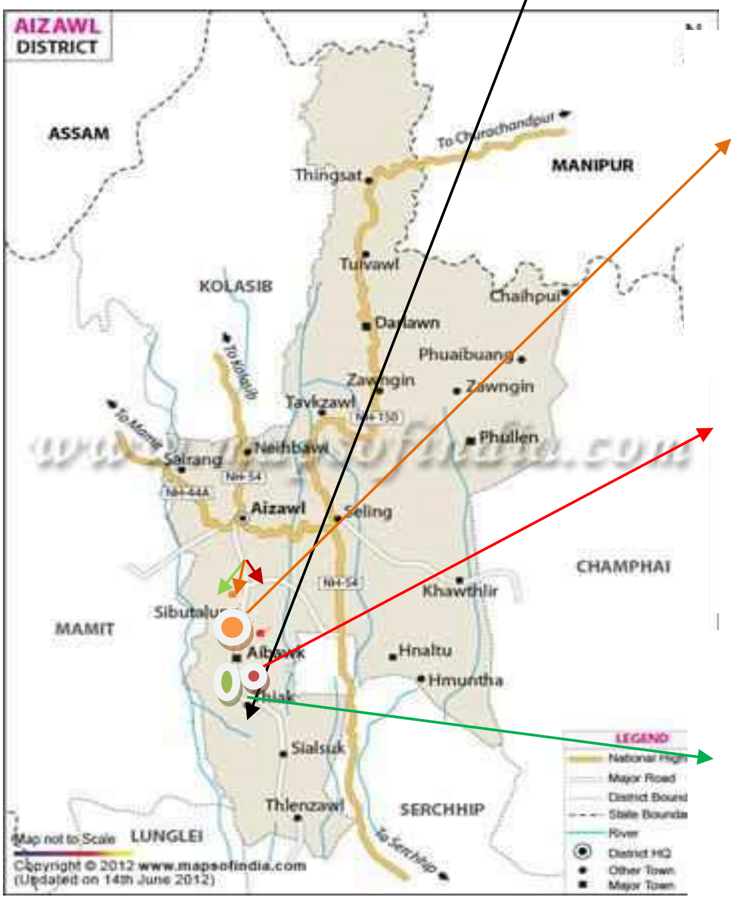
The surrounding nearby villages of Muallungthu are Falkawn, Kelsih, Tachhip, Melriat and Aibawk which are about 5 km from the village. According to census 2011, Muallungthu's population is 1,160. Out of this, 603 are males whereas the females count 557 here. This village has 174 kids in the age group of 0-6 years. Out of this, 80 are boys and 94 are girls. Literacy rate in Muallungthu village is 83%.

Out of total 1160 population 965 persons are educated here. Among males the literacy rate is 84% and the female literacy rate is 82%.

Agricultural status of Muallungthu village: The number of working people of Muallungthu village is 592, however, 568 are non-working out of which 466 persons are completely reliant on farming.

3.1.4. Map of the study sites





Farmer- Lalsangzuala
23°36′30″ N and 92°42′87″ E
Altitude-838 m; 2-3 years fallow

Farmer- C. Lalnunzira
23°35′69″ N and 92°43′09″ E
Altitude- 740 m, 5 years fallow

Farmer- Pu Rotlunga
23°35′66″ N and 92°48′08″ E
Altitude- 725 m, 10 years fallow

3.1.4. General characteristics of the soil

The surface soils of the hilly terrain are dark, highly leached and poor in basic nutrients, rich in iron and highly acidic with pH (4.5-5.5). Soils are well drained, deep to very deep, rich in organic carbon, low in available phosphorus content and high in available potash. The textures of surface soil are loam with clay content increasing with depth. The ratio of clay, silt and sand within the 50 cm of top soil in most cases varied from 20-30%, 35-45% and 25-45%, respectively. The pH and organic carbon decrease and clay content increase with depth. Soils are capable of providing substantial oxygen supply for plant growth and have the capability to retain moisture and maintain its supply throughout the growing seasons of most crops.

3.1.5. *Jhum* cultivation in the area

The practice of *jhum* farming involves slashing, burning and cropping without tillage of soil, and the cropped land is subsequently fallowed to attain pre-slashed forest through natural succession. All agricultural operations are performed manually, using only few traditionally and primitive tools and regeneration of forest and soil fertility are achieved cost-free and effortlessly. Cropping on *jhum* land in Mizoram is predominantly practiced for one year. Farmers have a general apprehension that the yields obtained from the second year of cropping are far less so they move to the new areas and; hence the second year cropping is scarce.

Rice is the main crop in *jhum* farming. Two varieties of upland rice, namely, “buhpui” and “tai” are popular among farmers. Mostly, rice is grown in monoculture; however, several crops are also mixed with rice in some areas, depending upon the requirements of the family. These crops include maize, *Colocasia*, *Brassica,* chillies, *Sesamum*, brinjal, ginger, cotton, and tapioca. Every year, shifting cultivators are allotted fallow lands by the village council through a lottery system. The area to be cultivated is decided by the cultivator on the basis of size and working capacity of his family. The forested fallow is slashed and cleared from December - January. The burning is done in March - April. Rice is sown mostly from the middle of April to the middle of May. Weeding is done twice or thrice from July - September, and rice is harvested from the end of October until the beginning of November. After the harvest, the land in left fallow and vegetative regeneration is allowed in it until the land becomes reusable. In the past, *Jhum* cycle was as long as 15-25 years but it was reduced to 5-6 years in recent years resulting in problems of land degradation and threats to the ecological balance of the region.

3.1.6. Climate of the area

Mizoram as a whole receives an annual total rainfall of about 3000 mm a year, with Aizawl receiving 2380 mm and Lunglei 3,178 mm. Rainfall is usually evenly distributed throughout the state. During rains the climate in the lower hills and river gorges is highly humid and exhausting for people, whereas it is cool and pleasant in the higher hills even during the hot season. A rather peculiar characteristic of the climate is the incidence of violent storms duringMarch to May. Strong storms arise from the north-west and sweep over the entire hills, often causing extensive damage to 'kacha' (temporary) dwellings and flowering perennials.

Mean annual temperature varies from 12^{o}C in winter to 30^{o}C in summer or occasionally it may go up. Winter is from November to February with a very little or no rain during this period. Spring lasts from end February to mid-April. Heavy rains start in June and continue up to August. September and October are the autumn months when the rain is intermittent.

Table 3.1.6. Weather parameters of the study areas (Aizawl district), Mizoram during 2013 - 2015

Month	**Temperature (^{o}C)**			**Relative humidity (%)**			**Rainfall (mm)**		
	2013	**2014**	**2015**	**2013**	**2014**	**2015**	**2013**	**2014**	**2015**
January	16.45	18.45	16.29	68.16	69	62.1	0	0	8
February	21.05	18.11	17.47	78.89	61.64	48.8	3.3	13.4	0
March	23.45	21.39	20.99	68.61	59.87	46.95	5.6	15.7	40.8
April	23.25	24.23	19.68	77.26	62.23	82	61.4	41.7	241.8
May	22.8	22.23	20.99	90.61	88.35	70.3	448.4	356.5	189.8
June	25.8	22.57	21.46	90.96	91.43	75.5	301.8	304.3	429.1
July	24.85	23.53	21.17	92.7	93.03	93.05	290.8	408.9	418.2
August	23.5	21.69	21.2	94.45	94.54	93.35	363.4	231.8	486
September	24.35	21.67	21.56	93.13	93.53	93	268.6	381.4	356.1
October	21.95	22.08	20.67	89.03	83.25	91.55	101.7	60.1	233.4
November	21.83	19.96	19.44	71.96	79.96	90.05	0	1.2	3.7
December	18.16	16.91	15.51	75.22	75	90.4	0	0	5.4

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

3.1.7. Vegetation of the area

The natural vegetation of Mizoram at high altitudes represents typical of "East-Himalayan subtropical wet hill forests", and that of low altitudes represent "tropical wet evergreen forests" (Champion and Seth, 1968). About 91% of total geographical area of the state is under forest cover. The regenerating forest vegetation of *Jhum* fallow is secondary successional type with dominance of *Melocanna baccifera* (Tawnenga, 1990). The associates of common tree species at these sites are: *Schima wallichii, Sterculia villosa, Callicarpa arborea, Emblica officinalis, Albizzia chinensis, Castonopsis tribuloide, Rhus succedanea, Toona ciliatea, Wendlandia tinctoria* (Singh *et al.*, 2014). The common understory species present in regenerating stands comprises of secondary species like species of bamboo (*Melocanna baccifera, Dendrocalamus* sp.) and grasses (*Imperata cylindrica, Saccharum longisetosum, Thysanolaena maxima).*

3.2. Experimental design and the establishment of treatments

The study was conducted on a chronosequence of three fallow ages namely 3 years (FL-3), 5 years (FL-5) and 10 years (FL-10) in Muallungthu village, Mizoram for three years during 2013-2015. The geographic position of the study sites are given in Map 3.1.4. All sites were almost similar in terms of topography, slope, aspect, hydrology, soil type, soil depth, and vegetation (age and composition) of adjacent forest fallow, and all have been managed using the same shifting cultivation practices up until the onset of the current fallow period. Forest fallow of different ages were slashed by the farmers in December 2012 and after drying the biomass present on the floor was burnt between 10 and 15th of March 2013. The intensity of burning on these sites varied with the amount of biomass burnt. The amount of biomass burnt was 1.8, 5.9 and 12.6 t ha^{-1}at FL-3, FL-5 and FL-10, respectively. The treatment was established later after the burning event in the first week of April 2013. In each site, about 1 ha area was marked within which 4 similar representative plots of about 10 m x 30 m were demarcated perpendicular to slopeand ascribed to one of the following three Treatments (T) and a Control (C). Different treatments plots, for example, inoculation with beneficial rhizosphere microbes (T_{micro+}), amendments of top soil from the adjoining forest fallows @ 2 t ha^{-1} (T_{soil+}) of similar ages with that of the burned plot and amendment of mixed litter (leaves and small twigs) (@ 5 t ha^{-1}) from adjoining forest fallows of similar ages of burned plot ($T_{litter+}$)were established in three of those plots, and the remaining plot was treated as control. Rice (*O. sativa*) was sown after the establishment of treatment plots by dibbling method in the last week of April 2013 and in subsequent years during the same time. Sowing of rice in T_{micro+} treatment was done by mixing the rice seeds along with the microbial inoculants for 2-3 hrs and sown inside the soil by dibbling method along with the microbial inoculants. Procedure of developing microbial in inoculants is described below. In addition, all the plots were seeded with common vegetable crops during the first year cropping only. Within each main treatment plot, 3 subplots (10 m x 10 m size) were demarcated to facilitate structured random sampling in 2013-15 years cropping. In addition (2013-14 years cropping), *Tephrosia candida*, a leguminous shrub species, was planted along the border of each plot and subplots. T_{soil+} was discontinued in 2015 because of very less response in previous two years.

In the burnt field, sprouts of the early successional plants like *Thysanolaena maxima* are prevalent with the onset of the pre-monsoon shower presumably facilitated by the interactions between the microbial colonizers and roots of these plants. Therefore, an attempt was taken to employ both rhizospheric and endophytic bacteria of early colonizers to enhance the growth of crop plant under field trial. Microbial inoculants was developed from rhizospheric and endophytic bacteria isolated from roots of *T. maxima* one of most dominant early successional plant collected from the burn sites in the second fortnight of March 2013. Isolates were screened for acidity and heat tolerance ability and multifaceted plant growth promoting properties *viz*. ability of pectinase, cellulose, and IAA production, nitrogen fixation; phosphate solubilization [P in $Ca_3(PO4)_2$, $AIPO_4$, $FePO_4$and phytate amended media]. Based on the results of the PGP attributes of early colonizers, 5 best strains were selected on the basis of their maximum scores achieved for multifaceted PGP properties and were used to formulate microbial consortium in finely grinded dry compost (passed through 1 mm sieve). 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 were 1.25 x 10^8 up to 3 months from the date of manufacture.

3.3. Soil sampling

A total of 15 composited soil samples (100-150 g) were collected randomly from three fallow lands before burning to understand the initial soil characteristics of the soil. Each composited sample represents the collection of soil samples from three random locations from the upper 10 cm soil depth and mixed together at each fallow. Similarly, a total of 72 composited (mixture of 3 random samples from each subplot) soil samples were collected after the establishment of treatments during two phases of crop growth (at the beginning crop growth and at the crop maturity). Collected samples were enclosed in polyethylene bags and transported to the laboratory. The samples were divided in two parts, one part was used a fresh to determine soil moisture (SM), available nitrogen (NO_3-N and NH_4-N), MBC, MBC, enzymes activity (PHA, DHA and DSA) and the other part was air-dried and used for the analysis of total organic carbon (TOC), total nitrogen (TN), Exchangeable (Ex) potassium (K), available P and pH. Fresh samples were kept in the deep freezer unless the samples were not analysed.

3.4. Determination of soil physico-chemical properties

3.4.1. Soil texture, moisture, bulk density and pH

Soil texture was determined using hydrometer the method as described in detail (Gee *et al.*, 1986). In brief, 50 g dry soil was taken in 500 ml beaker mixed with distilled water and hydrogen peroxide and transferred to 1L measuring cylinder and sodium hexametaphosphate was added. The sample reading was taken using hydrometer and temperature was also recorded. Moisture content was determined gravimetrically (Anderson and Ingram, 1993). Soil bulk density (g cm^{-3}) was measured using a metallic tube of known inner volume and estimating the dry weight of a unit volume of soil (Brady, 1984). Soil samples were analyzed for pH (1:2.5 soil/water suspension) using a standard pH meter (Mettler Toledo, Switzerland).

3.4.2. Soil C and N

Finely grinded (1mm) air dried soil was used to determine C and N by using a Hereaus CHN-O-S Rapid Auto-analyser at Central Instrument Laboratory, Mizoram University.

3.4.3. Soil available N (NH_4-N and NO_3-N)

Freshly collected soil samples were used for determination of available soil N. NH_4-Nwas estimatedby Indophenol Blue colour Method (Rowland, 1983). In brief, 20 g fresh soil was extracted with 100 ml of deionised water for 15 min shaking and filtered with Whatman No. 1 filter paper. Five ml of filtrate was placed in a 25 ml volumetric flask in which 8 ml Rochelle's reagent, 1 ml nitroprusside solution, 2 ml sodium phenate and 0.5ml sodium hypochlorite was added to develop blue colour. The intensity of blue colour was measured at 625 nm using spectrophotometer and concentration was obtained from the standard curve prepared for the known amount of ammonium concentration.

The supernatants obtained from the extraction fresh soil for ammonium determination was further used for the estimation of (NO_3-N) as method described by

Jackson (1958). Aliquot of 10ml was taken in 100ml beaker and were kept in water bath to dryness. After drying 2ml of phenol disulphonic acid was added followed by addition of distilled water and ammonium hydroxide to obtained yellow colour. Finally, intensity of colour was measured at 410 nm using spectrophotometer and concentration was obtained from the standard curve prepared.

3.4.4. Soil available phosphorus (P_{avail})

P_{avail} in soil was determined by stannous chloride blue colourmethod (Bray and Kurtz, 1945). In brief, fine grinded air dried soil (0.5 g) was extracted with 50 mL of 0.03N NH_4F 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 spectrophotometer and concentration of P was obtained from the standard curve.

3.4.5. Soil exchangeable Potassium ($K_{exchange}$)

Soil $K_{exchange}$ was determined by ammonium acetate extraction method as described by Hanway and Heidel, (1952). An aliquot (25 mL) of neutral normal ammonium acetate was added to 5 g fine 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.

3.4.6. Microbial biomass carbon (MBC)

MBC was determined using freshly collected soils by chloroform-fumigation-extraction method (Brookes and Joergensen, 2006). 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 desiccators and the other sub-sample kept in a desiccators 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. Each sub-sample was added 100 mL 0.5 M K_2SO_4 (1:4 ratio) and shook for 30 min at 200 rpm in an orbital shaker. 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 TOC by Walkley and Black (1947). The difference in C content between fumigated and non-fumigated sub-samples was determined and then, MBC was calculated using a conversion factor, K_{EC}=0.38 (Vance *et al*., 1987; Wu *et al*., 1990; Dilly and Munch, 1998). MBC content was expressed in μg g^{-1} (dw) soil.

3.4.7. Microbial biomass nitrogen (MBN)

MBN was also determined by chloroform-fumigation-extraction method (Brookes and Joergensen, 2006). For the estimation of MBN, supernatants obtained from fumigated and non-fumigated samples for determining MBC were used. Ten mL of the aliquot was kept in a digestion tube where 10 mL concentrated 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 in the samples was determined by following the regular Kjeldahl distillation 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 (prepared by dissolving mixture of 0.1 g bromocresol green and 0.07 g of Methyl red in 100 mL of ethanol) in a conical flask and the absorption of ammonia in boric acid was determined by titrating with standard 0.02 N H_2SO_4. 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_{EN} =0.45 (Gijsman *et al*., 1997; Jenkinson, 1988; Ross and Tate, 1993). MBN was expressed as µg g^{-1} (dw) soil.

3.4.8. N-mineralization (N_{min}) rates

N_{min} was measured *in situ* using buried bag technique (Eno, 1960) seasonally. At each site, soils from upper 10 cm depths were sampled and divided in two parts; one part was brought to the laboratory to measure soil available N (NH_4-N and NO_3-N) and the other part after removing large roots and organic debris was placed in polythene bag and incubated *in situ* and retrieved after two months for the estimation of N_{min} (nitrification and ammonification) rates. Ammonification and nitrification rates were obtained by subtracting initial concentration of NH_4-N and NO_3-N, respectively, from final concentration after one month and the resultant values were referred to as ammonification and nitrification rates. Net N_{min} was calculated as the sum of nitrification and ammonification rates per month.

3.4.9.*ß*-glucosidase activity (GSA)

β-glucosidase 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 μg (*p*NP) g^{-1} (dw) soil h^{-1}.

3.4.10. Dehydrogenase activity (DHA)

Dehydrogenase 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. In each test tube, 0.5 mL of 1% 2,3,5-triphenly-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 μg (TPF) g^{-1} (dw) soil h^{-1}.

3.4.11. Phosphomonoesterase activity (PHA)

Fresh sieved (1 mm) soil samples were used for phosphomonoestarase 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 CaCl2 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. phosphomonoestarase enzyme activity was expressed as μg (*p*NP) g^{-1} (dw) soil h^{-1}.

3.5. Determination of plant characteristics

3.5.1. Weeds composition and diversity

Floristic composition of the study site was recorded periodically from 2013-2015 (using plots of 50 cm x 50 cm) in all three fallow sites. The phytosociological data were obtained during three seasons (summer, rainy and winter) in all sites. The plant species collected were identified according to Gaur (1999) and Sharma (1980). Importance Value Index (IVI) of each species was calculated according to Curtis and McIntosh, 1951; Risser and Rice, 1971).

Similarity among the study sites within andacross different seasons was estimated using theSorenson similarity index (Sorensen, 1948) according to the following formula: S= 2c/a+b

Where, c= Number of common species between two plots (1 and 2); a = Number of species in plot 1; b = Number of species in sample plot 2.

Dominance-diversity curves were prepared by plotting species importance value index against the sequence of species (from highest to lowest IVI) (Whittaker, 1975).

Diversity of each study site across different seasons was estimated, using five diversity indices (D_1-D_5). The symbols used in computing D_1 to $D_5$are: S = total number of species, N=total sum of importance attribute of all species, pi = proportional importance of i^{th} species (ni/N), ni = importance attribute of each species and N_{max} = importance attribute of the most important species. Species diversity indices were calculated by using IVI.

D_1, Species count (Number of species/area in the present study the no. of species that occurred in quadrats sampled)

D_2, Margalef index (Clifford and Stephenson, 1975)

$$D_2=S-1/\ln N$$

D3, Menhinick index (Whittaker, 1977)

$$D_3=S/\text{sq root } N$$

Information statistic indices

D_4, Shannon-index (H') (Shannon and Weaver, 1949)

$$D_4 = -\Sigma pi \ln pi$$

D_5, Evenness (Pielou, 1966)

$$D_5=D_4/\ln S$$

3.5.2. Weed biomass

Aboveground biomass (AG) and belowground biomass (BG) was estimated using three random quadrats of 50 cm x 50 cm per treatment plot every time. This way a total of 12 quadrats were laid every time per site with a total of 108 quadrats across the 3 selected study sites in three seasons. The plants inside the quadrats were uprooted and enclosed in ploythene bags. The collected plant samples were brought to the laboratory and were washed, dried at 60-80ºC for 36-48 hours and weighed.

3.6. Fine root biomass and production

Root biomass was collected five times (at the time of slashing of forest vegetation, TSF; just after burning of biomass, JAB; at the time of seed sowing, TSS; at the time of crop maturity, TCM and harvest TCH) inyear (January-October 2013) from three secondary successionalfallowstands. Five soil monoliths were collected at random locations from each stand using a square steel core measuring 10 cm x 10 cm, 30 cm deep (volume 3000 cm^3). After retrieval, monoliths were separated vertically into three depths (0-10, 10-20 and 20-30) cm. The soil samples were soaked with water in a bucket and were washed with a jet of water over a twin sieve assembly; upper sieve of 2 mm mesh size andlower sieve of 0.5 mm mesh size to take out the root materials. Roots passing through the finer sieve (0.5 mm) were collected on a filter paper from the bucket. Further, the roots were divided into three different diameter classes (mm): ≤ 0.5, 0.5-2, 2-5. All roots categories except very fine roots (≤ 0.5 mm) was further separated into live or dead categories on the basis of general appearance (colour), cohesion between cortex and periderm and root elasticity (Leuschner *et al.*, 2007). Fine root biomass of all categories was oven dried at 80^{o}C for 48 hours to constant weight and weighed. The data on fine root abundance was expressed per unit area (g m^{-2}).

Annual fine root production was calculated assuming a single annual pulse of fine root production and computed net production as the sum of differences between annual maximum and minimum root standing biomass of different diameter classes (Tripathi *et al.*, 1999).

3.7. Crop biomass and production

Total biomass of rice at maturity was measured by harvesting 5 random quadrats (1 m x 1 m) from each of the subplots with a total of 15 quadrats from each treatment in three successive years (2013-15). This way rice was harvested from 60 quadrats every year. The rice crops were separated into leaf, stem, roots and seeds and weighed fresh, and small subsamples of each parts (~100 g) were brought to the laboratory and oven-dried separately at 70°C for 48 hours to constant weight.

Similarly, vegetable biomass was estimated by laying 5 random plots (measuring 2 m x 2 m) at the time of harvest from each sub-plot with a total of 60 plots from all sites during 2013 cropping. Vegetable components were also separated into leaf, stem, roots, tubers, flowers and fruits and weighed fresh and brought to the laboratory and sub- samples were dried at 70^{o}C for 48 hours. Rice and vegetable biomass was reported on oven dry weight basis (g m^{-2}) for all components.

Total above-ground production was calculated by using the biomass of different components of rice and vegetables at maturity within a year. Similarly, economic yield of rice and vegetables was calculated by collecting the rice grains with husk and fruiting bodies of the vegetable at the time of crop maturity. Belowground production was also calculated as the root biomass at the crop maturity.

The sums of different aboveground components of crop biomass at maturity was designated as aboveground net productivity (ANP) and root biomass at maturity was considered as below-ground net productivity (BNP). Total net productivity (TNP) was computed as the sum of ANP and BNP. The amount of C sequestered in crops was calculated as the product of component-wise annual crop production and its C concentration. Similarly, N uptake was calculated by multiplying the productivity of different parts of rice and vegetables by their N concentrations.

3.8. Litter decomposition

Freshly fallen leaf and branches which did not undergo decomposition was collected from each site during the month of February-March 2013 from the slashing site of the control plot. The litter samples were brought to the Laboratory and dried at room temperature. After adjusting for the initial moisture content, samples (equivalent to 5 g dry weight) were enclosed in nylon net (mesh size: 2 mm^2) bags (15x15 cm). Roots were collected by digging out soil monoliths of 0-15cm depth from each site and washed over a sieve system and oven dried at 35°C for 72 hours to constant weight. Root samples were separated into three diameter categories (≤2 mm, 2-5 mm in diameter) with the help of caliper. After adjusting for the initial moisture content, root samples of each categories (equivalent to 5 g dry weight) were also enclosed in nylon net (mesh size: 2 mm^2) bags (15x15 cm). The mesh size (2 mm) was large enough to permit aerobic microbial activity and allow free entry of small soil animals.

For determining litter decomposition rate, leaves, stems and roots (diameter size- 0.5-2 and 2-5) were collected during February-March and air dried. The litter materials were enclosed in nylon net bags and placed on the floor of different sites to measure the rate of decomposition (Bocock and Gilbert, 1957). The mesh size (2 mm) was large enough to permit aerobic microbial activity and allow free entry of small soil animals. Five bags containing decomposing litter were randomly recovered at 2-months intervals from each site. After recovery, the bags were placed in individual polythene bags and transported to the laboratory. The bags were opened and the recovered litter materials were air dried initially, brushed to remove, adhering soil particles and finally dried at 80^{o}C for 24h and weighted.

3.9. Chemical analysis of plant samples

The litter and other samples (rice and vegetables) collected were ground and passed through a 1-mm mesh screen for chemical analysis. All analyses were carried out in triplicates. C and N concentration were determined by a Heraeus CHN-O-S Rapid Auto-analyzer employing Sulphanilamide ($C_6H_8N_2O_2S$) standard.

Initial lignin was determined using Fibrotron Automatic Fibre Analyser System: Model: FRB 6, version 0.1. Lignin content of root material was determined by using 1 N H_2SO_4 and Cetyl Trimethyl Ammonium Bromide (CTAB). Weighed samples of 0.5g was placed into oven dried sintered glass crucibles. Crucibles along with materials were boiled initially at 350°C with 100 ml of Acid Detergent Solution (ADS) followed by boiling at reduced temperature at 250°C for 30 minutes. Then the crucibles were placed in hot air oven to dry the material and weighed. Percent lignin content in the material was calculated as: (weight of crucible + sample)–(weight of empty crucible) x 100/weight of original sample.

3.10. Computations

The mean relative decomposition rate (RDR) was calculated by using the formula:

RDR (mg $g^{-1}day^{-1}$) = ln (W_1-W_0)/ (t_1-t_0), where W_0= mass of litter present at time t^o, W_1= mass of litter at time $\boldsymbol{t_1}$**,** and $\boldsymbol{t_1}$**-** $\boldsymbol{t_0}$**=** sampling interval (days).

