Comparative study of impact of shifting cultivation and settled agriculture on soil fertility in Aizawl and Lunglei districts of Mizoram

THESIS

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BY:

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DECLARATION

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I, **C.B.Lalramliani,** hereby declared that the subject matter of this thesis entitled, "*Comparative study of impact of shifting cultivation and settled agriculture on soil fertility in Aizawl and Lunglei districts of 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.

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CERTIFICATE

This is to certify that the thesis entitled **“*Comparative study of impact of shifting cultivation and settled agriculture on soil fertility in Aizawl and Lunglei districts of Mizoram*”** submitted by **C.B.Lalramliani (Ph.D Regn. No. MZU/ Ph.D./ 264 of 02.06.2011)** in partial fulfilments of the requirements for the award of degree of **Doctor of Philosophy** in Forestry Department of the Mizoram University, Aizawl, embodies the record of original investigations carried by her under my supervision. She 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 of these has not been submitted by her for any degree to this or any other university**.**

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List of abbreviations and symbols

%	Per cent
C	Carbon
cm	Centimetre
cm^2	Centimetre square
dw	Dry weight
e.g.	*exemplia gratia*
et al.	*et alia* and others
etc	*et cetera*
g	Gram
h	Hour
ha	Hectare
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
m	Metre
m^2	Meter square
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
mg	Milligram
mg/kg	Milligram per kilogram
mm	Millimetre
N	Nitrogen
°C	Degree Celsius/Centigrade
P	Phosphorus
$P<0.01$	Significant level at 1 percent
$P<0.05$	Significant level at 5 percent
r	Correlation coefficient
SE	Standard error
SMB	Soil microbial biomass
SOC	Soil organic carbon
SOM	Soil organic matter
sp	Species
wt	Weight
yr	Year
mg	Microgram
mg g^{-1}	Microgram per gram

Preface

Litter decomposition is an important processes that improved soil fertility. This study is an effort to compare the level of soil fertility in two common practices (abandoned land following shifting cultivation and settled SALT farm) in Aizawl and Lunglei districts of Mizoram where no information is available. This study compared the level of soil fertility (organic C and total N), rates of organic matter and C and N release pattern, and quantitative and qualitative changes in water stable soil aggregates in different abandoned land following (fallow lands) shifting cultivation and two ages of settled SALT systems.

This study provides information on the rate of decomposition and mineralization of C and N of different parts of plant litters (green leaf, branch, fine root, coarse root litters) and soil physic-chemical characteristics in settled farm and different ages of fallow land in Aizawl and Lunglei districts of Mizoram.

This thesis emphasised the soil characteristics and litter decomposition, and C and N release and soil aggregates in different fallow and settled SALT farm of different shifting cultivation site and settled farm.

Chapter 1

INTRODUCTION

1.1. Global food production and demand

Exponential expansion in human population, particularly in the developing countries, has led to the extension of agricultural practices for increasing food production to satisfy dietary demand. This has resulted in the reduction of area under natural ecosystems like the forests, savannas and grasslands. Agriculture is the world's largest land use system occupying ~38% of the Earth's terrestrial surface. Over the past five decades, the farming community has had excellent successes in a substantial increase in the world food production to make food more affordable for the majority of the world's population, in spite of a doubling in population. (Dobermann and Nelson, 2013).

Rice is the staple food of the people of South-east Asia and about half of the world population subsist on this crop for their dietary demand (Manzoor *et al.,* 2006). In the next two decades world's population is expected to increase by ~2 billion and half of this increase in the population will occur in Asia where rice is the staple food (Gregory *et al.,* 2000). In the developing countries, there has been a strong trend in increasing productivity, particularly for cereals such as rice in Asia, wheat in irrigated and favourable production environments worldwide and maize in Mesoamerica and selected parts of Africa and Asia (Pingali and Heisey, 2001).

Generally, the crop yield is responsive to climates such as changes in temperature and rainfall patterns (Stern, 2007) and nutrients especially nitrogen (N), phosphorus (P) and potassium (K) (Seetraraman, 1980). The inflow of inorganic source of nutrients especially N has to be managed judiciously. Biofertilizers are carrier based inoculants containing cells of proficient strains of particular micro-organisms used by farmers for enhancing the yield of soil either by fixing atmospheric N or by stimulating plant growth through the synthesis of growth promoting substances as secondary metabolites (Chaudhury and Rai, 2007).

Rice is cultivated in 148 million hectares of land worldwide which accounts for nearly 10 percent of the world's arable land. In India, rice crop is cultivated in about 42.3 million ha of land which produces hardly 87 million tons grain per year, which is extremely low in comparison to rice production in other countries like Taiwan etc. The idea of intercropping rice with other crops in a rain-fed rice field has been proposed by Kar and Verma (2002). In this proposal emphasize was given on the other crops as an assured income source rather than the main crop.

1.2. Clearing of forest for agriculture

In general farming practices is an extension on forest land as a result of deforestation that contributes around 60% of total tropical deforestation (Wilkie *et al.*, 2000; Amor, 2008; Amor and Pfaff, 2008). Though rising farming yields has been the most important mode for increased food production for the last few decades, the intensification leads to more deforestation in some circumstances (Rudel *et al.*, 2009; Boucher *et al.*, 2011). Causes of deforestation including logging, land conversion to agriculture, wildfires, cutting down trees for firewood, and conflict over land rights tend to be caused by increased population growth and a need for more land mostly for agricultural production (Johnson and Chenje, 2008). Therefore, solutions to deforestation must comprise and advantage local people. Thus, solutions to deforestation must include and benefit local communities. The central goal of community forestry is to involve a group of local people in the sustainable management of forests for social and economic benefits. Intensification of small-scale agriculture can also reduce agricultural expansion into forested areas if the correct incentives are in place (Palm *et al.,* 2010).

Land-use change such as forest clearing, conversion from natural ecosystem to agricultural use and intensive cultivation depletes soil organic C (Balesdent *et al.,* 1998; Spaccini *et al.,* 2001; Emadi *et al.*, 2008) and enhances greenhouse gas emission (Lal, 2004). Cultivation practices disturb soil physical properties and release physically protected soil organic matter to result in oxidation of soil organic matter (Plante and McGill, 2002; Shang and Tiessen, 2003).

1.3. Shifting cultivation (*Jhum* farming) in the world

Jhum farming has been a common practice of cultivation in tropical, hilly areas of Southeast Asia, the Pacific, Latin America, the Caribbean, and Africa for millennia (Craswell *et al.,* 1997; Ramakrishnan, 1992; Thomaz, 2009). This practice supports about half a billion people around the world for their livelihood (Craswell *et al.,* 1997), particularly, in Central Africa, South America, Oceania, and Southeast Asia. It is practiced on about 30% of all arable land but providing food to only 8% of the world population indicating wide land to man ratio (Kumar, 2008). *Jhum* cultivation is practiced in the sloping uplands of Southeast Asia because of the widespread partition of such landscape in this region (Garrity, 1993). Every year, *Jhum* farming is reported to account for 60% forest loss worldwide Lele *et al.,* 2008). This practice of cultivation has a different term in different regions of the world, for example, swidden agriculture, shifting cultivation, slash-and-burn farming. This has been considered as an old-age method of farming system and considered to be a prevailing subsistence farming practice in the tropical regions across the world (Brady, 1996; Inoue *et al.,* 2010; Comte *et al.,* 2012). The ever-increasing population has created tremendous pressure on land to provide a basic requirement for survival of local inhabitants. Therefore, to meet these requirements, the limited natural resources are being over-exploited resulting in widespread ecosystem degradation (Grogan *et al.,* 2012). Van Vliet *et al.,* (2012) in a meta-analysis observed that *Jhum* farming is being practiced typically in the steep and hilly parts of Latin America, Central Africa and Southeast Asia and happens to be the leading cultivation system.

Each year, the farming community cut the vegetation on a particular area in winter, left it to dry, and then bur it *in situ* before planting a variety of annual crops to correspond with the return of the rains (Toky and Ramakrishnan, 1981a). Following a few years of cultivation, the land is abandoned for the recovery of vegetation and return of soil fertility by natural regeneration for few years while the villagers select other sites for agriculture during this period. Some cultural operations are involved in *Jhum* farming, for example, clearance of forest biomass by cutting, the release of nutrients accumulated in plants over time by flaming of slashed biomass that suppresses weeds, pests and diseases by soil sterilization, etc. (Tripathi and Barik, 2003; Thakuria and Sharma, 2014).

It is reported that following the land abandonment, the *Jhum* soils bring back its fertility (Ramakrishnan and Toky, 1981; Silva-Forsberg and Fearnside, 1997). Land degradation may increase as a result of cultivation on fragile lands, reduced use of fallow, increased tillage, mining of soil nutrients, and other potential results of intensification. On the other hand, investments in land improvements and more intensive soil fertility management practices may improve land conditions (Pender, 2001).

On the other hand, to build up a new method may be more difficult that make sure small cultivators and shifting cultivators to retain their livelihoods without additional deforestation (Shearman *et al.,* 2009). Soil management systems can have a great effect on soil physical, chemical, and biological properties. Conversion of forest to grassland and cropland can alter C and N dynamics. Shifting cultivation is probably one of the most misunderstood and controversial forms of land use system. In 1957, the FAO declared shifting cultivation the most serious land use problem in the tropical world (FAO, 1957). It is a conventional land utilizes arrangement that involves alternation of fields rather than crops and relies on the use of fallow to maintain the production of food.

1.4. Shifting cultivation scenario in India

Indigenous peoples particularly from Adivasis in Central and South India, Eastern Himalayas (e.g. Eastern Nepal, Northeast India, and the Chittagong Hill Tracts of Bangladesh and the adjacent areas across the border in Myanmar) practiced *Jhum* farming. The net decrease in forest covers due to *Jhuming* in northeast India was estimated to be 387 km^2 between 1989 and 1991, 448 km^2 between 1991 and 1993, and 175 km^2 between 1993 and 1995 (Shankar, 2001). *Jhum* cultivation is a distinctive aspect of farming in the hilly region of NE India. The biological diversity of ecosystems are worn and conserved by traditional communities through a variety of informal institutions and using traditional ecological knowledge in northeast India. Although, this practice is criticized due to low output and ecological disbalances; continuation of *Jhum* cultivation is intimately linked to ecological, socio-economic, cultural identity and land tenure systems of tribal communities (Deka and Sarmah, 2010). About 100 tribal communities consisting of more than 620,000 families in the region depend on *Jhuming* for their livelihood (Ramakrishnan, 1992). Each year, hill farmer slash vegetation on selected sites during winter months (January-February) and planting a variety of annual crops together to coincide with monsoon showers following the burning of the stand (Ramakrishnan and Toky, 1981), and to exploit available soil nutrients following burning. In India, people of eastern and north-eastern region practice shifting cultivation on hill slopes and 85% of the total cultivation is under *Jhum* cultivation (Singh and Singh, 1992).

The low productivity of shifting cultivation is associated with a number of problems viz. prevalence of *Jhum* cultivation, hilly terrain, unpredictable climate changes, low levels of modern input, poor infrastructure etc. (Karmakar, 2008; Barah, 2006; Grogan *et al.,* 2012).). The continuance of *Jhum* in the north-east states is closely linked to ecological, socio-economic, and cultural and land tenure systems of tribal communities. Since the community owns the lands, the village council or elders divide the *Jhum* land among families for their subsistence on a rotational basis (Rao and Ramakrishnan, 1989). *Jhum* cultivation in its more traditional and cultural integrated form is an ecologically and economically practicable system of agriculture as long as population densities are low and *Jhum* cycles are long enough to maintain soil fertility (Tawnenga *et al.,* 1996).

Jhum farming on sloping land may lead to enlarge soil run-off loss and crop variety. Soil erosion is a permanent phenomenon causing land degradation and deterioration of surface water quality. The *Jhum* farming harmfully affects the eco-restoration and ecological practice of forests and this leads to degradation of land causing soil erosion and finally converting forests into wastelands (Dwivedi, 2001). This cultivation practices cause tremendous loss of soil nutrients (Shahlace *et al.,* 1991) and degradation of natural vegetation. Shifting cultivation causes large-scale damage to the forests and has resulted in deforestation and denudation of hill slopes, exposure of rocks due to soil erosion, heavy silt loading on riverbeds and drying of perennial water resources (Goswami, 1968). Short *Jhum* farming cycle makes the land incompatible for agriculture and leads to substantial loss of soil nutrients through run-off and leaching (Borthakur *et al.,* 1979).

Jhum cultivation has been reported as an ideal form of agriculture in humid tropics in early days as long as the human population density is low and fallow periods are long enough to restore soil fertility (Watters, 1971; Grogan *et al.,* 2012). Rice is the major crop of the North-eastern region of India accounting for about 89% of the area and 92% of the total food grains production (Misra and Misra, 2006). The average productivity of the northeast region is very low as compared to the national productivity of rice in the country. With the rapid increase in the population, it is highly essential to increase the production of this staple diet of the people to be able to self-sufficient. Therefore, strengthening and improvement in *Jhum* cultivation are recommended rather than its replacement (Yadav, 2013).

1.5. Shifting cultivation in Mizoram

Shifting cultivation is the most important and predominant mode of raising food for forest farmers in Mizoram, north-eastern India. The agriculture is mainly done on hill slopes by *Jhum* cultivation method under rainfed condition (Vishwakarma *et al.,* 2006). A piece of land is slashed, burnt and cropped with no tilling the soil, and the cropped land is subsequently fallowed to control pre-slashed forest status through the natural sequence in *Jhum* farming (Uhl *et al.,* 1983; Ramakrishnan, 1993). A total of about 2 lakh hectares of land is under *Jhum* farming practice with approximately 63,000 ha being cultivated in a known year by 50,000 families (Anonymous, 1987). Agriculture land, housing supplies, firewood, medicine and food products are the forest products (Anonymous, 2006).

Cropping on *Jhum* lands in Mizoram is mainly practiced for one year. The second-year cropping is rare and mainly sustained on old *Jhum* fallows. Even in other parts of north-eastern India, the land is frequently fallowed after the first year of cropping, and second-year cropping is occasionally experienced with plantations of banana and pineapple. (Kushwaha and Ramakrishnan, 1987). The practice of *Jhum* has an integral method of nourishment and management. However, due to anthropogenic force, require of more food have cleared greater chunks of forests and fallow phase between two following cropping phases has come down to even 2 to 3 years (Grogan *et al.,* 2012; Xu *et al.,* 2009). This has led to the loss of soil nutrients and reduce harvest yield.

1.6. Plant litter decomposition and nutrient release

Nutrients availability and soil fertility in natural forest ecosystems are determined by the amount and seasonal patterns of litterfall and litter decomposition (Upadhyay and Singh, 1989; Tripathi and Singh, 1992a and b; 1995; Singh *et al.*, 1999; Fioretto *et al.*, 2003; Hobbie and Vitousek, 2000; Chen *et al.*, 2014). The amount of litter has a significant role on the rates of litter decomposition by maintaining microclimate, number and dynamics of decomposer organisms and nutrient availability in forest ground and mineral soil (Chen *et al.*, 2014; Sayer *et al.*, 2006). However, widespread deforestation may have a result on litter and fine root dynamics during many potential factors and processes, like changes in vegetation composition, which decreased litter inputs in the system (Holmes *et al.*, 2006). Few litters decompose fast due to the presence of more labile C whereas other may have higher concentrations of lignin or recalcitrant C which decompose slowly (Gessner *et al.*, 2010). Mortality of these fine root transfers a considerable amount of organic matter and nutrients into the soil and through rapid turnover rates, these fine roots regenerate available soil nutrients to support plant growth (Vogt *et al.*, 1986; Tripathi and Singh, 1994; 1996). Tree species with different substrate quality of litter exhibits different mineralization potential and decomposition behavior (Matambanengwe and Kirchman, 1995). Litter chemical quality has been found to critically affect decomposition rates of tree species that determines the soil fertility of the forest floor (Singh *et al.*, 1999; Fioretto *et al.*, 2003).

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). Decomposition is the breakdown of litter materials (i.e., dead plant, animal and microbial materials) into inorganic nutrients and CO_2 (Swift *et al.*, 1979). Leaching, fragmentation and chemical alteration of the dead organic matter by decomposition process produces CO_2 and mineral nutrients and a remnant pool of complex organic compounds (Berg and Staaf, 1981). The soil organic matter is classified on the basis of its turnover time into active, slow and passive fractions (Parton *et al.*, 1983). It has been reported that in the forest ecosystem, almost all the above-ground biomass (> 90% of the total net aboveground primary production) returns to the forest floor as litter-fall which constitutes the major substrate for plant species and soil decomposers (Swift *et al.*, 1979). Therefore, any change in the active soil organic matter component will also change nutrient availability (Roy and Singh, 1994).

1.7. Soil fertility and aggregation

The soil organic C cycle is important for the functioning of natural and agricultural ecosystems. The storage of organic C provides a nutrient resource and plays a critical role in nutrient cycling in terrestrial ecosystems (Campbell, 1978). Besides nutrient sources, the increases of soil organic matter and soil productivity partially mitigate C emission (Post *et al.*, 2004) and climate change (Hao *et al.*, 2002). Soil organic C in an ecosystem is controlled by soil management systems and environmental factors such as soil temperature and precipitation (Plante *et al.*, 2006).

Soil aggregates are the group of soil particles of different sizes joined by organic and inorganic materials, and their stability can be used as an index of soil structure. The structure of soil protects the soil organic matter and influences organic matter turnover and soil fertility.

Soil aggregation can be measured by wet and dry sieving procedure and provide useful information on soil aggregate stability that reflects the carbon sequestration potential of the soil. Water-stable aggregation is usually formed by macroaggregates (>250 μm) and microaggregates (<250 μm). Macroaggregation is very sensitive to changes in land use and cultivation practices, whereas microaggregation is comparatively stable. Soil aggregation varies according to climatic and management factors and is difficult to measure because of irregular shapes and sizes of soil aggregates.

The influences of soil organic carbon (SOC) contents on aggregate formation and stabilization have been widely reported (Six *et al.*, 2002). Tripathi *et al.*, (2008) have reported changes in the size of micro- and macro-aggregates in different land use systems from forests to savanna. Further, they reported that the changes in the proportion of micro- and macro-aggregates differ due to application N and P additions. The arrangement of soil protects the soil organic substance turnover and soil fertility (Elliot, 1986). The interactions of physical, chemical and biological processes in soils influence aggregate formation and stabilization (Jastrow and Miller, 1998; Six *et al.*, 2004; McCarthy *et al.*, 2008). Soil C losses are resulting from cultivation of natural ecosystem range from 10 to 55 percent (Noellemeyer *et al.*, 2008). As an indicator of soil susceptibility to runoff and erosion, soil aggregate stability is considered one of the main soil characteristics regulating soil erodibility (Barthes and Roose, 2002), and is related to soil organic matter contents and compositions (Bronick and Lal, 2005). Although soil aggregate stability is a highly complex indicator assessed by a wide range of soil properties, land management and vegetation recovery are among the very important influencing factors (Duffkova *et al.*, 2005; Shrestha *et al.*, 2007).

Cultivation can alter aggregation and aggregate size distribution (Beare *et al.*, 1994; Balesdent *et al.*, 2000; Paustian *et al.*, 2000; Six *et al.*, 2000). Soil fauna and their activities can affect soil aggregate, aggregate stabilization and C dynamics (Oades and Waters, 1991; Jastrow and Miller, 1998; Six *et al.*, 2004; Bronick and Lal, 2005). The stability of soil organic C in aggregates is related to its physical and chemical protection from the microbial action (Oades and Waters, 1991; Jastrow and Miller, 1998; Six *et al.*, 2004; Bronick and Lal, 2005). The understanding of soil C dynamics depends on the partitioning of soil C fractions into biological (Ajwa *et al.*, 1998) and size fractions of aggregates (Schulten and Leinweber, 1995).

Soil organic matter, microbial biomass and mineralizable C changes under different management systems. Some studies indicate that microbial biomass C significantly decreases with cultivation, but the conversion from cropland to pasture significantly increases soil microbial biomass (Haynes and Swift, 1990; Haynes *et al.*, 1991).

1.8. The Scope of the Study

Previously, *jhum* farming was sustainable because of the extensive fallow period (about 20-30 years), which provided adequate time for the soil to recover soil fertility and maintain farming production for a few years. In recent years, due to incredible raise in human inhabitants, the fallow period has significantly reduced to about 2-3 years, which is not allowing the soil to reinstate fertility to maintain new crops. This has resulted in large-scale forest degradation, decreasing soil fertility, and growing invasion by weeds species, which leads to degrading the atmosphere and disturbance of the ecological stability of this region. Considering the above disadvantages and constraints of the shifting cultivation system, a new profitable and sustainable agriculture system like permanent agriculture farming system is being tested in Lunglei district of Mizoram.

This study aims to understand the effect of different fallow lands after shifting cultivation practice and various crop cultivation periods under permanent agriculture system on soil fertility in Aizawl and Lunglei districts of Mizoram. This study was a step towards finding out an optimum level of soil fertility by using the principles of natural ecosystems to synchronize soil nutrients with that of crop nutrient demand for a profitable and sustainable farming system.

1.9. Major objectives

This study is designed to achieve the following major objectives in two agricultural practices of Mizoram.

1. To compare the level of soil fertility (organic C and total N) in different fallow periods in shifting cultivation and in varying ages of settled agriculture systems.
2. To determine the rate of litter decomposition and nutrient release pattern in shifting cultivation and settled agriculture systems.
3. To assess quantitative and qualitative changes in water stable soil aggregates in these farming systems.

Chapter 2

REVIEW OF LITERATURE

2.1. Shifting cultivation

The tropical dry forest ecosystem has been subjected to higher rates of deforestation and conversion into cropland and pasture than many other ecosystems (Houghton *et al.*, 1991). Forest to cropland conversion generally leads to reduce soil organic carbon stock (Davidson and Ackerman, 1993; Detwiler, 1986; Murty *et al.,* 2002; Nye and Greenland, 1964; Tripathi *et al.,* 2008). The stability of *Jhum* agro-ecosystem primarily depends upon the length of the fallow phase that allows re-growth of secondary forest. Thus, the varying length of the fallow phase directly affects the quantum of secondary forest biomass build-up leading to quantitative differences in subsequent slash load and ash release during burning (Ramakhishnan, 1998). Fire does not only burn out the slashed biomass but also the litter layer, and the uppermost humus layer which is a major part of the resources and habitats for soil organisms (DeBano *et al.*, 1998). In tropical agriculture systems, especially slash-and-burn situation farmers do not apply fertilizer to upland rice but have traditionally relied on fallowing their land to restore soil fertility and to reduce problems from insects and weeds (Nye and Greenland, 1960). In Bangladesh, extensive shifting agriculture practice due to increasing demand for food and fodder is the main driver of drastic deforestation and land degradation (Rasul *et al.,* 2004).

The overuse of natural resources by the local population results in the depletion of the biodiversity of forest communities, which is accompanied by species extinction and decreased in primary productivity (Ramakrishnan, 2003). Disturbances in ecological systems promote characteristics pattern of environmental heterogeneity and regulate ecosystem processes, population dynamics, species interactions and diversity (Davies, 2001). The decrease in the fallow period has led to the deterioration of faunal and microbial organisms, topsoil loss, and erosion during periods of heavy rainfall (Gafur, 2001).

Slashing and burning remained to be the easiest way not only to sanitize the soil, minimizing the weeds and soil pathogens but also to release the locked nutrients within the biomass as ash load which is considered to be more readily available nutrients forms (Juo and Manu, 1996). It has been reported that fire leads to changes in the chemical properties of soil with regard to the changes in quantity and quality of organic matter, soil moisture, availability of nutrients, exchange capacity, and base saturation (Certini, 2005). It is believed that following the land rejuvenate the *Jhum* soil and bring back its fertility (Ramakrishnan and Tokky, 1981; Silva-Forsberg and Fearnside, 1997). In one hand, burning of biomass imposes stress on soil biota community and its functioning (Malmstrom, 2012), while on the other hand burning of biomass enhances nutrient availability in soil (Nye and Greenland, 1960; Fritze *et al.*, 1994; Khanna *et al.*, 1994; Giardina *et al.*, 2000). In order to manage a burnt agriculture land more effectively, one must rely on the detailed knowledge of the fluxes and losses of nutrients incurred during and after the burning of slashed biomass (Raison, 1979).

