DECOMPOSITION DYNAMICS, MULCHING EFFICACY AND ALLELOPATHIC POTENTIAL OF LEAF LITTER OF *FLEMINGIA SEMIALATA* ROXB.

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN FORESTRY

PAUL LALREMSANG

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PAUL LALREMSANG

DEPARTMENT OF FORESTRY

SUPERVISOR

Prof. B. GOPICHAND

JOINT SUPERVISOR

Prof. KALIDAS UPADHYAYA

SUBMITTED

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN FORESTRY OF MIZORAM UNIVERSITY, AIZAWL

DECLARATION

I, **Paul Lalremsang**, hereby declare that the subject matter of this thesis entitled **"Decomposition dynamics, mulching efficacy and allelopathic potential of leaf litter of *Flemingia semialata* Roxb."** is the record of the work done by me, that the contents of this thesis did not form basis of the award of any previous degree or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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

(Paul Lalremsang)

(Supervisor)

(Head)

(Joint Supervisor)

DEPARTMENT OF FORESTRY
MIZORAM UNIVERSITY
(*A Central University*)
AIZAWL-796004, MIZORAM

Dr. B. Gopichand E-mail: gopiagri1@gmail.com Mobile: 8794154869
Professor

Certificate

This is to certify that the thesis entitled **"Decomposition dynamics, mulching efficacy and allelopathic potential of leaf litter of *Flemingia semialata* Roxb."** submitted by **Mr. Paul Lalremsang**, for the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl embodies the record of his original investigation under my supervision. He has duly registered and the thesis presented is worthy of being considered for the award of the Doctor of Philosophy (Ph.D) Degree. The work has not been submitted previously for any degree to this or any other University.

(Prof. B. GOPICHAND)
Supervisor

(Prof. KALIDAS UPADHYAYA)
Joint Supervisor

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List of abbreviations and symbols

Acronym/Symbol	Full form/Meaning
%	percentage
@	at the rate of
<,>	smaller and greater than
°C	degree Celsius
µg pNP g^{-1} h^{-1}	microgram p-nitrophenyl per gram per hectare
µg TPF g^{-1} h^{-1}	microgram triphenyl formazan per gram per hectare
µg Urea g^{-1} h^{-1}	microgram urea per gram per hectare
µg/g	microgram per gram
µL	micro litre
1m+f	one dose of mulch and fertilizer
1m+wf	one dose of mulch without fertilizer
2m+f	two dose of mulch and fertilizer
2m+wf	two dose of mulch without fertilizer
3m+f	three dose of mulch with fertilizer
3m+wf	three dose of mulch without fertilizer
ACP	Acid phosphatase
C	Carbon
C/N	carbon nitrogen ratio
C/P	carbon phosphorus ratio
Ca	Calcium
cm	centimetre

Acronym/Symbol	Full form/Meaning
CO_2	Carbondioxide
CRD	completely ramdomized block design
day^{-1}	per day
DMRT	Duncan's Multiple Range Test
DHY	Dehydrogenase
et al.	Et alia, 'and others'
g	gram
g day^{-1}	gram per day
g/kg	gram per kilogram
g/L	gram per litre
hrs	hours
IITA	International Institute of Tropical Agriculture
k	decay constant
K	Potassium
kg	kilogram
kg h^{-1}	kilogram per hectare
kg N ha^{-1}	kilogram of nitrogen per hectare
k_N	decay coefficient of nitrogen
k_P	decay coefficient of phosphorus
L	litre
Lignin/N	lignin nitrogen ratio
ln	logarithmus naturali
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MBP	Microbial biomass phosphorus
MPTs	Multipurpose trees and shrubs

Acronym/Symbol	Full form/Meaning
meq/100g	milliequivalents per 100 grams of soil
Mg	Magnesium
mg ha^{-1}	milligram per hecatre
mg/g	milligram per gram
mg/kg	milligram per kilogram
mg/L	milligram per litre
mg/mL	milligram per millilitre
min	minute
min^{-1}	per minute
ml	millilitre
mm	millimetre
N	Nitrogen
N/P	nitrogen phosphorus ratio
nm+f	no mulch and fertilizer
ns	not significant
P	Phosphorus
pH	potential of hydrogen
ppm	parts per million
r	correlation coefficient
RBD	Randomized Block Design
rpm	revolutions per minute

Acronym/Symbol	Full form/Meaning
sec	second
SOC	Soil organic carbon
t ha^{-1}	tones per hecatre
t_{50}	time require for fifty percent decay
t_{99}	time require for ninety-nine percent decay
TPF	Triphenyl formazan
TTC	Triphenyl tetrazolium chloride
URE	Urease
vice versa	the other way round
viz	namely
w/v	weight by volume
WUE	Water use efficiency
$year^{-1}$	per year