The annual decay constant (*k*) of litter components was calculated through the negative exponential decay model of Olson (1963): ln (x_1/x_0) = $^{-kt}$, where x_0 is the original mass of litter, $x_t$is the amount of litter remaining after time *t*, *t* is the time (year) and*k* is the decomposition rate ($year^{-1}$). The time required for 50% and 95% mass loss and nutrient releasewas calculated as t_{50}=0.693/*k* and t_{95}=3/*k*, respectively.

C and N accumulation and input in roots to soil profiles were calculated by multiplying the root biomass and production data of different root categories by their respective total C and N concentrations. Turnover of the root biomass was calculated as the ratio of annual net production to annual mean biomass. Similarly, turnover of C or N was calculated as annual input divided by annual mean accumulation of C or N in the soil profile.

Net change in per cent soil C in different treatments relative to control was calculated as: Net change in C (%) = {(C_t-C_c) x 100}/C_c

Where C_t is percent carbon content in treatment and C_c is carbon content in control plot.

3.11.Statistical analysis

All statistical analyses were performed using SPSS v.16. The data were analyzed with a one-way analysis of variance (ANOVA) using litter type, *Jhum* fallow lengths and treatments as factors in order to study the interaction effects of these factors on soil process level indicators. The differences in treatments were tested at 95% confidence limit. The different fallow lengths of burnt condition within a study site (Mizoram) were analyzed for differences among mean ranks in terms of each of the parameters.

Total seasonal root biomass (TRB) was correlated with abiotic parameters (e.g. mean monthly temperature, total monthly rainfall and soil parameters) to analyze seasonal variations between root biomass and corresponding abiotic parameters for all sites separately. Differences in standing fine root biomass, nutrients contents and fine root growth (production) between the fallow stands and between the different soil horizons and root categories were analysed using ANOVA followed by Tukey's Honest Significant (HSD).

Correlation coefficients analysis was performed between abiotic variables (i.e. monthly rainfall, mean air temperature, humidity, soil moisture) and soil parameters, litter mass lost during decomposition. Statistically significant differences were set with p-values <0.05 unless otherwise stated.

CHAPTER 4

RESULTS

The major findings of the research work are presented in the following sub heads:

4.1. Initial vegetation and soil characteristics of the study sites

Total number of woody species increased with increasing fallow age of the stand, whereas, the number of herbaceous species decreased during the course of fallow recovery (Table 4.1). Woody and herbaceous biomass increased together during the course of recovery. Among the initial soil parameters, the soil bulk density decreased (0.8 g cm^{-3}) in FL-10 compared to FL-3, whereas, soil TOC and nutrients (TN, available N and phosphorus and P) increased with increasing fallow ages (Table 4.1). The increase was significant (p<0.01) between FL-3 and FL-10 but in FL-5, it was not significant with the two fallows. Stocks of C, N, P_{avail} available N also increased during the course of recovery.

Table 4.1. Initial plant and soil characteristics in the three fallow chronosequence sites immediately before burning and establishment of treatment. Values are means±1SE; n=3.

Parameters	FL-3	FL-5	FL-10
Plant characteristics			
No. of woody species	4	8	15
Plant biomass (kg ha^{-1})	1020	4538	10100
No. of herb species	12	9	8
Herb biomass (g m^{-2})	76.5	132.0	251.0
Soil characteristics			
Bulk Density(g cm^{-3})	$1.0^{a} \pm 0.14$	$0.9^{ab} \pm 0.09$	$0.8^{b} \pm 0.12$
pH	$4.6^{a} \pm 0.22$	$4.9^{ab} \pm 0.24$	$5.5^{b} \pm 0.31$
Total organic carbon (%)	$2.2^{a} \pm 0.11$	$2.5^{ab} \pm 0.18$	$2.7^{b} \pm 0.15$
Carbon stock (t ha^{-1})	2.20	2.25	2.32
Total nitrogen (%)	$0.15^{a} \pm 0.02$	$0.21^{b} \pm 0.01$	$0.26^{c} \pm 0.01$
Nitrogen stock (kg ha^{-1})	150	207	216
C:N ratio	14.6	10.8	10.7
Available P (mg g^{-1})	$0.03^{a} \pm 0.01$	$0.04^{ab} \pm 0.01$	$0.06^{b} \pm 0.01$
Available P stock (kg ha^{-1})	4	5.4	6.4
NH_4-N (mg g^{-1})	$0.04^{a} \pm 0.01$	$0.05^{ab} \pm 0.01$	$0.07^{b} \pm 0.01$
NH_4 -N stock (kg ha^{-1})	5	6.3	7.2
NO_3-N (mg g^{-1})	$0.05^{a} \pm 0.01$	$0.06^{a} \pm 0.01$	$0.09^{b} \pm 0.02$
NO_3-stock (kg ha^{-1})	6	7.2	9.6

4.2. Changes in initial litter chemistry during fallows

Initial litter chemical quality varied significantly among different litter components and fallow ages (Table 4.2). Lignin contents were significantly higher in branch (20-32%) and coarse roots (21-30%) and lower in leaf (13-29%) and fine roots (16-21%). Similarly, branch (30-41%) and coarse roots (35-44%) showed higher C content compared to leaf (33-35%) and fine root (29-31%). Further, N content in leaf

(1.3-1.85%) and fine roots (0.9-1.3%) were significantly higher compared to branches and coarse roots (Table 4.2).

Table 4.2. Initial chemical composition (% except, C/N and lignin/N) of litter components (leave, branch, roots- <2 mm, 2-5 mm) from three different sites (FL-3, FL-5 and FL-10 years) Muallungthu village, Aizawl district, Mizoram, n=5.

Sites	Components		Lignin %	C %	N %	Lignin/N	C/N
3 years	Leaves		13.6±11	33±1.2	1.31±.12	10	25
	Branches		20.0±10	30±1.2	1.07±.12	19	28
	Roots	<2 mm	15.7±11	29±1.1	1.11±.15	14	26
		2-5 mm	21.0±12	35±1.0	0.99±.11	21	35
5 years	Leaves		19.1±13	34±1.2	1.55±.08	12	23
	Branches		27.1±11	37±1.1	1.29±.12	21	27
	Roots	<2 mm	23.3±11	30±1.1	1.31±.12	18	23
		2-5 mm	26.5±12	40±1.2	1.27±.1	21	31
10 years	Leaves		29.3±12	35±1.2	1.87±.12	16	18
	Branches		32.2±12	41±1.4	1.43±.12	21	29
	Roots	<2 mm	21.2±12	31±1.0	1.51±.15	14	21
		2-5 mm	30.2±12	44±1.1	1.36±.11	22	32

4.3. Changes in mass loss and litter chemistry during decomposition

Percent litter mass remaining varied widely among the litter components and fallow length (Table 4.3). Maximum mass loss occurred in leaf followed by fine root, coarse root and branch in all sites. The percent mass remaining at the end of decomposition was: 5.8-12% in leaf, 22-29% in fine root, 25-33% in coarse roots and 29.4-37% in branch. The higher decomposition was recorded at FL-10 followed by FL-5 and FL-3 (Fig. 4.1). As reflected by RDR values, mass loss rate was faster in initial two months period in all litter components which varied between 25% and 32%, and the same decreases in the later stages of decomposition (Fig. 4.1).

Table 4.3. Decomposition parameters and time required for various levels of decay (t_{50} 50%, t_{95} 95% mass loss), n=5.

Sites	Components	Mass remaining (% initial) 365 days	Daily decay rate (*k*)	t_{50} (days)	t_{95} (days)
FL-3	Leaf	12	5.81	119.30	516.45
	Branch	37.2	2.71	255.79	1107.33
	<2 mm	29.4	3.35	206.62	894.48
	2-5 mm	33.2	3.02	229.40	993.09
FL-5	Leaf	7.8	6.99	99.15	429.24
	Branch	33.2	3.02	229.40	993.09
	<2 mm	26.8	3.61	192.10	831.58
	2-5 mm	30	3.30	210.09	909.49
FL-10	Leaf	5.8	7.80	88.84	384.57
	Branch	29.4	3.35	206.62	894.48
	<2 mm	22	4.15	167.06	723.19
	2-5 mm	25.6	3.73	185.64	803.62

4.4. Pattern of C and N release during fallow recovery

Generally, the pattern of C stocks loss in the present study followed the pattern similar to that of mass loss in all sites (Fig. 4.1). However, the N stock loss showed a steady decrease followed by a slow release or slight increase in N stock which showed the tendency of N immobilization by microorganisms during the stage of decomposition followed by N mineralization (Fig. 4.2-4.3). Fine roots and leaf litter showed a relatively greater release of N than other components. The effect of initial litter quality on the decomposition rate was evaluated by correlating annual mass loss of different components against litter quality parameters: C, N, lignin, C/N ratio and lignin/N ratio. The C/N ratio in branch and coarse roots (Table 4.1) may partially be responsible for slow decomposition rate that affect the release of nutrients in soil.

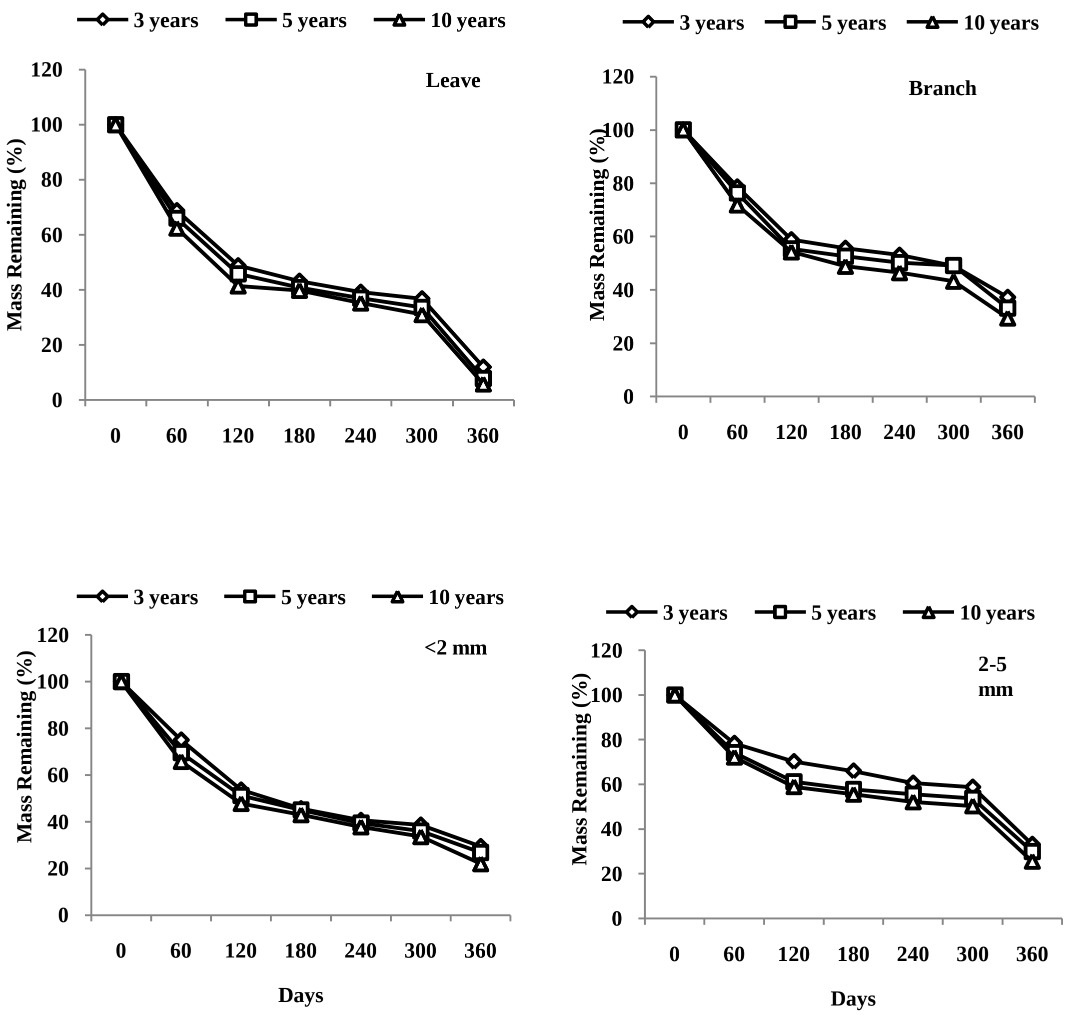


Fig 4.1. Mass remaining after litter placement in days for four litter components in different sites (FL-3, FL-5 and FL-10 years) respectively.

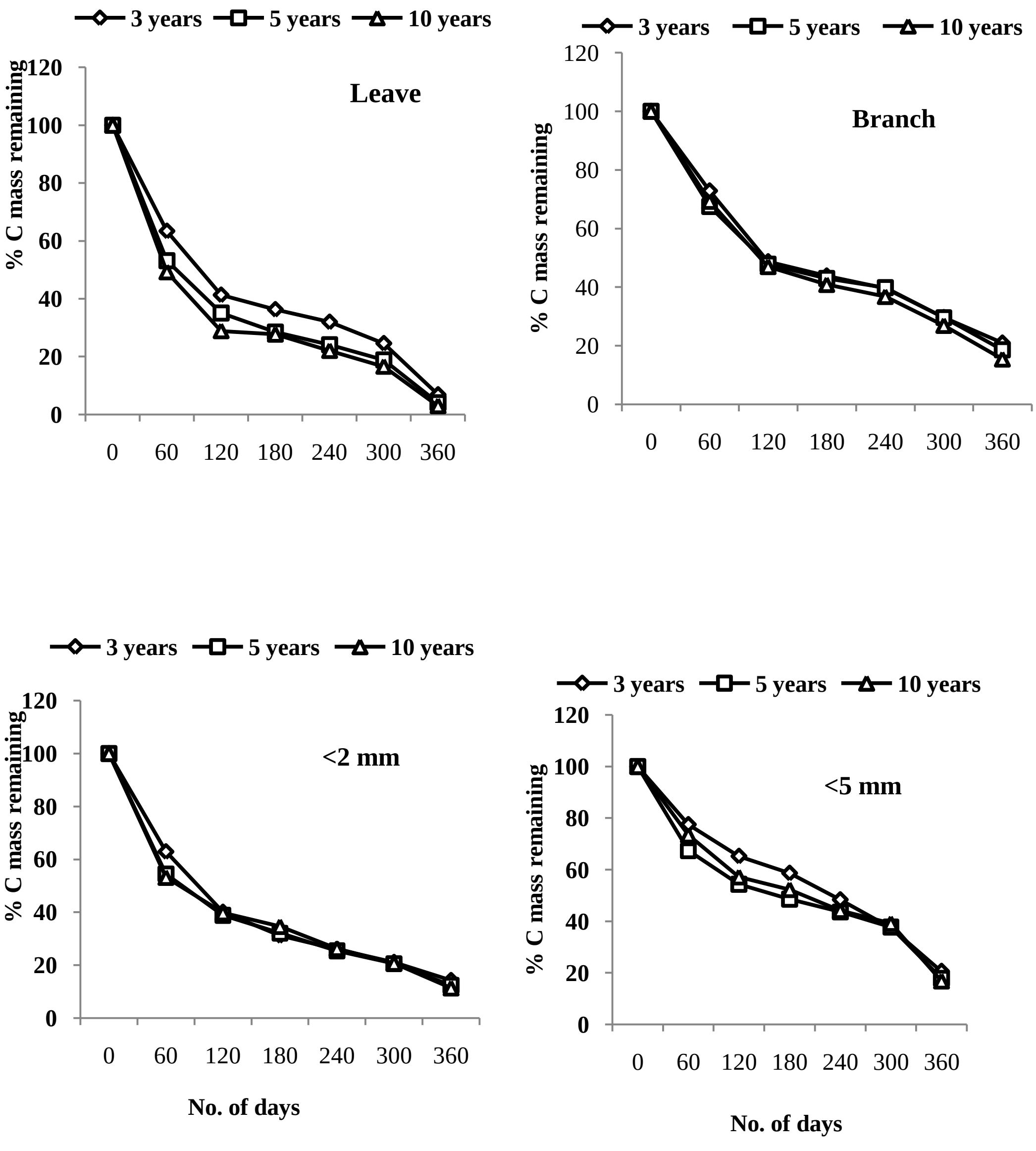


Fig 4.2. The amount of carbon stock remaining in different litter components in three sites during the course of decomposition.

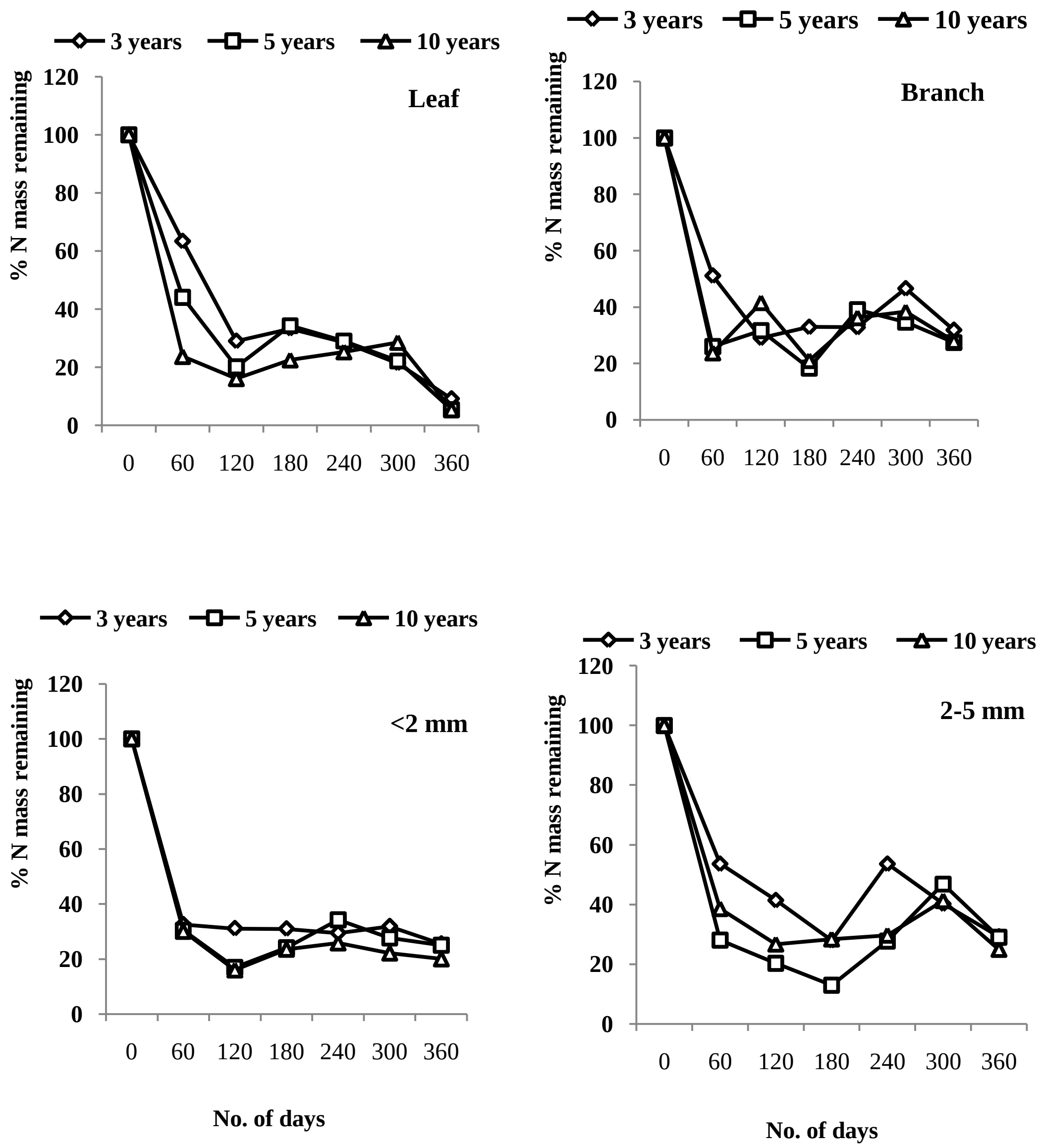


Fig 4.3. The amount of nitrogen stock remaining in different litter components in three sites during the course of decomposition.

4.5. Role of abiotic variables on mass loss, C and N release patterns

To understand the effect of the environmental factors on litter mass loss in the respective fallow lands, abiotic variables like soil moisture, air temperature, rainfall and relative humidity were correlated with mass loss rates. The values of correlation coefficient (r) with mass loss rates in different components and mean values (corresponding to litter bag retrieval intervals) were 0.42 SM, 0.36 for rainfall, 0.51 for air temperature, 0.41 for soil temperature and 0.30 for relative humidity. All r values were significant at $p<0.01$.

4.6. Changes in root biomass and necromass during fallow ages

Seasonal variations in the amount of root biomass were recorded in three fallow stands. Forest at the time of slashing (TSF) showed significant ($p<0.05$) differences with JAB and TSS in FL-3, FL-5 and FL-10. TRB was minimum at JAB (133, 149 and 175 g m^{-2} respectively in FL-3, FL-5 and FL-10) and maximum at TSF (525, 577 and 671 g m^{-2} respectively in FL-3, FL-5 and FL-10) (Fig. 4.4-4.5). Among fallow, TRB showed significant ($p<0.05$) increase from FL-3 (277 g m^{-2}) to FL-10 (396 g m^{-2}) (Fig. 4.4-4.5).

Significant spatio-temporal variations were recorded in the amount of TRB ($p<0.01$) at different time points (e.g. TSF, TSS, TCM and TCH) except JAB in three fallows. Similarly, live fine root biomass changed significantly ($p<0.01$) during various cropping events, for example, 451-561 g m^{-2} in TSF, 88-141 g m^{-2} in JAB, 125-198 g m^{-2} in TSS, 211-319 g m^{-2} in TCM and 283-448 g m^{-2} in TCH in three fallows. Seasonal variations in dead root biomass were less marked during various cropping events but the marked variations were observed with different fallows (Fig. 4.4-4.5).

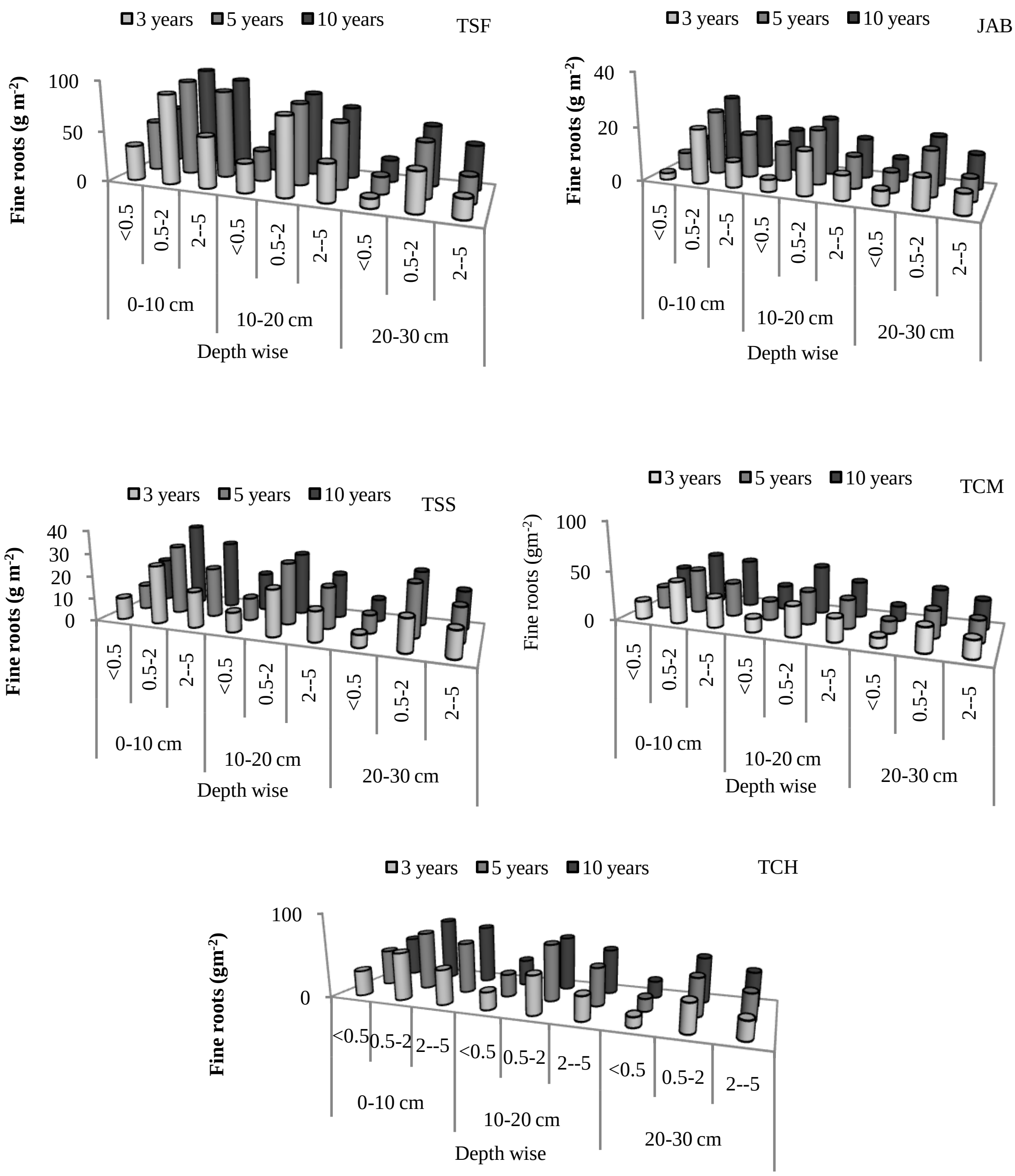


Fig 4.4. Seasonal variation in mean biomass of different diameter class root (g m^{-2}) of three fallow stands.