Extensive landscape transformations from natural forests to a multitude of vegetation types in Indian tropical regions are associated with various structural and functional changes in these ecosystems including fine roots (Tripathi and Singh, 1996; Upadhaya *et al.*, 2005; Tripathi *et al.*, 1999; Tripathi *et al.*, 2008). The plant litter production and decomposition are the two important processes which provide the main input of organic matter in soil and regulate the patterns of nutrient cycling in forest ecosystems (Facelli and Pickett, 1991; Singh *et al.*, 1999; Weltzin *et al.*, 2005). The chemical composition of forest floor litter seems to vary greatly depending on the length of the fallow phase (Cornwell *et al.*, 2008). Decomposition of organic detritus provides 70–90% of nutrients annually needed for forest growth (Vogt *et al.*,

1986) and is a complex microbe fauna mediated process, which is accelerated by favorable environmental conditions that enhance faunal and microbial activity (Swift *et al.,* 1979).

The biological inputs like litter falls and root exudates of the above-ground vegetations are thought to be the modulators of the diversity and activity of soil biota communities. According to Brunn *et al.,* (2006), the amount of nutrients accumulated depends primarily on the nutrient content in the biomass, the temperature threshold of respective nutrient elements and the quality of burning. In a tropical environment, the climatic seasonality characterized by alternating wet and dry periods plays a vital role in regulating the rates of litter decomposition (Tripathi and Singh, 1992a) by changing the population of microbial community on the decomposing organic matter (Arunachalam *et al.,* 1997). Further, the initial substrate quality of litter such as concentrations of cellulose, hemicelluloses and lignin, and nitrogen (N), phosphorus (P) and potassium (K) have been found to play a major role in litter decomposition in different ecosystems (Tripathi and Singh, 1992a; b; Osono and Takeda, 2004).

Land use change is among the important global change drivers forcing changes in the organization of terrestrial vegetation over the world (Balmford and Bond, 2005). The Intergovernmental Panel on Climate Change (IPCC) estimated global anthropogenic carbon emissions (IPCC 2007) of about 20% are due to land use change. In Southeast Asia during the 1990's annual contribution of CO_2 from land use changes are in the range of 0.3 to 0.5 Gt C year^{-1} (Achard *et al.,* 2002). These CO_2 emissions arise from changes in the pool of organic C in the aboveground biomass and in the pool of soil organic C following land use transitions. The soil is regarded as a nutrient pool of micro- and macro-nutrients. Trees 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 then the soil from the adjacent tree-less sites (Kater *et al.,* 1992).

2.2. Soil structure and properties

Development of soil structure and aggregation is a dynamic property of soil that depends upon parent material, climate, and management factors (Strudley *et al.*, 2008). Soil aggregation has been reported as an important process controlling plant growth and carbon (C) sequestration (Blanco-Canqui and Lal, 2004). Soil organic matter has been regarded as the single most important indicator of soil productivity (Haynes, 2005). The Structure of soil protects the soil organic matter and influences organic matter turnover and soil fertility (Elloitt, 1986). The organic matter in the soil is associated with the three types of physical units: the free primary particles (i.e., sand, slit and clay); macroaggregates; and microaggregates (Tisdall and Oades, 1982; Oedes, 1984). Soil organic matter is an important factor that controls the pools and fluxes of available nutrients and is protected by soil aggregates (Aoyama *et al.*, 1999).

The stability of soil aggregates varies due to agricultural management practices (Pirmoradian *et al.*, 2005), land use, and nutrient inputs (Tripathi *et al.*, 2008). Aggregate size is important in determining the dimension of pore space in the soil. The loss of organic matter reduces the proportion of macroaggregates in cultivated soil (Tisdall and Oades, 1980). Soil aggregation (formation of micro- and macro-aggregates), an important process controlling plant growth, protects soil against water erosion and helps in C sequestration (Blanco-Canqui and Lal, 2004; Roldan *et al.,* 2006).

The organic matter content of macroaggregates is reported to decrease, and the proportion of small aggregates increase with cultivation. Elloitt (1986) hypothesized that the loss of organic matter caused by cultivation is chiefly a loss of the organic material that binds individual microaggregates and not a loss of organic matter within microaggregates. Micro-aggregates (<0.3mm) consist of separate particles, especially clay, often coated with fine inorganic and organic materials. In contrast, macro-aggregates (>0.3mm) are the result of the binding up of micro-aggregates (Elliott, 1986; Monreal and Kodama, 1997). Macroaggregates are reported to contain significantly greater total C, and a residue derived C compared with whole soil (Bossuyt *et al.,* 2005). Microaggregates can unite to form macroaggregates through the action of temporary and transient binding agents (Elloitt, 1986). Oades (1984) postulated that microaggregates are formed at the center of macroaggregates.

The centre of Macroaggregates can be anaerobically leading to (1) increased solubility of cation like Fe and Mn, and hence greater stability of the soil organic matter through the bonding mechanism, (2) increased humification of the end product of the decomposition, and (3) an increased of weathering, which may result in the formation of amorphous aluminosilicates and, eventually, secondary fine clay particles (Tiedje *et al.,* 1984). The amount of macro-aggregates in soil is directly related to the microbial activity, stability and fertility of the soil (Lynch and Bragg, 1985). The agents responsible for soil aggregate stability are mainly organic in nature and are either present in free-living organisms in soil or associated with plant roots (Roldan *et al.,* 1994). In addition to mechanical entanglement by hyphae, extracellular polysaccharides of fungi and bacteria provide a cementing agent for soil aggregates (Chenu, 1993). Arbuscular mycorrhizal fungi (AMF) play a significant role in the stabilization of macroaggregates by depositing organic substances (Piotrowski *et al.,* 2004; Roldan *et al.,* 2006). N and phosphorous (P) additions in natural and modified ecosystems have been reported to affect the AMF infection in plant roots (Fransson *et al.,* 2000; Leuschner *et al.,* 2003).

By accumulating labile and more refractory soil organic matter fractions, macro-aggregates show great potential for sequestering C and retaining N in ecosystems (Blanco-Canqui and Lal, 2004; Billings, 2006). Soil quality is the capacity of the soil to support plant growth without causing degradation of the soil or the environment (Carter *et al.,* 1997; Doran and Parkin, 1994). Soil quality is closely linked to soil resilience which refers to the ability of the soil to restore soil functions following disturbance-resilient soils have a high soil quality and vice versa (Lal, 1997; Lal and Bruce, 1999). The production of enzymes by the microbes followed an economic theory where more enzymes were produced in abundance of the complex nutrient organic substrate and when the simple nutrient organic sources are scarce (Allison and Vitousek, 2005).

Roots are a major source supplying C to soil organic matter, the largest reservoir of the terrestrial C cycle (Mendez-Millan *et al.*, 2010; Rasse *et al.*, 2005; Schlesinger, 1997). More than half of the total soil organic C is found in sub-soils (Jobbagy and Jackson, 2000). However, Giregon *et al.*, (2010) found concentrated soil organic carbon in the topsoil where the highest root biomass is located. Some soil properties relating to soil acidity improve when soil organic matter (SOM) increases in the late stages of the fallow phase. The litter input may be supplying bases that are obtained via tree roots from further down the soil profile to the surface soil (Funakawa *et al.*, 2006).

In tropical soils, roots less than 1 or 2 mm in diameter commonly comprise a considerable proportion of the root biomass (Gower, 1987; Klinge, 1973; Stark and Spratt, 1977; Srivastava *et al.*, 1986). Fine root biomass, as well as production, turnover rates and nutrient content, depend strongly on both climatic and site variables, as concluded by Yuan and Chen (2010) based on a large data set for boreal forest ecosystems. Fine roots are the main source of soil organic carbon as they turnover more easily to soil than aboveground litter (Ruess *et al.*, 1996). Higher soil temperature increased the root production and mortality associated with soil nitrogen (N) availability (King *et al.*, 1999; Majdi and Ohrvik, 2004). As it is the top layer of soil, it is more sensitive to temperature and moisture fluctuations and to disturbances than the mineral soil below (Khomik *et al.*, 2006). It has been found that fine roots of trees and understory vegetation play an important role in the C and nutrient dynamics of forest soils, not enough quantitative data exist about their contribution to the C and nutrient budgets (Gower *et al.,* 1994; Bartelink, 1998; Matamala *et al.*, 2003). The plant community is a dynamic component which changes as a function of time; however, altitude, slope, aspect and rainfall play a key role in the formation of plant communities and their composition (Kharkwal *et al.,* 2005).

2.3. Litter decomposition

Tree biomass can increase soil fertility due to decomposition of litter or plant parts. The decomposed litter is humus, which increases soil fertility. The biochemical reactions involved in litter decomposition and nutrient cycling processes can be judged by measurement of soil enzymatic activities and availability of soil nutrients. Due to increase in soil organic matter, there is an improvement in soil physical properties. The decomposed litters provide sufficient available nutrient, which is utilized by crop plants. Intercropping improved soil aeration status compared with pure stands or mono-crop (Anihara *et al.,* 1991).

Most studies on litter decomposition was carried out on leaf materials decay while less attention was paid to woody debris decomposition (Kaarik, 1974; Harmon *et al.*, 1986), which significantly contributes to nutrient dynamics and carbon turnover of forest (Swift *et al.*, 1979; Vogt *et al.*, 1986; Harmon *et al.*, 1995). The main factor responsible for the decay rate of woody debris beside temperature and moisture content is nitrogen and lignin contents (Berg *et al.,* 1984). Hayes (1979) has reported that the nutrient content of non-leaf parts is generally much lower than that of the leaves and therefore, the speed of recycling of mineral nutrients largely depends upon the rate at which the leaf litter decomposes on the forest floor. The chemical composition of forest floor litter seems to vary greatly depending on the length of the fallow phase (Cornwell *et al.*, 2008).

The rate of litter decomposition is largely regulated by the prevailing climatic factors, organic-chemical nature (substrate quality) and the soil physicochemical and biological properties (Swift *et al.*, 1979; Virzo De Santo *et al.*, 1993; Berg *et al.*, 1995; Fioretto *et al.*, 1998). Litter decomposition in the terrestrial ecosystems is mainly regulated by two factors; climatic conditions and initial substrate quality of the litter (Tripathi and Singh, 1992; Swift *et al.*, 1979). The chemical litter quality and decomposition rates of tree species determined the soil fertility of the forest floor (Singh *et al.*, 1999; Fioretto *et al.*, 2003). Tree species with different substrate quality of litter exhibits different mineralization potential and decomposition behavior (Matambanengwe and Kirchman, 1995). Some types of litters have more easily decomposable labile C while other may have higher concentrations of lignin or recalcitrant C which is not easily decomposable (Gessner *et al.*, 2010).

The decomposition is also influenced by the physical environment in which decay takes place (Facelli and Pickett, 1991; Heal *et al.*, 1997; Sariyildiz *et al.*, 2005). Some studies found that among the climatic factors temperature is the most obvious of the factors that influence decomposition. Metabolic rates generally increase exponentially with temperature (Brown *et al.*, 2004) which suggests that decomposition should be highly sensitive to even small changes in temperature (Davidson *et al.*, 2006; Boyero *et al.,* 2011; Irons *et al.*, 1994). The production and decomposition of above- (such as leaf, branch) and belowground litter mainly fine root, Steinaker and Wilson (2005) are key processes linking plant and soil in the terrestrial ecosystem (Cusack *et al.*, 2009; Schindler and Gessner, 2009). Favorable climatic conditions promote microbial activity during decomposition whereas the initial chemical composition of labile material provides an available source of energy for the decomposers (Tripathi and Singh, 1992; Facelli and Pickett, 1991; Heal *et al.*, 1997; Boyero *et al.*, 2014).). The leaf litter and fine root are considered as fast C pools (Meier and Leuschner, 2010).

Tropical forest plays an important role in the global cycles of Carbon (C) and nutrients by storing significant fractions in the world’s vegetation and soil pools (Brown and Lugo, 1982; Brown *et al.,* 1993). Conversion of natural forest into different land use affects fundamental ecosystem functions such as C and the process of nutrient cycling (Lawrence, 2005; Jandl *et al.*, 2007) In most tropical countries, the largest source of CO_2 emissions is deforestation and land-use change (Gibbs *et al.*, 2007). Microbial inoculation is also an important strategy in eco-restoration processes of a degraded ecosystem (Harris, 2009).

Chapter 3

MATERIAL AND METHODS

3.1. Description of the study sites and climate

3.1.1. About Mizoram state

Mizoram is a hilly state located in the extreme part of North East India, covering an area of 21,081 km² which is situated at 21°56'-24°31' N latitude and 92°16'-93°26' E longitude exhibiting-moist tropical to sub-tropical climate. The state is bordered by Myanmar, Bangladesh, Assam, Manipur, and Tripura. Mizoram meaning land of highlanders has undulating topography with several troughs and peaks that range from 800 m to 2000 m amsl near the Myanmar border. The capital of the state is Aizawl with a mean elevation of 1132 m. The tropic of cancer, i.e., 23°30'N latitude cuts across the region in the undivided Aizawl district. This imaginary line divides the region into two almost equal parts (Pachuau, 1994).

The forest vegetation in the state of Mizoram falls under three major categories i.e., tropical wet evergreen forest, tropical semi-evergreen forest and sub-tropical pine forest (Champion and Seth, 1968). The Tropic of Cancer passes through the middle of the State.

As per 2011 census, Mizoram has recorded a population of 1,091,014 consisting of 552,339 males and 538,675 females. Mizoram falls under temperate zone having a sub-tropical climatic condition with short and dry winter. Rainfall was evenly distributed over the years with a total of 3,000 mm. In Aizawl town rainfall was 2,380 mm and Lunglei 3,178 mm. In the state, temperature varied from about 12^{o} C in winter (November to February) to about 30^{o}C in summer. There is generally no rain or very little rain during the winter months. Spring starts at the end of February and continues till the middle of April after that storms are prevalent with the onset of summer. In April and May, temperature goes up to 30^{o}C. The hills are covered by a haze. Heavy rains start in June and continue up to August. September and October are the autumn months when the rains cease and the temperature is usually between 19^{o}C and 25^{o}C.

Table 3.1. Weather parameters of the study areas (Aizawl district), Mizoram during 2012 and 2013.

Month	Maximum temperature (°C)		Minimum temperature (°C)		Average mean temperature (°C)		Relative humidity (%)		Rainfall (mm)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
January	26.3	27.3	5.6	5.6	15.95	16.45	74.77	68.16	20.3	0
February	30.05	31.4	10.4	10.7	20.225	21.05	62.7	78.89	7.3	3.3
March	33	32.7	11.3	14.2	22.15	23.45	65.41	68.61	46.9	5.6
April	33.3	34.5	12.1	12	22.7	23.25	81.26	77.26	264.7	61.4
May	30.5	32.9	15.4	12.7	22.95	22.8	84.25	90.61	175.6	448.4
June	30.7	32.9	16.3	18.7	23.5	25.8	92.6	90.96	474	301.8
July	29.8	30.7	19.2	19	24.5	24.85	91.7	92.7	252.4	290.8
August	31.2	28.9	18.3	18.1	24.75	23.5	90.22	94.45	465.9	363.4
September	30.9	30.7	18.5	18	24.7	24.35	91.6	93.13	363.9	268.6
October	29.5	31.3	16.1	16.5	22.8	23.9	87.25	83.22	215.1	82.4
November	26.6	31.4	11	13.8	18.8	22.6	86.3	67.45	121	0
December	28.1	27.6	8.8	10.7	18.45	19.15	71.29	68.77	0	0

Source: Meteorological Observation Station, Department of Environmental Studies, Mizoram University.

3.1.2. Study sites

3.1.2.1. Settled agriculture (Sloping Agriculture Land Technology, SALT trial farm)

The study site is located at Pukpui area, Lunglei district of Mizoram (22^{0} 53’ 30’’ N- 92^{0} 50’ 00’’ E). Pukpui is located in northern side of the Lunglei town which is away from 10 km.

Pukpui is located 10 Km away from the northern part of Lunglei town. Lunglei has 186 villages and an area of 4,538 km^2 with a population of 154,094 (as per census 2011).

Sloping agriculture land technology (SALT) is practiced in the farm. The farm was started on the year 2002 with 1-hectare area of land increasing every year successively up to 2010 down the hill slope. The crops planted on the farm are banana, maize, turmeric, citrus fruits, passion fruits, mangoes and pineapple. Nitrogen-fixing shrubs (*Flemingia macrophylla* and *Tephrosia candida*) are planted as dense hedgerows along slope contour, and a diverse range of crops are cultivated in the inter-row areas. A dense row of *Flemingia macrophylla* has been planted because the stems are strong to resist wind damage and litter and soil erosion. *Tephrosia candida* is planted throughout the farm because it produces large number of seeds and the seedlings that suppress weeds. The hedgerows are trimmed back to 1 m height every year for the availability of the sun light to the crops and other nitrogen-fixing trees are allowed to grow relatively tall to provide a nursing environment for young citrus plants. All dead branches of *Tephrosia* are placed on the ground to provide organic matter and nutrients to the plants. To maintain soil fertility, all dead and pruned leaf, twig and branch wood materials are scattered on the ground to suppress weeds and to add soil organic matter and nutrients to the soil through decomposition.

3.1.2.2. Shifting cultivation sites

Shifting cultivation sites were selected in Lengpui are about 30 km away from Aizawl city. The geographical area of Aizawl district is 3,576 km^2 and as per the 2011 census the population of the city 404,054. The climate of the area is typically monsoon with distinct seasons. The annual mean average rainfall of the area is ca. 2350 mm. The ambient air temperature ranges from 20 to 30°C in summer and 11 to 21°C in winter (Laltlanchhuanga, 2006). The entire area is under the regular influence of monsoon. It rains heavily from May to

September and the average rainfall is 254 cm, per annum. The average annual rainfall in Aizawl and Lunglei are 208 centimeters and 350 centimeters, respectively. Winter in Mizoram is normally rain-free. The forest vegetation falls under three major categories i.e., tropical wet evergreen forest, tropical semi-evergreen forest and sub-tropical pine forest (Champion and Seth, 1968). The practice of shifting cultivation, uncontrolled fire, falling of trees, agricultural expansion and road building has resulted in deforestation.

3.2. Agricultural practices in Mizoram

Fire is an integral part of the Mizo culture. Fire 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 practice is common and widespread in Mizoram resulting in a landscape dominated by mixed species of 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).

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 are high value crops that store and transport well (unlike bananas for example).

However, harvesting these subterranean crops involves opening up the soil and exposing it to erosional losses. Annual crops including wetland rice are continuously cultivated on Mizoram's more gentle slopes and valley bottoms. Localized special initiatives such as horticulture (e.g., Anthurium flowers), viticulture (wine grapes) and citrus fruit and oil palm plantations have been established, but require substantial government investment assistance that will only be a feasible option for a very small proportion of farmers. Poultry and piggery are the primary focus of animal husbandry. Cattles are rare although dairy farmers that have ready access to a milk market, and that make optimal use of farmyard manure seem to be successful on gentle slopes and terraces (Grogan *et al.,* 2012). Nevertheless, these farms rely heavily on a much larger neighboring area of surrounding post-fire successional vegetation for manual fodder collection. The availability of commercial (industrially manufactured) fertilizer was severely restricted by the Mizoram government in 2005 in a bid to achieve 'organic' agricultural production status within India and to avoid eutrophication of watersheds. Nevertheless, some farmers are acquiring and using small amounts of commercial fertilizer (e.g., diammonium phosphate, urea) especially on continuously cultivated slopes and terraces.

3.3. Experimental design

3.3.1. Soil sampling

Different *Jhum* fallow land of various ages (5, 10 and 14 years) and a reference forest was selected in Aizawl districts of Mizoram. In each fallow land and reference forest, a sample area of about 1 hectare was randomly demarcated. Within each sample area, 5 randomly located permanent plots measuring 20mx20m was marked. Soil samples were collected from these permanent plots periodically.

Similarly, five representative sample area of about 0.5 to 1 ha having different ages of cultivation (between 2 and 10 years) was marked in alternate years in the permanent farming system (SALT) located at Pukpui in Lunglei district of Mizoram where organic farming is practiced since 2002. Within each sample area 3-6 randomly located permanent plots measuring 5mx5m was marked for periodical soil sampling.

3.3.2. Measurement of litter decomposition

Decomposition kinetics of leaf and root components of two dominant tree species was recorded at different fallow lands following shifting agriculture and a reference forest in Lengpui area. Whereas, decomposition kinetics of different litter components (green leaves, branch, fine root, coarse root) of *T. candida* and *F. Macrophylla* was studied at two SALT farm in Pukpui. The rate of decomposition was studied using a nylon net bag technique (Bocock *et al.,* 1960). Air-dried litter samples different components (green leaves, leaves litter, branch, fine root and coarse root) equivalent to 7 g were enclosed in nylon net bags (1 mm mesh; 15 cm x 15 cm). These bags were placed on the ground and the roots litters were buried up to 10 cm soil depth for decomposition. Four bags per litter category were retrieved at 90 days interval. After recovery, the bags were placed in individual polythene bags and brought to the laboratory. The samples collected from bags were cleaned to remove soil particles and oven-dried at 105°C for 24 hours and weighed to know the mass remaining (decomposition rate). The dried collected material was ground separately in a Willeymill and passed through a 0.5 mm sieve to get powder for chemical analyses. Litter total C and N were determined by CNH auto analyzer.

3.3.2.1. Litter decomposition in settled agriculture (SALT)

Two different species of nitrogen-fixing shrubs viz. *Flemingia macrophylla* and *Tephrosia candida* were selected from two different sites (10yrs and 2yrs) in the same permanent farm. For determination of plant litter decomposition rate, different part of the plant i.e. mature senesced leaves attached to the plant, freshly fallen leaf litter samples and recently dead wood branches still attached to the plants were collected during June 2012. At the same time, fine roots (≤2mm in diameter) and coarse roots (≤5-10mm in diameter) were collected by digging out soil monoliths and then dried in an oven at 35°C for three days to a constant weight. After adjusting for the initial moisture content, all litter samples (equivalent to 7 g dry weight) were enclosed in a nylon net bags (mesh size: 2mm, 15 X 15cm).

A total of 200 bags were prepared for different litter categories, 20 bags each for different litter categories. Nylon net bags (15x15cm, 2mm mesh) containing 7 g air-dried leaf and wood litter were randomly placed on the plantation floors just above the soil surface and bags containing roots were buried in the soil to a depth of 10 cm in July 2012. Five bags containing decomposing litter were randomly recovered at three months intervals from each plantation site. The recovered litter materials were air dried, brushed to remove adhering soil particles, and finally dried at 80°C for 24 h and weighed.

Collected litter material was ground in a Willeymill and passed through a 0.5 mm sieve for chemical analyze. Total N and organic carbon were analyzed by CHN Auto-analyzer at Central Instrumental Laboratory, Mizoram University.

3.3.2.2. Shifting cultivation site

Two different dominant species were selected from each fallow land in Lengpui. Leaf and fine roots of *Makaranga indica* and *Schima wallichii* were collected from reference forest, 14 years and 10 years old fallow land and leaf and the fine root of *Bidens pilosa* and *A. puliginosa* were collected from 5 years old fallow land. All samples were collected during June 2012 and then dried in an oven at 35°C for three days to a constant weight. After adjusting for the initial moisture content, all litter samples (equivalent to 7 g dry weight) were enclosed in a nylon net bags (mesh size: 2mm, 15 X 15cm). A total of 160 bags were prepared for different litter categories, 20 bags each for different litter categories. Nylon net bags (15x15cm, 2mm mesh) containing 7 g air-dried leaf and wood litter was randomly placed on the plantation floors just above the soil surface, and bags containing roots were buried in the soil to a depth of 10 cm in July 2012. Five bags containing decomposing litter were randomly recovered at three months intervals from each plantation site. The recovered litter materials were air dried, brushed to remove adhering soil particles, and finally dried at 80°C for 24 h and weighed.

Collected litter material was ground in a Willeymill and passed through a 0.5 mm sieve for chemical analyse. Total N and organic carbon were analysed by CHN Auto-analyzer at Central Instrumental Laboratory, Mizoram University.

The daily instantaneous decay rate (k) of litter and root materials was calculated through the negative exponential decay model of Olson (1963): $W_t/W_0 = \exp^{(-kt)}$

where W_0 = initial weight and W_t = weight remaining after time t. As suggested by Olson (1963), time required for 50% and 95% weight loss was calculated as $t_{50} = 0.693/k$, $t_{95} = 3/k$.