Chapter 1
General Introduction

Litter decomposition is the major way of transfer of organic matter and minerals from vegetation to the soil surface (Berg and McClaugherty, 2008; Oladoye *et al*., 2008). Litter decomposition is a fundamental biogeochemical process influencing rates of carbon and nutrient cycling in forest ecosystems (Perry *et al*., 2008). Plant litter input in terrestrial ecosystems constitutes the main resource of matter and energy for a diverse community of soil biota. Litter decomposition is central to carbon (C) and nutrient cycling (Mooshammer *et al*., 2012; Handa *et al*., 2014). Release/ immobilization pattern of nutrients proceed through time in different ways depending on the mobility, concentration and biotic role of nutrients, activity of microorganisms and the physical environment. The leaf litter deposition and decomposition are recognized as critical pathways of organic matter and nutrient flux in the tropical forest. The product of litter decomposition facilitates the formation of soil organic matter and thus returns nutrients into the soil (Fioretto *et al*., 2003; Xuluc-Tolosa *et al*., 2003).

The decomposition of forest litter is the foremost pathways providing organic and inorganic elements for the nutrient cycling processes and maintenance of soil nutrient pool (Yu *et al*., 2004; Rawat *et al*., 2010). Litter production and decomposition is a key to biogeochemical process of forest ecosystem and varies with climate, season, substrate quality and type of soil biota (Vitousek *et al*., 1994; Sangha *et al*., 2006; Aerts, 1997; Swift *et al*., 1979). Decomposition of litter is a sequential process whereby complicated organic compounds are continuously degraded into simpler substances, releasing nutrients as byproducts of their breakdown (Yadav and Malanson, 2007). Litter decomposition regulates the buildup of soil organic matter (Jiang *et al*., 2013), provides soil nutrients for plant growth, and influences terrestrial net primary production (Almagro and Martinez-Mena, 2012).

The release of nutrients from decomposing litter is an important pathway of nutrient flux in forest ecosystems (Blair, 1988). Resource quality, decomposer organisms and physicochemical conditions influence decomposition of litter residues and thus recycling of nutrients. Resource quality means the chemical composition of plant residues such as C/N, lignin and polyphenol contents (Melillo *et al*., 1982; Palm and Sanchez, 1991; Tian *et al*., 1997). Physicochemical conditions include both biotic and plant material that helps in determining abiotic soil characteristics that in turn influence litter quality and ultimately the activity and composition of microbial and invertebrate communities (Wardle and Lavelle, 1997). Among multiple drivers of decomposition, differences in species traits are the predominant regulator of decomposition rates (Cornwell *et al*., 2008; Zhang *et al*., 2008). For instance, deciduous tree leaves decompose more rapidly than evergreen tree leaves due to its higher nutrient content and lower lignin concentrations (Swan *et al*., 2009; Reich *et al*., 1997). Litter decomposition encompasses ample breakdown of organic matter into CO_2 and nutrients through physical, biological and chemical pathways (Aerts, 1997). Slow decomposition rates result in the building up of organic matter and nutrient stocks in soil however, fast decomposition rates help to meet plant intake requirements (Isaac and Nair, 2005).

Leaf litter accumulation on the soil surface and subsequent decomposition is thus crucial for maintaining soil nutrient budget in nutrient poor tropical soils especially in humid highlands. Humid tropical are characterized by severe soil erosion and land degradation due to faulty agricultural practices. High rainfall and subsequent removal of top soil moisture with organic matter leads to poor soil moisture retention and water scarcity especially during post rainy months. Therefore, suitable methods of farming practices need to be developed in those regions which aim at conserving soil moisture. The protective effects of plant cover in agricultural fields have been utilized in every climatic zone for soil conservation practices (Gyssels *et al*., 2005). Several methods of soil moisture conservation techniques such as mulching, terracing and reduced tillage are being practiced nowadays in agricultural production. *Ex-situ* or *in-situ* mulching with plant litter has been a popularly used technique in tropics which not only provides benefit of soil moisture conservation, but also improves soil fertility.

The word ‘mulch’ is derived from the German word “molsch” which means soft or beginning to decay (Jacks *et al*., 1955). Mulches are materials that are applied to soil surface, as opposed to materials that are incorporated into the soil profile (Chalker-Scott, 2007). Mulch is a layer of material(s) that covers the soil surface and mulching is a water conservation technique that increases water infiltration into the soil thereby reducing soil erosion and surface runoff (Adekalu *et al*., 2007; Ghawi and Battikhi, 1986).