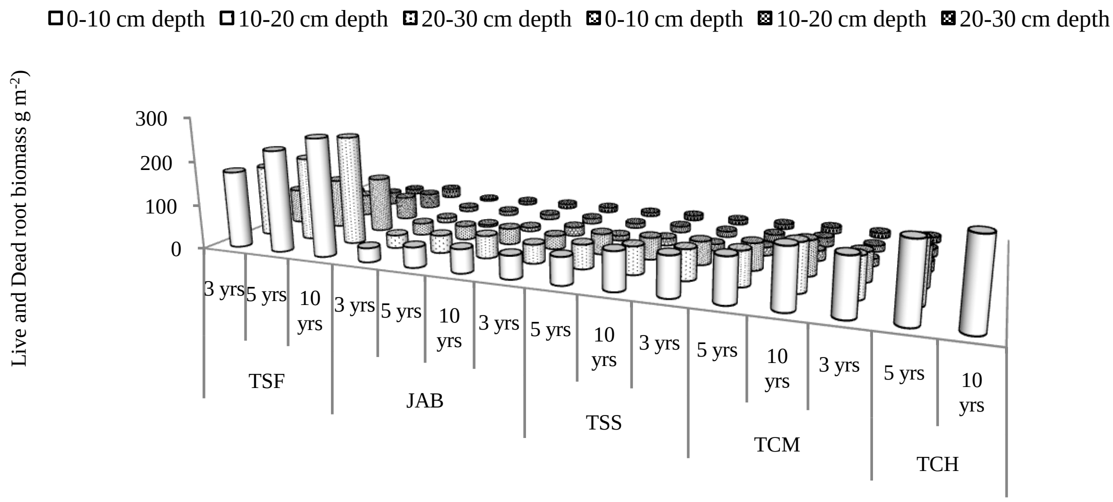


Fig 4.5. Changes in fine root biomass (FRB) and necromass in the three *jhum* stands, FL-3, FL-5 and FL-10 within the upper 30 cm soil depth. Vertical lines indicate standard error ±SE, n=15.

4.7. Correlation and regression analysis of TRB and soil parameters

Total root biomass was correlated and regressed against soil variables (e.g. SM, total N and MBC). SM was significantly (p<0.01) positively correlated with TRB in FL-3 (R^2=0.22), FL-5 (R^2=0.44) and FL-10 (R^2=0.31). Further, TN and MBC was also positively correlated with TRB in FL-3 (R^2=0.22 and R^2=0.51), FL-5 (R^2=0.24 and R^2=0.75) and 10 years (R^2=0.21 and R^2=0.52). In our study, maximum root biomass at TCH and minimum at JAB suggest positive correlations of root biomass with SM, TN and MBC (Fig. 4.6).

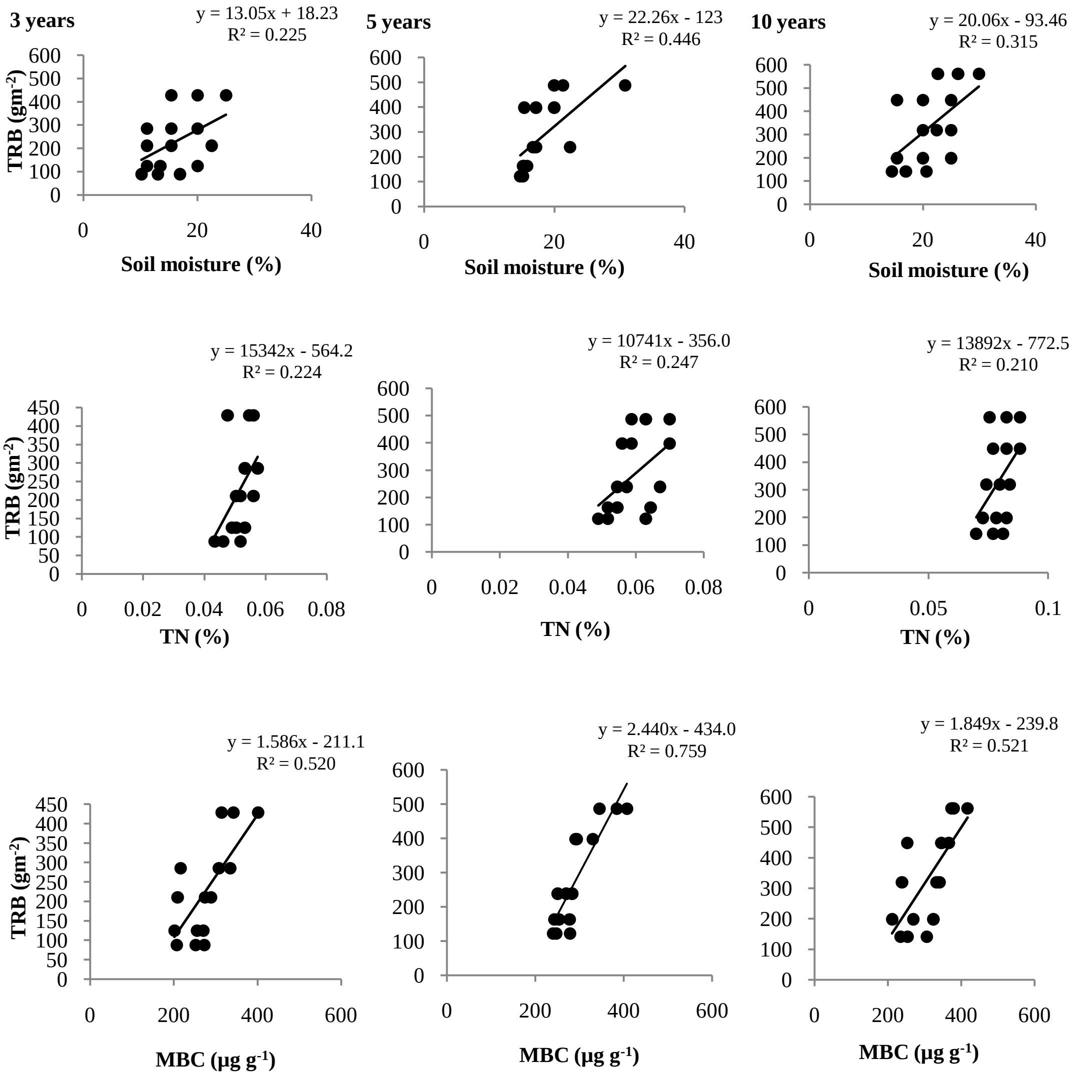


Fig 4.6. Relations between time period changes in total mean root biomass with soil moisture (SM), total Nitrogen (N) and microbial biomass carbon (MBC) in three sites.

4.8. Changes in root C and N concentrations

The concentration of C increases with root diameter However, N concentration decreased significantly ($p<0.01$) as the root diameter increased. Fine root (<0.5 mm) contains higher N content but, lower C content in all fallows. The concentrations of C and N in different root categories were significantly (p<0.01) higher in FL-10 compared to FL-3 but not with FL-5. The C: N ratio ranged from 14-16, 15-17 and 16-18, respectively in <0.5 mm, <2 mm and 2-5 mm (Table 4.4). Seasonal variations in C and N concentrations in roots were not significant.

Table 4.4. Changes in C and N concentrations (%) and C: N ratio in three fallow sites. The values are mean ±SE, n=15.

Fallow stands	Root categories	C (%)	N (%)	C:N ratio
FL-3	<0.5 mm	32.84	2.09	15.68
	0.5-2 mm	33.59	1.98	16.98
	2-5 mm	34.71	1.91	18.15
FL-5	<0.5 mm	34.20	2.24	15.25
	0.5-2 mm	35.47	2.18	16.30
	2-5 mm	36.36	2.05	17.74
FL-10	<0.5 mm	36.64	2.56	14.28
	0.5-2 mm	37.82	2.48	15.25
	2-5 mm	38.57	2.41	16.03

4.9. Changes in the amount of C and N associated with fine roots

Total C and N accumulations by different root categories differ significantly (p<0.5) in the soil profile to a depth of 30 cm in different fallow lands. The accumulations of C and N within soil profile generally followed the pattern similar to that of total organic matter (i.e. root biomass). Maximum organic matter, C and N were accumulated in upper soil depth (10 cm) followed by lower depths (10-20 and 20-30). The accumulations of C and N were greater at FL-10 compared to FL-3 and FL-5 (Table 4.5). Of the total C and N accumulated within 0-30 depth, maximum (42-

44%) occurred in the 0-10 cm soil depth and the minimum (22-25%) in the 20-30 cm in three fallow stands.

Table 4.5. Accumulation, production and input of organic matter, C and N through roots of categories in soil profile to a depth of 30 cm and turnover of organic matter in different fallows in Muallungthu village.

Fallow age/depth (cm)	**Accumulation (kg/ha)**			**Input (kg/ha)**			**Annual production (kg/ha)**			**Turnover rate (year-1)**
	OM*	C	N	OM*	C	N	OM*	C	N	OM*
3 years										
0-10	1147	425.8	22.9	1709	634.63	34.18	1020	378.9	20.4	0.89
10-20	947	351.5	18.9	1483	550.56	29.65	640	237.6	12.8	0.68
20-30	695	258.2	13.9	922	342.51	18.45	462	171.4	9.2	0.66
Total	**2789**	**1036**	**56**	**4114**	**1528**	**82**	**2122**	**788**	**42**	
5 years										
0-10	1427	570.8	32.8	2284	913.52	52.53	1411	564.5	32.5	0.99
10-20	1153	461.1	26.5	1510	603.72	34.71	1002	400.9	23.0	0.87
20-30	733	293.1	16.9	480	191.91	11.03	606	242.5	13.9	0.83
Total	**3313**	**1325**	**76**	**4274**	**1709**	**98**	**3020**	**1208**	**69**	
10 years										
0-10	1668	667.3	40.0	2368	947.18	56.83	1518	607.4	36.4	0.91
10-20	1325	530.0	31.8	1618	647.19	38.83	1090	435.9	26.2	0.82
20-30	962	384.9	23.1	977	390.60	23.44	790	315.8	18.9	0.82
Total	**3955**	**1582**	**95**	**4963**	**1985**	**119**	**3398**	**1359**	**82**	

OM*=organic matter. Turnover rates of C and N were almost similar to that of OM.

4.10. Changes in soil physico-chemical properties during forest fallows

Soil of the present study was sandy to sandy loam in texture. Soil BD variation from 1.0 g cm^{-3} was highest in FL-3 and lowest in FL-10 (0.7 g cm^{-3}). Treatment variations in soil BD were not significant, whereas, variations with fallow ages were significant (Table 4.6). Soil pH was minimum in FL-3 (4.6) and maximum in FL-10 (5.0).

Similarly, all other soil nutrients like TOC (32-35%), TN (30-38%), $K_{exchange}$ (26-41%), P_{avail}(30-37%), NH_4-N (25-40%) and NO_3-N (24-47%) were minimum in FL-3 and maximum in FL-10. Variations in soil pH and nutrients except BD were significant (p<0.05) between FL-3 and FL-10 (Table 4.6).The longer fallow supported narrower C: N ratio within soil profile, whereas, C: N ratio widened in shorter fallow.

Among treatments, soil nutrients like TN (21-50%) and NH_4-N (31-59%) increased significantly (p<0.05) over control in $T_{litter+}$ in different fallow lands. Significant p<0.05) increase over control in the level of P_{avail} (26-47%), $K_{exchange}$ (30-39%) and NO_3-N (22-50%) was recorded in T_{micro+} and $T_{litter+}$ (Table 4.6). Treatment effect in soil pH and TOC was not significant over control.

Table 4.6. Effect of the soil amendment/treatments on soil physico-chemical properties in the three fallow chronosequence sites (n=6). Bold and small letters represents significant (*p*<0.05) differences among ages and treatments, respectively.

Fallow period	Soil Properties	pH	TC (%)	TN (%)	$P_{avail.}$ ($mgkg^{-1}$)	$K_{Exchange}$ ($kgha^{-1}$)	NH_4-N ($mgkg^{-1}$)	NO_3-N ($mgkg^{-1}$)	C:N ratio
FL-3	Control	4.3^{a}	2.01^{a}	0.10^{a}	10.3^{a}	201.4^{a}	3.2^{a}	22.4^{a}	20.1
	T_{micro+}	4.7^{a}	2.23^{a}	0.14^{a}	14.9^{b}	204.7^{b}	5.1^{a}	29.2^{b}	15.7
	T_{soil+}	4.6^{a}	2.11^{a}	0.12^{a}	14.0^{a}	202.7^{a}	4.1^{a}	27.8^{a}	17.5
	$T_{litter+}$	5.0^{b}	2.37^{a}	0.15^{b}	18.2^{b}	208.2^{b}	6.0^{b}	31.1^{b}	15.3
FL-5	Control	4.5^{a}	2.10^{a}	0.12^{a}	14.1^{a}	224.7^{a}	5.1^{a}	30.9^{a}	17.5
	T_{micro+}	5.0^{a}	2.31^{a}	0.14^{a}	18.7^{b}	227.9^{b}	6.7^{a}	34.5^{b}	16.4
	T_{soil+}	4.7^{a}	2.19^{a}	0.13^{a}	16.4^{a}	225.7^{a}	5.9^{a}	30.1^{a}	16.1
	$T_{litter+}$	5.1^{b}	2.44^{a}	0.16^{b}	21.9^{b}	232.7^{b}	8.9^{b}	39.3^{b}	15
FL-10	Control	5.0^{a}	2.23^{a}	0.14^{a}	17.3^{a}	250.2^{a}	5.9^{a}	36.6^{a}	15.7
	T_{micro+}	5.2^{a}	2.34^{a}	0.16^{a}	23.7^{b}	253.4^{b}	8.2^{a}	57.1^{b}	14.3
	T_{soil+}	4.8^{a}	2.29^{a}	0.15^{a}	19.6^{a}	251.0^{a}	7.2^{a}	50.8^{a}	14.6
	$T_{litter+}$	5.3^{b}	2.56^{a}	0.17^{b}	27.3^{b}	258.9^{b}	12.0^{b}	69.9^{b}	14.7

4.11. Changes in soil microbial biomass and enzyme with fallows/treatments

In burnt fallow sites of Mizoram, the activities of GSA (30-36%), DHA (26-40%) and PHA (26-41%) were significantly (*p*<0.05) higher in longer fallow compared to short fallow. Enzyme activity was in the order of FL-10 > FL-5 > FL-3 (Table 4.7).

Table 4.7. Effect of the soil treatments on soil biochemical properties in the three fallow chronosequence sites (n=9). Bold and small letters represents significant (p<0.05) differences among ages and treatments, respectively.

Fallow periods	Treatments	GSA (μg *p*NPg^{-1} S h^{-1})	DHA (μgTPF g^{-1} S h^{-1})	PHA (μg*p*NP g^{-1} S h^{-1})	MBC (μg^{-1}g^{-1})	MBN (μg^{-1}g^{-1})	C:N ratio
FL-3	Control	253^a	0.90^a	517.75^a	395.8^a	9.28^a	44
	T_{micro+}	280^b	0.96^a	527.27^a	402.6^a	9.51^a	40.3
	T_{soil+}	262^a	0.92^a	521.52^a	398.9^a	9.37^a	44.3
	$T_{litter+}$	301^b	1.04^b	534.73^b	408.4^b	9.72^a	40.8
FL-5	Control	231^a	1.23^a	646.48^a	405.2^a	10.94^a	36.8
	T_{micro+}	258^b	1.28^a	653.25^a	410.3^a	11.14^a	37.2
	T_{soil+}	247^a	1.24^a	649.58^a	406.8^a	11.04^a	37
	$T_{litter+}$	264^b	1.33^b	659.51^b	416.4^b	11.31^a	37.8
FL-10	Control	154^a	1.41^a	823.55^a	434.5^a	11.87^a	36.2
	T_{micro+}	163^a	1.49^a	831.23^a	439.5^a	12.06^a	36.6
	T_{soil+}	156^a	1.46^a	826.79^a	436.0^a	11.93^a	36.3
	$T_{litter+}$	175^b	1.53^b	837.31^b	447.5^b	12.25^a	37.3

Among treatments, increased level (26-40%) of DHA over control was significant (p<0.05) in $T_{litter+}$ treatment in all sites. However, changes in soil PHA and GSA were marginal and not significant in all treatments (Table 4.7).

Microbial C and N were significantly (p<0.05) higher in FL-10 compared to FL-3. Level of increase in the values of MBC and MBN was 35-37% in FL-10, 33-34% in FL-5 and 29-32% in FL-3. The C: N ratio was found to vary with the length of fallows (Table 4.7).

Among different treatments, significant (p<0.05) increase (26-27%) in the level of MBC was noticed in $T_{litter+}$. However, MBN showed marginal increased over control in all sites.

4.12. Changes in N-mineralization (N_{min}) rates in fallow and treatments

Marked seasonal variations were observed in the level of N_{min} rates in all sites. In all sites, N_{min} rates were highest during rainy seasons and lowest during winter season. Seasonal variations in N_{min} rates were significant (p<0.01) in all sites however, there was no significant N_{min} rates in May 2013 and November 2013. The mineralization rates increased significantly (p<0.05) from 3 years to 10 years fallow. Seasonal variations in the amount of N_{min} rates ranged from 4.4-13 mg kg^{-1} in 3 years, 5.2-17 mg kg^{1}, in 5 years and 7-22 mg kg^{-1} in 10 years (Fig. 4.7). Among treatments, marginal increase in the amount N_{min} was recorded over control in T_{micro+} (10-15 mg kg^{-1}) and $T_{litter+}$ (11-16 mg kg^{-1}) andT_{soil+} (9-14 mg kg^{-1}) treatments (Appendix 1). Significant increase over control was only noticed in $T_{litter+}$ treatments in all fallows.

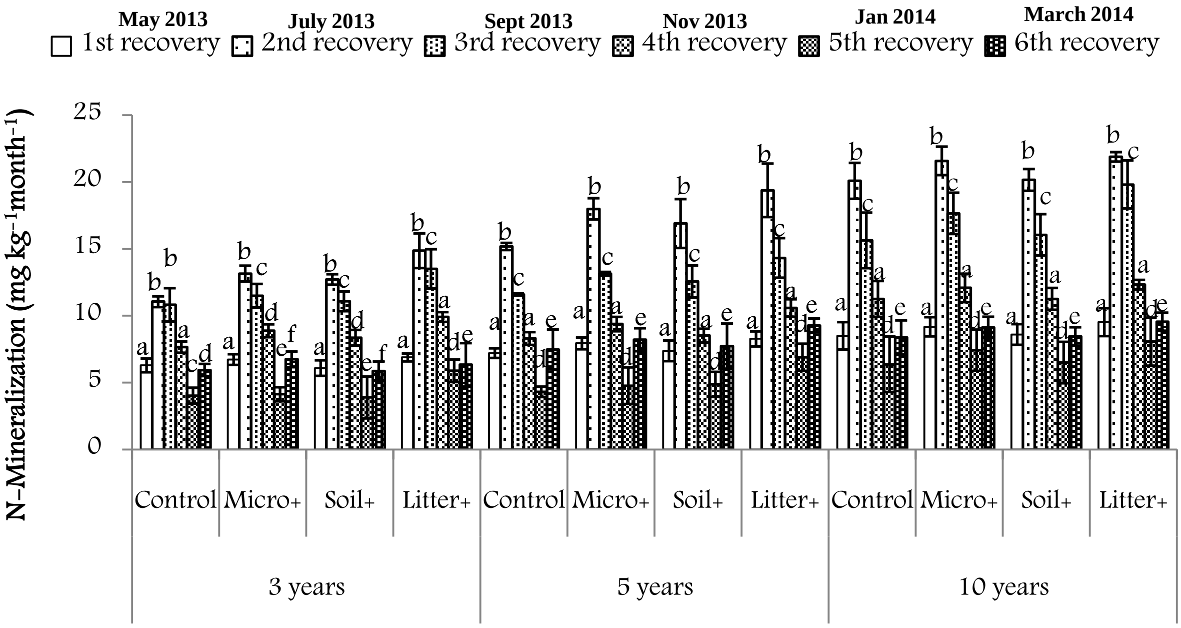


Fig 4.7. Periodical chnages in soil N_{min} rates (mg $kg^{-1}$$month^{-1}$) in *jhum* fallow site (3 years, 5years and 10 years). Small letter indicated significant (p<0.05) differences among monthly variations in the sites.

4.13. Changes in rice grain yield within fallow and treatments

Fallow length has significantly (p<0.01) increased the rice grain yield in 1st, 2nd and 3rd years except in case of 5 years. The grain yield was significantly (p<0.01) greater in the 1st cropping compared to the 2nd. Among the different treatments, $T_{litter+}$ and T_{micro+} have significant (p<0.01) increased in the grain yield. However, addition of soil marginally increased grain yield. In 1st cropping, greater increase (53-82%) over control was noticed in longer fallow stands (5 and 10 years) compared to 3 years (25%). In general, treatments have more pronounced effect on grain yield in the 2nd compared to the 1st cropping. Both T_{micro+} (23-46%) and $T_{litter+}$ (43-87%) has significantly (p<0.01) increased grain yield in 2nd. In 3rd year cropping, the rice yield had been reduced to 32% and 56% from 1st and 2nd year cropping. Among the different treatments, $T_{litter+}$ (70-87%) and T_{micro+} (78-89%) have significant (p<0.01) increased in the grain yield. In 3rd year cropping, greater increase (23-64%) over control was noticed in longer fallow stands (5 and 10 years) compared to 3 years (Table 4.8).

Table 4.8. Effects of the soil amendments in the three fallow chronosequence sites on rice grain yield (g m^{-2}) in three successive years. Different small superscript letters in columns show significant difference between treatments.

	1st Year Crop			**2nd Year Crop**			**3rd Year Crop**		
Treatments	FL-3	FL-5	FL-10	FL-3	FL-5	FL-10	FL-3	FL-5	FL-10
Control	108.02^{a}	109.5^{a}	134.61^{a}	52.4^{a}	66.1^{a}	84.4^{a}	14.9^{a}	25.2^{a}	73.4^{a}
	±6.7	±7.2	±8.1	±6.0	±5.8	±3.9	±1.6	±2.0	±2.3
T_{micro+}	117.2^{b}	134.0^{b}	157.62^{b}	76.3^{b}	81.5^{b}	121.8^{b}	21.4^{b}	32.7^{b}	84.2^{b}
	±2.1	±3.3	±5.4	±4.7	±9.5	±4.2	±2.3	±2.3	±2.5
T_{soil+}	109.49^{a}	129.71^{a}	146.78^{a}	63.5^{a}	75.0^{a}	103.2^{a}	-	-	-
	±7.3	±8.6	±5.7	±6.6	±5.4	±4.0d	-	-	-
$T_{litter+}$	135.36^{b}	199.09^{b}	206.12^{b}	98.2^{b}	94.6^{b}	156.4^{b}	19.2^{a}	29.1^{a}	82.4^{b}
	±5.8	±4.8	±6.1	±6.7	±7.3	±5.6	±1.6	±2.0	±2.4

4.14. Changes in total rice productivity in different fallow and treatments for three years cropping

The total rice production (aboveground and belowground) significantly declined (41-62%) in 2nd year cropping compared to the 1st year. The decrease was more pronounced (56-62%) in 3 years fallow compared to 5 and 10 years fallow (42-53%). Among the different treatments in 1st year cropping, T_{micro+} (36-56%) and $T_{litter+}$

(46-80%) significantly increased the total rice productivity (TRP) over control. Further, in 2nd year cropping, these two treatments (T_{micro+} and $T_{litter+}$) significantly increased TRP. T_{soil+} has marginal increase (10-40%) in TRP over control but was not significant. In 3rd year cropping (2015), the TRP reduced drastically from 1st years (23%) to 2nd year cropping (46%) (Fig. 4.8).

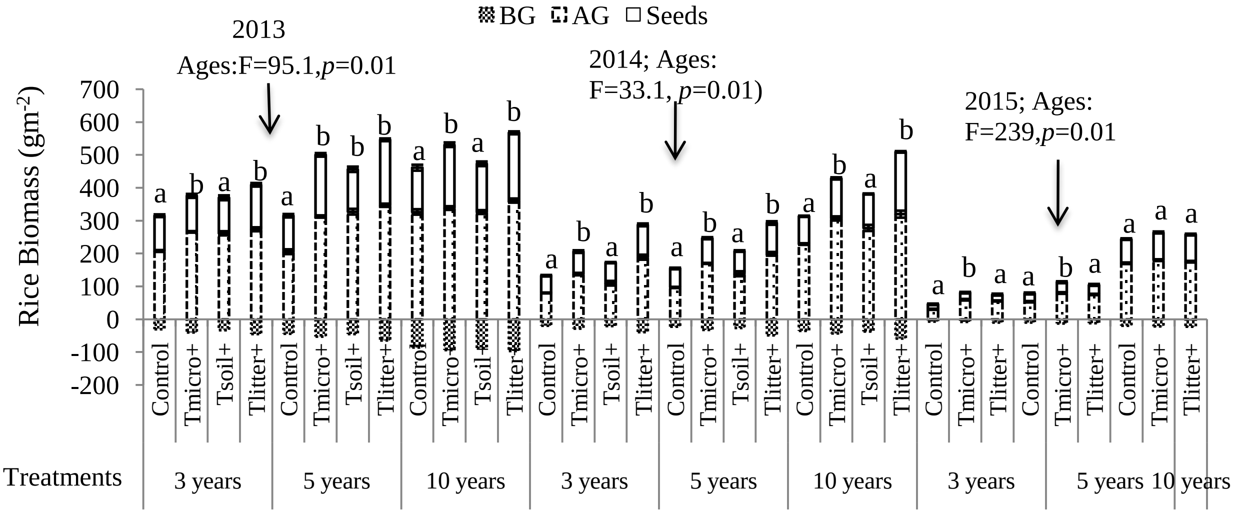


Fig. 4.8. Aboveground (Seed, shoot), belowground (root) (g m^{-2}) in different treatments and fallow stands in Mizoram. Values are means of three annual cycles (2013, 2014 and 2015). Vertical lines represent ± 1SE (n =3).

TRP was significantly high (60%) in 10 years compared to 5 years (24%) and 3 years (16%). Among the different treatments in 3rd year cropping T_{micro+} (58%-92%) and $T_{litter+}$ (61%-94%) significantly increased TRP over control. The TRP in 1st year cropping was recorded 60% and 2nd year cropping was recorded 29% and 3rd year was recorded 13% (Table 4.9).

Table 4.9. Aboveground, belowground and total rice productivity (g m^{-2} $year^{-1}$) over three successive years in response to the different soil amendments across the three fallow chronosequence; AB= Aboveground; BG= Belowground; TRP= Total Rice Productivity.