3.4. Soil sampling and analysis

Soil samples (0–10 cm depth) were collected from the randomly marked permanent plots (20m x 20m) for physic-chemical characterization. At each location, the soil was collected from three pits, composited and pooled as one replicate. These 3 random composite soil samples were used for detail soil physicochemical and biochemical properties. Each composite soil sample was divided into two parts; one part was stored at 4°C immediately after collection and used later for biochemical and microbiological analyses. Just before analysis, soil samples were incubated at 28±1°C for overnight and then passed through 1 mm sieve. Soil sampling was done periodically. After carefully removing the surface organic materials and fine roots, each composited moist field soil sample was air-dried and was sieved through a 2 mm mesh screen and transported to the laboratory for the determination of soil organic carbon and total nitrogen content. Soil pH was measured by using a glass electrode (1:5, soil: water). Organic C was analyzed by dichromate oxidation in a reflux system and titration with ferrous ammonium sulphate (Kalembasa and Jenkinson, 1973). Total N was estimated by the micro-Kjeldahl method (Jackson, 1958).

3.4.1 Soil aggregate analysis

Soil aggregates were analyzed by wet sieving method of Elliott (1986). Five soil samples were collected from permanent plots of each site randomly. Samples were collected as soil monoliths measuring (15x15x30cm) from 0-10cm soil layer. All sites were sampled at the end of the rainy season. The samples were allowed to air dry then gently passed through a sieve (<8 mm) in air-dried state to remove root material. Each sample was thoroughly mixed. Samples were stored until further analysis in polyethylene bags in a refrigerator at 5°C. Five sub-samples (50g each) were wet sieved by hand through a series of five sieves to obtain six soil aggregate size fractions: (i) >4.75 mm (ii) 2.0-4.75 mm (iii) 0.5-2.0mm (iv) 0.3-0.5mm (v) 0.053-0.3mm and (vi) <0.053mm. Before wet sieving, the soil samples had been vapour-wetted (misted); (Kemper and Rosenau, 1986), and then submerge in the water on the largest screen for 5 minutes before the sieving commenced. The soils were sieved underwater by gently moving the sieve 3 cm vertically 50 times over a period of 2 minutes through water contained in a shallow pan (Elliott, 1986).

Material remaining on the sieve was transferred to an aluminum container and dried at 60° C in a forced air oven. Soil passing a particular sieve remaining in the shallow pan was then transferred to the next finer sieve and the process repeated. For each sample, the aggregate >0.3mm were bulked as macroaggregates and those <0.3mm as microaggregates (Elliott, 1986).

Soil aggregates (micro- and macro) were further analysed for nutrient content. One subsample from each sample was air-dried and analysed for total C and total N using Heraeus CHN-O-S Rapid Auto-analyser.

3.4.2. Soil moisture content

Soil moisture content was determined through the gravimetrical method by drying the known amount of fresh soil in the oven and calculating the moisture content as the difference between fresh and dry soils as described by Anderson and Ingram (1993).

3.4.3. Soil pH

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

3.4.4. Soil total carbon (C) and Nitrogen (N)

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

Chapter 4

RESULT

4.1. Changes in soil characteristics

4.1.1. Changes in soil total carbon (C) in different fallow lands after shifting cultivation

Significant seasonal variations (*P*<0.001) in soil total carbon (C) was observed in all fallow lands at Lengpui. C increased significantly across the fallow ages (e.g. from 5 yrs, 10 yrs, 14 yrs old fallow land) and reached highest in the Reference forest in all seasons. Soil C content was comparatively lower during the winter season and an increasing trend was observed towards post-monsoon season (Fig 4.1A). Significant variations (*P*<0.001) was observed in soil C content among the different sites of Lengpui. Among the four site (5, 10, 14 years old fallow land and reference forest) the lowest soil carbon was observed during winter season and highest was observed during monsoon and post-monsoon season (Table 4.1). During winter season C content was lowest in 5 years old fallow land (2.01%), which increased to 2.12% in 10 years old fallow land and 2.23% in 14 years old fallow land, and reached to maximum in reference forest (2.55%).

Total C in summer followed a similar trend with lowest in 5 years old fallow land (2.71%) followed by 10 years old fallow (2.72%), 14 years old fallow (2.95%) and maximum in reference forest (3.03%). Corresponding values of soil C in monsoon and post-monsoon were: 2.78% in 5 years, 2.89% in 10 years, 3.07% in 14 years and 3.17% in reference forest; and 2.79% in 5 years 2.83% in 10 years, 3% in 14 years and 3.15% in reference forest.

Among different fallow sites at Lengpui, seasonal changes in C was more marked in 5 yrs fallow and less marked reference forest.

Table 4.1. Seasonal changes in soil carbon (%) in different fallow land at Lengpui site. Values are SE means ±1.

Sites	Winter	Summer	Monsoon	Post monsoon
5 years	2.0±0.0	2.7±0.0	2.7±0.0	2.7±0.0
10 years fallow	2.1±0.0	2.7±0.0	2.8±0.0	2.8±0.0
14 years fallow	2.2±0.0	2.9±0.0	3.0±0.0	3.0±0.0
Reference forest	2.5±0.1	3.0±0.0	3.1±0.0	3.1±0.0

4.1.2. Changes in soil organic carbon (C) in SALT farm (2 years and 10 years old)

Among the two sites of different ages with respect to time of their establishment at SALT farm at Pukpui. One site was established in the year 2002 and the other in 2010 so at the time of the start of this study in 2012, the age of one site was 2 years and the other site 10 years since the farming was started there. Small variations in the amount of soil C was noted in two sites (Table 4.2). However the site wise differences were not significant. Seasonal variations in the amount of soil C was noted in SALT farm (Fig. 4.1 B) as was observed in shifting fallow lands.

Table 4.2. Seasonal changes in soil organic carbon (C) in Pukpui site. Values are means ±1 SE.

Sites	Winter	Summer	Monsoon	Post monsoon
Age 10	2.7±0.0	2.7±0.0	2.8±0.0	2.8±0.0
Age 2	2.6±0.0	2.7±0.0	2.7±0.0	2.8±0.0

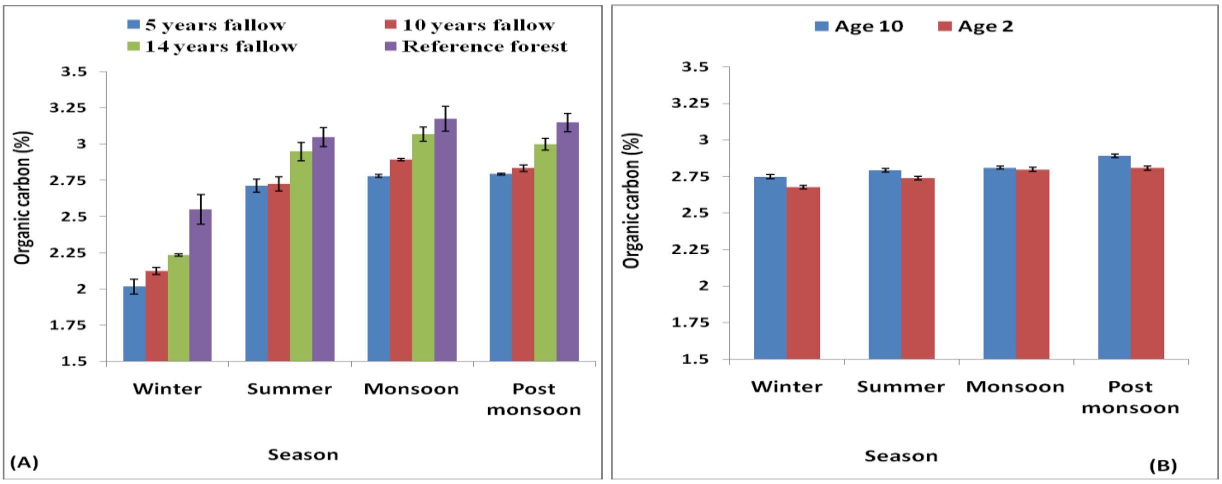


Figure 4.1. Seasonal changes in soil organic carbon (C) in different fallow lands; (A) Lengpui and settled farm; pukpui (B). Vertical lines indicate a standard error, n=3

4.1.3. Changes in soil total nitrogen (N) in different fallow lands (at Lengpui)

Soil total nitrogen showed comparatively lower seasonal variation in all the four sites at Lengpui. Soil total nitrogen content showed similar seasonal variations as reflected by soil C in these sites with lowest values during winter season and highest values during monsoon and post-monsoon seasons (Table 4.3). Lesser but significant difference was observed among the four sites with lowest total N content in 5 yrs fallow and highest in Reference forest (Fig 4.2 A).

Table 4.3. Seasonal changes in soil nitrogen (%) in different fallow lands.
Values are means ±1 SE.

Fallow age	Winter	Summer	Monsoon	Post monsoon
5 years	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0
10 years	0.3±0.0	0.3±0.0	0.3±0.0	0.4±0.0
14 years	0.3±0.0	0.3±0.0	0.3±0.0	0.4±0.0
Ref. Forest	0.3±0.0	0.3±0.0	0.4±0.0	0.4±0.0

4.1.4. Changes in soil total nitrogen (N) in the settled farm (2 years and 10 years)

Among the two sites at Pukpui, recently established site (2 years old) showed lowest soil total nitrogen (0.29%) in winter and highest (0.39%) in the previously established site (10 years old) in post monsoon season (Table 4.4). Seasonal variations were shown in Fig 4.2 B.

Table 4.4. Seasonal changes in soil nitrogen (%) in SALT farm site.
Values are means ±1 SE.

Sites	Winter	Summer	Monsoon	Post monsoon
Age 10	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0
Age 2	0.2±0.0	0.3±0.0	0.3±0.0	0.3±0.1

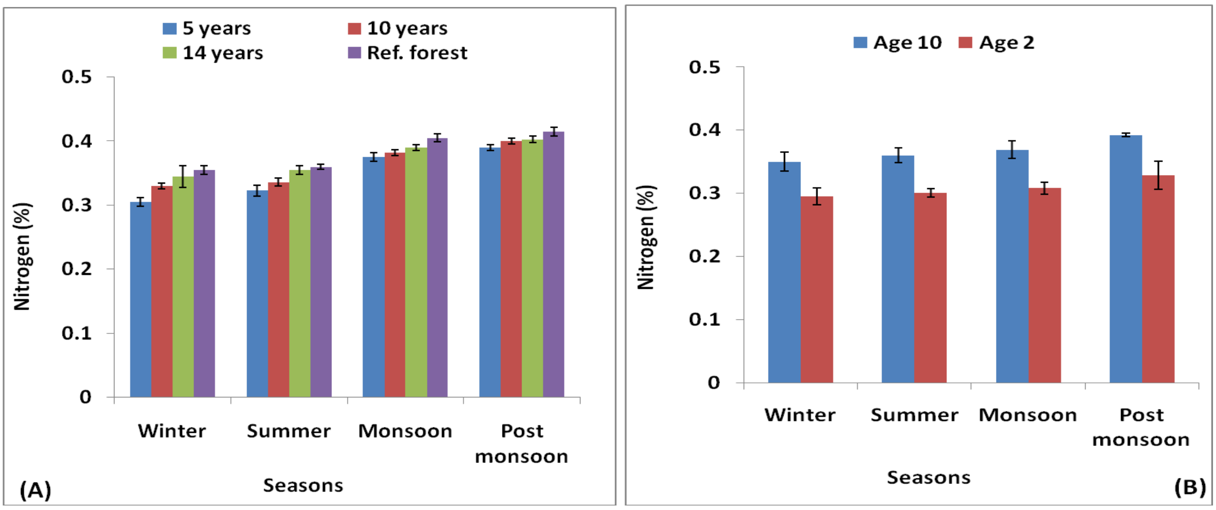


Figure 4.2. Seasonal changes in soil total nitrogen (N) in different fallow lands (A) at Lengpui and settled (SALT) farm at Pukpui (B). Vertical lines indicate standard error, n=3

4.1.5. Soil pH value in different sites

Soil pH showed significant variations among the sites. The pH of the soil of all the sites in Lengpui and Pukpui varied from (4.6 to 5.6) and the increase in the pH scale with a degree of disturbance was noted. The highest soil pH value was observed at 5 yrs fallow land with pH 5.6 followed by 10 yrs fallow, 14 years fallow and reference forest respectively among the Lengpui sites. Soil pH was strongly acidic (<5.0) in 14 yrs fallow, reference forest site at Lengpui and two ages of SALT farm sites at Pukpui (Fig 4.3).

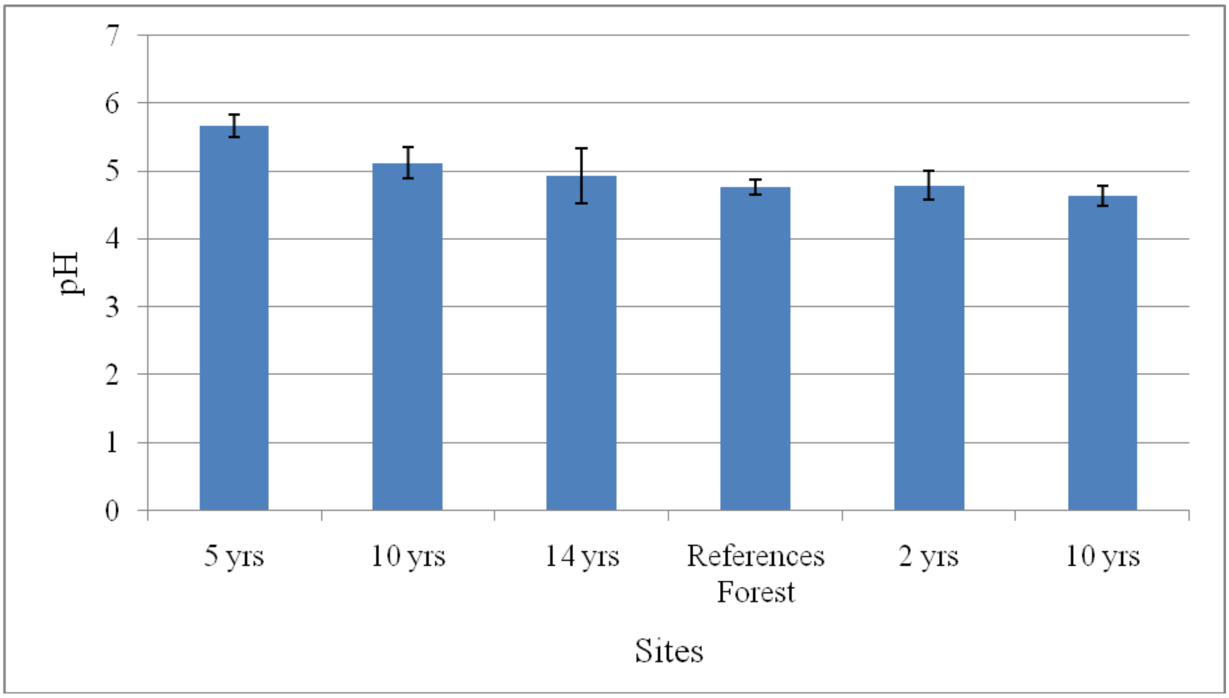


Figure 4.3. Soil pH in different fallow lands at Lengpui (5 yrs, 10 yrs, 14 yrs and Reference forest) and SALT farm at Pukpui (2 and 10 yrs). Vertical lines indicate a standard error, n=3

4.1.6. Soil moisture content in different sites

Soil moisture content showed significant seasonal variations in all sites. Highest soil moisture content was recorded in monsoon and post-monsoon seasons ranging from 36% (in 5 yrs fallow) to 48% (in Reference forest) in monsoon season and 33% (5 yrs fallow) and 45% (Reference forest) in post monsoon season. Lowest soil moisture content was observed during the dry winter season in all sites. Soil moisture content in monsoon and post monsoon seasons was highest in Reference forest and lowest in 5 yrs fallow (Fig 4.4).

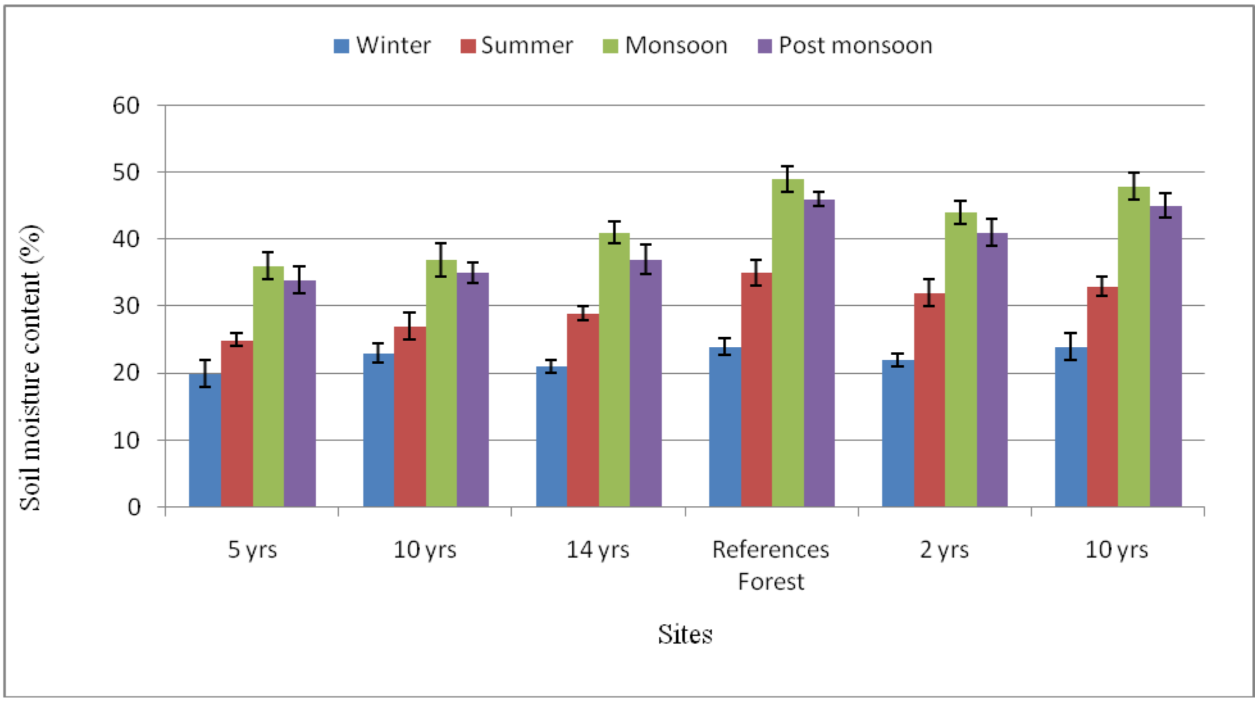


Figure 4.4. Seasonal changes in soil moisture content (%) in different fallow lands at Lengpui (5 yrs, 10 yrs, 14 yrs and Reference forest) and SALT farm Pukpui (2 years and 10 years old). The vertical line indicates a standard error, n=3

4.2. Litter decomposition and nutrient release

4.2.1. Mass loss during decomposition: SALT farm Pukpui

The highest mass loss was observed during the first recovery at 90 days after the placement of litter in all sites for all litter components (Fig 4.5).

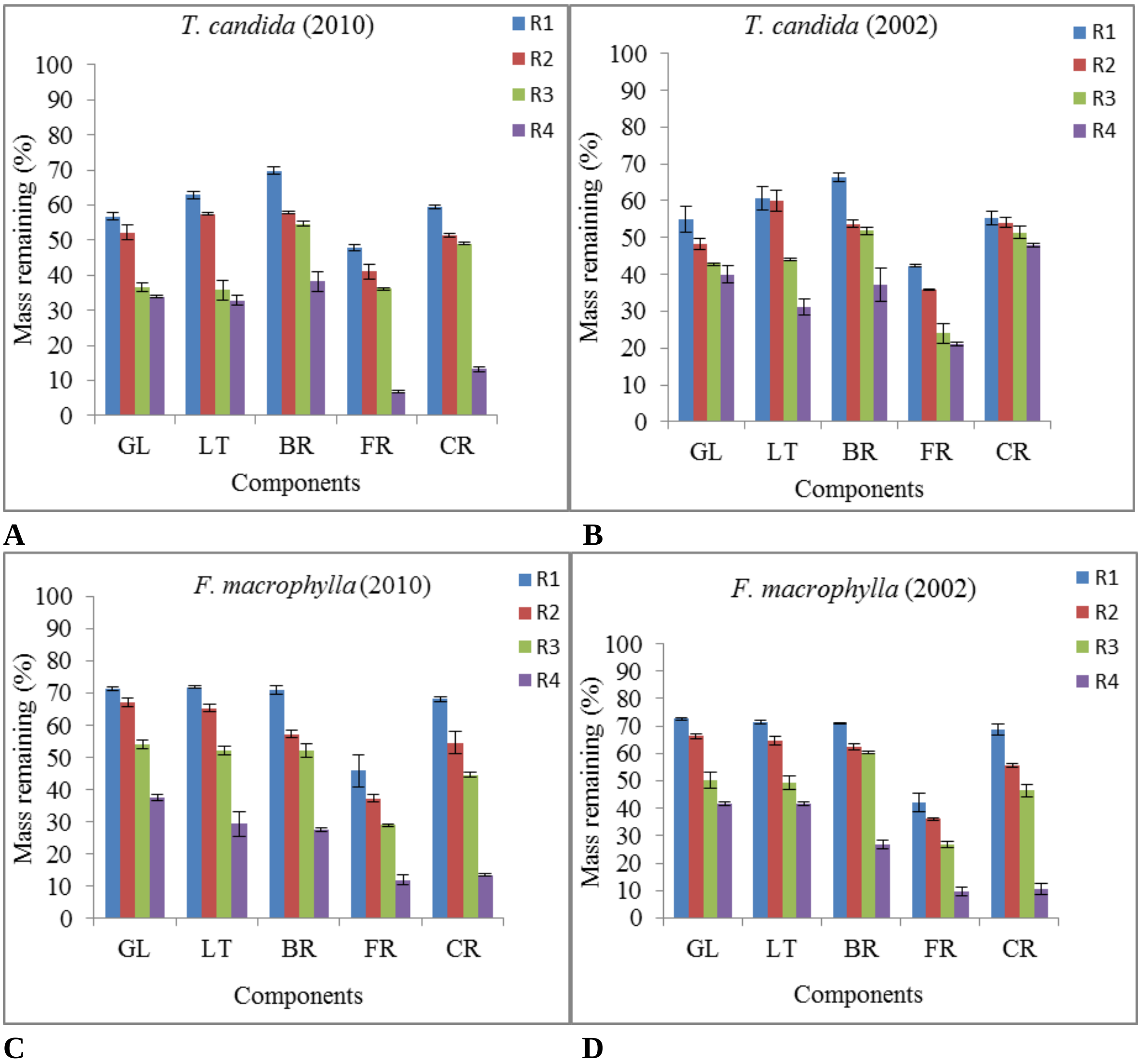


Figure 4.5. Mass remaining (%) of initial at 4 different stages (R1, R2, R3 and R4) of recovery of different components of both *F. macrophylla* and *T. candida* litter in the two study sites. Vertical lines indicate standard errors (± 1SE). GL=Green leaf, LT=Leaf litter, BR=Branch/Wood, FR=Fine root, CR=Coarse root. R1, R2, R3, and R4 are the stages of recovery (time since the placement of bag) i.e. 90, 180, 270 and 360 days, respectively.

The maximum mass loss was observed in fine root litter and minimum in wood litter of both *T. candida* and *F. macrophylla* in both the sites. In both species (*T. candida* and *F. macrophylla*), highest mass loss (59%) rate occurred during initial recovery (90 days of litter placement) and lowest (28%-32%) in wood litter in 10 yrs old farm. However, in 2 years old site, mass loss rates were about 51-52% in fine root litter and 30% in wood litter of these species during the first recovery (Figure 4.5).

The percentage mass of litter material remaining at two sites at the end of the study ranged: 2-7% for fine roots (<2mm), 4-11% for coarse roots (5-10 mm), 14-28% for branch, 10-21% for leaf of both species. The instantaneous annual decay rates (k) for different litter categories were: 2.6-3.5 for fine root and 1-2.6 for other categories. On the basis of k values, the time projections for 50% weight loss varied from 65-88 days for fine roots, 88-155 days for coarse roots and other components (Table 4.5). At the end of the study mass remaining of the different components were: about 3-7% for fine roots, 6.5-11% for coarse root, 14-28% for branch, 10-20% for leaves litter and 17-22% for green leaves (Table 4.5).