Mulching materials are broadly classified into three main groups: Organic mulch (e.g., plant products, animal wastes), inorganic mulch (synthetic materials) and special material mulch. The organic mulches are derived from organic substances like agricultural wastes (straw, stalks, sawdust, rice husks etc), plant litters and animal wastes (manures). The inorganic mulches include polyethylene plastic films which are petroleum products (Gill, 2014) and synthetic polymers (Kyrikou and Braissoulis, 2007). Besides this, some easily available special material includes sand and concrete have also been used for mulching but very rare. The effects of various mulching patterns on water conservation through rainwater harvesting for corn, wheat and mixed cultivation practices have also been reported in several recent studies (Ren *et al*., 2016; Wang *et al*., 2016). The popular organic mulching materials like straw and grass were found useful in increasing soil moisture availability by reducing soil evaporation and maintain soil temperature in order to increase crops production.

Cereal straw is a most common organic mulching material in almost all climatic areas and has several benefits after applying in the field and also suitable for soil moisture storage (Ji and Unger, 2001).Trash grass mulching also found to favour the growth of onions more than sawdust mulching (Mutetwa and Mtaita, 2014). Organic mulching materials also reduced direct evaporation from the wet soil surface (Agassi *et al*., 2004; Ji and Unger, 2001). The application of plastic mulch in agriculture has increased dramatically throughout the world since 2000 (Kyrikou and Briassoulis, 2007). Nowadays, plastic is used in all types of climate, seasons and soils for its numerous benefits in addition to enhancing soil temperature (Kasirajan and Ngouajio, 2012). Almeida *et al*., 2015; Ibarra *et al*., 2012 and Filipovic *et al*., 2016 also focused on the effects of mulching on soil water environment as well as on water use efficiency.

Mulching favourably influences soil moisture regime by controlling surface evaporation rate during summer and conserves soil moisture by reducing the evaporation rate. However, the amount of soil moisture conservation under different mulching materials differs in different soil types and climatic conditions. In general, mulching treatments store higher soil moisture compare to the bare soil (Chakraborty *et al*., 2008; Zhao *et al*., 2014). The upper surface layer of soil moisture is highly dynamic due to water vapour fluxes across the soil atmospheric interface (Bittelli *et al*., 2008). However, this fluctuation in soil moisture and temperature are reduced by mulching (Abouziena and Radwan, 2015). Plastic mulching treatment constantly stored soil moisture throughout soybean cultivation periods than other mulches and bare treatments exhibiting greater fluctuations (Kader, 2016).

The ability of plastic mulch to conserve soil moisture is greater than organic mulches (Charkraborty and Sadhu, 1994). However, Khan *et al*. (1988) found that mulching with rice straw to be more effective than plastic mulch. Begum *et al*. (2001) reported that soil moisture storage was highest in straw mulch when compared with different mulch treatments. Compost mulching reduces surface runoff during and after rainfall, reducing soil loss thereby increases infiltration (Bakr *et al*., 2015). Jordan *et al*. (2010) also reported similar results form a three year experiment on application of straw mulch under cultivated soils in semi-arid environment.

Mulching materials control soil temperature which can increase or reduced crop yield. In general, mulch effect on temperature regime of soil varies depending on the capacity of the mulch materials to reflect and transmit solar energy (Lamont, 2005). Paper mulching lowers soil temperature as compared to black plastic mulching or bare soil (Kader, 2016). Organic mulches reduce heat conduction into the surface soil by retaining incoming solar radiation (Komariah *et al*., 2008). These mulches reduce the maximum temperature but raise the minimum soil temperature (Begum *et al*., 2001). Zhang *et al*. (2009) recorded a 4°C decrease in soil temperature in the warmer period and a 2°C increase in soil temperature during colder period at 10 cm soil depth. The timing of soil temperature measurement and mulching thickness also cause variation in soil temperature (Zhang *et al*., 2009). Xiukang *et al*. (2005) found that plastic film mulch absorbs more solar radiation and reduces heat loss with a consequent increase in soil moisture and temperature which increase the growth and yield of crop. The effects of soil temperature on crop growth are however related to the climatic locations where the crop plants are grown. Black plastic mulch increases soil temperature (Ibarra *et al*. 2012), but reduces in silver colour plastic mulch when compared to bare soil (Lamont, 2005). Transparent plastic film is preferred to other colour plastic films for solarization since it increases soil temperature considerably (Komariah *et al*., 2011).