		1st year cropping			2nd year cropping			3rd year cropping		
	Treatments	AG	BG	TRP	AG	BG	TRP	AG	BG	TRP
FL-3	Control	315.6	30.5	346.1[a]	132.3	19.3	151.6[a]	45.2	6.6	51.8[a]
		±14.9	±4.1	±19.0	±3.5	±0.3	±3.7	±6.1	±2.3	±8.4
	T_{micro+}	489	53.2	542.2[b]	176.5	28.9	205.4[b]	80.7	8.3	89.0[b]
		±11.2	±5.9	±17.1	±2.9	±0.9	±3.8	±10.0	±2.3	±12.3
	T_{soil+}	373	39.8	412.8[a]	145.7	20.9	166.6[a]	-	-	-
		±13.6	±7.3	±20.9	±11.9	±1.7	±13.7	-	-	-
	$T_{litter+}$	570.9	55.4	626.3[b]	196.5	59.4	255.9[b]	74.8	9.7	84.5[c]
		±19.6	±5.3	±24.9	±1.5	±2.3	±3.8	±7.3	±2.9	±10.2
FL-5	Control	314.9	44	358.9[a]	154.4	12.4	166.8[a]	78.4	10.5	88.9[a]
		±17.3	±5.2	±22.5	±4.9	±0.4	±5.3	±8.8	±2.8	±11.6
	T_{micro+}	420.2	84.2	504.4[b]	246.4	31.4	277.8[b]	112.5	13.1	125.6[b]
		±14.1	±5.3	±19.4	±5.0	±0.6	±5.5	±6.7	±2.8	±9.5
	T_{soil+}	387.8	53.2	441[a]	207.4	26.1	233.5[a]	-	-	-
		±22.0	±8.0	±30.0	±13.2	±2.3	±15.5	-	-	-
	$T_{litter+}$	492	85.4	577.4[b]	292.7	39.2	331.8[b]	104.4	11.8	116.2[c]
		±15.4	±4.1	±19.5	±2.4	±0.3	±2.7	±6.4	±2.8	±9.3
FL-10	Control	419.9	38	458[a]	213.1	17.5	230.6[a]	243.7	20.3	264.0[a]
		±15.9	±9.0	±24.9	±5.5	±0.9	±6.4	±8.3	±2.3	±10.6
	T_{micro+}	538.6	86.4	625[b]	278.5	52.8	331.3[b]	263.9	21.8	285.7[a]
		±16.8	±6.9	±23.7	±17.9	±3.3	±21.1	±7.5	±2.9	±10.4
	T_{soil+}	477.1	46.5	523.6[a]	256.8	27.7	284.5[a]	-	-	-
		±21.3	±7.0	±28.3	±24.5	±0.6	±25.1	-	-	-
	$T_{litter+}$	578.9	93.8	672.7[b]	304.6	88.9	393.4[b]	257.5	22.7	280.2[a]
		±16.5	±4.3	±20.9	±27.7	±2.2	±29.9	±7.0	±2.6	±9.6

4.15. Changes in vegetable productivity in the first year cropping

The total vegetable production (aboveground and underground) increases with fallow age. Total vegetation production (TVP) was significantly increased (118-247%) and (88-148%) over control in $T_{litter+}$ and T_{micro+} treatment, respectively (Fig. 4.9).

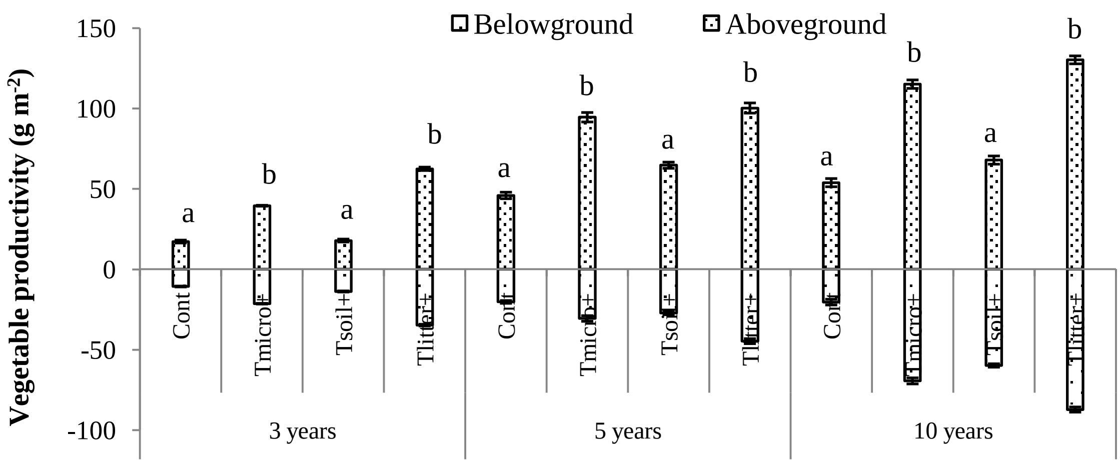


Fig. 4.9. Aboveground, belowground and total vegetable productivity (g m^{-2}) in different treatments and fallow stands in Mizoram. Vertical lines represent ± 1SE (n =3).

4.16. Changes in total net productivity in the first year cropping

Total crop productivity (rice plus vegetables) increases with the fallow age. Among the treatments, $T_{litter+}$ and T_{micro+} showed significant increase (152-175%) and (37-47%), respectively, over control in TNP. T_{soil+} has marginal increased in TNP which was not significant (Fig. 4.10).

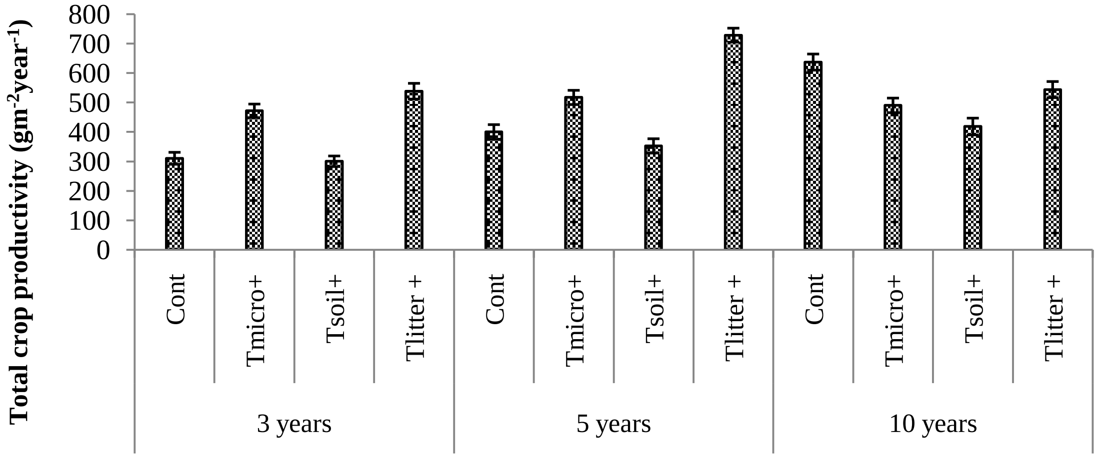


Fig. 4.10. Crop productivity in different treatments and fallow stands; Vertical lines represent ± 1SE.

4.17. Changes in C and N concentrations in rice and vegetable components

The percent C concentration variation occurred in different rice parts (seeds 36-46, leaves 32-43, stem 33-44.5 and roots 25-26%).Variations in C content were not significant in different treatments and fallow periods. The percent C concentrations also varied in different vegetable parts (fruits 35-45, leaves 34-42, stem 36-42 and roots 31-32). Variation in C concentration was not significant with respect to fallow length and treatment. However, N concentration varied significantly (p<0.01) in T_{micro+} and $T_{litter+}$ and between 3 and 10 years fallow ages. T_{soil+} showed marginal increase in N concentration which was not significant. N content in vegetable also varied significantly between treatments and with stand age. T_{micro+} and $T_{litter+}$ showed significant (p<0.01) increase in N concentration over control. T_{soil+} showed marginal increased but does not show significant difference (Table 4.10).

Table 4.10. Changes in rice and vegetables N (%) concentration in different treatments and fallows in Mizoram

Fallow lands (FL)		Rice				Vegetables			
		Control	T_{micro+}	T_{soil+}	$T_{litter+}$	Control	T_{micro+}	T_{soil+}	$T_{litter+}$
3 years	Seed/Fruits	1.39^{a} ±0.13	1.61^{b} ±0.15	1.50^{a} ±0.12	1.75^{b} ±0.17	2.05^{a} ±0.18	2.43^{b} ±0.16	2.28^{a} ±0.15	2.50^{b} ±0.14
	Leave	1.33^{a} ±0.12	1.58^{b} ±0.13	1.46^{a} ±0.10	1.70^{b} ±0.15	1.98^{a} ±0.17	2.37^{b} ±0.14	2.21^{a} ±0.14	2.46^{b} ±0.13
	Stems	1.29^{a} ±0.10	1.47^{b} ±0.13	1.39^{a} ±0.13	1.67^{b} ±0.12	1.51^{a} ±0.13	1.87^{b} ±0.17	1.62^{a} ±0.16	1.99^{b} ±0.18
	Roots	0.73^{a} ±0.07	0.94^{b} ±0.10	0.81^{a} ±0.9	1.08^{b} ±0.12	1.34^{a} ±0.13	1.47^{b} ±0.12	1.35^{a} ±0.14	1.59^{b} ±0.14
5 years	Seed/Fruits	2.29^{a} ±0.25	2.62^{b} ±0.12	2.52^{a} ±0.11	2.61^{b} ±0.15	2.97^{a} ±0.12	3.23^{b} ±0.16	3.10^{a} ±0.14	3.28^{b} ±0.16
	Leave	2.22^{a} ±0.23	2.54^{b} ±0.08	2.48^{a} ±0.08	2.56^{b} ±0.14	2.95^{a} ±0.13	3.15^{b} ±0.15	3.07^{a} ±0.13	3.21^{b} ±0.14
	Stems	1.85^{a} ±0.20	2.09^{b} ±0.08	1.93^{a} ±0.15	2.14^{b} ±0.11	1.49^{a} ±0.15	1.64^{b} ±0.14	1.51^{a} ±0.14	1.79^{b} ±0.17
	Roots	0.88^{a} ±0.07	1.15^{b} ±0.09	1.05^{a} ±0.13	1.24^{b} ±0.12	1.28^{a} ±0.24	1.49^{b} ±0.19	1.44^{a} ±0.17	1.66^{b} ±0.14
10 years	Seed/Fruits	2.55^{a} ±0.11	2.68^{b} ±0.09	2.59^{a} ±0.06	2.80^{b} ±0.13	3.03^{a} ±0.15	3.16^{b} ±0.13	3.09^{a} ±0.15	3.29^{b} ±0.12
	Leave	2.47^{a} ±0.10	2.61^{b} ±0.07	2.54^{a} ±0.04	2.71^{b} ±0.10	2.95^{a} ±0.13	3.12^{b} ±0.14	3.05^{a} ±0.13	3.26^{b} ±0.13
	Stems	2.12^{a} ±0.07	2.23^{b} ±0.18	2.20^{a} ±0.12	2.31^{b} ±0.12	1.61^{a} ±0.16	1.77^{b} ±0.15	1.69^{a} ±0.15	1.82^{b} ±0.14
	Roots	0.96^{a} ±0.11	1.20^{b} ±0.05	1.07^{a} ±0.11	1.31^{b} ±0.26	1.59^{a} ±0.17	1.63^{b} ±0.16	1.62^{a} ±0.16	1.72^{b} ±0.16

4.18. C sequestration and N uptake in different treatments and fallow periods

Total soil C and N stock was calculated for two consecutive years (2013-14). Total soil carbon stock (t ha^{-1} in 0-10 cm depth) in different fallow/treatment was maximum in 10 years (2.2-2.5) fallow followed by 5 years (2.1-2.4) and 3 years (2-2.3) (Table 4.11). However, maximum carbon stock (t ha^{-1} year^{-1}) was recorded in $T_{litter+}$ followed by T_{micro+} and T_{soil+} .The magnitude of vegetation C sequestration (kg ha^{-1} year^{-1}) in first year cropping was maximum in 10 years fallow (1881-3726) fallowed by 5 years (1560-2839) and 3 years fallow (1137-2295). Among the treatments, $T_{litter+}$ showed the highest carbon sequestration fallowed by T_{micro+} and T_{soil+}. Vegetation C sequestration in 2nd year followed the pattern similar to that of the 1st year cropping, however with reduced rates compared to first year. In 2nd year cropping, maximum reduction in vegetation C sequestration occurred in 3 years fallow and minimum in 10 years (Table 4.11).

Total soil N stock (kg ha^{-1}in 10 cm depth) was maximum in 10 years fallow (126-153) followed by 5 years (120-144) and 3 years (100-135). However, maximum N stock (kg ha^{-1}) was recorded in $T_{litter+}$ fallowed by T_{micro+} and T_{soil+}. Total net uptake of N (kg ha^{-1}year^{-1}) in first year cropping was maximum (110-209) in 10 years and minimum (45-117) in 3 years. The maximum N uptake was occurred in $T_{litter+}$ followed by T_{micro+} and T_{soil+}. In 2nd year, maximum reduction in N uptake occurred in 3 years fallow and minimum in 10 years. $T_{litter+}$ and T_{micro+} had minimum reduction in vegetation N uptake in 2nd year cropping compared to first year (Table 4.18). Maximum build up of C was observed in FL-10 and minimum in FL-3. Among the treatments, $T_{litter+}$ showed maximum C followed by T_{micro+} and T_{soil+}. Further, maximum build up was noticed in 1st year cropping which then gradually decreased from 2nd year and 3rd year cropping (Table 4.11).

Table 4.11. Pools and fluxes of carbon and nitrogen in soil and vegetation in different fallow lands and treatments of Mizoram in 1st year. Values in parentheses represent second year C sequestration/N uptake as percent of 1st year

FL-3	**Control**	**T_{micro+}**	**T_{soil+}**	**$T_{litter+}$**
Soil C stock (t ha^{-1}, 10 cm)*	2.0	2.2	2.1	2.3
Soil N stock (kg ha^{-1})	100	126	120	135
Vegetation C sequestration(kg $ha^{-1}year^{-1}$)	1137 (49)	1849 (45)	1210 (46)	2295 (50)
Vegetation N uptake (kg ha^{-1} $year^{-1}$)	45 (50)	87 (47)	59 (46)	117 (52)
FL-5	**Control**	**T_{micro+}**	**T_{soil+}**	**$T_{litter+}$**
Soil C stock (kg ha^{-1})*	2.1	2.3	2.1	2.4
SoilN stock (kg ha^{-1})	120	140	130	144
Vegetation C sequestration(kg ha^{-1} $year^{-1}$)	1560 (55)	2209 (64)	1878 (61)	2839 (66)
Vegetation N uptake (kg ha^{-1} $year^{-1}$)	78 (56)	136 (65)	108 (62)	159 (67)
FL-10	**Control**	**T_{micro+}**	**T_{soil+}**	**$T_{litter+}$**
Soil C stock (kg ha^{-1})*	2.2	2.3	2.2	2.5
SoilN stock (kg ha^{-1})	126	144	135	153
Vegetation C sequestration(kg ha^{-1} $year^{-1}$)	1881 (58)	3165 (63)	2532 (58)	3726 (68)
Vegetation N uptake (kg ha^{-1} $year^{-1}$)	110 (58)	181 (65)	140 (58)	209 (69)

*****Soil carbon stock was calculated up to 10 cm soil depth

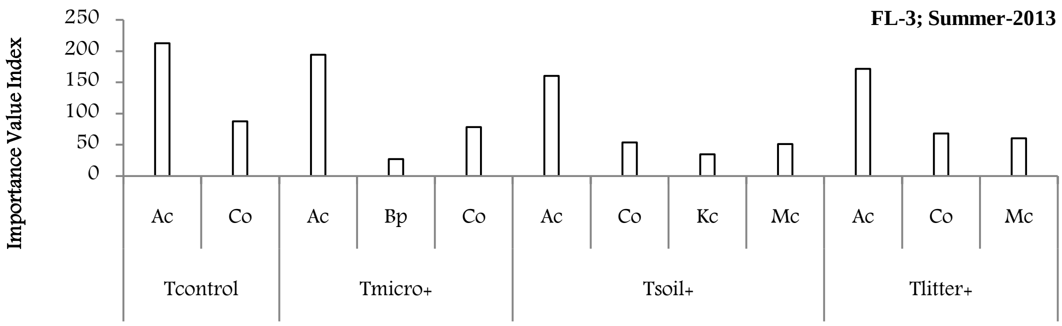
4.19. Changes in weed diversity in different fallows for three cropping (2013-15)

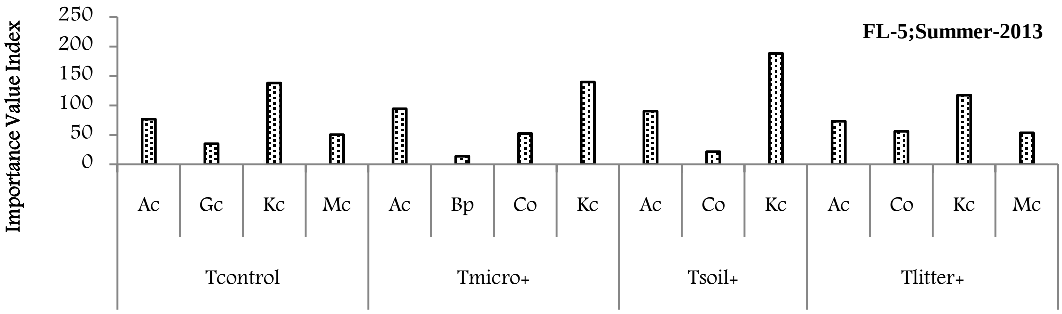
A total of 16 plant species from 9 families (Angiosperms) were recorded during the study period. Considering all study sites together in a season, maximum flora was recorded in the rainy season (14) followed by summer (13) and winter (12). The herbaceous species belong to family are Asteraceae (6), Fabaceae (2), Apiaceae

(1), Costaceae (1), Rubiaceae (1), Melostomaceae (1), Oxalidaceae (1), Phylanthaceae (1), Compositae (1), Malvaceae (1). In terms of total number of plant species recorded during survey visits, the diversity order at each site was rainy (2013- 11 species, 2014- 14 species and 2015-10 species were recorded) > summer (2013- 8 species, 2014-12 species and 2015-8 species were recorded) > winter (2013-7 species, 2014-8 species and 2015- 8 species were recorded) throughout the three cropping years.

4.20. Changes in Importance Value Index (IVI) in different treatments and fallows for three years.

During first year cropping in summer season (2013), *Ageratum conyzoides* (T_{contol}=212; T_{micro+} =194; T_{soil+} =160 and $T_{litter+}$=171) was dominant (IVI) among all the species in all treatments which was followed by *Chromolaena odorata* (T_{contol}=88; T_{micro+}=74; T_{soil+}=54 and $T_{litter+}$=68) as co-dominant in 3 years fallow site. *Knoxia corymbosa* (T_{contol}=138; T_{micro+} =140; T_{soil+} =188 and $T_{litter+}$=117) was dominant (IVI) among all the species in all treatments followed by *Ageratum conyzoides* (T_{contol}=98; T_{micro+} =94; T_{soil+} =90 and $T_{litter+}$=73) *a*s co-dominant in 5 years fallow site. *Knoxia corymbosa* (T_{contol}=138; T_{micro+} =154; T_{soil+} =112 and $T_{litter+}$=113) was found highest IVI in all the treatments followed by *Ageratum conyzoides* (T_{contol}=95; $T_{litter+}$=62) and*Chromolaena odorata* (T_{micro+} =44 and T_{soil+} =74) was found co-dominant in 10 years fallow site (Fig. 4.11).





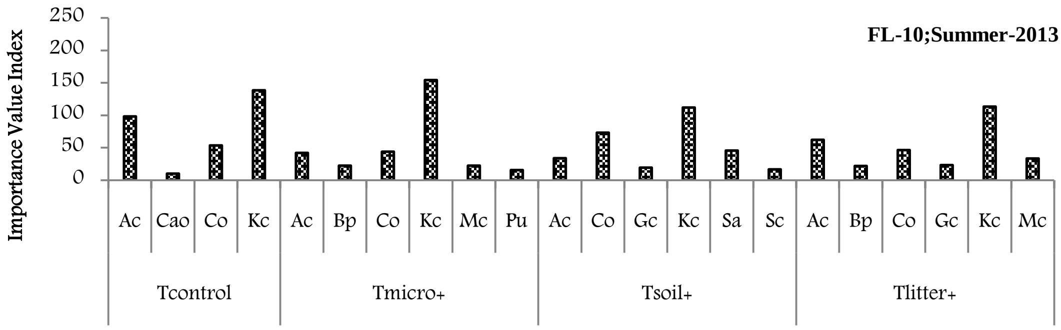
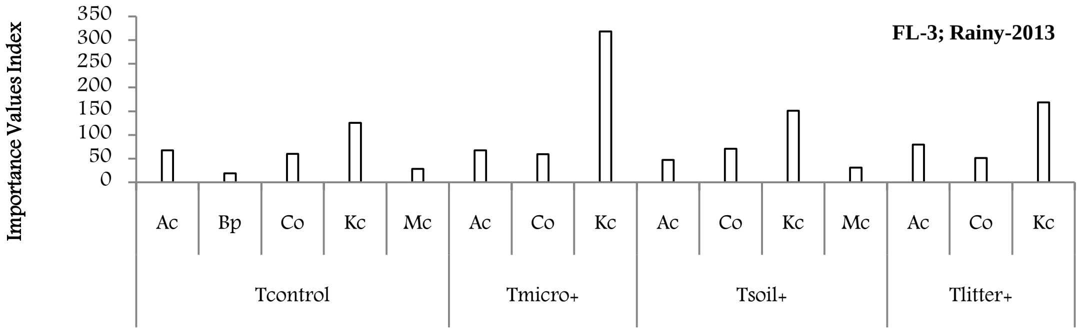
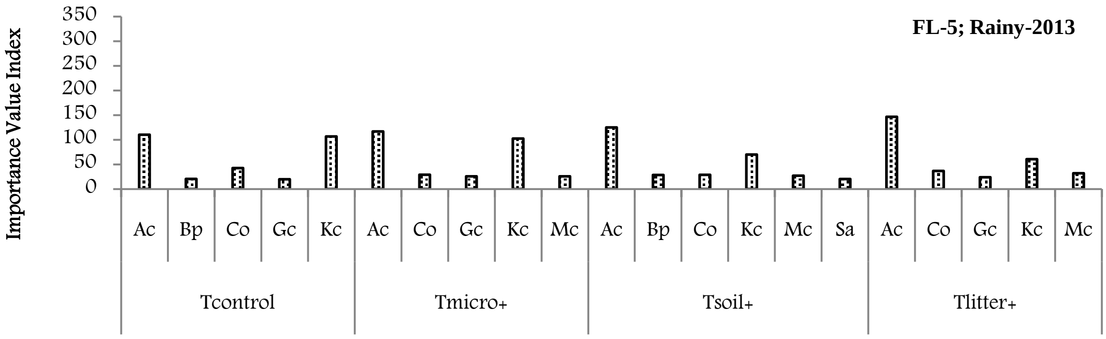


Fig 4.11. Changes in weed composition in different treatments and fallows for Summer, 2013. T_{micro+}= microbial inocula; T_{soil+}=soil amendment and $T_{litter+}$=litter amendment. Abbreviations of capital and small letters represent first letters of generic and species names of weeds (Ac= *Ageratum conyzoides*; Ai=*Ageratum indicum*; Ag= *Allardia gabra*; Co= *Chromolaena odorata*; Kc= *Knoxia corymbosa*; Bp= *Bidens pilosa;* Mc= *Mikania cordata*; Gc= *Gynura crepidioides*; Sa= *Spilanthes acemella*; Sd= *Scoparia dulcis*; Os=*Oxalis stricta*.

During rainy season (2013), *Chromolaena odorata*was found highest IVI ($T_{litter+}$=82) followed by *Ageratum conyzoides* ($T_{litter+}$=74) as co-dominant in 3 years fallow site. *Spilanthes acemella* was found highest dominant (T_{micro+}=88) followed by *Chromolaena odorata* (T_{micro+}=62) as co-dominant in 5 years site. *Ageratum conyzoides*was dominant (IVI) among all species in the treatments (T_{contol}=101; T_{soil+} =101) followed by *Chromolaena odorata* (T_{contol}=95) and *Scoparia dulcis* (T_{soil+} =45) as co-dominant in 10 years site (Fig.12).





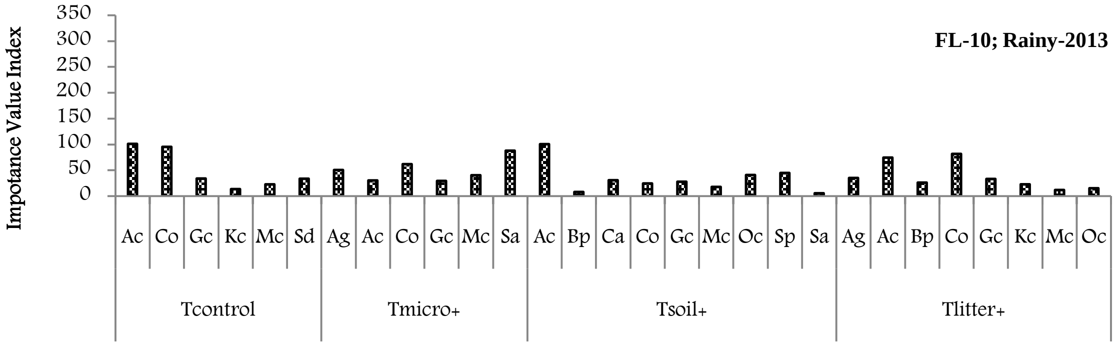


Fig 4.12. Changes in weed composition in different treatments and fallows in Rainy season 2013. Treatment and species abbreviations are given in Fig 4.10.