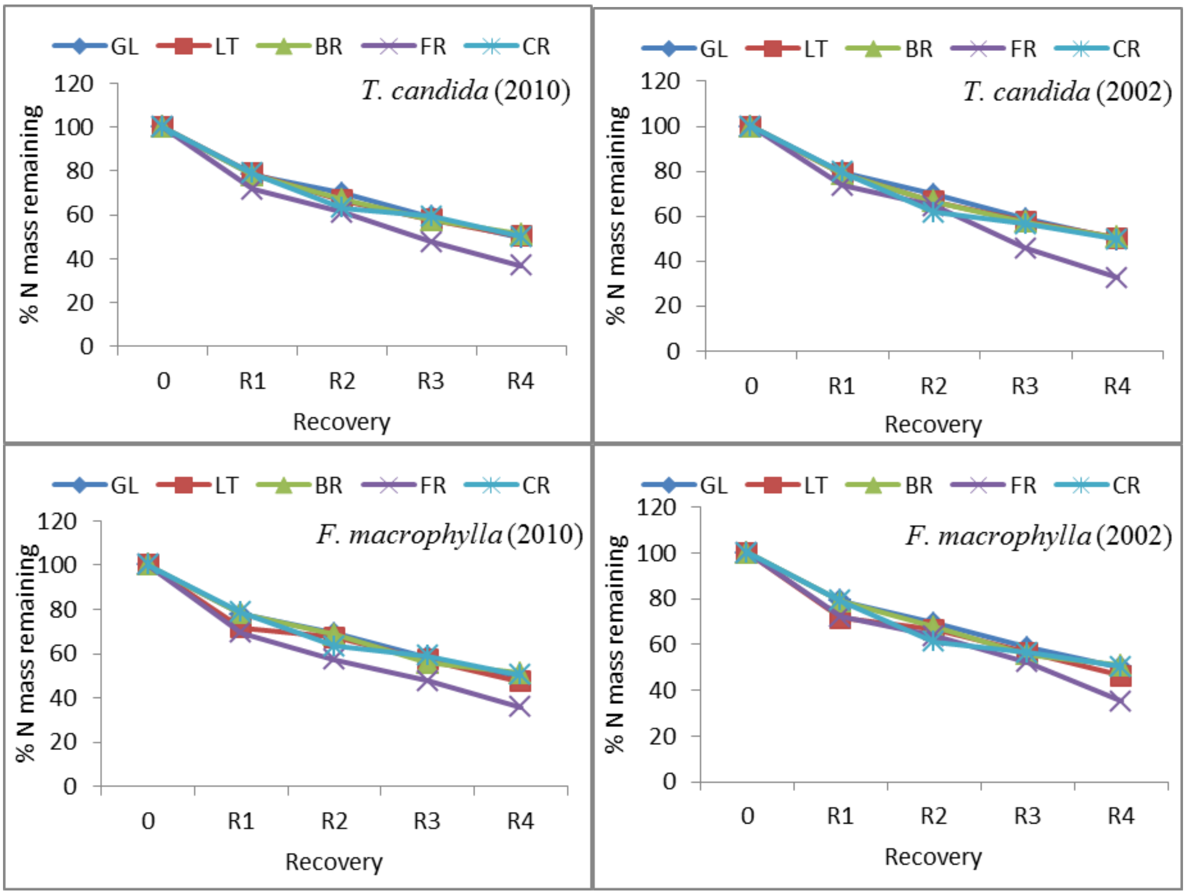
Table 4.5. Decomposition parameters for mass loss and time required for 50% and 95% decay (t_{50} and t_{95}).

Sites	Litter components	Mass remaining (% initial) 365 days	Annual decay rate (k)	t_{50} (days)	t_{95} (days)
2002	*T. candida*				
	Green leaf	17.5	1.74	133.81	628.23
	Leaf litter	10.71	2.23	104.42	490.24
	Branch	21.42	1.54	151.40	710.83
	Fine root	4.85	3.02	77.10	362.01
	Coarse root	7.24	2.03	89.37	414.92
	F. macrophylla				
	Green leaf	21.42	1.54	155.4	710.83
	Leaf litter	20.42	1.54	151.40	710.83
	Branch	14.28	1.94	119.8	562.71
	Fine root	7.14	2.63	88.37	414.92
	Coarse root	6.57	2.33	99.99	328.61
2010	*T. candida*				
	Green leaf	18.9	1.66	150.12	657.85
	Leaf litter	17.92	1.66	140.12	657.85
	Branch	28.21	1.26	184.32	865.37
	Fine root	2.85	3.5	65.60	307.98
	Coarse root	7.14	2.63	88.37	414.92
	F. macrophylla				
	Green leaf	18.92	1.66	140.12	657.85
	Leaf litter	17.5	1.74	133.81	628.23
	Branch	16.28	1.94	119.8	562.71
	Fine root	3.57	3.33	69.99	328.61
	Coarse root	10.71	2.23	104.42	490.24

4.2.2. Nutrient release pattern in SALT farm

Considerable loss of C and N occurred during the initial 90 days of decomposition for all litter categories. About 30-50% C and N remained at the end of recovery for all litter types.

Highest release of C and N was recorded in the fine root category of both species in both sites (Fig 4.6) and (Table 4.6 - 4.13).



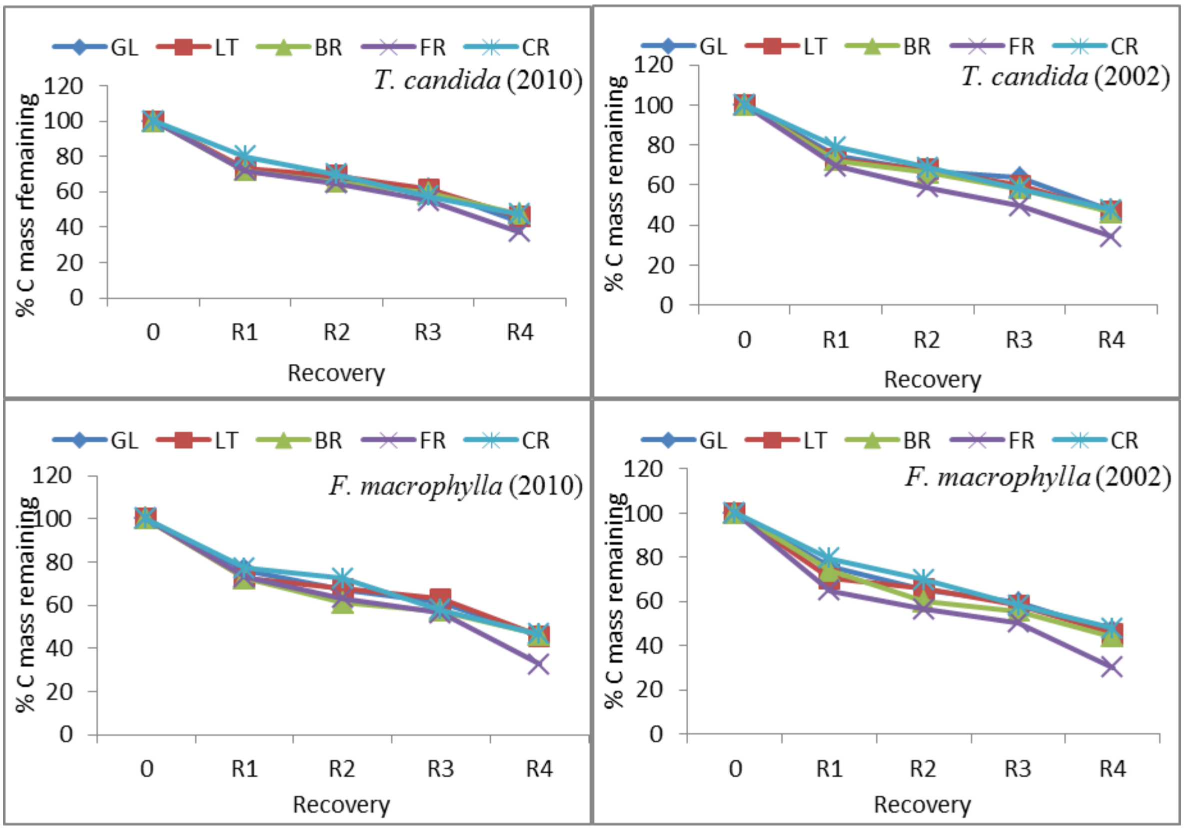


Figure 4.6. Temporal changes in carbon and nitrogen stocks in different litter components during the course of decomposition. GL=Green leaf, LT=Leaf litter, BR=Branch/Wood, FR=Fine root, CR=Coarse root. R1, R2, R3, and R4 are the stages of recovery (time since the placement of bag) i.e. 90, 180, 270 and 360 days, respectively.

Table 4.6. Changes in N stock remaining at different time point in different litter components of *T.candida* during the course of decomposition in 10 years old SALT farm.

Parts of *T.candida*	Percent N mass remaining (days)				
	0	90	180	270	365
Green leaves	100	79.5±1.8	69.8±0.8	58.7±1.4	49.7±2.0
Leaf litter	100	79.0±1.6	66.5±1.8	57.7±1.8	50.3±1.5
Branch	100	78.8±2.4	66.5±2.3	57.5±1.8	50.5±1.9
Fine root	100	73.8±1.1	64.5±1.0	45.7±1.1	32.5±1.8
Coarse root	100	79.5±0.6	61.7±1.3	56.5±1.5	49.7±1.2

Table 4.7. Changes in N stock remaining at different time point in different litter components of *F. macrophylla* during the course of decomposition in 10 years old SALT farm.

Parts of *F.macrophylla*	Percent N mass remaining (days)				
	0	90	180	270	365
Green leaves	100	79.3±1.1	69.2±0.4	58.7±0.7	50.0±0.9
Leaf Litter	100	71.5±3.7	66.5±1.5	56.5±1.4	46.3±0.8
Branch	100	78.7±2.3	67.7±1.6	55.5±1.7	50.7±0.8
Fine root	100	72.2±1.1	63.7±1.1	52.2±0.7	35.2±1.4
Coarse root	100	79.0±0.7	61.2±0.9	56.5±1.3	50.2±0.8

Table 4.8. Changes in N stock remaining at different time point in different litter components of *T.candida* during the course of decomposition in 2 years old SALT farm.

Parts of *T.candida*	Percent N mass remaining (days)				
	0	90	180	270	365
Green leaves	100	78.2±1.5	69.7±1.3	59.0±1.2	49.7±1.2
Leaf Litter	100	79.0±1.5	66.5±1.7	57.7±1.7	50.3±1.5
Branch	100	78.0±1.6	67.0±1.4	57.5±1.4	51.2±1.7
Fine root	100	71.5±1.3	61.0±1.4	47.7±1.7	36.9±1.0
Coarse root	100	79.0±1.0	63.2±2.2	59.2±0.8	49.9±1.2

Table 4.9. Changes in N stock remaining at different time point in different litter components of *F. macrophylla* during the course of decomposition in 2 years old SALT farm.

Parts of *F.macrophylla*	Percent N mass remaining (days)				
	0	90	180	270	365
Green leaves	100	77.9±1.8	69.1±0.4	58.3±0.8	49.6±0.6
Leaf Litter	100	71.7±3.2	67.3±1.4	57.4±1.5	47.4±0.8
Branch	100	78.2±1.5	68.6±0.9	55.9±1.3	51.1±0.9
Fine root	100	69.5±1.7	57.4±1.9	47.8±2.8	35.8±1.4
Coarse root	100	78.7±0.5	63.5±1.0	59.0±2.5	50.4±2.5

Table 4.10. Changes in C stock remaining at a different time point in different litter components of *T.candida* during the course of decomposition in 10 years old SALT farm.

Parts of *T.candida*	Percent C mass remaining (days)				
	0	90	180	270	365
Green leaf	100	74.8±3.4	67.2±1.5	63.5±1.4	47.2±1.6
Leaf Litter	100	72.9±3.4	67.8±1.7	59.7±1.8	46.5±1.2
Branch	100	72.2±1.4	66.0±1.12	58.1±1.3	46.2±0.7
Fine root	100	69.4±1.1	58.7±0.8	49.6±0.4	34.1±0.5
Coarse root	100	79.0±0.8	68.6±0.9	58.1±1.5	47.5±0.7

Table 4.11. Changes in C stock remaining at different time point in different litter components of *F. macrophylla* during the course of decomposition in 10 years old SALT farm.

Parts of *F.macrophylla*	Percent C mass remaining (days)				
	0	90	180	270	365
Green leaf	100	76.06±2.273	65.617±1.01	59.472±1.04	46.346±0.776
Leaf Litter	100	70.486±5.132	65.703±3.904	58.257±3.56	45.593±2.683
Branch	100	74.057±4.828	59.971±1.57	55.732±1.962	44.011±1.554
Fine root	100	64.837±3.866	56.465±2.694	50.558±2.6	30.143±1.277
Coarse root	100	79.316±0.669	69.879±0.919	58.332±1.516	47.804±0.863

Table 4.12. Changes in C stock remaining at different time point in different litter components of *T.candida* during the course of decomposition in 2 years old SALT farm.

Parts of *T.candida*	Percent C mass remaining (days)				
	0	90	180	270	365
Green leaf	100	72.7±4.4	66.9±3.2	61.4±2.7	42.5±4.0
Leaf Litter	100	73.4±3.8	69.2±2.6	61.4±3.0	45.8±1.6
Branch	100	72.0±1.7	65.6±0.3	59.2±0.9	47.3±0.3
Fine root	100	72.0±0.6	64.7±1.2	55.0±1.4	37.3±0.4
Coarse root	100	79.9±0.6	69.7±2.3	57.6±1.9	47.4±1.3

Table 4.13. Changes in C stock remaining at different time point in different litter components of *F. macrophylla* during the course of decomposition in 2 years old SALT farm.

Parts of *F.macrophylla*	Percent C mass remaining (days)				
	0	90	180	270	365
Green leaf	100	76.1±2.5	67.1±1.3	61.1±0.9	46.1±0.6
Leaf Litter	100	72.3±4.4	67.6±3.7	62.8±2.7	45.7±2.1
Branch	100	72.2±3.4	60.9±2.0	57.3±3.1	46.3±1.4
Fine root	100	72.9±2.1	63.1±1.0	56.2±1.1	32.5±0.3
Coarse root	100	77.1±1.6	72.3±1.8	57.9±0.8	46.4±0.2

N release was faster in fine roots compared to the other litter categories (Tables 4.6-4.9). The fine root of *F. macrophylla* showed a greater amount of C release than *T. candida* in both the study sites (Table 4.10-4.13), although differences were not significant between the pattern of C and N release.

4.2.3. Mass loss during decomposition in fallow lands and reference forest

The highest rate of decomposition was recorded during the period between the placement of litter bags and the first recovery in all sites. Fine root decomposes faster than leaf litter in all fallow lands. After one year <20% mass of fine root component was remaining at all site.

4.2.3.1. Reference forest

Generally, fine root of two species (*M. indica* and *S. wallichii*) at reference forest site decomposes faster than leaf litter category of these species (Table 4.14, Fig 4.7). However, at the end of the percent mass remaining was almost equal for both components of these species (i.e. 28-30%).

4.2.3.2. Fallow land following shifting cultivation (14 years old)

M. indica decomposes slowly during initial 270 days of decomposition and roots of *M. indica* and leaf and root of *S. wallichii* decomposes faster (Table 4.15, Fig 4.7 b). However, the mass remaining at the end of the one year was almost equal.

4.2.3.3. Fallow land following shifting cultivation (10 years old)

Leaves and roots of *S.wallichii* decompose faster than the leaves and roots of *M.indica* during initial 270 days (Table 4.16, Fig. 4.7 c). At the end of the study mass remaining of leaf and roots did not differ significantly.

4.2.3.4. Fallow land following shifting cultivation (5 years old)

Leaf and roots of two species (*A. puliginosa* and *B. pilosa*) decompose almost similarly during the course of the study (Table 4.17, Fig. 4.7 d). Considerable mass loss of these components was recorded during first 90 days of litter decomposition followed by a consistent weight loss.

Table 4.14. Mass remaining (%) to initial at 4 different stages (90days, 180days, 270days and 365days) of recovery on different components of both *M.indica and S.wallichi* in reference forest sites.

Ref forest	Percent mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	73.21	63.57	55.89	30.53
M.indica root	100	58.92	52.85	45.71	27.85
S.wallichii leaves	100	69.64	67.42	61.60	31.07
S.wallichii root	100	57.85	52.5	43.57	29.28

Table 4.15. Mass remaining (%) to initial at 4 different stages (90days, 180days, 270days and 365days) of recovery on different components of both *M.indica and S.wallichi* in 14 years old fallow land sites.

14 years old fallow land	Percent mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	72.85	68.57	62.85	33.75
M.indica root	100	58.57	52.82	46.60	27.85
S.wallichii leave	100	57.50	52.14	47.67	29.28
S.wallichii root	100	55.17	47.85	45.00	28.57

Table 4.16. Mass remaining (%) to initial at 4 different stages (90days, 180days, 270daya and 365days) of recovery on different components of both *M.indica and S.wallichi* in 10 years old fallow land sites.

10 years fallow land	Percent mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	73.21	64.28	58.21	33.03
M.indica root	100	68.25	64.46	56.42	28.57
S.wallichii leave	100	59.67	54.46	48.92	27.50
S.wallichii root	100	55.60	52.21	44.64	26.78

Table 4.17. Mass remaining (%) to initial at 4 different stages (90days, 180days, 270days and 365days) of recovery on different components of both *B.pilosa and A.puliginosa in* 5 years old fallow land sites.

5 years old fallow land	Percent mass remaining (days)				
	0	90	180	270	365
B.pilosa leaves	100	57.50	46.35	38.57	26.07
B.pilosa root	100	54.92	45.35	40.17	23.39
A.puliginosa Leave	100	55.35	47.67	42.50	26.78
A.puliginosa Root	100	52.14	46.25	39.46	23.21

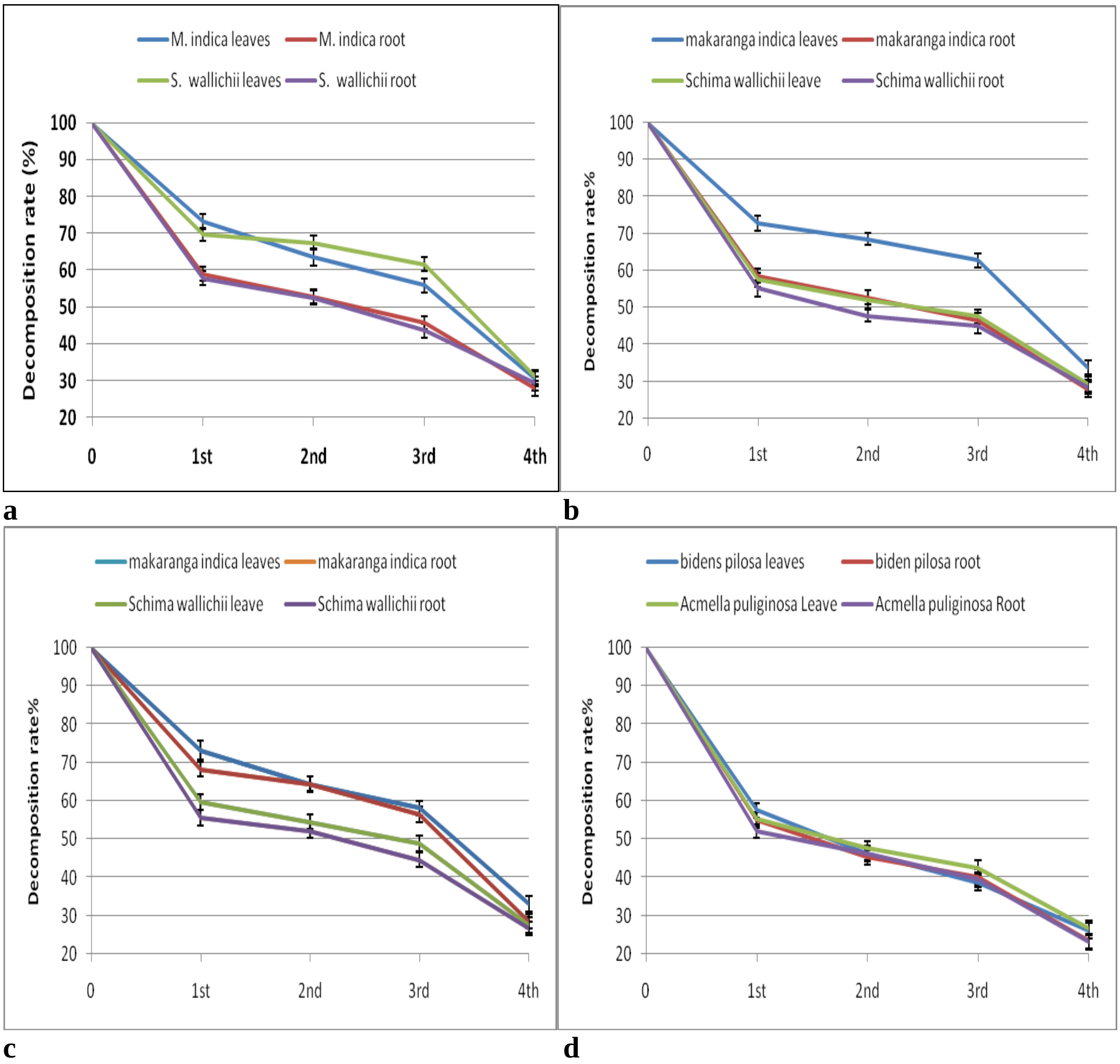


Figure 4.7. Litter decomposition at Lengpui site: Reference (a), 14 years fallow (b), 10 years fallow (c) and 5 years fallow (d).

4.2.4. N stock remaining in different fallow lands

4.2.4.1. Fallow land following shifting cultivation (5 years old)

The pattern of N release in fine root and leaf components of B.pilosa and A.puliginosa was almost similar in 5 years old fallow following shifting cultivation (Table 4.18, Fig. 4.8 a). N release was faster during initial 90 days and in the last phase of decomposition (during 270-360 days).

4.2.4.2. Fallow land following shifting cultivation (10 years old)

The pattern of N release did not vary between components and species. However, the rate of release was faster during initial 90 days and last 90 days during an annual cycle in 10 years old fallow following shifting cultivation (Table 4.19, Fig. 4.8 b).

4.2.4.3. Fallow land following shifting cultivation (14 years old)

N loss was almost similar in all the components of the two species (Table 4.20, Fig. 4.8 c) in 14 years old fallow following shifting cultivation. Considerably decrease in N concentration occurred in initial 90 days during decomposition followed by a slow release during 90-180 days and there was consistent release noted during the 180-360 days of decomposition.

4.2.4.4. Reference forest

In general, the pattern of N release of all components was almost similar without any significant difference either among the components or species (Table 4.21, Fig. 4.8 d). N release followed a pattern similar to that of the 14 years old fallow, for example, showing fast release during initial 90 days and 180-360 days but slow release during 90-180 days.

Table 4.18. Changes in N stock remaining at different time point in different litter components of *B.pilosa* and *A.puliginosa* during the course of decomposition in 5 yrs old fallow land.

5 yrs old fallow land	Percent N mass remaining (days)				
	0	90	180	270	365
B. pilosa leaves	100	73.4±2.0	67.7±1.2	60.5±0.7	49.0±0.7
B. pilosa root	100	74.0±1.5	63.3±0.8	60.8±0.8	44.9±0.3
A. Puliginosa leaf	100	76.5±0.8	71.1±1.2	57.0±1.4	47.3±0.7
A. Puliginosa root	100	74.6±1.3	68.8±0.9	58.1±0.6	46.2±0.5

Table 4.19. Changes in N stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in 10 yrs old fallow land.