During winter season (2013), *Mikania cordata* was found highest IVI in the treatments (T_{contol}=107 and T_{soil+} =169) and *Ageratum conyzoides* (T_{soil+} =136) and *Chromolaena odorata* ($T_{litter+}$=144) as dominant followed by *Ageratum conyzoides* (T_{contol}=107) and *Mikania cordata* (T_{micro+} =76 and $T_{litter+}$=77) and *Knoxia corymbosa* (T_{soil+} =77) as co-dominant in 3 years fallow site. *Ageratum conyzoides* was dominant (IVI) among all species in all treatments (T_{contol}=120; T_{micro+} =129; T_{soil+} =132 and $T_{litter+}$=150) followed by *Chromolaena odorata* (T_{micro+} =69; T_{soil+} =70 and $T_{litter+}$=84) and *Knoxia corymbosa* (T_{contol}=78) *a*s co-dominant in 5 years fallow site. *Ageratum conyzoides* was dominant (IVI) among all the species in all the treatments (T_{contol}=161; T_{micro+} =130; T_{soil+} =115 and $T_{litter+}$=102) followed by *Spilanthes acemella* (T_{contol}=61 and T_{micro+}=52) and *Chromolaena odorata* (T_{soil+}=67) and *Mikania cordata* ($T_{litter+}$=60) as co-dominant in 10 years fallow site (Fig. 4.13).

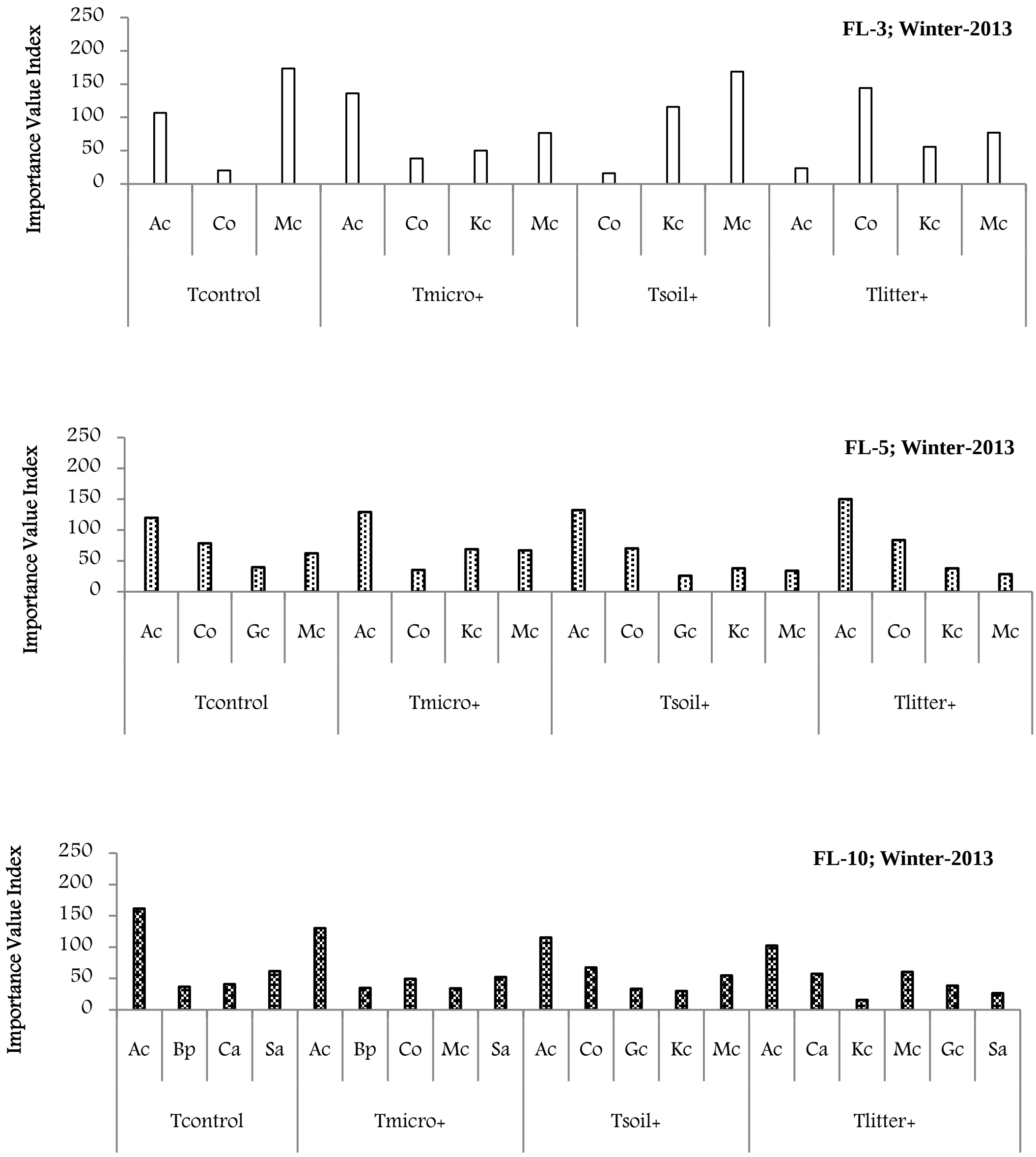


Fig 4.13. Changes in weed composition in different treatments and fallows in Winter season of 2013. Treatment and species abbreviations are given in Fig 4.10

During second year cropping in summer season (2014), *Ageratum conyzoides* was dominant (IVI) among all species in all the treatments (T_{contol}=135; T_{micro+} =118; T_{soil+} =129 and $T_{litter+}$=173) which was followed by *Spilanthes acemella* (T_{micro+}=66 and $T_{litter+}$=57) and *Mikania cordata* (T_{contol}=56 and T_{soil+}=50) as co-dominant in 3 years fallow site. *Ageratum conyzoides* was dominant (IVI) in all treatments (T_{contol}=134; T_{micro+} =141; and $T_{litter+}$=128) and *Knoxia corymbosa* (T_{soil+} =110) followed by *Chromolaena odorata* (T_{contol}=102; T_{micro+} =59; and $T_{litter+}$=69) and *Ageratum conyzoides* (T_{soil+} =100) *a*s co-dominant in 5 years fallow site. *Knoxia corymbosa* was found highest IVI in all the treatments (T_{contol}=126; T_{micro+} =107; T_{soil+} =135 and $T_{litter+}$=131) followed by *Ageratum conyzoides* as co-dominant (T_{contol}=66; T_{soil+}=116) and *Mikania cordata* (T_{micro+} =81 and $T_{litter+}$=99) as co-dominant in 10 years fallow site (Fig. 4.14).

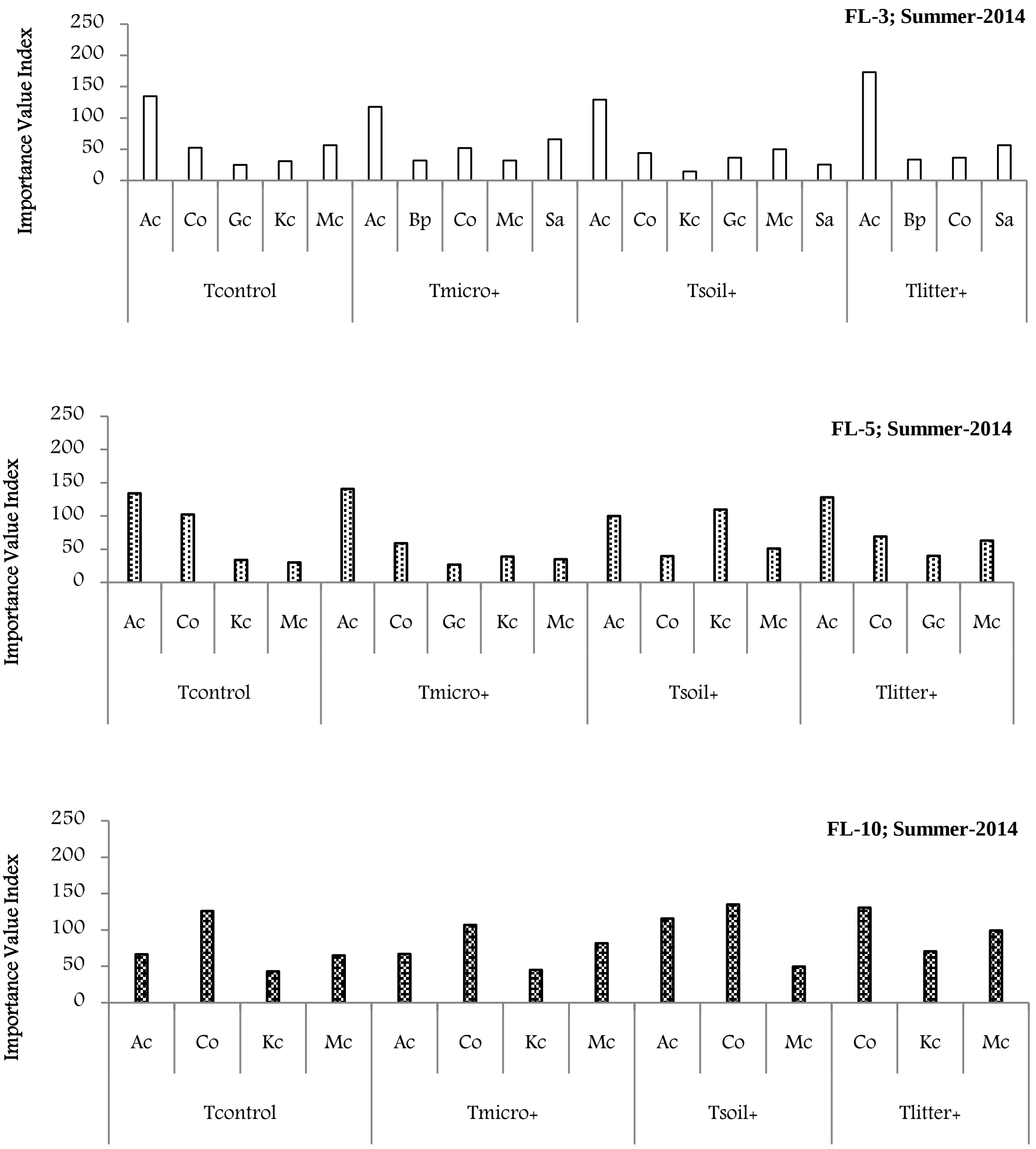
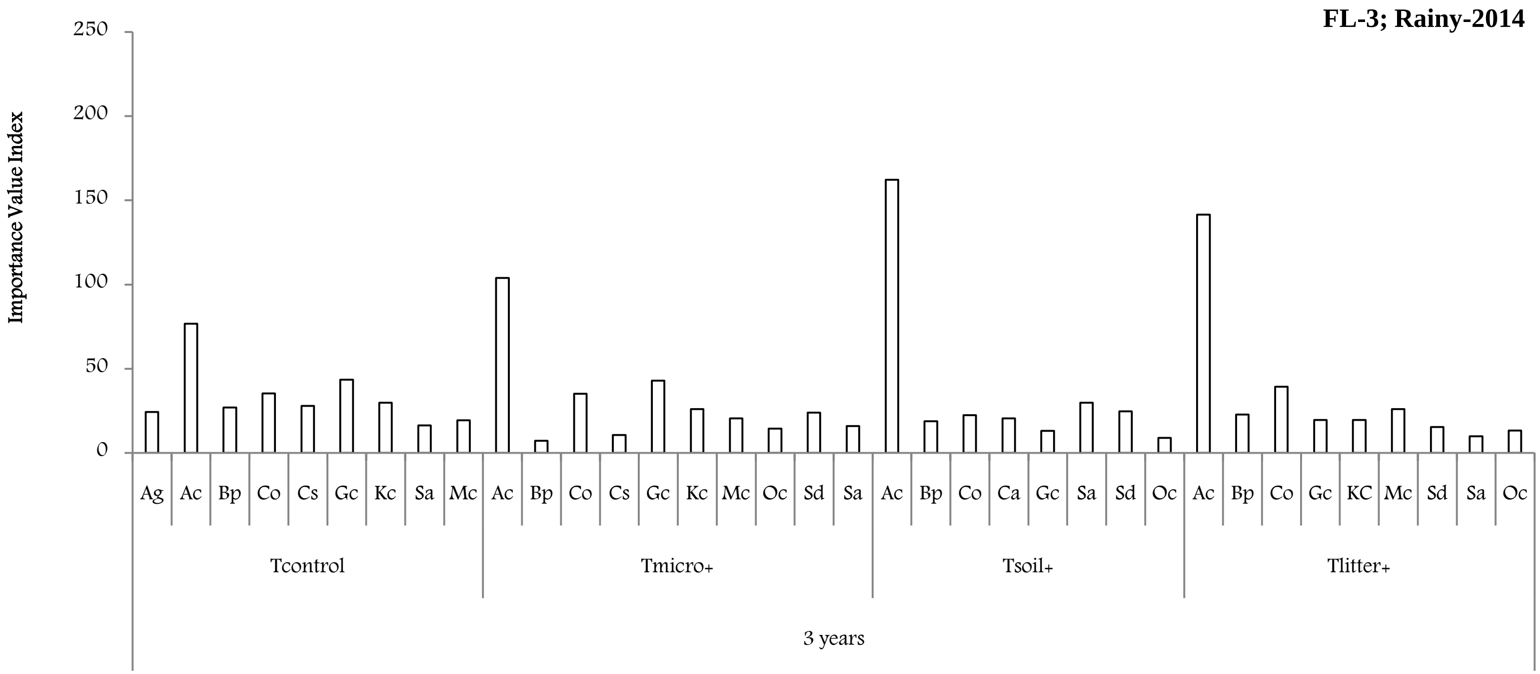


Fig 4.14. Changes in weed composition in different treatments and fallows in Summer season 2014. Treatment and species abbreviations are given in Fig 4.10

During rainy season (2014), *Ageratum conyzoides* was dominant (IVI) among all species in all the treatments (T_{contol}=77; T_{micro+}=104; T_{soil+} =162; $T_{litter+}$=141) followed by *Gynura crepidioides* (T_{contol}=43 and T_{micro+}=43) *Spilanthes acemella* (T_{soil+} =30) and *Chromolaena odorata* ($T_{litter+}$=39) as co-dominant in 3 years site. *Ageratum conyzoides* was found highest dominant (T_{contol}=141; T_{soil+} =145 and $T_{litter+}$=126) and *Knoxia corymbosa* (T_{micro+}=145) followed by *Knoxia corymbosa* (T_{contol}=91; T_{soil+} =97 and $T_{litter+}$=60) and *Ageratum conyzoides* (T_{micro+}=94) as co-dominant in 5 years site. *Ageratum conyzoides* was found highest IVI (T_{contol}=92; T_{micro+}=130; T_{soil+} =130; $T_{litter+}$=148) followed by *Chromolaena odorata* (T_{contol}=79; T_{micro+}=47; T_{soil+} =52; $T_{litter+}$=59) as co-dominant in 10 years fallow site (Fig.4.15).


FL-3; Rainy-2014
Importance Value Index
250
200
150
100
50
0
Ag
Ac
Bp
Co
Cs
Gc
Kc
Sa
Mc
Ac
Bp
Co
Cs
Gc
Kc
Mc
Oc
Sd
Sa
Ac
Bp
Co
Ca
Gc
Sa
Sd
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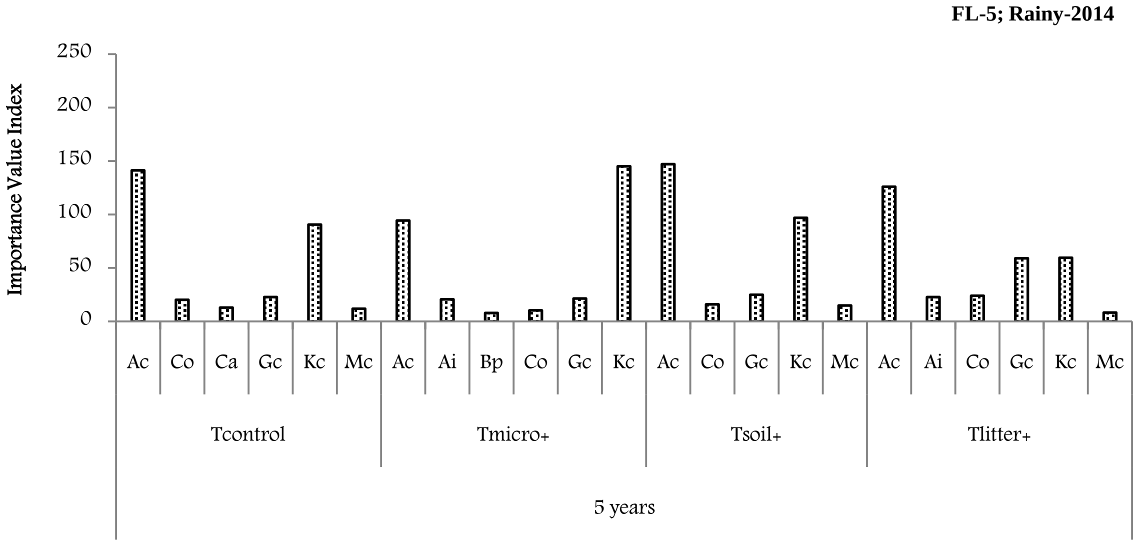
Tsoil+
Tlitter+
3 years



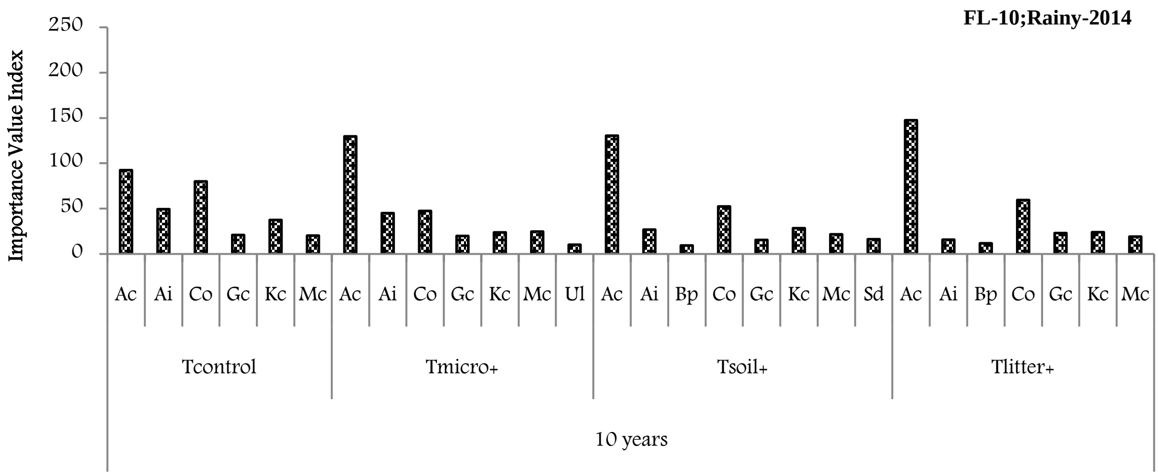


Fig 4.15. Changes in weed composition in different treatments and fallows in Rainy season 2014. Treatment and species abbreviations are given in Fig 4.10

During winter season (2014), *Ageratum indicum* was found dominant (T_{contol}=73; T_{micro+} =68; T_{soil+} =61 and $T_{litter+}$=49) and *Gynura crepidioides* as co-dominant in 3 years fallow site. *Ageratum indicum* was found dominant (IVI) among all the species in treatments (T_{micro+} =30; T_{soil+} =28 and $T_{litter+}$=50) followed by *Gynura crepidioides* ($T_{litter+}$=88); *Knoxia corymbosa* (T_{contol}=58) and *Ageratum conyzoides* (T_{micro+} =53; T_{soil+} =46) *a*s co-dominant in 5 years fallow site. *Gynura crepidioides* was found highest IVI in all treatments (T_{contol}=45; T_{soil+} =53; T_{soil+} =37 and $T_{litter+}$=48) and *Chromolaena odorata* as co-dominant followed by *Ageratum indicum*and *Mikania cordata*in 10 years fallow site (Fig.4.16).

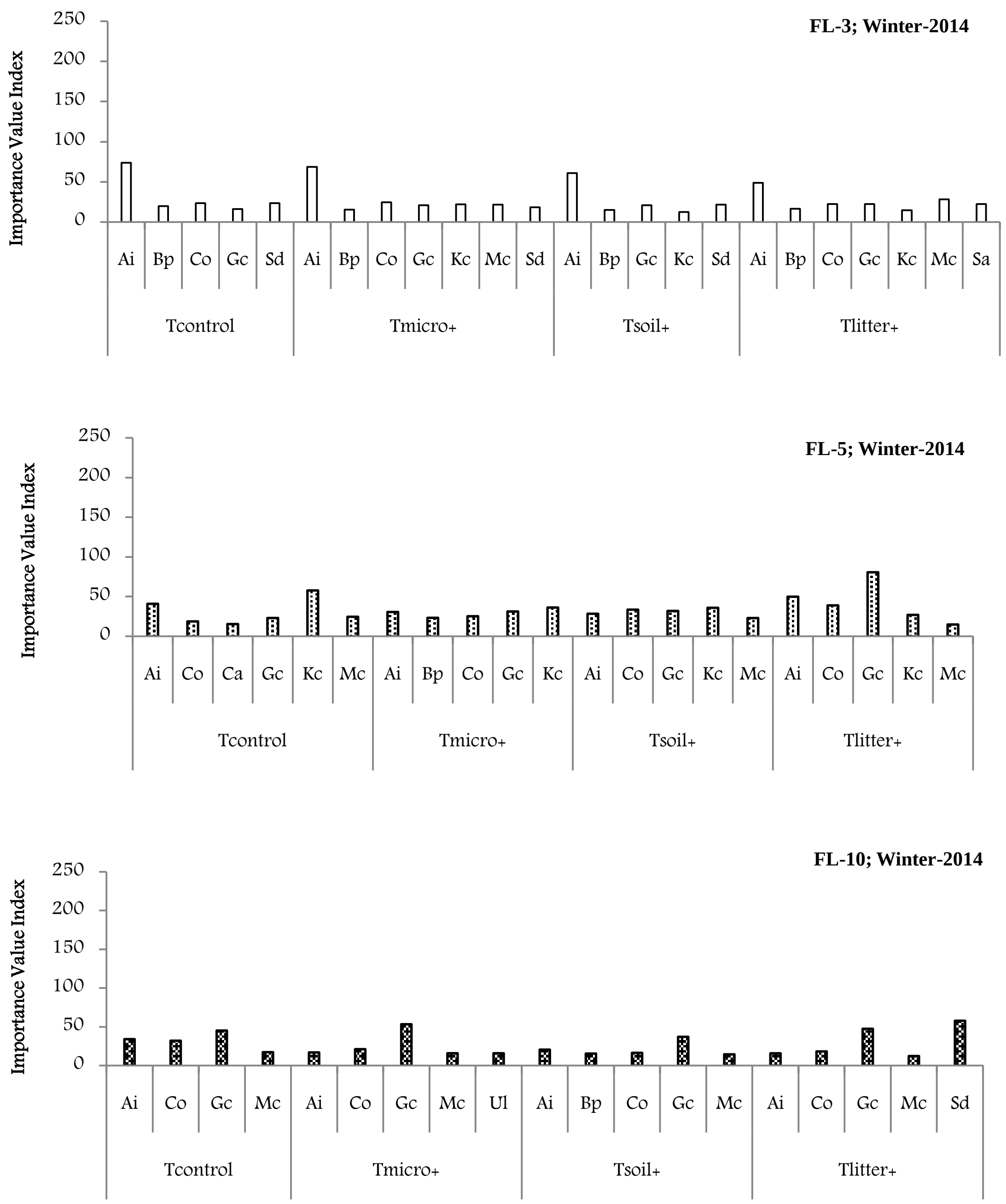
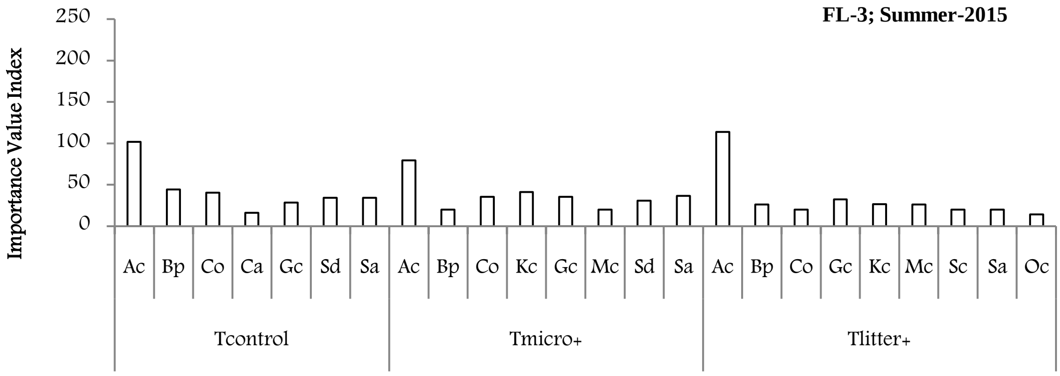
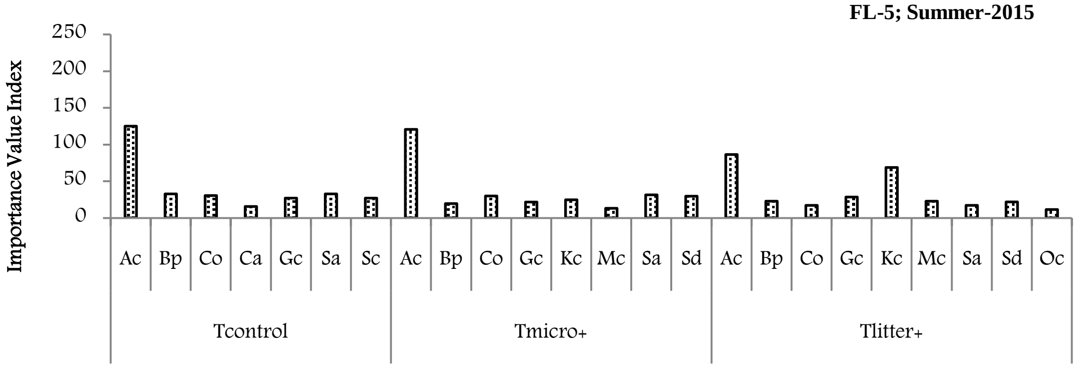


Fig 4.16. Changes in weed composition in different treatments and fallows in Winter season 2014. Treatment and species abbreviations are given in Fig 4.10

During third year cropping in summer season (2015), *Ageratum conyzoides* was found dominant (IVI) among all species in all the treatments (T_{contol}=102; T_{micro+} =79 and $T_{litter+}$=114) followed by *Biden pilosa* (T_{contol}=44); *Mikania cordata* (T_{micro+} =41) and *Gynura crepidioides* ($T_{litter+}$=32) as co-dominant in 3 years fallow site. *Ageratum conyzoides* was found dominant (IVI) in all treatments (T_{contol}=120; T_{micro+} =86; and $T_{litter+}$=96) followed by *Knoxia corymbosa* ($T_{litter+}$=69); *Biden pilosa*/ *Spilanthes acemella* (T_{contol}=33) and *Chromolaena odorata*/ *Scoparia dulcis* (T_{micro+} =30) *a*s co-dominant in 5 years fallow site. *Ageratum conyzoides* was found highest IVI in all the treatments (T_{contol}=104; T_{micro+} =102 and $T_{litter+}$=89) followed by *Gynura crepidioides* (T_{contol}=55) and *Knoxia corymbosa* (T_{micro+} =44 and $T_{litter+}$=39) as co-dominant 10 years fallow site (Fig. 4.17).





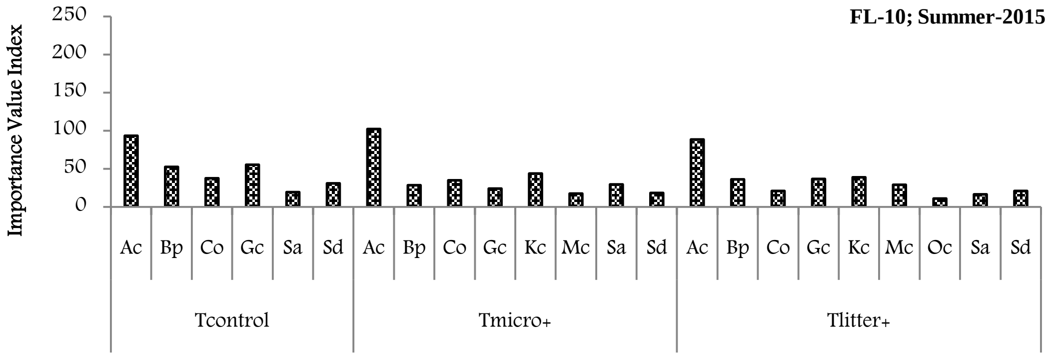
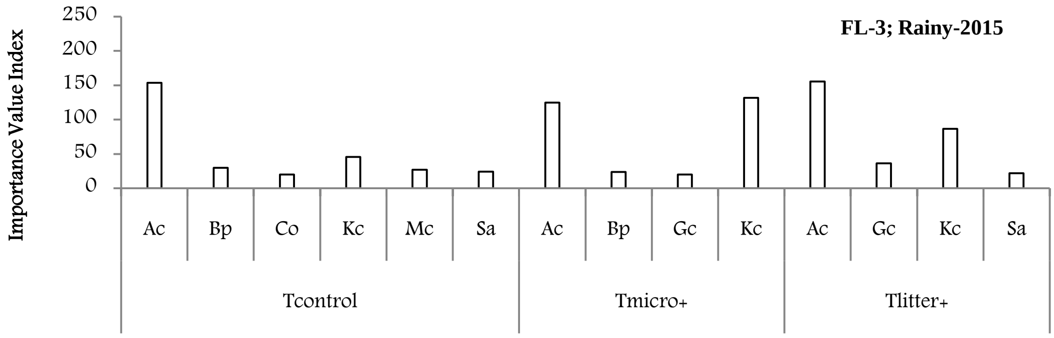
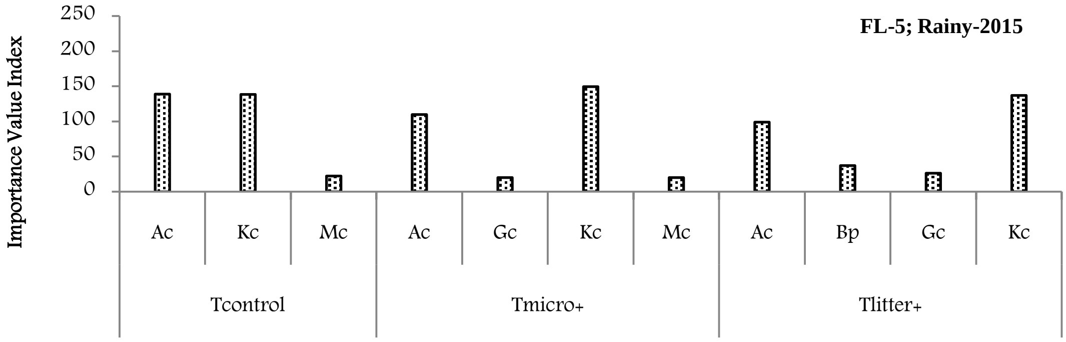


Fig 4.17. Changes in weed composition in different treatments and fallows in Summer season 2015. Treatment and species abbreviations are given in Fig 4.10

During rainy season (2015), *Ageratum conyzoides*was found dominant (IVI) among all species in treatments (T_{contol}=154 and $T_{litter+}$=155) and *Knoxia corymbosa* (T_{micro+}=132) followed by *Ageratum conyzoides* (T_{micro+}=125) and *Knoxia corymbosa*(T_{contol}=46 and $T_{litter+}$=87) as co-dominant in 3 years site. *Knoxia corymbosa* (T_{contol}=139; T_{micro+} =150 and $T_{litter+}$=137) was found highest dominant followed by *Ageratum conyzoides* (T_{micro+}=110 and $T_{litter+}$=99) and *Mikania cordata* (T_{cont+}=22) as co-dominant in 5 years site. *Chromolaena odorata* was found dominant (IVI) among all species in treatments (T_{micro+}=106); *Gynura crepidioides* ($T_{litter+}$=79) and *Knoxia corymbosa* ($T_{control+}$=59) followed by *Allardia gabra* (T_{contol}=62; T_{micro+} =93 and $T_{litter+}$=86) as co-dominant in 10 years site (Fig. 4.18).





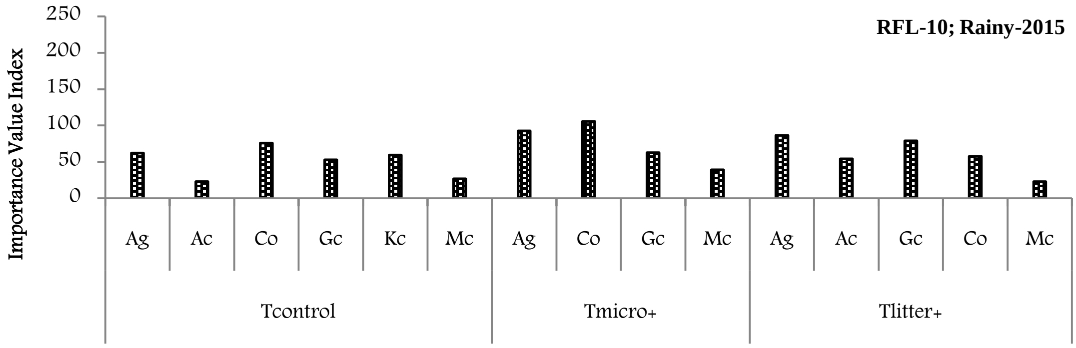
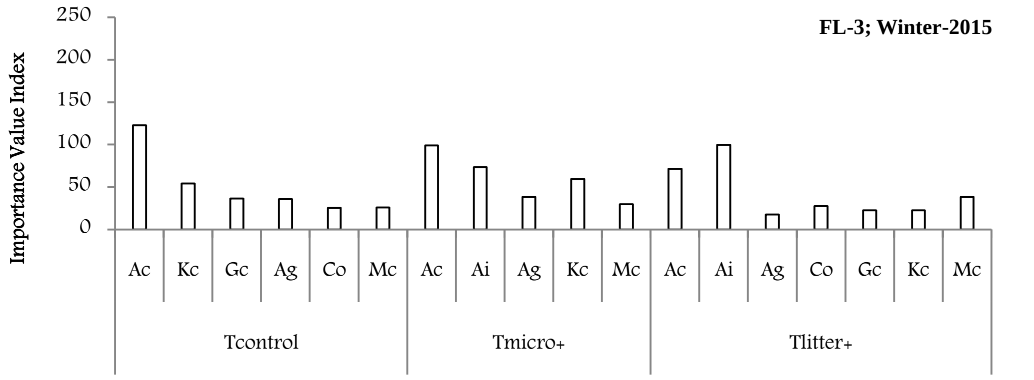
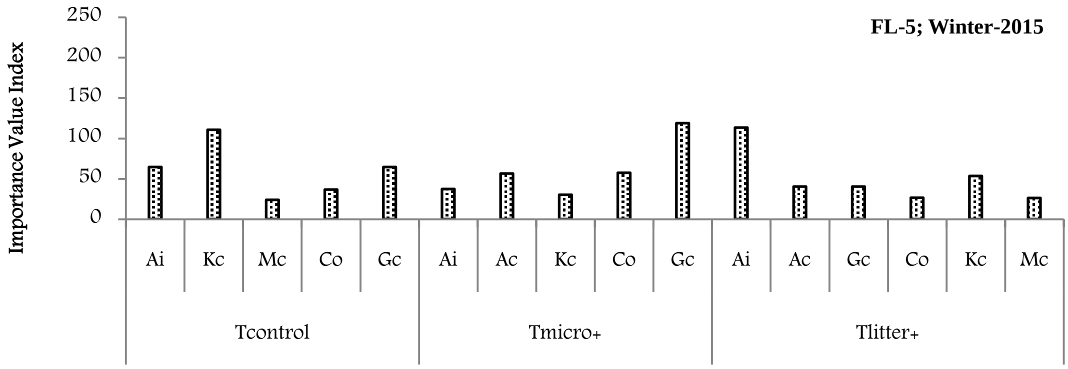


Fig 4.18. Changes in weed composition in different treatments and fallows in Rainy season 2015. Treatment and species abbreviations are given in Fig 4.10

During winter season (2015), *Ageratum conyzoides* was found highest IVI in the treatments (T_{contol}=123 and T_{micro+}=99 and *Ageratum indicum* ($T_{litter+}$=100) as dominant followed by *Ageratum indicum* (T_{micro+} =73); *Ageratum conyzoides* ($T_{litter+}$=71) and *Knoxia corymbosa* (T_{contol}=54) as co-dominant in 3 years fallow site. *Gynura crepidioides*was found dominant (IVI) among all the species in treatments (T_{micro+} =119); *Ageratum indicum* ($T_{litter+}$=113) and *Knoxia corymbosa* (T_{contol}=111) followed by *Ageratum indicum*/*Gynura crepidioides* ($T_{control+}$=64); *Chromolaena odorata* (T_{micro+}=57) and *Knoxia corymbosa* ($T_{litter+}$ =53) *a*s co-dominant in 5 years fallow site. *Oxalis stricta* was found dominant (IVI) among all the species in all the treatments (T_{contol}=89); *Chromolaena odorata* ($T_{litter+}$=81) and *Gynura crepidioides* (T_{micro+}=80) followed by *Gynura crepidioides* (T_{contol}=81 and $T_{litter+}$=49); *Chromolaena odorata* (T_{micro+} =73) as co-dominant in 10 years fallow site (Fig.4.19).





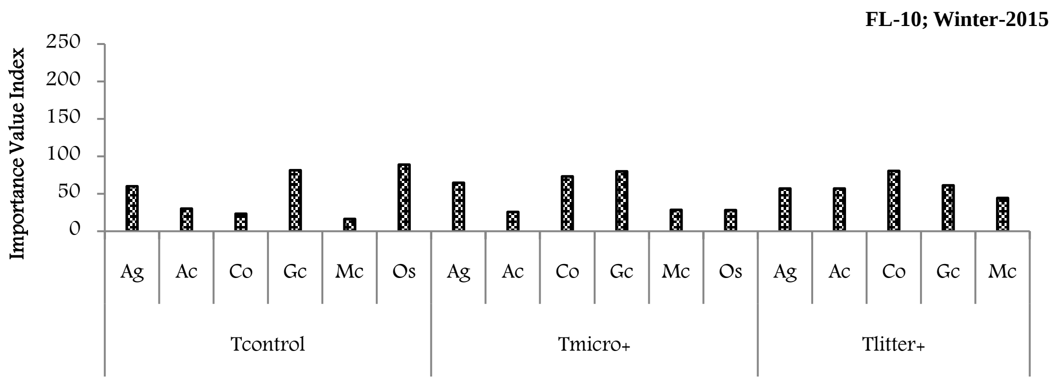


Fig 4.19. Changes in weed composition in different treatments and fallows in Winter season 2015. Treatment and species abbreviations are given in Fig 4.10

4.21 Seasonal changes in weed diversity in different fallows and treatments for three consecutive years (2013-15).

Tables (4.12-4.14) summarize seasonal changes in the occurrences weed diversity calculated through different indices in different fallow periods (FL-3, FL-5 and FL-10) using IVI of species. Different index ranked the site diversity differently. The species diversities (Shannon index, Simpson index, Margalef index and Evenness index were found to be maximum in the rainy season compared to summer and winter seasons in all fallow sites.

Shannon index values increased from 3 years to 10 years and T_{micro+} and $T_{litter+}$ showed highest Shannon index followed by T_{soil+} and $T_{control}$ among treatments however, Shannon index decreased from 2013 to 2015. Simpson index decreased gradually from 3 years to 10 years. T_{micro+} and $T_{litter+}$ showed minimum values compared to T_{soil+} and $T_{control}$ among treatments. Simpson index also decreased from 2013 to 2015. Margalef index showed increased from 3 years to 10 years and T_{micro+} and $T_{litter+}$ showed maximum values compared to T_{soil+} and $T_{control}$ among treatments. Margalef index values increased from 2013 to 2015. Species Evenness increased from 3 years to 10 years where T_{micro+} and $T_{litter+}$ maximum values compared to T_{soil+} and $T_{control}$ among treatments. Species Evenness starts decreased from 2013 to 2015 periods (Tables 4.12-4.14).

Table 4.12. Seasonal changes in weed diversity estimates at different fallow lands (FL-3, FL-5 and FL-10) using different diversity indices for three consecutive years (2013-14).

		SUMMER				RAINY				WINTER			
Sites		Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index
FL-3	T_{cotrol}	0.6	0.67	0.21	0.87	1.56	0.33	0.93	0.93	1.19	0.51	0.56	0.8
	T_{micro+}	0.85	0.64	0.4	0.76	1.71	0.23	0.91	0.95	1.46	0.36	0.87	0.98
	T_{soil+}	1.19	0.5	0.61	0.86	1.92	0.28	1.47	0.87	1.49	0.32	0.89	0.96
	$T_{litter+}$	0.98	0.52	0.41	0.88	1.88	0.24	1.25	0.89	1.64	0.28	1.05	0.95
FL-5	T_{cotrol}	1.26	0.4	0.59	0.92	1.38	0.37	0.66	0.83	1.31	0.33	0.54	0.92
	T_{micro+}	1.17	0.42	0.59	0.84	1.38	0.38	0.64	0.83	1.29	0.36	0.6	0.92
	T_{soil+}	0.84	0.6	0.4	0.76	1.55	0.38	0.82	0.83	1.42	0.4	0.82	0.94
	$T_{litter+}$	1.33	0.31	0.59	0.96	1.37	0.45	0.62	0.78	1.19	0.46	0.64	0.92
FL-10	T_{cotrol}	1.14	0.42	0.6	0.82	1.42	0.37	0.72	0.93	0.87	0.54	0.56	0.93
	T_{micro+}	1.44	0.52	0.98	0.8	0.59	0.69	0.38	0.96	1.27	0.39	0.75	0.96
	T_{soil+}	1.58	0.32	0.98	0.88	1.21	0.46	0.55	0.94	0.85	0.52	0.52	0.9
	$T_{litter+}$	1.61	0.32	0.91	0.87	0.98	0.52	0.35	0.93	1.21	0.42	0.48	1.22

Table 4.13. Seasonal changes in weed diversity estimates at different fallow lands (FL-3, FL-5 and FL-10) using different diversity indices for three consecutive years (2014-15).

		SUMMER				RAINY				WINTER			
Sites		Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index
FL-3	T_{cotrol}	1.42	0.41	0.89	0.96	1.01	0.18	1.46	0.41	0.91	0.27	1.47	0.41
	T_{micro+}	1.56	0.32	0.87	0.98	0.92	0.29	1.61	0.35	0.98	0.22	1.64	0.41
	T_{soil+}	1.48	0.38	1.05	0.95	0.6	0.6	1.27	0.24	0.97	0.23	1.64	0.41
	$T_{litter+}$	1.13	0.57	0.56	0.8	0.82	0.46	1.41	0.32	0.82	0.36	1.26	0.42
FL-5	T_{cotrol}	1.2	0.42	0.64	0.92	1.36	0.46	0.84	0.61	1.69	0.35	1.08	0.87
	T_{micro+}	1.4	0.44	0.82	0.94	1.3	0.47	0.83	0.73	1.57	0.38	0.9	0.89
	T_{soil+}	1.3	0.33	0.6	0.92	1.23	0.48	0.67	0.65	1.59	0.37	0.9	0.93
	$T_{litter+}$	1.3	0.35	0.54	0.92	1.5	0.38	0.83	0.73	1.57	0.33	0.89	0.89
FL-10	T_{cotrol}	1.31	0.35	0.48	1.22	1.64	0.27	0.82	0.95	1.64	0.4	1.07	0.93
	T_{micro+}	1.34	0.3	0.75	0.96	1.64	0.4	0.99	0.93	1.63	0.46	1.24	0.89
	T_{soil+}	1.02	0.42	0.56	0.93	1.71	0.41	1.16	0.91	1.63	0.44	1.25	0.92
	$T_{litter+}$	1.07	0.42	0.52	0.9	1.52	0.49	0.98	0.87	1.55	0.56	1.23	0.87

Table 4.14. Seasonal changes in weed diversity estimates at different fallow lands (FL-3, FL-5 and FL-10) using different diversity indices for three consecutive years (2015-16).

		SUMMER				RAINY				WINTER			
Sites		Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index	Shannon Index	Simpson Index	Margalef Index	Evenness Index
FL-3	T_{cotrol}	0.9	0.25	1.6	0.41	0.9	0.21	1.69	0.5	0.85	0.25	1.31	0.45
	T_{micro+}	0.99	0.17	1.84	0.41	0.78	0.3	0.71	0.56	0.88	0.23	1.26	0.1
	$T_{litter+}$	0.89	0.33	2.09	0.35	0.85	0.24	0.94	0.53	0.89	0.2	0.99	0.51
FL-5	T_{cotrol}	0.79	0.42	1.53	0.41	0.69	0.43	0.66	0.5	0.82	0.29	1.01	0.51
	T_{micro+}	0.82	0.41	1.75	0.39	0.65	0.47	0.62	0.47	0.73	1.14	0.96	0.43
	$T_{litter+}$	0.93	0.25	2	0.4	0.63	0.47	0.41	0.57	0.85	0.3	1.25	0.47
FL-10	T_{cotrol}	0.85	0.27	1.27	0.47	0.71	0.51	1.09	0.41	0.82	0.35	1.23	0.46
	T_{micro+}	0.91	0.27	1.73	0.44	0.67	0.44	0.56	0.48	0.84	0.26	1.01	0.52
	$T_{litter+}$	0.97	0.21	1.95	0.44	0.65	0.53	0.64	0.45	0.87	0.28	1.43	0.44

4.22. Total AG and BG weed biomass in different fallows and treatments for three consecutive years (2013-2015)

The total weeds biomass (AG and BG) significantly declined (23-43%) in 3rd year cropping compared to the 1st year and 2nd year cropping. The decrease was more pronounced (23-28%) in 3 years fallow compared to 5 years (33-35%) and 10 years fallow (39-43%). Among the different treatments in 1st year cropping, T_{micro+} (5-19%) and $T_{litter+}$ (14-37%) significantly increased the total weed biomass (TWB) over control. Further, in 2nd year cropping, these two treatments (T_{micro+} = 4-7% and $T_{litter+}$= 8%-14%) significantly increased TWB. T_{soil+} hasmarginal increase in TWB over control but was not significant. In 3rd year cropping (2015), the TWB reduced drastically from 1st years (47-48%) to 2nd year (37-48%) cropping. The TWB was recorded high in 10 years (39%) compared to 5 years (33%) and 3 years (28%). Among the different treatments, T_{micro+} (3-5%) and $T_{litter+}$ (4-8%) significantly increased the TWB over control. The TWB in 1st year cropping was recorded 43% and 2nd year cropping was recorded 34% and 3rd year was recorded 23% (Fig 4.20).

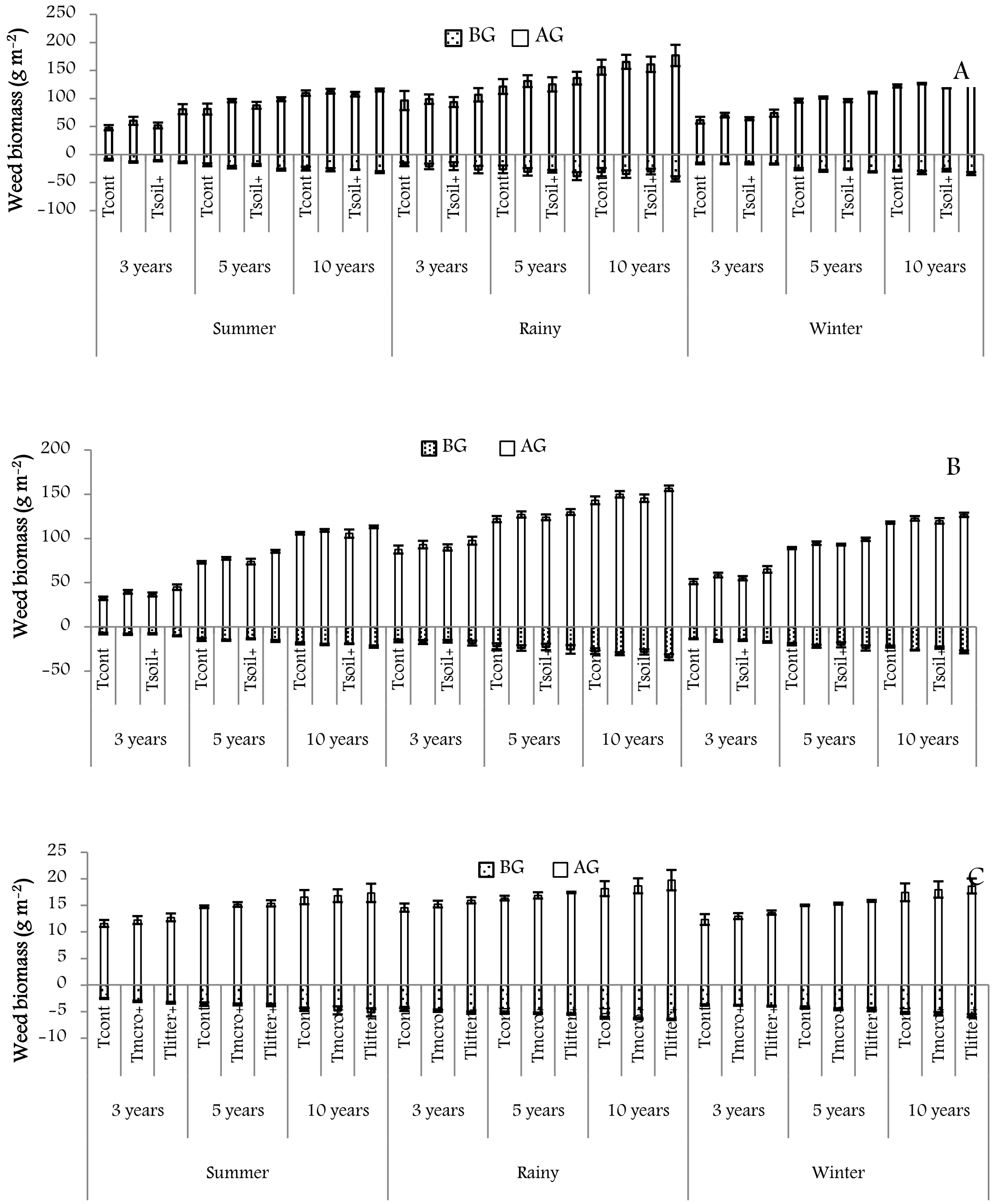


Fig 4.20. Changes in weed biomass (AG and BG) in different fallows and treatments for three consecutive years (2013-15). Capital letters A, B and C indicates weed biomass in 2013, 2014 and 2015, respectively.

Seasonal weed biomass in different soil treatments and different fallows for three consecutive years (2013-15) is shown in figure 4.19. The TWB in different seasons was in the order: rainy > summer > winter. The 10 years and 5 years exhibited much greater standing weeds compared to 3 years. Rainy season (2013-15) showed the highest weed biomass record (10938.4 g m^{-2}) followed by summer (8986 g m^{-2}) and winter (7837 g m^{-2}). Statistical analysis state that treatments (T_{micro+} and $T_{litter+}$) showed significant increased (p<0.05) over control in all fallow lands. However, T_{soil+} showed marginal increased but did not show significant increased over control in all the sites. Fallow ages and seasons also showed significant increased (p<0.05) from 2013-15 period (Fig. 4.20).

CHAPTER 5

DISCUSSION

5.1. General characteristics of shifting cultivation

Shifting cultivation or *Jhum* is one of the pre-dominant forms of agriculture in the hilly region of moist tropical forests of NE India, which causes huge loss of forest cover in the species rich tropical rain forest of the region (Ramen, 2000; Yadav, 2013). In this system of cultivation, fallow management is one of the primitive practice associated with crop rotation (Karlen *et al.,* 1994) which continues throughout the arid and semiarid regions of West Asia and North Africa (Ryan *et al.,* 2008).Therefore, the fallow phases of varying ages of *jhum* cycles are important in enhancing our scientific understanding of the impact of fire on nutrient cycling processes that recovers through the interactions of shift in plant community and soil microbiota. The regenerated plant biomass of the secondary forest stand accumulated over time play a key role in restoration of ecological soil functions of *jhum* lands. Ecological restorations in these ecosystems are driven by varying degree of relationships in the pattern of accumulation of forest floor litters, release of locked nutrients within plant biomass and microbiologically induced biochemical reactions in *jhum*soils upon burning that depend on the length of the fallow period. Therefore, an understanding of the impact of fallow length on the nutrient cycling potentials of *jhum* soils would be of great significance in formulating sustainable nutrient management practices for enhancing *jhum* productivity (Saplalrinliana, 2016). Further, changes in the weed diversity and occurrences during fallow recovery and various treatments are important to formulate weed management strategies in shifting cultivation sites which is the major problem in the region.