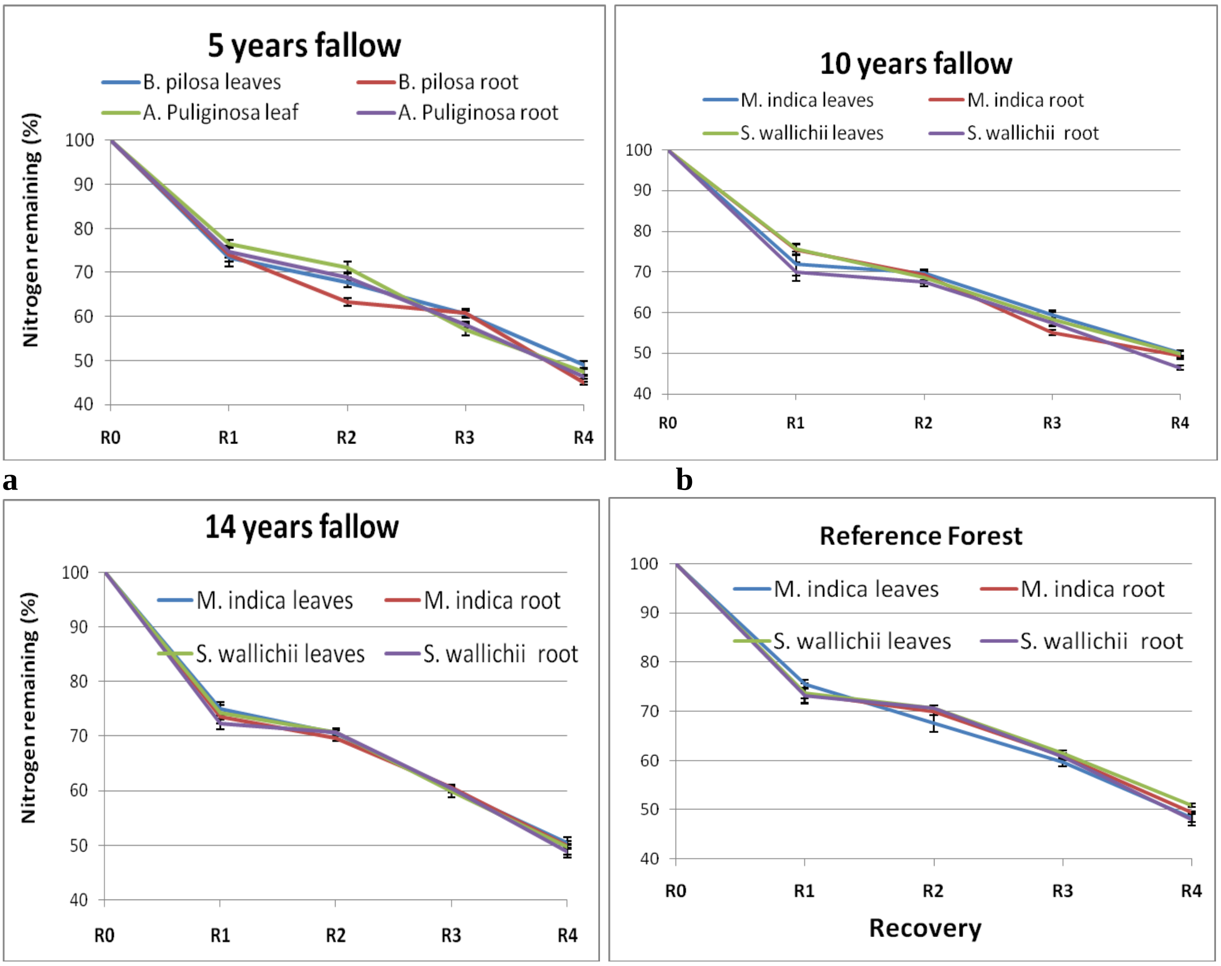
10 yrs old fallow land	Percent N mass remaining (days)				
	0	90	180	270	365
M. indica leaves	100	72.0±2.8	69.8±0.6	59.5±0.9	49.9±0.6
M. indica root	100	75.4±1.4	69.2±1.3	55.1±0.5	49.5±0.9
S. wallichii leaves	100	75.6±1.3	68.5±1.3	58.3±1.6	49.8±0.9
S. wallichii root	100	70.0±2.3	67.6±1.2	57.5±0.6	46.4±0.5

Table 4.20. Changes in N stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in 14 yrs old fallow land.

14 yrs fallow land	Percent N mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	74.9±1.2	70.5±0.4	60.2±0.2	50.4±0.3
M.indica root	100	73.5±1.2	69.6±0.6	60.5±0.6	49.8±0.3
S.wallichii leaves	100	74.3±1.3	70.6±0.4	59.9±1.0	49.6±1.8
S.wallichii root	100	72.2±0.9	70.6±0.6	60.4±0.7	48.8±0.5

Table 4.21. Changes in N stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in reference forest.

Reference forest	Percent N mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	75.5±0.7	67.5±1.7	59.7±0.9	48.4±0.8
M.indica root	100	73.5±2.0	69.8±0.6	60.8±0.5	49.4±0.3
S.wallichii leaves	100	73.7±1.0	70.6±0.5	61.4±0.5	50.9±0.3
S.wallichii root	100	73.1±1.3	70.6±0.5	60.7±0.7	48.1±1.3



a b c d

Figure 4.8. Changes in nitrogen stocks during the course of decomposition in different litter categories in Fallow lands and Forest (Lengpui Site). R1=90 days, R2=180 days, R3=270 days, R4=365 days

4.2.5. Carbon mass remaining in fallow lands

4.2.5.1. Fallow land following shifting cultivation (5 years old)

In 5 years old fallow, C release was almost similar for all components of the two species (Table 4.22, Fig. 4.9 a). However, the C release pattern was highly seasonal showing about 30% release during first 90 days with marginal change during 90-180 days followed by about 20% release during the last phase (180-360 days).

4.2.5.2. Fallow land following shifting cultivation (10 years old)

C release in root and leaf components of *M. indica* and *S. wallichii* did not vary significantly during the initial 90 days except *S. wallichii* root, but it varied during the later phase of decomposition (Table 4.23, Fig. 4.9 b). C release in *S. wallichii* root was faster in the initial phase of decomposition, whereas, C release was more pronounced during the later phase of decomposition of *S. wallichii* of leaf. Release of C from *M. indica* root was slowest among all components during the later phase of the decomposition.

4.2.5.3. Fallow land following shifting cultivation (14 years old)

C release did not vary between two species and components (leaf and roots) during the course of decomposition (Table 4.24, Fig 4.9 c). C release in all components of the two species was faster in first 90 days of decomposition and last 180 days of decomposition (from 180-360 days).

4.2.5.4. Reference forest

In reference forest, carbon release was slowest in *M. indica* root and fastest in *M. indica* leaf (Table 4.25, Fig. 4.9 d). C release from *S. wallichii* leaf and root was in between C release from *M. indica* leaf and roots.

Table 4.22. Changes in C stock remaining at different time point in different litter components of *B.pilosa* and *A.puliginosa* during the course of decomposition in 5 years old fallow land site.

5 yrs old fallow land carbon	Percent C mass remaining (days)				
	0	90	180	270	365
B.pilosa leaves	100	72.6±1.0	70.1±0.3	61.0±0.4	50.9±0.3
B.pilosa root	100	70.9±0.6	68.7±0.6	60.7±0.6	49.0±1.8
A.puliginosa leaf	100	72.4±0.8	69.6±0.5	61.9±0.9	49.2±0.8
A.puliginosa root	100	69.0±2.9	68.8±0.7	60.6±1.1	49.9±0.3

Table 4.23. Changes in C stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in 10 years old fallow land site.

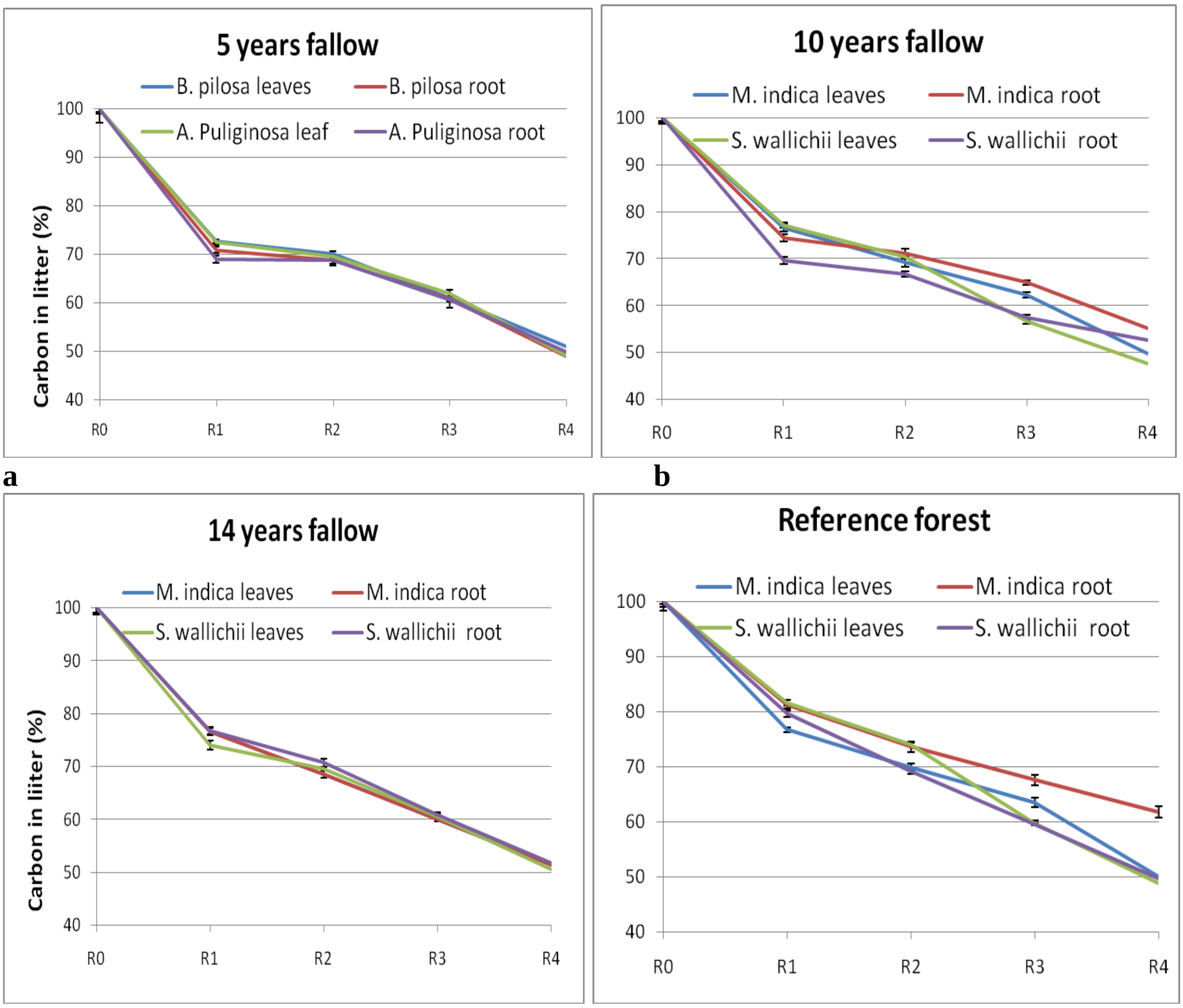
10 yrs old fallow land	Percent C mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	76.6±1.3	69.1±0.9	62.2±0.8	49.7±0.6
M.indica root	100	74.4±0.9	71.1±0.7	64.8±0.8	55.1±0.4
S.wallichii leaves	100	77.1±0.7	70.2±0.5	56.6±0.2	47.6±0.5
S.wallichii root	100	69.6±0.8	66.6±0.7	57.3±0.5	52.5±0.5

Table 4.24. Changes in C stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in 14 years old fallow land site.

14 years fallow land	Percent C mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	76.6±1.2	68.5±0.6	60.0±0.6	51.4±0.3
M.indica root	100	76.6±1.2	68.5±0.6	60.0±0.6	51.4±0.3
S.wallichii leaves	100	74.1±0.8	69.6±0.8	60.5±0.2	50.4±0.5
S.wallichii root	100	76.7±1.1	70.7±0.7	60.8±0.7	51.7±0.6

Table 4.25. Changes in C stock remaining at different time point in different litter components of *M. indica* and *S. wallichii* during the course of decomposition in reference forest site.

reference forest	Percent C mass remaining (days)				
	0	90	180	270	365
M.indica leaves	100	76.7±1.6	69.9±0.4	63.4±0.5	50.0±0.8
M.indica root	100	81.1±1.7	73.5±0.6	67.5±0.8	61.8±0.7
S.wallichii leaves	100	81.5±0.5	74.0±0.5	59.7±0.3	48.9±0.4
S.wallichii root	100	79.7±0.5	69.1±0.7	59.5±0.5	49.6±0.2



a **b**

c **d**

Figure 4.9. Changes in Carbon stocks during the course of decomposition in different litter categories in Fallow lands and Forest (Lengpui Site) R1=90 days, R2=180 days, R3=270 days, R4=365 days

4.3. Changes soil aggregate characteristics

4.3.1. Soil Aggregates

Among all the sites in fallow lands following shifting cultivation at Lengpui and SALT farm at Pukpui, soil macroaggregates fractions (>4.75 mm) was in order of reference forest (34.2%)> SALT farm of 10 years at Pukpui (26.7%)> 14 years old fallow land (18.6%)> SALT farm of 2 years old (18.1%)>10 years old fallow land (14.5%)> 5 years old land (6.3%) (Table 4.26). Smaller soil particle sizes (2-4.75 mm and 0.5-2.0 mm) showed a reverse trend which were in order: 5 fallow land>10 years fallow land>14 years fallow land>SALT farm 10 years old>Refrence forest> SALT farm 2 years old (Table 4.26). Soil fraction size (0.3-0.5 mm) showed an almost haphazard trend. Overall macroaggregates in the fallow land were significantly maximum in Reference forest (65%) and minimum in 5 years old fallow land (54%). In SALT farm it was maximum in 10 years and minimum in 2 years old (Table 4.26).

The fractions size of soil macroaggregates (0.053-0.3 mm) was highest in SALT farm 2 years old (44.9%) followed by fallow land 14 years old (31.5%), 10 years old fallow (27.5%), reference forest (25.2), SALT farm 10 years old (24.9%) and 5 years old fallow land (21.7%). Soil microaggregates (<0.053 mm) was highest in 5 years old fallow land (23.8%) followed by 13.0% in SALT farm 2 years old, 12.6% in 10 years old fallow land, 11.9% in SALT farm 10 years old, 10.8% in 14 years old fallow and minimum in reference forest (10.3%).

In general soil microaggregates showed an almost opposite trend of macroaggregate size distribution in these sites (Table 4.26).

Table 4.26. Proportions of aggregates in size fractions (%) in different sites. Values are means of five replicates (±SE). Values within the same column followed by the same letter are not significantly different.

Macroaggregates (mm)					**Total**	**Micro-aggregates (mm)**	**Total**	
Sites	**> 4.75**	**2.0-4.75**	**0.5-2.0**	**0.3-0.5**		**0.053-0.3**	**<0.053**	
Reference forest	**34.2±2.4b**	**11.0±1.2a**	**12.6±0.6b**	**7.0±0.3b**	**64.9±0.9b**	**25.2±0.5b**	**10.3±0.2a**	**35.1±0.9b**
14 yrs	**18.6±3.4a**	**10.4±2.2a**	**10.2±0.2dc**	**18.5±0.8d**	**57.7±0.5c**	**31.5±0.5c**	**10.8±0.7a**	**42.3±0.5c**
10 yrs	**14.5±0.7a**	**12.4±0.8a**	**22.6±2.6a**	**10.4±1.0a**	**59.9±0.9a**	**27.5±0.9a**	**12.6±0.1ab**	**40.1±0.9ac**
5 yrs	**6.3±0.7d**	**16.5±0.4b**	**24.9±1.8a**	**6.8±0.2b**	**54.6±1.6c**	**21.7±1.0b**	**23.8±0.6c**	**45.4±1.6c**
Settled farm (SALT)								
2 yrs	**18.1±1.2a**	**3.0±0.3c**	**7.1±0.4d**	**13.8±0.7c**	**42.1±1.9d**	**44.9±1.8d**	**13.0±1.5b**	**57.9±1.9d**
10 yrs	**26.7±0.7c**	**10.2±1.0a**	**12.0±1.3bc**	**14.2±0.9c**	**63.2±0.7a**	**24.9±0.6b**	**11.9±0.9b**	**36.8±0.7ab**

4.3.2. (g. kg^{-1}. Organic carbon) in different sites and soil aggregate size fractions

Among all the sites of fallow lands at Lengpui and SALT farm at Pukpui, level of soil carbon (g. kg^{-1}) was highest in reference forest (26.19) in the fractions size >4.75mm followed by age 10 SALT farm (25.75), 14 years old fallow land (21.88), 10 years old fallow land (11.30), 2 years old SALT farm (7.05) and the lowest (6.93) in 5 years old fallow (Table 4.27). The level of soil carbon (g. kg^{-1}) of the fractions size (2.0-4.75 mm) was highest in 14 years old fallow land (27.61) followed by reference forest (24.22), 10 years old SALT farm (24.21), 10 years old fallow land (11.90), 2 years old SALT farm (11.70), and the lowest (7.05) in 5 years old fallow land (Table 4.27)

Level of soil carbon (g. kg^{-1}) of the fractions size 0.5-2.0mm was highest in reference forest (33.05) followed by age 10 settled SALT farm at Pukpui (30.79), 14 years old fallow land (28.79), 2 years old settled farm at Pukpui (12.30), 10 years old fallow (9.98) and the lowest in 5 years old fallow land (8.84). Similarly, the level of soil carbon (g. kg^{-1}) of the fractions size 0.3-0.5 mm was highest in reference forest (34.98) followed by 10 years old settled SALT farm (31.45), 14 years old fallow land (16.56), 10 years old fallow (12.97), 2 years old SALT farm (9.11) and the lowest (3.25) in 5 years old fallow land (Table 4.27).

The level of soil carbon (g. kg^{-1}) in one of the microaggregates (fractions size 0.053-0.3 mm) was also highest in reference forest (21.22) followed by age 10 settled SALT farm (20.27), 14 years old fallow land (19.83), 10 years old fallow (9.38), 2 years old settled SALT farm at Pukpui (5.95) and the lowest in 5 years old fallow land (5.92). Level of Soil total C (g. kg^{-1}) of smaller microaggregate fraction (<0.053mm) was highest in reference forest (23.01) followed by age 10 settled SALT farm Pukpui (19.29), 14 years old fallow land (18.88), 10 years old fallow (9.78), 5 years old fallow land (9.51) and the lowest in 2 years old settled farm (8.75).

Among all the sites in fallow lands at Lengpui and SALT farm at Pukpui, level of carbon (g. kg^{-1}) in soil macroaggregates was highest in reference forest (29.56) followed by 10 years old settled SALT farm at Pukpui (27.98), which decreased to 23.71 in 14 years old fallow land in Lengpui, followed by 11.54 in 10 years old fallow land, 10.04 in 2 years old settle SALT farm at Pukpui and 6.52 in 5 years old fallow land (Table 4.27). Comparing all fallow and SALT farm sites, level of carbon (g. kg^{-1}) in microaggregates was highest in reference forest (22.11), followed by 19.68 in age 10 settled SALT farm at Pukpui site, 19.35 in 14 years old fallow land in Lengpui, 9.58 in 10 years old fallow land, 7.71 in 5 years old fallow land and lowest (7.35) in 2 years old settle SALT farm at Pukpui. Significantly (*P*<0.05)) higher C content was observed in microaggregates than macroaggregates (Table 4.27).

Table 4.27. Carbon (g. kg^{-1}) content in different soil aggregate size fractions. Different small letters indicates significant differences among sites. Different small letters indicates significant differences among sites. Values are ±1 SE.

	Macroaggregates (mm)					**Microaggregates (mm)**		
Sites	**>4.75**	**2.0-4.75**	**0.5-2.0**	**0.3-0.5**	**Mean**	**0.053-0.3**	**<0.053**	**Mean**
Reference forest	26.19a±0.33	24.22a±0.24	33.05b±0.18	34.98b±0.48	29.56b±0.19	21.22a±0.24	23.01b±0.35	22.11b±0.22
14 yrs	21.88b±0.57	27.61b±0.83	28.79c±0.35	16.56c±0.61	23.71c±0.43	19.83a±0.07	18.88a±0.44	19.35a±0.25
10 yrs	11.30e±0.98	11.90d±0.78	9.98d±0.12	12.97e0.35	11.54e±0.49	9.38c±0.12	9.78cd±0.31	9.58d±0.15
5 yrs	6.93cd±0.24	7.05c±0.33	8.84d±0.29	3.26d±0.24	6.52d±0.17	5.92b±0.29	9.51c±0.18	7.71c±0.19
Settled farm (SALT)								
2 yrs	7.05d±0.13	11.70d±0.48	12.30c±0.52	9.11f±0.37	10.04f±0.32	5.95d±0.23	8.75df±0.13	7.35c±0.13
10 yrs	25.75a±0.29	24.21a±0.24	30.79a±0.44	31.45a±1.03	27.98a±0.43	20.27a±0.18	19.29a±0.78	19.68a±0.48

4.3.3. Total nitrogen (g. kg^{-1}) in different soil aggregate size fractions

Among all the sites of fallow lands at Lengpui and SALT farm at Pukpui, level of total nitrogen (g. kg^{-1}) of the fractions size >4.75mm was highest in reference forest (2.78) followed by 10 years old settled SALT farm at Pukpui (2.06), 14 years old fallow land (1.47), 10 years old fallow land (1.45), 2 years old settled SALT farm at Pukpui (1.15)and the lowest (0.63) in 5 years old fallow land (Table 4.28). Total nitrogen (g. kg^{-1}) of lower fractions size (2.0-4.75 mm) was highest in reference forest (2.14), followed by 10 years old settled farm (2.03), 14 years old fallow land (1.63), 2 years old settled farm (1.04), 10 years old fallow land (1.03) and the lowest (0.55) in 5 years old fallow land (Table 4.28).

Total nitrogen (g. kg^{-1}) in soil aggregate fraction size (0.5-2.0 mm) was highest in reference forest (2.33), 10 old settled SALT farm (2.20), 14 years old fallow land (1.84), 10 years old fallow (0.95), 2 years old settled SALT farm (0.94) and the lowest in 5 years old fallow land (0.75). However, total nitrogen (g. kg^{-1}) in 0.3-0.5 mm size fraction was highest in reference forest (2.53) followed by 10 old settled SALT farm at Pukpui (2.30), 10 years old fallow land (1.48), 14 years old fallow (1.28), 2 years old settled SALT farm (0.89) and the lowest (0.55) in 5 years old fallow land (Table 4.28).

Total nitrogen (g. kg^{-1}) in one of the microaggregate fractions size (0.053-0.3 mm) was highest in reference forest (1.85) followed by 10 years old settled SALT farm in Pukpui (1.80), 14 years old fallow land (1.48), 10 years old fallow (0.96), 5 years old fallow land (0.35)and the lowest in 2 years old settled SALT farm in Pukpui (0.35). Similarly, total nitrogen (g. kg^{-1}) in fractions size (<0.053 mm) was highest in reference forest (2.17) followed by age 10 settled SALT farm in Pukpui(2.07), 14 years old fallow land (1.57), followed by 10 years old fallow

(1.14), 5 years old fallow land (0.95) and the lowest in age 2 settled SALT farm in Pukpui (0.47) (Table 4.28).

Among all the sites, total nitrogen (g. kg^{-1}) in soil macroaggregates was highest in reference forest (2.44) followed by 10 years old settled SALT farm at Pukpui site (2.15), 14 years old fallow land in Lengpui (1.56), 10 years old fallow land (1.23), 2 years old settle SALT farm at Pukpui (1.0) and lowest in 5 years old fallow land (0.62). However, total nitrogen (g. kg^{-1}) in soil microaggregates was highest in reference forest (22.11) followed by 10 years old settled SALT farm at Pukpui site, 14 years old fallow land at Lengpui (19.35), 10 years old fallow land (9.58), 5 years old fallow land (7.71) and lowest in 2 years old settle farm at Pukpui site (7.35) (Table 4.28).

Table 4.28. Total nitrogen (g. kg^{-1}) in different soil aggregate size fractions. Different small letters indicate significant differences among sites. Values are ±1SE.