Litter nutrient content in different *jhum* fallow reflects the successional pattern of secondary forest stand. Various litter types accumulated during the course of time depending on the length of fallow period contains different types of aboveground and belowground biomass. The quantity and quality of litter significantly differ during the secondary succession of forest. Such differences in the litter input and chemistry is mainly depends on the changes in species during secondary forest (Singh *et al*., 2014; AESL, 2015). Result of the present study indicates that the shorter fallow (FL-3 and FL-5) contains small shrubs and lower plants compared to longer fallow (FL-10), and longer fallow exhibit more dominance of woody vegetation. This reflects that the efficiency of short fallow lands would be less in converting light energy to carbohydrates compared to a thickly foliaged, matured secondary forest (Chapin *et al.*, 2002).

Total number of woody species increased with increasing fallow age of the stand, whereas, the number of herbaceous species decreased during the course of fallow recovery (Singh *et al*., 2014). This may be useful for avoiding species competition for nutrient availability, light, water, shelter, etc. The lignin content in litters of FL-10 fallow was higher compared to that in shorter fallow (FL-3, FL-5), which may be due to the presence of bigger lignified tree species in older fallow phase. Since forest floor litters of such longer fallow consisted not only tender leafy parts but also harder twigs and fallen debris of tree trunks and therefore, high lignin content of leaf litters in older fallows is the result of the presence of more matured plant and tree species (Pettersen, 1984; Lalnunzira and Tripathi, 2018).

In addition to forest floor litter, following the slashing and burning results in the death of considerable amount of roots (fine and coarse) that undergo decomposition and add significant amount of organic matter and nutrients to the soil (Tripathi and Singh 1994; Wapongnungsang *et al*., 2017). Remarkable these roots are less affected by the burning as they are down the soil and therefore, they follow decomposition process similar to that of natural forest ecosystems. The amount and the initial chemical characteristics of these roots vary with the age of the fallow as result of changes in species composition (Singh *et al*., 2014). Therefore, the rate of input of organic matter addition to the soil may vary with fallow age and this may be an important determinant of changes in the soil organic matter and nutrient during fallow ages.

5.2. Changes in root biomass and necromass during fallow ages

In the present study, minimum TRB at JAB and maximum at TSF could be due to rapid disappearance of root biomass particularly in 0-10 cm soil depth after the burning event (Leppälammi-Kujansuu *et al.*, 2014). Among fallows, TRB significantly ($p<0.05$) increased from FL-3 to FL-10. This may be due to less root biomass in FL-3 site compared to FL-10 which was resulted due to decreasing vegetation cover and soil fertility (Singh *et al.*, 2014). Higher plant diversity, aboveground biomass and soil nutrients availability through decomposition of accumulated litters may also be the potential cause for higher root formation. Higher root biomass and production in FL-10 could be attributed to higher nutrients and organic matter (Girardin *et al.*, 2013).

In general, most microbial activity occurs in the upper soil layers (0-10 cm) which are more nutritious and porous (Giregon *et al.*, 2010). Present study showed that in all three fallows about 80% of roots were in the upper 10 cm soil depth (Gautam and Mandal, 2012; Barbhuiya *et al.*, 2012) and remaining in lower depths. Therefore, it appears that the upper soil horizon permits a higher concentration of fine root tips which decreases towards lower soil layers as the soil nutrient content decreases. Kochsiek *et al.* (2013) reported that higher fine root biomass, production, length, and area in sandy loam compared to clay soil. Data in the present study is in conformity with the above findings. Nutrients that are released from the litter are not leached down the soil profile (Fukuzawa *et al.*, 2007) but are transferred directly to the surface of the roots which are intermingled with the decaying matter. This may be one of the reasons for the greater fine root production in the top 10 cm of soil in this study.

Significant spatio-temporal variations were recorded in the amount of TRB ($p<0.01$) at different time points (e.g.TSF, TSS, TCM and TCH) except JAB in three fallows. Seasonal variations in dead root biomass were less marked during various cropping events but the marked variations were observed with different fallow. This could be because of conversion of total live roots into dead after burning followed by their decomposition and formation and death of new roots during cropping phase (Kitajima *et al.*, 2010). At the time of biomass burning flame temperature shoots more than 1000 ^{0}C that could not be recorded by the laser thermometer. After the burning, soil temperatures to a depth of 2 cm reached 150-200^{o}C in fallow sites in Muallungthu village area. Similar results were reported by Giardina *et al.* (2000) slash and burn cultivation in Mexico. After burning, reduction in the amount of TRB ranged from 63-73% in the 0-10 cm soil depth in different fallow. Jorge *et al.* (2000) reported 83% decrease in the amount of total root mass.

5.3. Root nutrients and its role in the functioning of forest fallows

In the present study, fine root (<0.5 mm) contains higher N content but, lower C content in all fallows. Similar observation was reported by Gordon and Jackson (2000). They observed significant inverse relationship between root diameter and N concentrations and significantly (p<0.01) positive correlation of root diameter with C content (Comas and Eissenstat, 2009).

In the present study, maximum organic matter occurred in the 0-10 cm soil depth and the minimum (22-25%) in the 20-30 cm in three fallow stands (Barbhuiya *et al.*, 2012). The fine root turnover rates in the present study (0.66-0.99 yr^{-1}) were comparable to the range (0.77-1.44 yr^{-1}) reported for different forests like boreal, temperate, and tropical forests of the World (Finer *et al.*, 2011; Yuan and Chen, 2010). In the present study root production increases with the age of fallow which indicate that the root growth in the present study is strongly affected by the soil fertility of the site. Finer *et al.*, (2011) suggested that a significant proportion of organic matters and nutrients are being added to the soil through roots particularly fine roots in Japan. Fine root production and turnover have also been reported to vary due to site quality and species composition in forest ecosystem (Shrestha and Chen, 2010; Fukuzawa *et al.*, 2013).

Occurrence of peak fine roots biomass in rainy indicate that favorable temperature and enhanced availability of soil nutrients through decomposition promotes the vegetative growth of tree and herbaceous plants that positively affects the fine roots (Yuan and Chen, 2010). In the present study, maximum root biomass at TCH and minimum at JAB suggest positive correlations of root biomass with SM, TN and MBC. These soil variables found to play significant role in determining the distribution of roots particularly in upper soil profile which contained greater mass of fine roots than the other soil depths, thus, fine roots with higher nitrogen concentrations shows significant correlations with soil nitrogen content (Zhen *et al.*, 2013).

The fine roots have been widely reported to play an important role in the functioning of variety of natural forests and modified ecosystems by returning about 40-50% organic matter, C and nutrients (Tripathi and Singh 1994). In the present study, we found that with an annual accumulation (kg ha^{-1}) 2789-3955 organic matter, 1036-1582 C and 56-95 N within the soil profile to a depth of 30 cm; roots return 4114-4963 organic matter, 1528-1985 C and 82-119 N in different fallow lands following the burning due to root mortality that may ensure better production through release of C and N during the course of time. Interesting to note that bulk of soil nutrients are lost through erosion on the steep slopes which may not be available for the plants to grow. The addition of nutrients from the dead roots may be an important mechanism that may sustain soil fertility and crop productivity in shifting agriculture in this region.

This study suggests that fine root growth and productivity is strongly influenced by the soil water availability. Further, SM and MBC play an important role in determining the amount of fine root in short fallows while during the succession (older fallows) TN regulates the amount of fine roots. Shifting cultivation with increased shortening of fallow periods have significantly decreased aboveground biomass with increased proportional allocation to belowground to boost up the ecosystem production during shorter fallows. Increased proportion of very fine roots (<0.5 mm) in short fallow compared to long fallow with enhanced weed species compared older fallow may help accelerate uptake of nutrients and addition of organic matter and nutrients upon mortality due to rapid turnover rates (<1 year) that may lead to enhance soil fertility and crop productivity.

5.4. Changes in litter chemistry and mass loss in different fallows

Among initial litter concentrations lignin, C and N plays an important role in the rate of early stages of litter decomposition in all fallow sites (Wapongnungsang *et al*., 2017; Lalnunzira and Tripathi, 2018). The ratios of lignin/N and C/N were found to play significant role during early and later stages of decomposition. This reflects the important roles played by tissue chemistry on the rate of decomposition. Previous studies suggest that root decomposition is strongly influenced by tissue chemistry (Melillo *et al.,* 1982). In the present study, lignin contents were significantly higher in branch and coarse roots and lower in leaf and fine roots. Similarly, branch and coarse roots showed higher C content compared to leaf and fine root. The period of rapid mass loss in roots could have been caused by chemical characteristics of the roots by themselves or by some attribute of the belowground decomposition environment (Ostertag and Hobbie, 1999). Further, N content in leaf and fine roots were significantly higher compared to branches and coarse roots. Leaf and fine root components have been widely reported to have high N content compared to branch and coarse roots (Tripathi and Singh 1992a; Tripathi *et al.,* 2005; Tripathi *et al.,* 2006).

Maximum mass loss occurred in leaf followed by fine root, coarse root and branch in all sites. The higher decomposition was recorded at FL-10 followed by FL-5 and FL-3. As reflected by RDR values, mass loss rate was faster in initial two months period in all litter components and the same decreases in the later stages of decomposition. Thus, similar findings have been reported by Munthali *et al.* (2015) in *T. candida* and *T. vogelii*. Wapongnunsang *et al.* (2017) also reported similar findings in the decomposition of different components of *T. candida* in different fallows in shifting cultivation sites of Mizoram. The annual decay constant (*k*) for different litter component in the present study were higher (3.3-6.9) than those reported for dry tropical Sal forests (1.6-2.2) by Sharma *et al.,* 1990b and bamboo savanna (1-1.5) by

Tripathi and Singh, 1992b. The literature has shown that variation in leaf decomposition rate among species and categories greatly affected by the litter quality.

In the present study, lower C/N and lignin/N ratio in leaf and fine roots compared to branch and coarse roots reflected rapid decomposition in former than later. Rapid mass loss in fine roots may be affected by root chemical characteristics or by belowground decomposition environment (Ostertag and Hobbie, 1999). The ratios of lignin/N and C/N were found to play significant role during early and later stages of decomposition (Tripathi and Singh 1992a; Tripathi *et al.*, 2006; Pandey *et al*., 2007).

The initial mass loss in the first recovery of the present study may be related to the water soluble such as sugars, amino acids and soluble phenolics and labile substances during the initial period (Wang *et al.,* 2004). Further, slow rate of decomposition at later stage may be attributed to decline in easily decomposable compounds from the litter and increased amount of recalcitrant materials such as lignin, hemicelluloses and soil microbial products (Saviozzi *et al.,* 1997). Slow decomposition in branch and coarse root may be because of the presence of more stable polysaccharides like lignin, waxes and polyphenols (Zech *et al.*, 1997). The daily instantaneous decay constant (k), number of days required for 50% (T_{50}) and 95% (T_{95}) decomposition for all litter components were in the order: leaf>fine root>coarse root>branches. Previous studies have shown that roots decompose more slowly particularly greater root (Vivanco and Austin, 2006) than other components among species. Our results suggest that root decomposition was influenced by root diameter i.e. faster in fine roots having high hemi cellulose and cell soluble concentrations (Ostertag and Hobbie, 1999).

5.5. C and N release and factors affecting their rates during fallows

In the present study, the pattern of C stocks loss was similar to that of mass loss in all fallows. However, the N stock loss showed a steady decrease initially followed by a slow release or slight increase in N stock later which indicated a tendency of N immobilization by microorganisms during the stage of decomposition followed by N mineralization (Barnes *et al.*, 1998). The C/N ratio in branch and coarse roots may partially be responsible for slow decomposition rate that affect the release of nutrients in soil (Fosu *et al.*, 2007; Wapongnungsang *et al*., 2017). Hoorman *et al.*, (2010) reported that the critical values of C/N required for plant residues to transit from immobilization to mineralization was 20:1. The present result showed that the C/N ratio in litter component was above this critical value which tends to slow down the rate of decomposition in plant residues.

To estimate the effect of the environmental factors on litter mass loss in the respective fallow lands, abiotic variables like soil moisture, air temperature, rainfall and relative humidity were correlated with mass loss rates. The values of correlation coefficient (r) with mass loss rates in different components and mean values (corresponding to litter bag retrieval intervals) were 0.42 SM, 0.36 for rainfall, 0.51 for air temperature, 0.41 for soil temperature and 0.30 for relative humidity. Values of correlation coefficient were significant at $p<0.01$. The highest litter decomposition rates in the wet season reflect the favorable effect of rainfall and associated variables on decomposition of different sizes of roots and litter in all sites. However, lower soil moisture and temperature during winter period reduced the activity of microorganisms in the soil which therefore reduced the rates of decomposition (Tripathi and Singh, 1992a; Wapongnungsang *et al*., 2017). In the present study, mass loss rate was significantly positively correlated with abiotic factors. This reflects that the rainfall and its associated variables like temperature and soil moisture significantly affected the litter decomposition in all sites by promoting litter microorganisms. The present study demonstrates that abiotic factors play vital role in litter decomposition and C and N release in tropical evergreen forest fallows of Mizoram, northeast, India.

Present study showed that the litter decomposition rate was faster in FL-10 compared to FL-3 and FL-5 (Mayer, 2008). This may related to soil abiotic variables like soil moisture, soil temperature as these variables have been reported to play a vital role in decomposition especially in monsoon periods compared to winter period (Tripathi and Singh, 1992b; Ostertag *et al.,* 2008). Study also found that leaf fine roots decompose faster compared to branch and coarse roots. This related to litter chemistry (e.g. concentration of lignin in initial litter) of these components. The leaf and fine roots decompose faster because of less lignin and C/N ratio in the initial litter compared to thick branches and coarse roots (Zech *et al.*, 1997).

5.6. Soil properties under different fallows and the influence of burning

The slashing and burning of successional secondary forest as well as the length of the fallow period caused variations in the physico-chemical attributes of *jhum* soils (Kavadias *et al.,* 2001). Many researchers reported that Mizoram soils are strongly acidic in reaction (Tawnenga, 1997; Gorgan *et al.*, 2012; Tripathi *et al.*, 2017; Lungmuana *et al.*, 2017), which is conformity with the present findings. This could be related to the additions of more cations during burning and humic acid during the course of organic matter decomposition (Granged *et al.*, 2011; Lungmuana *et al.*, 2017). Due to burning activities, organic matter content had been reduced from the secondary forests which reduce the bulk density (Biswas *et al.,* 2012). The significant decrease in BD from FL-3 to FL-10 may be due to the higher accumulation of soil organic matter in the longer length fallow (Gupta *et al.*, 2010; Sarkar *et al.*, 2015). Similar observation of decreasing BD with increase in age of secondary forest was reported by Jia *et al.* (2005). The increased in pH right 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 $K_{exchange}$ (Certini, 2005). Increasing pH with increasing fallow length (FL-3, FL-5 and FL-10) was recorded in our experimental study site where similar observation was also reported by (Kulmala *et al.*, 2014).

The burning of organic matters has been reported to have number of micro-environmental changes on soil surface, for instance, decrease soil porosity, aeration, water holding capacity, moisture content and increase in soil erosion that accelerate nutrient losses, particularly on steeply sloped areas like Mizoram where huge amount of top soil along with nutrients are carried out each year due to torrential rains (Grogan, 2012; Tripathi *et al.*, 2017). The removal of organic matters and nutrients through runoff may not have significantly affected crop productivity in older fallow compared to younger fallow because of the huge accumulations of nutrients for longer time. The wide gap in carbon storage between FL-3 and FL-10 fallow lands could be regarded as rapid carbon accumulation as a result of vegetation development (Chaplot *et al.,* 2010). According to Ramakrishnan and Kushwaha (2001), secondary forest fallow with more than 25 years will have more soil nutrient availability and better crop yield compared to young fallow. Length of forest fallow period played an important role in conserving the soil health promoting the soil nutrients and soil enzyme activities for longer fallow period. Soil conservation measures may decrease the soil nutrient loss through erosion, leaching, etc during cropping periods every year. A fallow period of >10 years prove to conserved better soil nutrients and soil health than shorter fallow during the cropping period throughout the year.

In the present study, the effects of burning was more prominent in older fallow (FL-10) as expected compared to younger fallow (FL-3) in *jhum* cycles of Mizoram. Decreased soil organic C content after burning has been widely reported in the past (Fernandez *et al.,* 1997; Wanshnong *et al.* 2013), which is the result of alteration in soil organic C content as a result of higher topsoil temperature (242°C± 10°C)(0-2 cm depth) during burning that causes burning of forest floor leading to limited incorporation of litter materials in burnt plots (Tinker *et al.,* 1996). Findings indicated that the significant increase in soil organic C with increase in fallow length (FL-3 to FL-10) was due to increased accumulation of organic matterSarkar *et al.,* 2015). Recently, Wanshnong *et al.* (2013) reported change in biological pools of C, N and P in acidic alfisols of *Citrus* orchard in North East India with respect to changes in hill slope and burning. They reported that the rate of degradation of soil quality is more aggressive under burnt situation of older fallow as compared to that in younger fallow and the reason cited was more vegetation biomass in the older fallow compared to shorter fallow. The significant increase in microbial biomass (C and N) and enzyme activities with increased fallow length may be due to the addition/accumulation of more organic matter in the soils that act as a storehouse and regulates availability of soil nutrients under different fallow periods in the present study. On the other hand, after the exposure of soil to burning start accelerate the soil erosion process which greatly reduced soil nutrient content (Choudhuty *et al.*, 2015). These may be attributed due to higher temperature during burning or due to accumulation of more biomass in the longer periods (Tawnenga, 1997). The same observation was recorded in the present study in different fallow of Mizoram. In the present study, almost all soil nutrients decreased after burning and increase during the onset of the monsoon. The intensity of the decrease or increase was significantly positively affected by the fallow ages. The findings clearly signify the fact that the combined impacts of burning and length of fallow period lead to deterioration of soil quality in shorter fallow (FL-3) length and eventually it gradually diminishes as the age of the fallow length increases (10 and 15/20 years) (Saplalrinliana, 2016).

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 N_2 (Raison, 1979). The content of available N has a declining trend after burning (Ramakrishnan and Toky, 1981). In this study, soil available N content decreased with the increasing length of the fallow periods. Past findings indicated that burning activity decrease the content of soil available N, but as the fallow length increases available N tends to increase gradually (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.

5.7. Soil physico-chemical and bio-chemical changes with fallows and treatments

Soil physical chemical properties like pH, TOC, TN, $P_{avail.}$, $K_{exchange}$,available N (NH_4-N, NO_3-N) significantly (p<0.05) increased in $T_{litter+}$ treatment compared to control treatment in all the fallow lands. The addition of litter amendments of different fallow land slightly increased soil pH than control plot. Similar result was reported by Sarkar *et al.* (2010) under the potted condition where ground leaf litters of different tree species were added as amendment in an experiment under red amaranth cultivation in Bangladesh. Further, the increase in soil pH after leaf litter incorporation was recently demonstrated by Ma *et al.* (2014) in Maryland, USA.

Increase in soil organic C content in $T_{litter+}$ compared to control soil can probably be asserted to the addition of comparable amounts of forest litters. Such increase in soil organic C from 1.22% to 2.53% after application of leaf litters were observed in Bangladesh (Sarkar *et al.,* 2010). Increase in soil organic C through leaf litter addition and decomposition was also demonstrated recently in Italy where litters from secondary forest successions increased the soil organic C 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 soil organic C due to addition of addition of jackfruit leaf litter. The lignin content of litters (i.e. branches, stem) from 15 and 20 yrs fallow period was more as compared to shorter fallow period i.e. 5 and 10 years fallow and this may be the cause for lesser decomposition leading to more accumulation of soil organic C in amended soils. Likewise, addition of litter amendments showed differential effect on the availability of soil N (NH_4-N and NO_3-N). Soil P_{avail} significantly increase (p<0.05) in litter amended soil than control plot in all the fallow land. Such variable response of soil P_{avail} to litter additions might be due to net P mineralization. Sarkar *et al.* (2010) also noticed that soil P_{avail} content tend to increase with the incorporation of different types of litters.

Higher content of $K_{exchange}$ in litter amended soils was also observed and could be correlated with the potassium contents in the litters. Similar results were reported by Parsakhoo and Jalilvand (2009) for the higher $K_{exchange}$ as result of addition of iron wood leaf litters in forest soils of Iran. Sarkar *et al.* (2010) has highlighted about such increase in K content in leaf litter amended soils as compared to control. Increase (2-3 times) in K content has also been reported in Canada after addition of pine needle litters (Nevzat *et al.,* 2003).

In the present study, increased enzyme activity like DHA and GSA was observed in the litter amendment plot that may be due to the increased source of energy for microbes that enhance the microbial activity. Similar result was reported by Li *et al.* (2014) where DHA and GSA activities tend to increase after the litter amendment in microcosm experiment conducted in Southern China. The activity of DHA was found highest in FL-10 as compare to FL-5 and FL-3 in the present study. Similar results were also obtained from the other study where litters of longer fallow length supported higher activity of DHA compared to shorted fallow length (Haripal and Sahoo, 2013). Activities of GSA is known to increase with increase in soil organic C as described by Miller and Dick (1995) and such increase in soil organic C could be brought about by the incorporation of forest floor litters in the soil. Our study also revealed that the increase in soil organic C and activity of GSA was observed in the litter amended treatment.

In the present study, changes in PHA were marginal after the addition of litter in the soil, however, changes in PHA were significant with respect to fallow length as result of burning. There are different views about the decrease in the activity of PHA after burning conducted in oak-hickory forest of Missouri (Eivazi and Bayan, 1996). Baldwin *et al.* (2001) reported that burning increased the available P content in soil and activities of PHA reduced as a result of P stress condition in terrestrial plant to signal PHA enzymes from the roots. In the present study, PHA analysis was not recorded right after burning though physical chemical soil analysis was recorded as above result stated.

The burning of vegetation and length of fallow enhanced the MBC, MBN in litters amended soils compared to control soils. The MBC and MBN significantly (p<0.05) increased with litters of increasing fallow length which also 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 had followed similar patterns which could also be attributed to the amount and type of biomass content in forest floor. The increase in MBN was also observed in secondary vegetation succession in semiarid abandoned lands of Loess Plateau of China (Jiang *et al.,* 2009).

In addition to litter amendments, microbial inoculation treatment in the present study clearly indicate positive response on changes in chemical and biological properties of soils and reducing stress impacts on crop physiology. Such positive responses were more prominent in 10 years soils compared to that in 3 years soils. Since the microbial inoculation was prepared taking into account the PGP activities (e.g. IAA production, P solubilisation, pectinase and cellulose activities, N_2- fixation) by the rhizobacteria. Besides, the members of the microbial inoculants were native to *jhum* soils and were well adapted to burnt soil condition as has been tested for their ability to heat tolerance and acidity tolerance. Therefore, the positive impacts of microbial inoculation could provide adaptive benefit to crops against environmental stresses associated with *jhum* soils (Thakuria, 2015).

In the present study, N_{min} rates varied significantly between the seasons (p<0.01) with higher N_{min} rates during the rainy season in all sites. N_{min} rate was higher in longer fallows (FL-10) compared to shorter fallow (FL-3 and FL-5). This may be due to higher nutrients concentrations in forest floor as soil rich in organic matter tend to have high N_{min} rates (Bhuyan *et al.,* 2014). Higher mineralization rates in wet season might also be due to elevated soil temperature and moisture content during this period in the forest ecosystems (Eghball, 2000; Numan *et al.,* 2000). Favourable microclimate in rainy season may induce microbial activity that accelerates the rate of N_{min}. Decreased N_{min} rates during the winter period could be associated with the low rates of decomposition due to decreased microbial activity and greater immobilization of inorganic N (Bhuyan *et al.,* 2014). The present study indicates that soil biochemical properties responded rapidly to chemical changes in soils resulting from human induced land use/land cover alterations. There was a considerable degree of correlation between various chemical and biochemical properties measured (Islam and Weil, 2000). The values of the above parameters bulk density, pH, C, N, NH_4-N, NO_3-N, and N_{min} rates lies well within the range given by range reported by researcher around the world {e.g. Das *et al.* (1997) in a subtropical humid forest of Meghalaya; Bhuyan *et al.* (2004) in Eastern Himalaya; Biswas *et al.* (2012) in Chittagong Hill Tracts and Tripathi *et al.* (2005) in Northern forest of Japan}. Among treatment effect, litter amendment showed the maximum effect over control in all fallow sites. This may be due to the accumulation of organic matter and nutrients that have been released to the soil through decomposition during the monsoon season (Sarkar *et al.,* 2015). Microbial inoculation treatment also affected the rates of N_{min} over control as result of the positive role played by PGP rhizobacteria in making N available in the soil.

5.8. Changes in weed species composition and biomass with fallows and treatments

In most weed management strategies, more attention has been paid to crop yield than to biological productivity of crops and weeds. Weed management strategies have generally involved application of herbicides alone, whereas little information is available when herbicides are applied in combination with various soil amendments. Lack of weeds provided lower competition for the various natural resources needed by crops, and consequently, facilitated higher crop TNP and crop yield.

The pattern of arrival and departure or turnover of the three most dominant species was analyzed in the course of succession after abandonment of cultivated lands. The most common dominated species that occurred throughout the year were *Ageratum conyzoides*which is known to be the most invasive species in the study site during the period of 2013-15 and some common species found throughout the years were *Knoxia corymbosa, Chromolaena odorata and Mikania cordata*. The present study revealed that chronosequential pattern of plant species turnover differs among species. While some plant species only grow on lands currently under cultivation and totally disappear immediately after abandonment, others only colonize the abandoned lands at different stages of the succession and with different degree of dominance (Plieninger *et al.,* 2013). Some colonized the earlier stages of the succession, others colonize the later stages, and yet other colonizes the middle stage. It was also shown that some plant species colonize consecutive stages of succession and other appears, disappear and reappear during different seasons (Mitja *et al*., 2007).