	Macroaggregates (mm)					**Microaggregates (mm)**		
Sites	>4.75	2.0-4.75	0.5-2.0	0.3-0.5	Mean	0.053-0.3	<0.053	**Mean**
Reference forest	**2.78b±0.07**	**2.14a±0.09**	**2.33a±0.07**	**2.53b±0.03**	**2.44b±0.01**	**1.85a±0.11**	**2.17a±0.12**	**2.01b±0.03**
14 yrs	**1.47c±0.01**	**1.63b±0.02**	**1.84b±0.04**	**1.28c±0.02**	**1.56c±0.09**	**1.48b±0.04**	**1.59b±0.06**	**1.53c±0.01**
10 yrs	**1.45c±0.02**	**1.03d±0.08**	**0.95d±0.02**	**1.48c±0.01**	**1.23e±0.03**	**0.96d±0.03**	**1.14d±0.05**	**1.05e±0.03**
5 yrs	**0.63d±0.03**	**0.55c±0.09**	**0.75c±0.03**	**0.55d±0.02**	**0.62d±0.02**	**0.37c±0.04**	**0.95c±0.04**	**0.66d±0.03**
Settled farm (SALT)								
2 yrs	**1.15e±0.03**	**1.04d±0.03**	**0.94ed±0.02**	**0.89e±0.04**	**1.00f±0.01**	**0.35c±0.05**	**0.47e±0.05**	**0.45f±0.06**
10 yrs	**2.06a±0.07**	**2.03a±0.06**	**2.20a±0.08**	**2.30a±0.21**	**2.15a±0.05**	**1.80a±0.02**	**2.07a±0.06**	**1.94a±0.03**

Chapter 5

DISCUSSIONS

The state of Mizoram has ~89% forest cover, but the majority of them are a secondary forest. Shifting cultivation is widely practiced in the state which is carried out by the majority of the population for their livelihood. This practice involves slashing and burning of a piece of forest land followed by cropping for one or two years depending on the soil fertility status of the fallowed land and abandonment for few years (5-20 years) to recover soil fertility. Due to increased population, the fallow length has drastically decreased to <5 years which has posed serious economic and social constraints because of decrease in soil fertility. To overcome this problem, there are initiatives from the Government of Mizoram and public to convert this practice into settle farm. Among such initiatives, SALT farms are practiced by many farmers in Lunglei and Aizawl districts of Mizoram. This study is an effort to compare the level of soil fertility in these two common practices (abandoned land following shifting cultivation and settled SALT farm) of the state where no information is available.

Therefore, this study compared the level of soil fertility (organic C and total N), rates of organic matter and C and N release pattern, and quantitative and qualitative changes in water stable soil aggregates in different abandoned land following (fallow lands) shifting cultivation and two ages of settled SALT systems. The effect of forest degradation has been well reported for changes in plant diversity and aboveground plant biomass (Singh *et al.*, 2014). The experimental findings of the present work are discussed as follows:

5.1. Soil characteristics of different shifting and settled farm

The findings of the present study showed that there is a drastic change in the physicochemical and biochemical properties of soil in 0-10 cm depth among the different sites in Lengpui and Pukpui. Some other studies found that soil nutrients content in many ecosystems increases with forest age (Werner, 1984; Silver *et al.,* 1996). Clearing and cultivation of forested lands resulted in deterioration of soil properties compared to soils under well-stocked natural forest. Among the four sites at Lengpui, significant seasonal variations ($P<0.001$) soil organic carbon (SOC) was observed at all sites. Soil organic C content was comparatively lower during the winter season and an increasing trend was observed towards post-monsoon season. This may be due to the high litter input and the deposits of mineralized C of the preceding rainy season during dry winter season as low soil temperature and low moisture reduces the microbial enzymatic activity of litter decomposing enzymes because most of the enzymes are hydrolytic in nature.

Soil moisture content in monsoon and post-monsoon seasons was highest in Reference forest and lowest in 5 yrs fallow land. This may be attributed to the thick canopy of the reference forest which reduces evaporation and increased high water retention by soil organic matter. On the other hand, the low soil moisture content at 5 yrs fallow may be due to direct exposure of forest ground to sunlight because of sparse vegetation and low soil organic content. The soil moisture content decreases as a function of increasing degree of disturbance, which is maximum in monsoon season and minimum in dry seasons in all sites. The higher moisture content during monsoon seasons is related to high and regular rainfall.

Soil moisture may also be responsible for the seasonal variations in MBC in different forest stands, as soil water content was significantly related to MBC concentrations (Chen *et al.,* 2003; Bohlen *et al.,* 2001). Litter accumulation on the forest floor is positively linked with litter decomposition and plays a significant role in the maintenance of soil moisture content and other microclimatic conditions (Ramakrishnan and Toky, 1981; Arunachalam *et al.*, 1996; Reddy, 2010; Mishra, 2010; Tripathi *et al.,* 2012). Nayak and Srivastava (1995) have also reported a similar trend from the humid sub tropical soils in north east India. Higher mineralization rates in the wet season might also be due to elevated soil temperature and moisture content during this period in the forest ecosystems (Cassman and Munns, 1980; Eghball, 2000; Numan *et al.*, 2000).

Significant variations (P<0.001) was observed in soil organic content among the different sites of Lengpui. Short fallow (5 yrs old) showed lowest soil organic carbon content followed by 10 yrs old fallow land, 14 yrs old fallow land and highest in Reference forest in all seasons. Compared to the four shifting fallow sites at Lengpui, the two sites aged 10 years after cultivation and aged 2 years after cultivation at Pukpui showed lower seasonal variations. A similar trend as that of Lengpui was observed in the two sites of Pukpui with the lowest value during the winter season and increasing towards post-monsoon season. This reflects that the amount of C accumulates during the process of stand development in fallow land and time since the cultivation in SALT farm due to significant litter input every year. Seasonal variations in soil C content in the four fallow lands at Lengpui was higher than that of the two settled SALT farms at Pukpui. It may be due to the land use systems adopted at Pukpui where continuos addition of C by *Tephrosia candida* and *Flemingia macrophylla* hedgerow and occasional exogenous input in the form of dung by the farmers.

The similar seasonal pattern has been observed for soil N in all these sites where in addition to above inputs N fixation by two species growing in the hedgerows has been found to play an important role in the N dynamics. Soil total N is either derived from the organic matter or eventually added to the soil organic matter through fixation by microbes and become available to the plants. The rate of total N was recorded highest during the rainy season in all the study sites in Lengpui and Pukpui. Higher mineralization rates in the wet season might also be due to elevated soil temperature and moisture content during this period in the forest ecosystems (Cassman and Munns, 1980; Eghball, 2000; Numan *et al*, 2000). Minimum mineralization rates during the winter period could be associated with the low decomposition rates because of low microbial activities and greater immobilization of inorganic N (Bhuyan *et al.*, 2014).

Soil pH is mostly related to the nature of the parent material, climate, organic matter and topographic situation (Tamirat, 1992). The pH of the soil of all the sites in Lengpui and Pukpui varied from (4.6 to 5.6) and the increase in the pH scale with a degree of disturbance was noted. Among all the sites, lower values of soil pH in the reference forest and 14 years old fallow land in Lengpui could be a result of the greater accumulation of partially decomposed organic matter on the sites. Intense runoff and leaching of basic cations during the monsoons may also be likely contributing factors to lower pH levels in these soils (Hassan and Majumder, 1990).

5.2. Litter decomposition, and C and N release

Among all litter categories in shifting fallow lands at Lengpui and settled farm at Pukpui sites, the decomposition rate of root was highest which was possibly because of lower lignin to nutrient ratios in the root material than other litter category. Lignin has been reported to significantly affected litter decomposition and C and N release pattern in different ecosystems (Tripathi and Singh 1992 a, b; Tripathi *et al.*, 2006; Pandey *et al.*, 2007). Roots differed from leaves and woody parts of plants in their nutrient release patterns, which is in accordance with Tripathi and Singh (1992 a, b). The decomposing roots were buried and thus experienced different moisture conditions, different microbial communities, and closer proximity to mineralized nutrients than other category of litters. Decomposition rate may be influenced by a characteristic such as leaves type, sclerophylla and root diameter class (Berg, 1984; McClaugherty *et al.*, 1984; Fahey *et al.*, 1988); Metrosideros is fairy sclerophyllous leaf (Cordell *et al.*, 1998). Parton *et al.*, (2007) observed that leaf and root decomposition were slowest in cold dry regions such as tundra and boreal forests and fastest in tropical regions. This may be due to the low litter decomposition rate during dry winter as low temperature reduces microbial activity and also low moisture content reduces the enzymatic activity of litter decomposing enzymes.

Rapid litter decomposition during the first phase are mainly due to easy decomposability od molecules rich in energy and the period of incubation is monsoon season which was influenced by the rainfall. Therefore, enhanced microbial activity of decomposer organisms coupled with favourable climatic variables increases the rate of decomposition in the early stage. However, slower decomposition in the later stage of decomposition was because of the breakdown of lignin consists of very large and complex molecules in the post monsoon period i.e. (winter and summer) along with low precipitation. Root having low cellulose contents decomposed faster rate (Tripathi and Singh, 1992 a, b).

Fine roots and leaf litter showed a higher rate of decomposition of organic C and total N than other litter components in all the study sites. Knorr *et al.,* (2005) reported that litter decomposition is inhibited by N additions when fertilization rates exceed by 2 to 20 times the atmospheric N deposition level. The decomposition rates and initial chemical characteristics of roots were also consistent with the range of values reported in the limited number of root decomposition studies conducted in forests (e.g., Berg, 1984; McClaugherty, *et al.*, 1984; Fahey *et al.*, 1988; Aber *et al.*, 1990; Bloomfield *et al.*, 1993; Camire *et al.*, 1991; Burke and Raynal, 1994; Lohmus and Ivask, 1995). Other studies on leaves have also suggested that soil environment did not influence decomposition rates as strongly as tissue chemistry. For example, in Wisconsin hardwood forests in which leaf litter (*Acer saccharum*) was decomposed along a natural fertility gradient (McClaugherty *et al.*, 1985), site effects were found to be negligible.

The highest litter decomposition rates in the wet season reflect the favorable effect of rainfall and associated variables on the decomposition of different sizes of all litter components in all the sites. However, lower soil moisture and temperature during winter reduced the activity of microorganisms (decomposers) in the soil which therefore reduced the rates of decomposition (Tripathi and Singh, 1992 a, b). In the present study rainfall and its associated variables (soil moisture, humidity) are considered to play a vital role in the process of decomposition as compared to air temperature. Direct influences of moisture contents on fine root respiration; have been previously observed by Chen *et al.*, (2000) for unsaturated soils. Higher organic C and total N were found in the all litter component of Pukpui site because *Tephrosia candida* and *Flemingia macrophylla* are nitrogen fixing plants.

5.3. Soil aggregates in different fallow and settled SALT farm

The depth of sampling of soil is an important factor for evaluating soil stability. The averages of all the size ranges in macro and micro aggregates showed high organic content in Reference forest and 14 yrs fallow of Lengpui and 2002 site of Pukpui. There was considerable site to site variability in the amount of microbial C and N associated with macro and micro-aggregates. Wardle (1992) concluded that different cover plants grown on similar soil types often support different amounts of microbial biomass and that this reflects both the amount and quality of organic matter returned to the soil. Sites which were poorer in total soil C and N exhibited greater C and N immobilization. The microbial C and N limitation declines as more C and N becomes available (Wardle, 1992). Several studies suggested plant roots were important binding agents at the scale of macro-aggregates (e.g. Thomas *et al.,* 1993). The direct effect of roots on aggregation was the greatest with perennial vegetation species due to the enhancement of their extensive fine root systems with soil.

Among all the sites in Lengpui and Pukpui, organic carbon (g. kg^{-1}) in soil macro-aggregates and micro-aggregates were highest in reference forest i.e 29.56 and 22.11 in reference forest. Corresponding values of total nitrogen (g. kg^{-1}) in macro-aggregates and micro-aggregates in reference forest were: 2.44 and 2.21. There are reports that fungi dominate in macro-aggregates and bacteria dominate in micro-aggregates (Tisdall and Oades, 1982). The presence of bacteria within micro-aggregates has been demonstrated by electron microscopy (Foster, 1988; Gupta and Germida, 1988). Soil management systems such as cultivation and irrigation can alter soil particle distribution through the soil profile (Jaiyeoba, 2003). Cote *et al.,* (2000) found soil carbon and nitrogen mineralization are related to forest type and age. Jia *et al.,* 2005 suggested soil organic carbon and total nitrogen increased quickly with secondary forest succession. The proportion of silt-plus-clay in aggregates is negatively related to the SOC content as it plays an important role in the protection and stabilization of soil C. Six *et al.,* (2002) suggested that silt- and clay-protected soil organic matter (SOM) is one of the three protected SOM pools. The C in this smallest fraction size is more stabilized than the other size classes (Wilson *et al.,* 2009; Six *et al.,* 2002; 1998). The stabilization of soil organic C by association with silt- and clay-sized particles is directly related to the silt-plus-clay content of the soil (Six *et al.,* 2002).

The duration of cultivation has a significant effect on soil particle distribution. Jaiyeoba (2003) reported that clay contents of deeper samples increase with the length of cultivation due to clay translocation from the surface horizon. However, Paz- Gonzalez *et al.,* (2000) found that particle size fractions were not significantly different under contrasting management practices (natural vegetation and cultivated field).

Cultivation practices disturb soil aggregates releasing C from physical protection and proportionally increases mineralizable organic C (Kocyigit and Rice, 2004). Some studies report a significant reduction of macroaggregates in agricultural lands (Janzen *et al.*, 1992; Cambardella and Elliott, 1992). Cultivation generally decreases macroaggregate stability and results to increase of relatively stable microaggregates (Six *et al.,* 1999; 2000). Generally, water-stable aggregates provide physical protection for C and reduce soil erodibility, which is enhanced by root and faunal activity. Penetration of root in the soil decreases the proportion of relatively unstable macroaggregates and increases the proportion of relatively stable microaggregates (Six *et al.,* 2004). In the study site, the fine root biomass increased with the forest age and with age of the settled SALT farming practices. This report is in conformity with the report of Wen *et al.*, (1999). Fine roots probably influenced the soil structure around the roots and induced the formation of microaggregates through colonization of microorganisms.

Zheng *et al.,* (2011b) reported that the conversion of cropland to forest land improved soil structure and nutrient content. After the vegetation recovery, soil physical structure degradation was limited, thus the soil was likely to have low infiltration rates and prone to erosion. The size of the aggregates influences the metabolic activity and type of soil organisms, and the pore space and hydric regime of soils (Robert & Chenu, 1995; Monreal and Kodama, 1997). Along with variation in aggregate size, the nutrient addition may change the quality of soil aggregate because of varying association of organic compound. Higher contents of total N in soil macro- and microaggregates was found in settled SALT farm at Pukpui site which may be because of nitrogen fixing shrubs (*Tephrosia candida* and *Flemingia macrophylla*) planted as as hedgerow.

Chapter 6

Summary and conclusions

Mizoram has very high forest cover (~89%) but majority are secondary forests as abandoned fallow lands following shifting cultivation practiced by the majority of population for their livelihood. Increased population pressure in recent years has led to decrease in the length of fallow (<5 years), which consequently posed serious economic and social problems as a result of decreased soil fertility. Therefore, the Government of Mizoram and public are trying to convert this practice into the settled farm, e.g. SALT farms. This study compared the level of soil fertility in these two common practices (abandoned land following shifting cultivation and settled SALT farm) of the state where information is scanty.

Therefore, this study compared the levels of soil fertility (organic C and total N), rates of organic matter and C and N release pattern, and quantitative and qualitative changes in water stable soil aggregates in different abandoned land following (fallow lands) shifting cultivation and two ages of settled SALT systems. The effect of forest degradation has been well reported for changes in plant diversity and aboveground plant biomass (Singh *et al.*, 2014). Soil management systems such as cultivation and irrigation can alter soil particle distribution through the soil profile (Jaiyeoba, 2003). Land use change from forest to a multitude of ecosystem types and in addition of N and P have been reported to significantly alter quantitative and qualitative changes in soil aggregates in dry tropical ecosystems (Tripathi *et al.*, 2008). The duration of cultivation has a significant effect on soil particle distribution and levels of soil fertility in different ecosystems.

A total of four sites 3 fallow lands of different ages and natural forest in Lengpui and two sites of different ages (since they have been cultivated) of SALT farms were selected in Pukpui, Lunglei district. The two groups of land use systems have different ecological characteristics because of changes in the litter input rates due to fallow ages and establishment of hedgerows of two N fixing shrubs *Flemingia macrophylla* and *Tephrosia candida*.

The aims of this experiment were to compare the level of soil fertility (organic C and total N) and to assess quantitative and qualitative changes in water stable soil aggregates in different fallow periods in shifting cultivation and in varying ages of settled agriculture systems. Soil total N and organic C were studied from 10 cm soil depth from all the selected sites in Pukpui and Lengpui.

This study has shown that among all the different sites in Lengpui and Pukpui, highest (38.80%) seasonal change in soil total C occurred in 5 years old fallow land at Lengpui (2.01-2.79%) and lowest (4.9%) in 2 years old SALT farm at Pukpui site (2.67 - 2.80%). Seasonal changes in soil total nitrogen followed the pattern similar to total C. Among all the sites in Lengpui and Pukpui total C (g. kg^{-1}) in soil macroaggregates were highest in reference forest (29.56) and lowest in 5 years old fallow land (6.52). Total C (g. kg^{-1}) in microaggregates was highest in reference forest (22.1) and lowest in 2 years settled SALT farm at Pukpui (7.35). Total nitrogen (g. kg^{-1}) in soil macroaggregates was highest in reference forest (2.44) and lowest in 5 years old fallow land (0.62). Total nitrogen (g. kg^{-1}) in soil microaggregates was highest in reference forest (22.11) and lowest in age 2 settled SALT farm Pukpui site (7.35). The difference in soil C and soil moisture contents in soil geomorphological units may explain the unequal soil aggregate distribution. This result indicates that land use change strongly modified soil properties and soil aggregation in different ages of fallow land and in the settled farm. Most of the soil C was stored in macroaggregates and the greatest quantities of this were found in the reference forest. Therefore, macroaggregates play a critical role in C sequestration in natural forest ecosystems, and are more sensitive to changes of soil management. Thus conversion of natural forest to cropland resulted in a significant reduction in the proportions of soil aggregates and soil C and N in aggregates and this may significantly contribute to global warming.

The rate of litter decomposition and C and N release pattern of common tree litter from fallow lands following shifting cultivation and *Tephrosia candida* and *Flamingia macrophylla* from settled SALT farm were determined. Different category of litter; aboveground litter (mature senesced leaves attached to the plant, freshly fallen leaf litter samples and recently dead wood branches still attached to the culm) and below ground (coarse root $\leq$5-10mm in diameter and fine root $\leq$2mm in diameter) were selected from all the sites to analysed the rate of litter decomposition and C and N release by using litter bag technique. The major findings are summarized below:

Litter decomposition rates were highest in the reference forest compared to other sites. Decomposition during the first stage was rapid because the period of incubation is monsoon season and the rainfall influenced the rate of decomposition and the molecules are easy to breakdown and rich in energy. However, the later stage of litter decomposition rate was lower. Decomposition rate was slowest during the dry season.

Among all different litter components, fine root litter showed highest rates of decomposition and branches of nitrogen fixing shrub shows lowest rate of decomposition in all the study sites. High reduction C and N release occurred at the first recovery for all litters. About 30-50% of C and N remained at the end of recovery for all litter types. Among the litter component fine root of *F. macrophylla* shows comparatively greater amount of C release pattern than *T. candida* in both the study sites. In conclusion, settled SALT farm is aggrading soil fertility during the course of farming practice and it is recommended as the sustainable farming system in the region. Abandoned fallow lands following shifting cultivation work well after about decade so needs proper time to sustain soil fertility.

Table 6.1. Comparative accounts of soil fertility levels of two ecosystems studied.

	Settled agriculture			Shifting fallow land				Ref forest
Soil fertility parameters	2yrs	10yrs	Mean	5yrs	10yrs	14yrs	Mean	
1) Seasonal changes in soil organic carbon (%)								
Winter	2.67 ±0.017	2.74 ±0.013	2.7	2.01 ±0.051	2.12 ±0.025	2.23 ±0.006	2.12	2.55 ±0.104
Summer	2.73 ±0.045	2.79 ±0.017	2.7	2.71 ±0.045	2.72 ±0.048	2.95 ±0.064	2.79	3.05 ±0.064
Monsoon	2.79 ±0.065	2 .81 ±0.030	2.8	2.78 ±0.010	2.89 ±0.007	3.07 ±0.050	2.91	3.17 ±0.085
Post monsoon	2.8 ±0.025	2.89 ±0.012	2.8	2.79 ±0.006	2.83 ±0.022	3 ±0.040	2.87	3.15 ±0.064
2) Seasonal changes in soil nitrogen (%)								
Winter	0.29 ±0.006	0.35 ±0.014	0.32	0.3 ±0.006	0.33 ±0.004	0.34 ±0.017	0.32	0.35 ±0.006
Summer	0.3 ±0.003	0.36 ±0.012	0.33	0.32 ±0.008	0.33 ±0.006	0.35 ±0.006	0.35	0.36 ±0.004
Monsoon	0.3 ±0.004	0.36 ±0.013	0.33	0.37 ±0.006	0.38 ±0.004	0.39 ±0.004	0.38	0.4 ±0.004
Post monsoon	0.32 ±0.11	0.39 ±0.002	0.35	0.39 ±0.004	0.4 ±0.004	0.4 ±0.004	0.39	0.41 ±0.006
3) Seasonal changes in soil moisture content (%)								
Winter	22	24	23	20	23	21	21.3	24
Summer	32	33	32.5	25	27	29	27	35
Monsoon	44	48	46	36	37	41	38	49
Post monsoon	41	45	43	34	35	37	35.3	46
4) Soil pH value								
	4.7	4.6	4.7	5.6	5.1	4.93	5.24	4.7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SALT FARM
PASS NO - 128/87
AREA - 3 Hactares
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REFERENCES

Aber J.D., Melillo J.M., Mc Claugherty C.A. (1990). Predicting longterm patterns of mass loss, nitrogen dynamics, and soil organic matter formation from initial fine litter chemistry in temperate forest ecosystems. *Canadian Journal of Botany* **68:** 2201–2208.

Achard F., Eva H.D., Stibig H.J., Mayaux P., Gallego J., Richards T. and Malingreau J. (2002). Determination of Deforestation Rates of the World's Humid Tropical Forests. *Science* **297:** 999–1002.

Ajwa H.A., Rice C.W., Sotomayor D. (1998). Carbon and nitrogen mineralization in tall grass prairie and agricultural soil profiles. *Soil Science Society of America Journal* **62:** 942–951.

Allison S.D. and Vitousek P.M. (2005). Responses of extracellular enzymes to simple and complex nutrient inputs. *Soil Biology & Biochemestry* **37:** 937-944.

Alves D.S., Soares J.V., Amaral S., Mello E.M.K., Almeida S.A.S., da Silva O.F. and Silveira A.M. (1997). Biomass of primary and secondary vegetation in Rondonia, western Brazilian Amazon. *Global Change Biology* **3**: 451–461.

Amor D. (2008). *Road impact on deforestation and jaguar habitat loss in the Sel Maya.* Ph. D. dissertation. Ecology Department, Nicholas School of the Environment, Duke University.

Amor D. and Pfaff A. (2008*). Early history of the impact of road investments on deforestation in the Mayan forest.* Working Paper, Nicholas School of the Environment and Sanford School of Public Policy, Duke University, Durham, NC, USA.

Anihara J., Ae N. and Okada K. (1991). Root development of pigeon pea and chickpea and its significance in different cropping system. In: Phosphorus nutrition of grain legumes in the semi-arid tropics (Johanson, C., Lee K.K. and Sahrawat, K.L. Eds), ICRISAT, pp. 183-194.

Anonymous (1987). *Basic statistic for north eastern region* (Shillong: North–Eastern Council).

Anonymous (2002). Forest certification and biodiversity: opposites or complements. Discussion paper prepared for the GEF*, International Tropical Timber Organization*, Yokohama Japan.

Anonymous (2005). *Ecosystems and Human well-being: synthesis*. Millennium ecosystem Assessment. Island Press, Washington DC.

Anonymous (2006). Statisical Hand Book of Mizoram, (2006). Directorate of Economics & Statistics, Ail, Mizoram, India. pp. 5 and 106.

Aoyama M., Angers D.A., N'dayegamiye A. and Bissonnette N. (1999). Protected organic matter in water-stable aggregates as affected by mineral fertilizer and organic application. *Canadian Journal of Soil Science* **79:** 419–425.

Arunachalam A., Maithani K., Pandey H.N. and Tripathi R.S. (1996). The impact of disturbance on detrital dynamics and soil microbial biomass of *a PinusKesiya* forest in northeast India. *Forest Ecology and Management* **88:** 273 – 282.

Arunachalam A., Pandey H.N., Tripathi R.S. and Maithani K. (1996). Biomass and production of fine and coarse roots during regrowth of a disturbed subtropical humid forest in north-east India. *Vegetatio* **123:** 73-80.

Arunachalam K., Arunachalam A., Tripathi R.S. and Pandey H.N. (1997). Dynamics of microbial population during the aggregation phase of a selective logged sub-tropical humid forest in North east India. *Tropical Ecology* **38**: 333-341.

Balesdent J., Besnard E., Arrouays D., Chenu C. (1998). The dynamics of carbon in particle size fractions of soil in a forest cultivated sequence. *Plant and Soil* **201:** 49–57.

Balesdent J., Chenu C., Balabane M. (2000). Relationships of soil organic matter dynamics to physical protection and tillage. *Soil &Tillage Research* **53:** 215–230.

Balmford A. and Bond, W. (2005). Trends in the state of nature and their implications for human well-being. *Ecology Letters* **8:** 1218–1234.

Barah B.C. (2006). Agricultural Development in North-East India: Challenges and Opportunities. National Centre for Agricultural Economics and Polocy Research, Library Avenue, Pusa, New Delhi.

Bartelink H. H. (1998). A model of dry matter partitioning in trees. *Tree Physiology* **18:** 91-101.

Barthes B., Roose E. (2002). Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. *Catena* **47:** 133–149.

Beare M., Cabrera M., Hendrix P., Coleman D. (1994). Aggregate protected and unprotected organic matter pools in conventional and no-tillage soils. *Soil Science Society of America Journal* **58:** 787–795.

Berg B. and Staaf H. (1981). Leaching accumulation and release of Nitrogen in decomposing forest litter. In: Terrestrial Nitrogen Cycle. Processes, Ecosystem, Strategies and Management Impacts. Clark F.E. and Rosswall T. (eds.) Ecol. Bull (Stockholm) **33:** 163-178.

Berg B. (1984). Decomposition of root litter and some factors regulating the process: long-term root litter decomposition in a Scots pine forest. *Soil Biology and Biochemistry* **16:** 609–617.

Berg B., Calvo de Anta R., Escudero A., Gardenas A., Johansson M.B., Laskowski R., Madeira M., Malkonen E., McClaugherty C., Meentmeyer V. and Virzo De Santo A. (1995). The chemical composition of newly shed needle litter of Scots pine and some other pine species forest. *Canadian Journal of Botany* **73:** 1423-1435.

Bhuyan S.I., Tripathi O.P. and Khan M.L. (2004). Effect of season, soil and land use pattern on soil N-mineralization, Ammonification and Nitrification: A study in Arunachal Pradesh,Eastern Himalaya. *International Journal of Environmental Science,* **5:** 1.

Billings S. (2006). Soil organic matter dynamics and land use change at a grassland/forest ecotone. *Soil Biology & Biochemistry* **38:** 2934–2943.

Binkely D. and Vitousek P. (1989). Soil nutrient availability. In: Pearcy, R.W., Ehloringer, J., Monney, H.P., Rundel, P.W. (Eds.), Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall, London, pp. 75-96.

Blanco-Canqui H., Lal R. (2004). Mechanisms of carbon sequestration in soil aggregates. *Critical Reviews in Plant Sciences* **23:** 481–504.

Bloomfield J., Vogt KA., Vogt D.J. (1993). Decay rate and substrate quality of fine roots and foliage of two tropical tree species in the Luquillo Experimental Forest, Puerto Rico. *Plant Soil* **150:** 233–245.

Bohlen P.J., Groffman P.M., Driscoll C.T., et al. (2001). Plant-soil-microbial interactions in a northern hardwood forest. *Ecology* **82:** 965–78.

Borthakur D.N., Prasad R.N., Ghosh S.P., Singh A., Awasthi R.P., Rai R.N., Varma A., Datta H.H., Sachan J.N. and Singh M.D. (1979). Agro forestry based farming system as an alternative to Jhuming. Reprinted from Seminar Proceedings on Agro-forestry organised by ICAR at Imphal, Manipur, Pp. 32p

Bossuyt H., Six J., Hendrix P.F. (2005). Protection of soil carbon by microaggregates within earthworm casts. *Soil Biology & Biochemistry* **37:** 251–258.

Boucher D., Elleas P., Lininger K., May Tobin C., Roquemore S., Saxon E. (2011). The root of the problem: What's Driving Tropical Forest Today? Union of Concerned Scientists Cambridge, Massachusetts.

Boyero L., Cardinale B.J., Bastian M. and Pearson R.G. (2014). Biotic vs. Abiotic Control of Decomposition: A Comparison of the Effects of Simulated Extinctions and Changes in Temperature. PLOS ONE 9(1): e87426. doi:10.1371/journal.pone.0087426.

Boyero L., Pearson R.G., Gessner M.O., Barmuta L.A. and Ferreira V. (2011). A global experiment suggests climate warming will not accelerate litter decomposition in streams but may reduce carbon sequestration. *Ecology Letters* **14:** 289–294.

Brady N.C. (1996). Alternatives to slash-and-burn: A global imperative. *Agroforestry Ecosystem Environment* **58**: 3–11.

Bronick C.J., Lal R. (2005). Soil structure and management: A review. *Geoderma **124*****:** 3–22.

Brown J.H., Gillooly J.F., Allen A.P., Savage V.M. and West G.B. (2004). Toward a metabolic theory of ecology. *Ecology* **85:** 1771–1789.

Brown S. and Lugo A. E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* **14:**161-187.

Brown S., Iverson L. R., Prasda, L. and Liu D. (1993). Geographical distributions of carbon in biomass and soils of tropical Asian forests. *Geocarto International* **8:** 45-59.

Bruun T.B., Mertz O. and Elberling B. (2006). Linking yields of upland rice in shifting cultivation to fallow length and soil properties. *Agricultural Ecosystem Environment* **113**: 139–149.

Burke M.K., Raynal D.J. (1994). Fine root growth, phenology, production, and turnover in a northern hardwood forest ecosystem. *Plant Soil* **162:**135–146.

Cambardella C.A., Elliott E.T. (1992). Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Science Society of America Journal* **56:** 777–783.

Camire C., Cote B., Brulotte S. (1991). Decomposition of roots of black alder and hybrid poplar in short-rotation plantings: nitrogen and lignin control. *Plant Soil* **138:**123–132.

Campbell C.A. (1978). Soil organic carbon, nitrogen and fertility. In Soil Organic Matter, Schnitzer M, Khan SU (eds). Elsevier Scientific: Amsterdam; 173–271.

Carter M.R., Gregorich E.G., Anderson D.W., Doran J.W., Janzen H.H. and Pierce F.J. (1997). Concepts of soil quality and their significance. In Gregorich, E.G., and Carter, M.R. (eds.), Soil Quality for Crop Production and Ecosystem Health. *Elsevier, Amsterdam* pp. 1–19.

Cassman K.G. and Munns D.N. (1980). Nitrogen mineralization as affected by soil moisture, temperature and depth. *Soil Science Society of America Journal* **44:** 1233-1237.

Certini G. (2005). Effects of fire on properties of forest soils: a review. *Oecologia* **143:** 1–10.

Champion H. and Seth S.K. (1968). *A revised survey of forest types of India*. Government of India Press, New Delhi.

Chaudhary S.K. and Rai M. (2007). Biofertilizers: A boon to vegetable production. *Agrobios Newsletter* 5(10):17.

Chen C.R., Xu Z.H., Blumfield T.J. (2003). Soil microbial biomass during the early establishment of hoop pine plantation: seasonal variation and impacts of site preparation. *Forest Ecology and Management* **186:** 213–25.

Chen H., Gurmesa G.A., Liu L., Zhang T. and Fu S. (2014). Effects of Litter Manipulation on Litter Decomposition in a Successional Gradients of Tropical Forests in Southern China. PLoS ONE 9(6): e99018. doi:10.1371/journal.pone.0099018.

Chen H., Harmon M.E., Griffiths R.P., Hicks W. (2000). Effects of temperature and moisture on carbon respired from decomposing woody roots. *Forest Ecology and Management* **138:** 51–64. doi: http://dx.doi.org/10.1016/S0378-1127(00)00411-4.

Chenu C. (1993). Clay- or sand-polysaccharide associated as models for the interface between microorganisms and soil-water related properties and microstructure. *Geoderma* **56:** 143–156.

Comte I., Davidson R., Lucotte M., de Carvalho C.J.R., de Assis O.F., da Silva B.P. and Rousseau G.X. (2012). Physicochemical properties of soils in the Brazilian Amazon following fire-free land preparation and slash-and-burn practices. *Agriculture Ecosystem & Environment* **156:** 108–115.

Cordell S., Goldstein D., Mueller-Dombois D., Webb D., Vitousek P.M. (1998). Physiological and morphological variation in *Metrosideros polymorpha*, a dominant Hawaiian tree species along an altitudinal gradient: the role of phenotypic plasticity. *Oecologia* **113:** 188–196.

Cornwell W.K., Cornelissen J.H.C., Amatangelo K., Dorrepaal E., Eviner V.T., Godoy O., Hobbie S.E., Hoorens B., Kurokaw H., Perez H.H., Quested H.M., Santiago L.S., Wardle D.A., Wright I.J., Aerts R., Allison S., van Bodegom P.M., Brovkin V., Chatain A., Callaghan T.V., Diaz S., Garnier E., Gurvich D.E., Kazakou E., Klein J., Read J., Reich P.B., Soudzilovskaia N.A., Vaieretti M.V. and Westoby M. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology Letters* **11:** 1065–71.

Cossalter C. and Pye-Smith C. (2003). Fast-wood forestry, myths and realities. Forest Perspectives no. 1, CIFOR, Bogor Indonesia. Pp.54. **DOI:** 10.17528/cifor/001257

Cote L., Brown S., Pare D., Fyles J., Bauhus J. (2000). Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood. *Soil Biology & Biochemistry* ***32*****:** 1079–1090.

Craswell E.T., Sajjapongse A., Howlett D.J.B. and Dowling A.J. (1997). Agroforestry in the management of slopping lands in Asia and the pacific. *Agroforestry system* **38:** 121-137.

Cusack D.F., Chou W.W., Yang W.H., Harmon M.E., Silver W.L., Team T.L. (2009). Controls on long-term root and leaf litter decomposition in neotropical forests. *Global Change Biology* **15:** 1339-1355.

Davidson E.A. and Ackerman I.L. (1993). Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils. *Biogeochemistry* **20:** 161–193.

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

Davies O. (2001). A Theology of compassion. Metaphysics of Difference and renewal of tradition. Grand Rapids: Eardmans.

DeBano L.F., Neary D.G. and Ffolliott P.F. (1998). Fire’s effects on ecosystems. John Wiley and Sons, New York.

Deka and Sarmah D. (2010). Shifting cultivation and its effects in regarding of perspective in Northern India. *International Journal of Commerce and Business Management* **3(2):** 157-165.

Detwiler R. (1986). Land Use Change and the Global Carbon Cycle: The Role of Tropical Soils. *Biogeochemistry* **2:** 67–93.

Dobermann A. and Nelson R. (2013*). Opportunities and Solutions for Sustainable Food Production*. Background paper for the High-Level Panel of Eminent Persons on the Post-2015. Pp.1- 11.

Doran J.W. and Parkin T.B. (1994). Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., and Steward, B.A. (eds.), Defining Soil Quality for Sustainable Environment. *Soil Science of America* Madison, pp. 3–21Special publication No 35.

Duffkova R., Kvitek T., Voldrichova J. (2005). Soil organic carbon and nitrogen characteristics in differently used grasslands at sites with drainage and without drainage. *Plant, Soil and Environment* **51:** 165–172.

Dwivedi A.P. (2001). *Agroforestry Principles and Practices*, (Oxford & IBH Publishing Company Private Limited, New Delhi), pp- 365.

Eghball B. (2000). Nitrogen mineralization from field-applied beef cattle feedlot manure and compost. *Soil Science Society of America Journal* **64:** 2024-2030.

Elliott E.T. (1986). Aggregate structure and carbon, nitrogen and phosphorus in native and cultivated soils. *Soil Science Society of America Journal* **50:** 627–633.

Emadi M., Baghernejad M., Fathi H., Saffar M. (2008). Effects of land use change on selected soil physical and chemical properties in north highlands of Iran. *Journal of Applied Sciences* **8:** 496–502.

Facelli J.M. and Pickett S.T.A. (1991). Plant litter: its dynamics and effects on plant community structure. *Botanical Review* **57:** 1–32.

Fahey T.J., Hughes J.W., Pu M., Arthur MA.. (1988). Root decomposition and nutrient flux following whole-tree harvest of northern hardwood forest. *For Science* **34:** 744–768.

FAO (1957). Shifting cultivation. Unasylva **11:** 9-11.

Fioretto A., Musachio A., Andolfi A. and Virzo De Santo A. (1998). Decomposition dynamics of litters of various pine species in a Corsican pine forest. *Soil Biology Biochemistry* **30:** 721-727.

Fioretto A., Papa S. and Fuggi A. (2003). Litterfall and litter decomposition in a low Mediterranean shrub land. *Biology and Fertility of Soils* **39:** 37-44.

Foster R.C. (1988). Microenvironment of soil microorganisms, *Biology and Fertility of Soils* **6:** 189-203.

Fransson P.M.A., Taylor A.F.S. and Finlay, R.D. (2000). Effects of continuous optimal fertilization on belowground ectomycorrhizal community structure in a Norway spruce forest. *Tree Physiology* **20:** 599–606.

Fritze H., Smolander A., Levula T., Kitunen V. and Malkonen E. (1994). Wood–ash fertilization and fire treatments in a Scots pine forest stand: effects on the organic layer, microbial biomass and microbial activity. *Biology and Fertility of Soils* **17:** 57–63.

Funakawa S., Hayashi Y., Tazaki I., Sawada K. and Kosaki T. (2006). The main functions of the fallow phase in shifting cultivation by the Karen people in northern Thailand: a quantitative analysis of soil organic matter dynamics. *Tropics* **15:** 1–27 doi:**10.3759**/tropics.15.1.

Gafur A. (2001). Effects of shifting cultivation on soil properties, erosion, nutrient depletion, and hydrological responses in small watershed of the Chittagong Hill Tracts of Bangladesh. PhD Dissertation, The Royal Veterinary and Agricultural University, Copenhagen.

Garrity D.P. (1993). Sustainable land-use systems for sloping uplands in South East Asia. In: Ragland, J., Lal, R. (eds.), *ASA Special Publication No* **56:** 41–66.

Gessner M.O., Swan C.M., Dang C.K., McKie B.G. and Bardgett R.D. (2010). Diversity meets decomposition. *Trends in Ecology and Evolution* **25:** 372–380.

Giardina C.P., Sanford Jr., Robert L., Dockersmith, I.C. and Jaramillo V.J. (2000). The effects of slash burning on ecosystem nutrients during the land preparation phase of shifting cultivation. *Plant Soil* **220:** 247–260.

Gibbs H.K., Brown S., Niles J.O. and Foley J.A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters* **2:** 045023–045036.

Giregon O., Daniel H., Lockwood P., McHenry M. and McLeod M. (2010). Root contributions to long-term storage of soil organic carbon: theories, mechanisms and gaps. 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia.

Goswami P.C. (1968). *Shifting Cultivation and its Control in the Garo Hills*, (Soil Conservation Department of Assam).

Gower S. T., Gholz H. L., Nkane K. and Baldwin V. C. (1994). Production and allocation patterns of pine forests. *Ecological Bulletin* **43:** 115-135.

Gower S.T. (1987). Relations between mineral nutrient availability and fine root biomass in two Costa Rican tropical wet forests: A hypothesis. *Biotropica* **19:** 171-175.

Gregory P.J., Ingram J.S. and Kobayashi T. (2000). Rice production and Global change. *Global Environronment &. Research* **2:** 71-77.

Grogan P., Lalnunmawia F., and Tripathi S.K. (2012). Shifting cultivation in steeply sloped regions: A review of management options and research priorities for Mizoram state, Northeast India. *Agroforestry System* **84**: 163–177.

Gupta V. V. S. R. and Germida J. J. (1988). Distribution of microbial biomass and its activity in different soil aggregate size classes and affected by cultivation. *Soil Biology & Biochemistry* **20:** 777-786.

Hao Y., Lal R., Owens L.B., Izaurralde R.C., Post W.M., Hothem D.L. (2002). Effect of crop land management and slope position on soil organic carbon pool at the North Appalachian experimental watersheds. *Soil & Tillage Research* **68:** 133–142.

Harmon M.E., Franklin J.F., Swanson F.J., Sollim P., Gregory S.V., Lattin J.D., Anderson N.H., Cline S.P., Aumen N.G., Sedel J.R., Lienkaemper G.W., Cromack K. and Cummins K.W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advanced Ecological Research* **15:** 133-302.

Harris J. (2009). Soil microbial communities and restoration ecology: Facilitators or followers? *Science* **325**: 573-574.

Hassan M.M. and Majumder A.H. (1990). Distribution of organic matter in some representative forest soils of Bangladesh. *Indian Journal of Forestry* **13:** 281–287.

Hayes A.S. (1979). The microbiology of plant litter decomposition. *Scientific Progress (London)* **66:** 25–42.

Haynes R.J., Swift R.S., Stephen R.C. (1991). Influence of mixed cropping rotations (pasture-arable) on organic matter content, water stable aggregation and clod porosity in a group of soils. *Soil & Tillage Research* **19:** 77–87.

Haynes R.J., Swift R.S. (1990). Stability of soil aggregation relation to organic constituents and soil water content. *Journal of Soil Science* **41:** 73–83.

Haynes R.J. (2005). Labile organic matter fractions as central components of the quality of agricultural soils. *Advanced Agron*omy **85:** 221-268.

Heal O. W., Anderson J. M., Swift M. J. (1997). Plant litter quality and decomposition. CAB International, Wallingford, UK, pp 3-45.

Hobbie S.E. and Vitousek P.M. (2000). Nutrient limitation of decomposition in Hawaiian forests. *Ecology* **81:** 1867–1877.

Holmes K.W., Chadwick O.A., Kyriakidis P.C., de Filho E.P.S. and Soares J.V. (2006). Large area spatially explicit estimates of tropical soil carbon stocks and response to land-cover change. *Global Biogeochemical Cycles* **20:** GB3004.

Houghton R.A., Lefkowitz D.S., Skole D.L.(1991). Change in the landscapes of Latin America between 1850 and 1985. *Forest Ecology and Management* **38:** 143-172.

Inoue Y., Kiyono Y., Asai H., Ochiai Y., Qi J., Olioso A., Shiraiwa T., Horie T., Saito K. and Dounagsavanh L. (2010). Assessing land-use and carbon stock in slash and burn ecosystems in tropical mountain of Laos based on time-series satellite images. *International Journal of Applied Earth Observation and Geoinformation* **12**: 287–297.

Irons J.G., Oswood M.W., Stout R.J. and Pringle C.M. (1994). Latitudinal patterns in leaf litter breakdown: is temperature really important? *Freshwater Biology* **32:** 401–411.

Jackson M.L. (1958). Soil Chemical Analysis. Prentice-Hall, Englewood Cliffs, NJ.

Jaiyeoba I.A. (2003). Changes in soil properties due to continuous cultivation in Nigerian semiarid Savannah*.* *Soil & Tillage Research* **70:** 91–98.

Jandl R., Lindner M., Vesterdal L., Bauwens B., Baritz R., Hagedorn F., Johnson D.W., Minkkinen K. and Byrne K.A. (2007). How strongly can forest management influence soil carbon sequestration? *Geoderma* **137:** 253–268.

Janzen H.H., Campbell C.A., Brandt S.A., Lafond G.P., Townley-Smith L. (1992). Light fraction organic matter in soils from long-term crop rotations. *Soil Science Society of America Journal* **56:** 1799–1806.

Jastrow J.D., Miller R.M. (1998). Soil aggregate stabilization and carbon sequestration: Feedbacks through organomineral associations. In Soil Processes and the Carbon Cycle, Lal R, Kimble JM, Follett RF, Stewart BA (eds). CRC Press: Boca Raton, FL; 207–223.

Jia G.M., Cao J., Wang C.Y., Wang G. (2005). Microbial biomass and nutrients in soil at the different stages of secondary forest succession in Ziwulin, northwest China. *Forest Ecology and Management* **217:** 117–125.

Jobbagy E.G. and Jackson R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* **10:** 423 – 436.

Johnson, Rebecca L. and Chenje M. (2008). Africa: Atlas of our Changing Environment (Nairobi, Kenya: United Nations Environment Programme (UNEP).

Juo A.S.R. and Manu A. (1996). Chemical dynamics in slash and burn agriculture. *Agriculture Ecosystem and Environment* **58**: 49–60.

Kaarik A.A. (1974). Decomposition of wood. In: Biology of Plant Litter Decomposition. (;p'[=Eds. Dickinson, C.H. and Pugh, G.J.F.) Academic Press, London, pp. 129-174.

Kalembasa S.J. and Jenkinson D.S. (1973). A comparative study of titremetric and gravimetric methods for the determination of organic carbon in soil. *Journal Science Food and Agriculture* **24:** 1085–1090.

Kar G. and Verma H.N. (2002). Improved sustainability of rainfed upland sub-humid ecosystem of water shed based on probabilistic rainfall. In: Hydrology and Watershed, B. Venkateswara Rao, K. Ram Mohan Reddy, C. Sarala and K. Raju (eds), BSP Publication, Vol. 1, pp. 318-327.

Karmakar K.G. (2008). Agriculture and rural development in north-eastern India: The role of NABARD. *ASCI Journal of Management* **37(2):** 89-108.

Kater L.J.M., Kante S. and Bundelman A. (1992). Karite (Vitellaria perdova) and nere (Parkia biglobosa) associated with crops in South Mali. *Agroforestry Systems* **18(2):** 89-105.

Khanna P.K., Raison R.J., and Falkiner R.A. (1994). Chemical properties of ash derived from *Eucalyptus* litter and its effects on forest soils. *Forest Ecology and Management* **66**: 107–125.

Kharkwal G., Mehrotra P., Rawat Y.S. and Pangtey Y.E.S. (2005). Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan region of India. *Current Science* **89(5):** 873-878.

Khomik M., Arain M.A. and McCaughey J.H. (2006). Temporal and spatial variability of soil respiration in a boreal mixedwood forest. *Agriculture Forest Meteorology* **140:** 244–256.

King J.S., Pregitzer K.S., and Zak D.R. (1999). Clonal variation in above- and below-ground growth responses of Populus tremuloides Michaux: Influence of soil warming and nutrient availability. *Plant and Soil* **217:** 119-130.

Klinge H. (1973). Root mass estimation in lowland tropical rainforests of central Amazonia. Brazil. I. Fine root masses of a pale yellow latosol and a plant humus podzol. *Tropical Ecology* **14:** 29-38.

Knorr M., Frey S.D., Curtis P.S. (2005). Nitrogen additions and litter decomposition: a meta analysis. *Ecology* **86**: 3252–3257. doi: 10.1890/05-0150.

Kocyigit R., Rice C.W. (2004). Carbon dynamics in tallgrass prairie and wheat ecosystems. *Turkish Journal of Agriculture and Forestry* **28:** 141–153.

Kumar S. (2008). Report of the inter-ministerial national task force on rehabilitation of shifting cultivation areas. 20th September, New Delhi.

Kushwaha S.P.S. and Ramakrishnan P.S. (1987). An analysis of some agro-ecosystem types of north-eastern India. *Proceedings Indian National Science Academy* **52:** 161-168.

Lal R. and Bruce J.P. (1999). The Potential of World Cropland Soils to Sequester C and Mitigate the Greenhouse Effect. *Environmental Science & Policy* **2:** 177–185.

Lal R. (1997). Degradation and Resilience of Soils. Philosophical Transactions of the Royal Society of London Series B- *Biological Sciences* **352:** 869–889.

Lal R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science* **304:** 1549–1700.

Lawrence D. (2005). Regional-scale variation in litter production and seasonality in tropical dry forests of southern Mexico. *Biotropica* **37:** 561–570.

Lele N., Joshi P.K., Agrawal S.P. (2008). Assessing forest fragmentation in northeastern region (NER) of India using landscape matrices. *Ecological Indicators* **8(5):** 657-663.

Leuschner C., Hertel D., Schmid I., Koch O., Muhs A. and Holscher D. (2003). Stand fine root biomass and fine root morphology in old growth beech forests as a function of precipitation and soil fertility. *Plant and Soil* **258:** 43–56.

Lohmus K., Ivask M. (1995). Decomposition and nitrogen dynamics of fine roots of Norway spruce (*Picea abies* (L.) Karst.) at different sites. *Plant Soil* **168–169:** 89–94.

Lynch J.M. and Bragg E. (1985). Microorganisms and soil aggregate stability. *Advances in Soil Science* **2:** 134–170.