The present study, weed species richness (number of individual species) increases steadily in FL-3 and reached its peak in the FL-5, then decreases a little in FL-10. An FL-3 and FL-5 fallow doesn't show much differences in weed diversity count however, FL-10 showed some differences (Sharma *et al*., 2016). Rainy season was recorded highest species density followed by summer and winter according to the above study. During rainy season soil moisture favored occurrence of larger number of the herbaceous plant species and their population on account of semi-arid climate of this area (Sharma and Upadhyaya, 2002). However, only a few species occurred throughout the study period evidently due to the wide ecological amplitude of these species under the prevailing climatic conditions (Gairola *et al*., 2011). The proportions of the abundance of individuals also differ in different stages of the succession. Shannon-Wiener diversity index show that species diversity increases upon abandonment of cultivated land compared with the other arable lands. Weed species diversity was in decreasing order: FL-10>FL-5>FL-3. The pattern of increase and decrease in species diversity correspond proportionately to that of species richness along with the course of the succession (Singh *et al*., 2016). The above study revealed that although fewer species were found in FL-3 compared to FL-5 and FL-10 fallows, however, the density was highest in the FL-3 compare to FL-10. The species evenness was also highest FL-10 fallow and the lowest in 3 fallow. Total species count at each site in different seasons showed a common trend of maximum flora in rainy season and minimum in summer, suggesting a general increase in species diversity with moisture availability in tropical habitats (Singh *et al*., 2014). However, independent and variable diversity response of these habitats is intelligible in terms of range of diversity variation across different seasons.

Among treatments effect, more individual species and density were recorded in $T_{litter+}$ and T_{micro+} in all fallows. These could be due to the accumulation of organic matter by various litters and adding microbial innocula to the soils which helps greater micro-organism to work faster in the soil especially during monsoon and release it nutrients and get benefited to the plants and crops in the study sites (Sarkar *et al*., 2015). It also found that FL-10 showed rapid growth rate and species diversity compared to FL-3. This appears likely due to better soil conditions at older age and low soil nutrients younger age. Reduction of plant diversity due to land-use change and environmental stress has been found in various ecosystems (Wilsey and Potvin, 2000).

The percentage contribution of TWB declined with the ages (FL-3>FL-5>FL-10). Comparatively greater production of weed phytomass in FL-10 followed by FL-5 then FL-3 may be due to shorter *jhum* cycle. Under short jhum cycle, such as 3 years or 5 years, community is maintained more or less in permanent state of arrested succession (Kushwahaet *al.*, 1981 and Zinke *et al.*, 1978). However, when succession progresses for a longer period, such as 10 years or more, weed growth is suppressed by immigration of boreal elements (Saxena and Ramakrishnan, 1984). Among the treatments, litter amendment and microbial consortium showed the greater weed biomass followed by soil amendment compared to control plot in all sites. These could be due the more nutrient availability that the plants/crops grow faster and bigger, taller compare to the un-treat plot. Rainy season seems to be recorded greater biomass compared to summer and winter season. This could due to the role of microorganism plays in the soil which decomposed the litter into organic matter and releases nutrients and take up by plant. The weed biomass declined from first year cropping to third year cropping in the present study. These could be due to the declining of soil nutrients availability and exposure to the soil such as erosion, leaching, etc. after first year cropping (Tawnenga, 1997).

5.9. Impact of fallow age on total rice productivity

In a tropical agro-ecosystem, measurement of crop biological productivity is important for agronomic as well as ecological point of view (Singh *et al.,* 2007). In the present study, significant enhancement of crop productivity with the length of fallow periods (FL-3 Vs FL-10) has been found to be related to the organic matter accumulation (2 and 12 t ha^{-1}). Addition of greater soil nutrients through previous organic matter accumulation following by burning in FL-10 fallow compared to FL-3 fallow may enhance the level of crop productivity in longer fallow. Higher crop productivity in longer fallow was also reported earlier (Tokey and Ramakrishna, 1981; Tawnenga *et al.,* 1996). Greater crop uptake of soil nutrients in 1^{st} year cropping to compensate high crop productivity in this year cropping (Tawnenga, 1990) that may reduce the soil fertility in the 2^{nd} year and consequent cropping. This has led to increase total productivity and grain yield in 1^{st} year cropping compared to the 2^{nd} and 3^{rd} year cropping in all fallows in the present study. Decreased productivity from the 2^{nd} and 3^{rd} year cropping has been reported to be related to exhaustion of soil nutrients through run-off, leaching and plant uptake (Ramakrishnan *et al.,* 1981; Pandey *et al.,* 1993). The rice grain yield in the present study was recorded highest (1080-2060) kg ha^{-1} $year^{-1}$ in the 1st year followed by (525-1560) kg ha^{-1} $year^{-1}$ in the 2nd year and (149-824) kg ha^{-1} $year^{-1}$ in the 3rd year. Higher rice yield in the 1st year cropping compared to 2nd and 3rd year cropping could be due to the accumulation of better organic matters during burning event (Tawnenga *et al.,* 1996; Sarkar *et al.,* 2015). The rice yield in the present study is towards the range reported in Indian dry-land conditions 600-1800 kg ha^{-1} by Ghoshal and Singh (1995) and 800-1200 kg ha^{-1} by Kushwaha and Singh (2005).

5.10. Changes in crop productivity, C and N in plant and soil with fallows and treatments

The present study revealed that the effect of different treatment on TNP of rice and vegetable crops were in order of $T_{litter+}$>T_{micro+}>T_{soil+}. The addition of litter microbial inoculants have significantly (p<0.05) enhanced crop productivity in all fallows during three years of cropping. Phongpan and Mosier (2003) found significant grain yield responses in wet rice following the application of urea and urea plus wheat straw in rice- fallow- rice cropping sequence in central Thailand. In the present study, litter amended soil (Sarkar *et al.,* 2010) recorded the highest rice yield compared to control plot in all the sites throughout the three consecutive years. Litter amendment (@5 t ha^{-1}) in the 1st year contained tissue nutrients (~75 kg N ha^{-1}, 5 kg P ha^{-1} and 2.5 kg K ha^{-1}) which released nutrients slowly during crop growth period. This has enhanced synchronization of nutrient release with that of crop nutrient demand and decrease the possibility of nutrient loss due to runoff and leaching during three years. Further, T_{micro+} treatment has five dominant phosphate solubilizing rhizosphere microbes to enhance available P around the roots that could compensate the crop P demands in P limited condition in this region (Thakuria, 2015).

The percent C concentration of rice and vegetables was recorded maximum in FL-10 and minimum in FL-3 in the study site. The C concentration was highest in seed grain in rice and stem part in vegetables. This suggests that rice seeds and stem are the main sourcefor C content from the soil which may be partially responsible for nutrient uptake from the soil (Fosu *et al*., 2007). N concentration varied significantly and found highest nutrients content (p<0.01) in T_{micro+} and $T_{litter+}$ compared to control plot. Further, total soil C stock, C sequestration and build-up of soil organic C was noticed maximum in longer fallow (FL-10) period than shorter fallow (FL-3). Among the treatment plots, addition of litter amendment has the highest record followed by microbial inocula and soil amendment over the control plot. This could be due to the accumulation of higher organic matters in the longer fallow (Sarkar *et al.*, 2015) and addition of forest litter (Novara *et al.*, 2015) and treating with microbial inocula (Thakuria, 2015) in the treated plots respectively.

CHAPTER 6

SUMMARY AND CONCLUSION

Slash- and- burn agriculture locally called *jhum* agro-ecosystem is a unique combination of ecology of natural and derived ecosystems like agro-ecosystems.In this system,fallow period represents building up of soil properties during secondary succession and cropping phase represents the primitive forms of agricultural practice carried out by slashing and burning of above-ground forest biomass and breaking the functional linkages with below-ground components. As a whole the practice is aninteractive process where soil microorganisms transform organic substrates by releasing mineral elements and thevegetation adds energy to the soil as litter and root exudates, and hence strongly influences the establishment of plants. Therefore, understanding of the importance of relationship among the quantity and quality of biological inputs both above-ground and below-ground and the associated soil nutrient cycling processes are among the important goals of ecology to effectively sustain the functioning of tropical forest ecosystems afcing continuous disturbances and derived ecosystems like shifting cultivation.

Shifting cultivationin Mizoram region was once ecologically sound and economically feasible in the past because prolonged fallow periods (>20 years) allowed sufficient time for the ecosystem to recover between two cropping cycles. In recent years, however, due to increasedpopulation the fallow period has been considerably decreased to < 5 years. This has led to considerably decrease soil fertility (organic matter, soil water, nutrients and soil microflora) and increase emergence of weeds and consequently decrease crop productivity which pose serious concerns for livelihoods of poor farmers. This study used a chronosequence of shifting cultivation sites that had been fallowed for 3, 5 and 10 years to test the potential for practical and locally feasible soil amendment treatments to mitigate the impacts of short fallow periods.

The study was conducted at three fallow lands of 3 years (FL-3), 5 years (FL-5) and 10 years fallow (FL-10) in Muallungthu village, Mizoram. The geographic position of the study sites lie between $23^{0}36'30''$ N lat. and $92^{0}42'87''$ E long. for FL-3, $23^{0}35'69''$ N lat. and $92^{0}43'09''$ E long. for FL-5 and $23^{0}35'66''$ N lat. and $92^{0}48'08''$ E long. for FL-10.The aim of this experiment was to assess the interactive effects of burning, length of fallow ages and the effects of addition of litter amendmentand microbial inoculants on the burnt soils of 3, 5 and 10 year fallow fallows. The effects of addition of litter amended soil and microbial inoculants on the physiological stresses of *jhum* crops were determined for understanding the potential roleof these inputs in ameliorating the overall stresses to the *jhum* soil. In order to understand the role of burning and length of fallow periods on the quality of *jhum* soils, a set of soil quality indicator parameters were analysed for different fallow periods under burnt field conditions in the study site of Mizoram.

The spatial and temporal distributions of fine root biomass were studied in different fallow ages within 30 cm soil depth. The roots were divided into four diameter classes (<0.5 mm, 0.5-2 mm, 2-5 mm). C and N contents in different categories of roots were analyzed. The amount of C and N stored up to 30 cm soil depth of different sites and nutrient returned through root production and turnover were assessed. The rates of decomposition of litters; aboveground and belowground i.e. different diameter roots in three *jhum* ecosystems were studied through litter bag techniques. In addition, plant species diversity and aboveground (AB) and belowground biomass (BG) were investigated at thesefallows. Occurrences of weed species at each site were also recorded periodically for three consecutive years. Herbaceous biomass for these sites was also estimated to identify the weed species and to study weed diversity, population structure and species composition in *jhum*rice cultivated of Muallungthu village in Aizawl District, Mizoram.

Seasonal variations in the amount of fine roots were recorded in three *jhum* fallow (FL-3, FL-5 and FL-10) stands. TRB were maximum at TSF and minimum at JAB in all fallows which then gradually increased at the onset of monsoon. Comparing among the fallows, TRB showed an increasing pattern from FL-3 to FL-10 fallows. After burn, TRB was recorded maximum at TCH in all fallows. The changes in root biomass between different seasons showed significant (p<0.05) differences in all fallows. The findings revealed that the depth wise distribution pattern of roots in different soil profile was affected by the disturbance of forest *jhum* floor. Higher values of root biomass were observed in the upper soil layer as compared to the other soil depths. The concentration of roots in the upper soil depth (0-10 cm) was considerably higher in FL-10 followed by FL-5 and FL-3. The significant decrease in fine root biomass with increase in soil depth was redcordedin all sites. The turnover of very fine roots was considerably higher than that of other diameter class root for all fallows. Fine root turnover in the older *jhum* fallow were greater than in young *jhum* fallow. Fine root biomass showed significant positive correlations with abiotic variables like soil moisture and temperature.

The result stated that N concentration decreased significantly as the root diameter increased in all fallow stands in all seasons. However, the change in root C concentration was opposite to N with higher values in greater root diameter. Fine roots (<0.5mm) contains maximumamount of N but minimum C in all the fallow stands. The amount of nutrients concentration in different root categories was considerably higher in older fallow compared with the younger fallow showing significant differences for both C and N. The total amount of C and N stored in different root categories within 30 cm increased significantly with fallow ages.

The findings of the present study revealed that the litter decomposition rates were higher in the older fallow period (FL-10) than the younger fallow (FL-3 and FL-5) sites. Highest litter decomposition rate was observed in first recovery as a result of wetcondition caused by monsoon period of the year. Higher relative decomposition rates (RDR) were found in first and second wet period. Among the four different litter components, fine root and leaf litter showed higher rates of decomposition with higher RDR and mass loss rates in all study fallow sites. The pattern of C stock lost during decomposition followed a pattern similar to that of mass loss with maximum mass loss occurred in the first recovery. N stock showed an initial increase followed by a gradual decreased later during the course of decomposition. At the end of the decomposition study, fine root and leaf litter showed highest N loss than other components.

The results of studied survey revealed that the length of fallow lands (FL-3, FL-5 and FL-10) and associated burning practice in the shifting cultivation had significant influence on soil BD and other soil chemical properties like pH, TOC, TN, Available N (NH_4-N, NO_3-N), P_{avail} and $K_{exchange}$. Soil BD and the length of the fallow periods maintained an inverse relationship and on the other hand all other soil nutrients showed a positive relationship with the length of the fallow period. The experimental design of the studied sites revealed that the litter amendment had positive influence on soil properties and thus itretards the negative impact of burning on soil properties. Secondly, the microbial inoculants have also greatly improved soil properties and crop production. The effect of burning and fallow age was positively affected the amount of TOC, Available N, P_{avail} and $K_{exchange}$ indicating the greater extent of benefits to soil properties upon burning biomass from longer fallow length. This finding clearly states that instead of frequent burning of biomass of shorter fallow land, the less frequent burning of biomass of longer fallow land is more beneficial in terms of improving soil fertility in *jhum* soils.

The results revealed that thelength of the fallow periods and associated burning practice had significant influence on soil biochemical properties. The length of fallow periods maintained a significant positive relationship with the activity of GSA, DHA, and PHA under *jhum* land. The experimental design of the studied site indicated that the $T_{litter+}$ and the activity of T_{micro+} on fallow lands soils exerts strong effects on the activity of soil enzymes. The activity of DHA, PHA and GSA were significantly changed and influenced due to the interaction effect of burning and litter type in *jhum* land. So, the $T_{litter+}$ soils with the fallow ages can not only change the soil enzyme activities but also indicated a possible shift in the nutrient cycling processes. The negative response of MBC and MBN towards burning practice could be change by amending the soils with forest litters and with microbial inoculants.

The result revealed that N_{min} rates changesseasonally (P<0.05) with highest and lowest values recorded during wet and dry seasons, respectively, in all sites. The highest N_{min} was recorded in the older fallow whereas minimum was recorded in younger fallow. Among the treatments, significant increase in N_{min} rates was recorded in litter amendment plots followed by microbial inoculants over control.

The findings of the study site revealed that the rice grain yield was significantly higher in 1styear cropping compared to 2nd and 3rd year. Among the different treatments, $T_{litter+}$ and T_{micro+} have significant increased in the grain yield. However, addition of soil marginally increased grain yield. The present study revealed that the rice grain yield reduced to 32% from 1st year to 2nd year and 56% from 2nd year to 3rd year. The TRP was more than double in FL-10 and about one and a half times in FL-5 compared to FL-3.

The total crop productivity (rice plus vegetables) increases with the fallow age. Further, total vegetable production (AG and BG) also increased with fallow age. Among the treatments, $T_{litter+}$ and T_{micro+} showed significant increase over control in TNP in all fallows. T_{soil+} has marginally increased TNP which was not significant.

The percent C concentrations varied in different vegetable parts. N concentration varied significantly in T_{micro+} and $T_{litter+}$ plots and between 3 and 10 years fallows. T_{micro+} and $T_{litter+}$ showed significant increase in N concentration over control.

The findings of the study site revealed that a total of 16 weed plant species belonging to 9 families (Angiosperms) were present during the period of the study. Considering all study sites together in a season, maximum flora was recorded in the rainy season (14) followed by summer (13) seasons and winter (12) season. Out of total number of weed species recorded during course of study, significantly higher number of species were recorded in rainy season (e.g. 11 in 2013, 14 in 2014 and 10 in 2015) followed by summer (e.g. 8 in 2013,12 in 2014 and 8 in 2015) and winter (e.g. 7 in 2013, 8 in 2014 and 8 in 2015). *Ageratum conyzoides* was most dominantspecies in most of the treatments and fallows in all the seasons. *Ageratum indicum, Biden pilosa, Knoxia corymbosa, Chromolaena odorata, Mikania cordata* and *Gynura crepidioides* were the other dominant species present in all the seasons.

Seasonal changes in the occurrences of weed diversity wascalculated through different indices in different fallows (FL-3, FL-5 and FL-10) using species IVI. Weed diversity were found to be maximum in the rainy season compared to summer and winter seasons in all sites. Shannon-Wienerdiversity index was highest in 3 years and lowest in 10 years. Shannon index was highest in $T_{litter+}$ followed by T_{micro+}, T_{soil+} and $T_{control.}$ Weed diversity decreased from 2013 to 2015. Simpson's index followed the pattern similar to that of Shannon-Wiener index. Treatment effect on weed diversity by Margalef index was same as above. In contrast to the above, Margalef index increased from 2013 to 2015. Species Evenness followed the pattern similar to that of Shannon-Wiener index.

The findings revealed that the total weed biomass (AG and BG) significantly declined in 3rdyear cropping compared to the 1styear and 2nd year cropping. Among different treatments T_{micro+} and $T_{litter+}$ significantly increased the TWB over control throughout the cropping year. Rainy season showed the highest weed biomass record (10938.4 g m^{-2}) followed by summer (8986 g m^{-2}) and winter (7837 g m^{-2}).

The above study clearly demonstrates that longer fallow period supports higher quantity of forest floor litters that maintains higher soil nutrient availability and efficentC, N and P cyclings. The process of biomass slashing and burning exerts negative impacts on the accumulation of forest floor litters and thereby it reduces the inherent capacity for cycling of C, N and P in soils due decreased microflora. 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 could be a possible way of compensating the detrimental effects of burning. These findings clearly state 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 study also demonstrate that higher amount of fine root biomass and leaf litters production in forest fallowsmaintainsbulk nutrient capital in the soil that was adequately balanced by the pulse release of nutrients through decomposition processes to support high production in these forests.

Older *Jhum* fallow produces greater amounts of very fine roots (<0.5 mm) compared to younger *jhum* fallow to exploit limited nutrients from greater soil volume and add substantial amount of organic matter and nutrients to the soil through their rapid turnover rates (<1 year) that leads to accelerate the process of recovery at these sites.It is concluded that the quantity and quality of different categories of fine roots and leaf litter components along with their varying turnover rates play a significant role in secondary succession in semi-evergreen subtropical forestsof Mizoram.This study also demonstrates that the significant effect of fallow age on TNP and grain yield during the first year cropping compared to second and third year cropping. Litter amendments and microbial inoculation have considerably improved crop productivity and grain yield in all stands during three years of cropping. Further studies are needed to test the combined effect of additions of litter and soil microbes on soil fertility and crop productivity in shifting cultivation sites.

Weed management is a fundamental practice, failure of which may result in severe losses in terms of yield and economic return. Weed is a serious problem in the shifting cultivation site which signiofiacntly reduces rice yield and therefore, ecological management of weed without the use of the herbicides has been a huge challenge for the weed researchers and rice farmers in this region. Weeds are dynamic in nature and a shift in their abundance and dominance is likelyto change with management practices. Integrated approaches like use of clean certified seeds, higher seeding densities, cultivation of competitive variety, crop rotation, and water and fertilizer management followed by manual weeding can be tried for sustainable weed control.Moreover, any weed management approach should be aimed at controlling weeds only during critical period of weed competition for a more cost-effective and eco-friendly weed management. 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 length with slash and burn activities for achieving higher *jhum* productivity as well as ecosystem sustainability.

In conclusion, the locally available litter material and microbial inoculation from the rhizosphere soil of early regenerating plant have been found to considerably increase the productivity and soil fertility and has immense potential to be used for the improvement soil fertility even in the shorter fallow of shifting cultivation and can beneficially be used as an important tools to sustain crop productivity and food security in the region.

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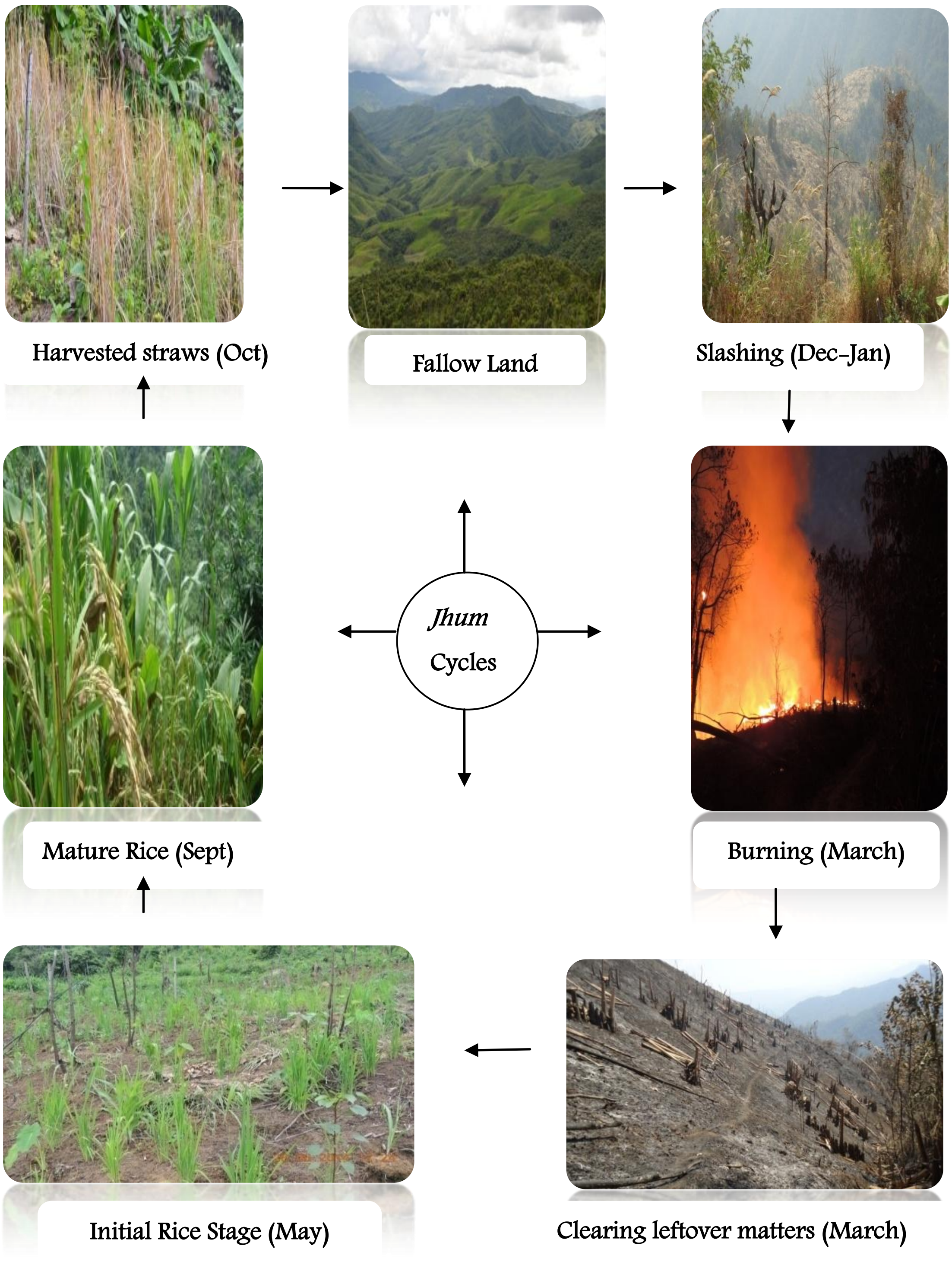

Photo-plate-1: General cycle of shifting cultivation in Mizoram





Photo-plate: 2: Site survey with professors and scholars on March 2013 at Muallungthu village of Mizoram district

Farmer –Lalsangzuala; GPS-23^{0}36′30″ N and 92^{0}42′87″ E; Elevation-838 m, 1 t b

Farmer:-C. Lalnunzira ; GPS-23^{0}35′69″ N and 92^{0}43′09″ E; Elevation- 740 m, 4.5 t

Farmer- Lte Pu Rotlunga; GPS-23^{0}35′66″ N and 92^{0}48′08″ E; Elevation- 725 m, 10

Photo-plate:-3: Site location with GPS reading in different fallow site

Photo-plate-4: Collection of composited soil samples from the study sites

Photo-plate-5: Laboratory analysiswork

Nylon net bags placed on the study sites

Periodical recovery of nylon netbags from the study sites

Photo-plate-6: Recovered nylon bags placed in the laboratory

2 weeks old

3 weeks old

5 weeks old

3 months 15 days old

3 months 27 days old

4 months 10 days old

Harvesting (Sept)

Leftover Straw

Rice sample packed

Photo-plate-7: Stages of rice maturity in shifting cultivation of Muallungthu village of Mizoram

FL-3 (3 years)

FL-5 (5 years)

FL-10 (10 years site)

Photo-plate-8: Rice growth in different fallow lands in Muallungthu village of Mizoram

Solanum melongena

Colocasiasp.

Gingiber officinalle

Psophocacarpus tetragolobus

Zanthoxylum rhetsa

Bottle guard

Maize

Cucurbita moschata

Capsicum frutescens

Photo-plate-9: Common vegetables found in the shifting cultivation sites

Photo-plate-10: Some of the common vegetables stored by farmers for the next sowing

FL-3 (3 years)

FL-5 (5 years site)

FL-10 (10 years)

Photo-plate-11: Weed growth in different shifting cultivation sites in Muallungthu village

Chromolaena odorata

Knoxia corymbosa

Bidens pilosa

Ageratum conyzoides

Ageratum indicum

Thysanolaena maxima

Gynura crepidioides

Cucurma caesia

Sachharum longisetosum

Photo-plate-12: Common early generating species in shifting cultivation sites

Villagers making fire lines before burning the slashed site

Villagers taking rest and drinking red tea on a bamboo cup

Villagers making final touch fire line before light fire on the site

Villagers waiting for the wind direction to light fire in the site

Burning from one site according to wind direction

Photo-plate-13

Fire burning at maximum temperature

Burning forest floor

Right after burn (R-L)

Photo-plate- 14

VITA

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