Majdi H. and Ohrvik J. (2004). Interactive effects of soil warming and fertilization on root production, mortality, and longevity in a Norway spruce stand in Northern Sweden. *Global Change Biology* **10:** 182-188.

Malmstrom A. (2012). Life–history traits predict recovery patterns in Collembola species after fire: a 10 year study. *Journal of Applied Soil Ecology* **56:** 35–42.

Manzoor Z., Ali R.I., Awan T.H., Khalid N. and Ahmad M. (2006). Appropiate time of nitrogen application to fine rice, Oryza sativa. *Journal of Agriculture Research* **44(4):** 261-267.

Matamala R., Gonzalez-Meler M., Jastrow J., Norby R. and Schlesinger W. (2003). Impacts of fine root turnover on forest NPP and soil C sequestration potential. *Science* **302:** 1385-1387.

Matambanengwe F. and Kirchman H. (1995). Litter from tropical savanna woodland (Miombo): chemical composition and C and N mineralization. *Soil Biology and Biochemistry* **27:** 1639–1651.

McCarthy J.F., Ilavsky J., Jastrow J.D., Mayer L.M., Perfect E., Zhuang J. (2008). Protection of organic carbon in soil microaggregates via restructuring of aggregate porosity and filling of pores with accumulating organic matter. *Geochimica et Cosmochimica Acta* **72:** 4725–4744.

McClaugherty C.A., Aber J.D., Melillo J.M. (1984). Decomposition dynamics of fine roots in forested ecosystems. *Oikos* **42:** 378–386.

McClaugherty C.A., Pastor J., Aber J.D., Melillo J.M. (1985). Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. *Ecology* **66:** 266–275.

Meier I.C. and Leuschner C. (2010). Variation of soil and biomass carbon pools in beech forests across a precipitation gradient. *Global Change Biology* **16:** 1035-1045.

Mishra A.K., Misra J.P. (2006). Sustainable Development of Agriculture in Northeastern India: A Quest for More Economical and Resourceful Sustainable Alternatives. ENVIS Bulletin, *Himalayan Ecology* **14 (2):** 4-14.

Mishra B.P. (2010). A study on the micro environment, litter accumulation on forest floor and available nutrients in the soil of broad – leaved, mixed pine and pine forests at two district altitude in Meghalaya, northeast India. *Current Science* **90 (12):** 1829 – 1833.

Monreal C.M. and Kodama H. (1997). Influence of aggregate architecture and minerals on living habitats and soil organic matter. *Canadian Journal of Soil Science* **77:** 367–377.

Murty D., Kirschbaum M.U.F., Mcmurtrie R.E. and Mcgilvray H. (2002). Does Conversion of Forest to Agricultural Land Change Soil Carbon and Nitrogen? A Review of the Literature. *Global Change Biology* **8:** 105–123.

Nayak D.C. and Srivastava R. (1995). Soil of shifting cultivated areas in Arunachal Pradesh and their suitability for land use planning. *Journal of Indian Society of Soil Science* **43**: 246 – 251.

Noellemeyer E., Frank F., Alvarez C., Morazzo G., Quiroga A. (2008). Carbon contents and aggregation related to soil physical and biological properties under a land-use sequence in the semiarid region of central Argentina. *Soil & Tillage Research* **99:** 179–190.

Numan N., Morgan M.A., Scott J. and Herlily, M. (2000). Temporal changes in nitrogen mineralization, microbial biomass, respiraion and protease activity in a clay loam soil under ambient temperate. *Biology and Environment, Proceeding of the Royal Irish Academy* **2:** 107-114.

Nye P.H. and Greenland D.J. (1960). *The soil under shifting cultivation*. Common wealth Bureaux of Soils Technical Communication No. 51. Commonwealth Agricultural Dureaux, Farnham, UK. 156.

Nye P.H. and Greenland D.J. (1964). Changes in the Soil after Clearing Tropical Forest. *Plant and Soil* **21:** 101–112.

Oades J.M. (1984). Soil organic matter and structural stability: Mechanism and implications for management. *Plant and Soil* **76:** 319-337.

Oades J.M., Waters A.G. (1991). Aggregate hierarchy in soils. *Australian Journal of Soil Research* **29:** 815–828.

O.E., Sala F.S., Chapin III J.J., Armesto E., Berlow J., Bloomfield R., Dirzo E., Huber Sanwald L.F., Hunneke R.B., Jackson A., Kinzig R., Leemans D.M., Lodge H.A., Mooney M., Oesterheld N.L., Poff M.T., Sykes M., Walker D.H., Wall (2000). Global biodiversity scenarios for the year 2010, *Science* **287:** 1770-1774.

Osono T. and Takeda H. (2004). Accumulation and release of nitrogen and phosphorus in relation to lignin decomposition in leaf litter of 14 tree species. *Ecological Research* **19:** 593–602.

Pachuau, Rintuanga (1994). Geography of Mizoram. R.T. Enterprise Publication Aizawl, Mizoram.

Palm C.A., Smukler S.M., Sullivan C.C., Mutuo P.K., Nyadzi., G.I and Walsh, M.G. (2010). Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa. *Proceedings of the National Academy of Sciences,* **107:** 19661-19666.

Pandey R.R., Sharma G., Tripathi S.K. and Singh A.K. (2007). Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in north-eastern India. *Forest Ecology and Management* **240:** 96–104.

Parton W.J., Anderson D.W., Cole C.V. and Stewart J.W.B. (1983). Simulation of organic matter formation and mineralization in semi-arid agroecosystems. In Nutrient Cycling in Agriculture Ecosystems (R. R. Lowrance, R. L. Todd, L. E. Asmussen and R. A. Leonard, Eds), pp. 533-550. College of Agriculture Experimental Station Publication No. 23. The university of Georgia Press, Athens. GA.

Parton W., Silver W.L., Burke I.C., Grassens L., Harmon M.E., Currie W.S., King J.Y., Adair E.C., Brandt L.A., Hart S.C., Fasth B. (2007). Global-scale similarities in nitrogen release patterns during long-term decomposition. *Science* **315:** 361–364. doi:10. 1126/science.1134853.

Paustian K., Six J., Elliott E.T., Hunt H. (2000). Management options for reducing CO2 emissions from agricultural soils. *Biogeochemistry* **48:** 147–163.

Paz-Gonzalez A., Vieira S.R., Taboada Castro M.T. (2000). The effect of cultivation on the spatial variability of selected properties of an umbric horizon. *Geoderma* **97:** 273–292.

Pender J. (2001). Rural population growth, agricultural change and natural resource management in developing countries: A review of hypotheses and some evidence from Honduras. In: N. Birdsall.http://www.ifpri.org/sites/default/files/publications/eptdp48.pdf

Pingali P. and Heisey P.W. (2001). Cereal-Crop Productivity in Developing Countries. In Alston, J.M., P.G. Parday & M.J. Taylor (eds.) *Agricultural Science Policy.* Washington, DC, International Food Policy Research Institute and Johns Hopkins University Press.

Piotrowski J.S., Denich T., Klironomos J.N., Graham J.M. and Rillig, M.C. (2004). The effects of arbuscular mycorrhizas on soil aggregation depend on the interaction between plant and fungal species. *New Phytologist* **164:** 365–373.

Pirmoradian N., Sepashkhah A.R., Hajabbasi M.A. (2005). Application of fractal theory to quantify soil aggregates as influenced by tillage treatments. *Biosystems Engineering* **2:** 227−234.

Plante AF, Conant R.T., Paul E.A., Paustian K., Six J. (2006). Acid hydrolysis of easily dispersed and microaggregate-derived silt-and clay-sized fractions to isolate a resistant fraction of soil organic matter. *European Journal of Soil Science* **34:** 243–248.

Plante A.F., McGill W.B. (2002). Soil aggregate dynamics and retention of organic matter in laboratory-incubated soil with differing simulated tillage frequencies. *Soil & Tillage Research* **66:** 79–92.

Post W.M., Izaurralde R.C., Jastrow J.D., McCarl B.A., Amonette J.E., Bailey V.L., Jardine P.M., West T.O., Zhou J.Z. (2004). Enhancement of carbon sequestration in US soils. *Bioscience* **54:** 895–908.

Raison R.J. (1979). Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: a review. *Plant Soil* **51:** 73–108.

Ramakrishnan P.S. and Toky, O.P. (1981). Soil nutrient status of hill agro – ecosystem and recovery pattern after slash and burn agriculture (jhum) in north – east India. *Plant and soil* **60:** 41-64.

Ramakrishnan P.S. (2003). Linking natural resources management with sustainable development of traditional societies. *Tropical Ecology* **44:** 43-54.

Ramakrishnan P.S. (1998). Sustainable development, climate change and tropical rain forest landscape. *Climatic Change* **39:** 583–600.

Ramakrishnan P.S. (1992). Shifting agriculture and sustainable development: an interdisciplinary study from north-eastern India (ed, Jeffers, J.N.) Parthenon, Paris.

Ramakrishnan P.S. (1993). Shifting agriculture and sustainable development: an interdisciplinary study from north-eastern India (Unesco and Oxford University Press) pp 424.

Rao K.S., Ramakrishnan P.S. (1989). Role of bamboos in nutrient conservation during secondary succession following slash and burn agriculture in north-east India. *Journal of Applied Ecology* **26:** 625-633.

Rasul G., Thapa G.B., Zoebisch M.A. (2004). Determinants of and-use changes in the Chittagong Hill Tracts of Bangladesh. *Applied Geography* **24:**217–240.

Reddy M.B.K. (2010). Vegetation types and their influence on some secondary nutrients and micro nutrients in soils of Meghalaya forests. *Indian Forester* 1445 – 1459.

Robert M., Chenu C. (1995). Water potential soil microhabitats and microbial development. In: *Environmental Impact of Soil Component Interactions, Land Quality, Natural and Anthropogenic Organics* (eds Laung PM, Berthelin J, Bollag JM, McGill WB, Page AL), pp. 75-87. Lewis Publisher, Chalsea, MI.

Roldan A., Carrasco L. and Caravaca F. (2006). Stability of desiccated rhizosphere soil aggregates of mycorrhizal Juniperus oxycedrus grown in a desertified soil amended with a composted organic residue. *Soil Biology & Biochemistry* **38:** 2722–2730.

Roldan A., Garcia-Orenes F. and Lax A. (1994). An incubation experiment to determine factors involving aggregation changes in arid soil receiving urban refuse. *Soil Biology & Biochemistry* **26:** 1699–1707.

Roy S. and Singh J.S. (1994). Consequences of habitat heterogeneity for availability of nutrients in a dry tropical forest. *Journal of Ecology* **82:** 503-509.

Rudel T.K., Defries R.S., Asner G.P and Laurance W.F. (2009). Changing drivers of deforestation and new opportunities for conservation. *Conservation Biology* **23:** 1396-1405.

Sariyildiz T., Anderson J.M. and Kucuk M. (2005). Effects of tree species and topography on soil chemistry, litter quality, and decomposition in Northeast Turkey. *Soil Biology & Biochemistry* **37:**1695–1706.

Sayer E.J., Tanner E.V.J. and Lacey A.L. (2006). Effects of litter manipulation on early stage decomposition and meso-arthropod abundance in a tropical moist forest. *Forest Ecology and Management* **229:** 285–293.

Schindler M.H. and Gessner M.O. (2009). Functional leaf traits and biodiversity effects on litter decomposition in a stream. *Ecology* **90:** 1641-1649.

Schlesinger W.H. (1997). Biochemistry: an analysis of global change. San Diego C.A. Acadamic Press / Elsevier.

Schulten H.R., Leinweber P. (1995). Dithionite/citrate/bicarbonate extractable organic matter in particle-size fractions of a Haplaquoll. *Soil Science Society of America Journal* **59:** 1019–1027.

Seetraraman R. (1980). Rice, In: Hand book of Agriculture. Jaiswal, P.L., Wadhwani, A.M., Singh, R., Chhabra, N.N. and Sarma, P.S.N.(eds.), ICAR Publication, Rajendra Ravindra Printers(P) Ltd, New Delhi, pp. 760-773.

Shahlace A.K., Nutter W.L., Burroughs E.R and Morris L. A. (1991). Runoff sediment production from burned forest sites in Georgia Picdoment, *Water Resource Bull* **27 (3):** 493.

Shang C., Tiessen H. (2003). Soil organic carbon sequestration and stabilization in karstic soils of Yucatan. *Biogeochemistry* **62:** 177–196.

Shankar R.T.R. (2001). Effects of habitat structure and adjacent habitats on birds in tropical rainforest fragments and shaded plantations in the Western Ghats, India. *Biodiversity Conservation* **15**: 1577–1607. doi: **10.1007**/s10531-005-2352-5.

Shearman P.L., Ash J., Mackey B., Bryan J.E and Lokes B. (2009). Forest conversion and degradation in Papua New Guinea 1972-2002. *Biotropica* **41:** 379-390.

Shrestha B.M., Singh B.R., Sitaula B.K., Lal R., Bajracharya R.M. (2007). Soil aggregate- and particle-associated organic carbon under different land uses in Nepal. *Soil Science Society of America Journal **71***: 1194–1203.

Silva–Forsberg M.C. and Fearnside P.M. (1997). Brazilian Amazonian caboclo agriculture: effect of fallow period on maize yield. *Forest Ecology & Management* **97:** 283–291.

Silver W.L., Scatena F.N., Johnson A.H., Siccama T.G. and Watt F. (1996). At what temporal scales does disturbance affect below-ground nutrient pools? *Biotropica* **28:** 441-457.

Singh J., Borah I.P., Barua A., Baruah K.N. (1996). Shifting cultivation in north east India - An Overview. Newsletters, Rain Forest Research Institute Deovan, Jorhat, Assam, India. pp-48.

Singh J. S. and Singh S. P. (1992). *Forests of Himalaya*, Gyanodaya Prakashan, Nainital, pp. 294.

Singh K.D., Sinha B., Ashutosh S. (2010). Techniques of survey and planning for conservation and sustainable use of biodiversity in Mizoram. *Ministry of Environment and Forests, Delhi*.

Singh K.P., Singh P.K. and Tripathi S.K. (1999). Litterfall, litter decomposition and nutrient released patterns in four native species raised on coal mine spoil at Singrauli, India. *Biology Fertility of Soils* **29:** 371-378.

Singh Sh.B., Mishra B.P. and Tripathi S.K. (2014). Recovery of Plant Diversity in Sub-Tropical Forests of Mizoram, India: A case study from Stone mining area. *Issues and Trends of Wild Conservations in Northeast India* 157-162.

Six J., Bossuyt H., Degryze S., Denef K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil & Tillage Research* **79:** 7–31.

Six J., Callewaert P., Lenders S., De Gryze S., Morris S.J., Gregorich E.G., Paul E.A., Paustian K. (2002). Measuring and understanding carbon storage in afforested soils by physical fractionation. *Soil Science Society of America Journal **66***: 1981–1987.

Six, J., Elliott, E.T., Paustia, K., Doran, J.W. (1998). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of America Journal **62***: 1367–1377.

Six J., Elliott E.T., Paustian K. (1999). Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal* **63:** 1350–1358.

Six J., Elliott, Paustian K. (2000). Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. *Soil Biology & Biochemistry* **32:** 1099–2103.

Spaccini R., Zena A., Igwe C.A., Mbagwu J.S.C., Piccolo A. (2001). Carbohydrates in water-stable aggregates and particle size fractions of forested soils in two contrasting tropical ecosystems. *Biogeochemistry* **53:** 1–22.

Sritastava S.K., Singh K.P. and Upadhyay R.S. (1986). Fine root growth dynamics in teak *(Tecrona grandis* Linn. F.) *Canadian Journal of Forest Research* **16:** 1360-1364.

Stark N. and Spratt M. (1977). Root biomass and nutrient storage in rain forest oxisols near San Carlos de Rio Negro. *Tropical Ecology* **18:** 1-9.

Steininger M.K. (1996). Tropical secondary forest growth in the Amazon: age, area and change estimation with Thematic Mapper data. *International Journal of Remote Sensing* **17:** 9–27.

Stern N. (2007). The Economics of Climate Change. The Stern review. Cambridge University Press, Cambridge, UK.

Strudley M.W., Green T.R., Ascough II JC.(2008). Tillage effects on soil hydraulic properties in space and time: State of the science. *Soil Tillage Research* **99:** 4−48.

Swift M.J., Heal O.W. and Anderson J.M. (1979). Decomposition in terrestrial ecosystems. Blackwell, Oxford, UK.

Tamirat T. (1992). Vertisol of Central Highlands of Ethiopia; Characterization and Evaluation of Phosphorus Statues.MSc Thesis, Alemaya University, Ethiopia.

Tawnenga, Shankar, U. and Tripathi S. (1996). Evaluating second year cropping on jhum fallows in Mizoram, north-eastern India—Phytomass dynamics and primary productivity. *Journal of Bioscience* **21(4):** 563-575.

Thakuria D. and Sharma U.C. (2014). Shifting cultivation; coexistence of forest and agriculture. *NAAS News* **14 (4):** 4–8.

Thomas R.S., Franson R.L., Bethelenfalvay G.J. (1993). Separation of vesicular-arbuscular mycorrhizal fungus and root effects on soil aggregation. *Soil Science Society of America Journal* **57:** 77–81.

Thomaz E.L. (2009). The influence of traditional steep land agriculture practises on runoff and soil loss. *Agriculture Ecosystem and Environment* **130:** 23-30.

Tiedje J.M., Sexstone A.J., Parkin T.B., Revsbech N.P., Shelton D.R. (1984). Anaerobic processes in soil. In: Tinsley J., Darbyshire J.F. (eds). Biological processes and soil fertility, vol II. Martinus Nijhoff/Dr W Junk Publisher, The Hague, pp 197-212.

Tisdall J. M. and Oades J. M. (1980). The management of ryegrass to stabilize aggregates of a red-brown earth. *Australian Journal of Soil Research* **18:** 415-422.

Tisdall J. M. and Oades J. M. (1982). Organic matter and water-stable aggregates in soil. *Journal of Soil Science* **33:** 141-163.

Toky O.P., Ramakrishnan P.S. (1981a). Cropping pattern and yields in agricultural systems of the northeastern hill region of India. *Agroecosystem* **7:** 11-25.

Tripathi R.S., Barik S.K. (2003). Shifting Cultivation in North East India. Proc. Approaches for increasing agricultural productivity in hill mountain ecosystem. ICAR research complex for NEH region, Umiam, Meghalaya, India. Pp- 317-322.

Tripathi S.K. and Singh K.P. (1992a). Abiotic and litter quality control during the decomposition of different plant parts in dry tropical bamboo savanna in India. *Pedobiologia* **36:** 109–124.

Tripathi, S.K. and K.P. Singh (1992b). Nutrient immobilization and release pattern during plant decomposition in a dry tropical bamboo savanna, India. *Biology and Fertility of Soil* **14:**191-199.

Tripathi S.K. and Singh K.P. (1996). Culm recruitment, dry matter dynamics and carbon flux in recently harvested and mature bamboo savannas in the Indian dry tropics. *Ecological Research* **11:** 149-164.

Tripathi S.K. and Singh K.P. (1995). Litter dynamics of recently harvested and mature bamboo savannas in a dry tropical region of India. *Journal of Tropical Ecology* **11:** 403-417.

Tripathi S.K., Kushwaha C.P. and Basu S.K. (2012). Application of fractal theory in assessing soil aggregates in Indian tropical ecosystems. *Journal of Forestry Research* **23 (3):** 355 – 364.

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

Tripathi S.K. and Singh K.P. (1994). Productivity and nutrient cycling in recently harvested and mature bamboo savannas in dry tropical region in India. *Journal of Applied Ecology* **31:**109-124.

Tripathi S.K., Singh, K.P. and Singh P.K. (1999). Temporal changes in spatial pattern of fine root biomass and nutrient concentrations in Indian Bamboo savanna. *Applied Vegetation Science* **2:** 229 -238.

Tripathi S.K., Sumida A., Shibata H., Ono K., Uemura S., Kodama Y. and Hara T. (2005). Growth and substrate quality of fine root and soil nitrogen availability in a young Betula ermanii forest of Northern Japan: Effects of the removal of understory dwarf bamboo (Sasa kurilensis). *Forest Ecology and Management* **212:** 278-290.

Tucker J.M., Brondizio E.S. and Moran, E.F. (1998). Rates of forest regrowth in eastern Amazonia: a comparison of Altamira and Bragantina regions, Pará State, Brazil. *Interciencia* **23:** 64–73.

Uhl C., Jordan C.F. and Montagnini E. (1983). Traditional and innovative approaches to agriculture on Amazon basin terra firma sites In: *Nutrient cycling in agricultural ecosystems* (eds) R.R., Lowrance, R.L., Todd, L.E., Asmussen and R.A., Leonard (Athens: University of Georgia, College of Agriculture Experimental Station, special publication 23) pp 73-95.

Upadhaya K., Pandey H.N., Law P.S. and Tripathi R. (2005). Dynamics of fine and coarse roots and nitrogen mineralization in a humid subtropical forest ecosystem of northeast India. *Biology and Fertility Soils* **41:** 144-152.

Upadhyay V.P. and Singh J.S. (1989). Patterns of nutrient immobilization and released in decomposing forest litter in central Himalaya. *Indian Journal of Ecology* **77:** 127-146.

Van Vliet N., Mertz O., Heinimann A., Langanke T., Adams C., Messerli P., Leisz S., Pascual U., Schmook B., Schmidt-Vogt D., Castella J.C., Jorgensen l., Birchthomsen T., Hett C., Bruun T.B., Ickowitz A., Vu K.C., Yasuyuki K., Fox J., Dressler W., Padoch C. and Ziegler A.D. (2012). Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. *Global Environmental Change* **22:** 418–429.

Verinumbe I. (1991). Agroforestry development in north eastern Nigeria. In: Special Issue. Agroforestry: principles and practices. Proceedings of an international conference, 23-28 July, 1989, at the University of Edinburgd, U.K., (Jarvis P.G. eds). *Forest Ecology and Management* **45 (1-4):** 298-308.

Virzo De Santo A., Berg B., Rutigliano F.A., Alfani A. and Fioretto A. (1993). Factors regulating early-stage decomposition of needle litter in five different coniferous forests. *Soil Biology & Biochemistry* **25:** 1423-1433.

Vishwakarma A.K., Pathak K.A. and Bajendra A. (2006). Evaluation of sowing dates on growth and yield of soyabean in Mizoram, *Indian Journal of Hill farming* **19 (1&2):** 48-51.

Vogt K.A., Vogt D.J. and Grier C.C. (1986). Production, turnover and nutrients dynamics of above- and below-ground detritus of world forests. *Advance Ecological Research* **15:** 303-377.

Wardle D.A. (1992) A comparative assessment of factors which influences microbial biomass carbon and nitrogen levels in soils. *Biological Reviews* **67:** 321-358.

Watters R.F. (1971) Shifting cultivation in Latin America. Food and Agricultural Organization, Rome.

Weltzin T., Weisensel N., Franczyk D., Burnett K., Klitz C. and Bean P. (2005). Eating disorder in men: *Update journal of Men's health and Gender* **2:** 186-193.

Wen D.Z., Wei P., Kong G.H., Ye W.H (1999). Production and turnover rate of fine roots in two lower subtropical forest sites at Dinghushan. *Acta Phytoecologia Sinica* ***23*****:** 361–369. (In Chinese).

Werner P. (1984). Changes in soil properties during tropical wet forest succession in Costa Rica. *Biotropica* **16:** 43-50.

Wilkie D., Shaw E., Rotberg F., Morelli, G. and Auzels P. (2000). Roads, development and conservation in the Congo Basin. *Conservation Biology* **14:** 1614-1622.

Wilson G.W.T., Rice C.W., Rillig M.C., Springer A., Hartnett D.C. (2009). Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: Results from long-term field experiments. *Ecology Letters* ***12*****:** 452–461.

Xu Y., Zhang S., Malhotra A., Edelman- Novemsky., Ren M., Schla ma M. (2009). Charecterization of of tafazzin splice varients from humans and fruit flies. *Journal of Biological Chemistry* **284 (42):** 29230-29239.

Yadav P.K., Sarma K., Dookia S. (2013). The Review of Biodiversity and Conservation Study in India Using Geospatial Technology, *International Journal of Remote Sensing and GIS*, 2, pp. 1-10.

Zheng Z.C., Wang Y.D., Li T.X., Yang Y.M. (2011b): Effect of abandoned cropland on stability and distributions of organic carbon in soil aggregates. *Journal of Natural Resources* ***26*****:** 120–127. (In Chinese).