Soil moisture and temperature being substantially influenced by mulching affect soil microbiology. The type and colour of mulch materials also control soil microbiological properties (Moreno and Moreno, 2008). Organic mulches add nutrient to the soil by microbes after decomposition, help in carbon sequestration (Ning and Hu, 1990) and works as fertilizer after use. Mulches increase soil nutrients after decomposition under appropriate water and temperature levels (Chalker-Scott, 2007). Green crops and animal manures used as mulch generally supply nutrient at higher rates than other mulches like straw, wood chips and bark. The biological and chemical properties of soil play an important role for regulating organic matter decomposition, carbon sequestration and nutrient mineralization that are crucial for soil health. Smets *et al*. (2008) reported mulching at the soil surface improved soil hydrologic characteristics by affecting the physical and chemical properties of soil. Mulches reduced deterioration of soil quality by preventing runoff and reducing soil loss that improves soil aeration, soil structure, organic matter content and physical properties of soil (Jordan *et al*., 2010).

Mulching with legumes litter has been reported to produce higher concentrations of soil nutrients compared to grasses and crop residues (Adekiya *et al*., 2017). *Tithonia* has been found to produce high biomass and was reported as an effective biomass for mulching, increasing yield of rice and tomato (Liasu and Achakzai, 2007) and also an effective nutrient source for maize, beans and vegetables. Olabode *et al*. (2007) reported that *Tithonia diversifolia* with its high nutrient status is a potential soil improver for enhanced productivity. The plant is recommended for use as a green manure or as a major component of compost manure. The application of compost prepared using pruning materials has been shown to effectively increase the porosity and water-holding capacity of soils (Takahashi *et al*. 2009). Pruning materials' compost used for mulching contains higher concentrations of cellulose and hemicellulose with a large amount of lignin, and it consequently has a higher mineralizable C content than conventional compost (Liu and Takahashi, 2019). Tree litter from *Uapaca kirkiana*, *Brachystegia spiciformis* and *Julbernardia globiflora* are also used as mulch in Southern Africa (Nyathi and Campbell, 1995). *Tephrosia vogelii*, *Crotolaria juncea*, *Sesbania sesban* and *Crotolaria grahamiana* are also grown to improve soil fertility and residues for mulching in conservation agricultural systems. (Waddington, 2003).

Leaf litter obtained from several multipurpose trees and shrubs grown as plantations or under agroforestry systems can be utilized as excellent organic mulching material either for *ex-situ* or *in-situ* applications. Of late agroforestry has been a popularly advocated land use system for soil and water conservation throughout the world. In the tropical highlands such as in North Eastern part of India maintaining sustainability in agricultural production is a major challenge and therefore, agroforestry has been included in many governments land use programmes in this region.

Agroforestry is a collective name for all land-use systems and practices where woody perennials are deliberately grown on the same land management unit as agricultural crops and/or animals, either in spatial mixture or in temporal sequence. There must be significant ecological and economic interactions between the woody and non-woody components (Lundgren, 1987). As a science, agroforestry integrates perspective from agriculture, ecology and rural development. Agroforestry systems take advantage of trees for many uses, to hold the soil, to increase fertility through nitrogen fixation, or through binding materials form deep in the soil and depositing them by leaf fall, to provide shade, construction materials, foods and fuel. In this system, particular attention is placed on multipurpose trees and perennial shrubs. The most important of these trees are legumes because of their ability to fix nitrogen and thus make it available to other plants. The trees can be planted in different ways *viz*. individual trees, scattered trees, lines of trees with crops (alley cropping), strips of trees along contour and waterways, living fences, windbreaks, shelterbelts, terrace planting on hills etc. The addition of pruning of six-month-old inoculated *Leucaena leucocephala* increased the subsequent maize yield from 2.2 t $ha^{-1}$to 4.6 t ha^{-1} (Sanginga *et al*., 1986).

Kang *et al*. (1981) shows a research result from IITA (International Institute of Tropical Agriculture) that *Leucaena*/maize alley cropping could sustain maize yields of 2 t ha^{-1} and higher yields with the application of fertilizer. Due to this encouraging result at IITA, alley cropping research spread to other parts of Africa (Arap-Sang, 1986), India (Rao *et al*., 1991), South America (Szott *etal*., 1991), the Phillipines (Maclean *et al*., 1992) and Indonesia (Parera, 1986). However, in spite of all the important benefits provided by nitrogen fixing trees and shrubs, some of the tree species are found to inhibit the growth of the adjacent crops when grown together a phenomenon known as allelopathy. However, allelopathy between different species may cause stimulatory or inhibitory effects. Therefore, it is important that the allelopathic nature of woody perennials must be considered before integrating it with annual crops under an agroforestry system.

Allelopathy is the inhibition of growth of one plant by chemical compounds (allelochemicals) that are released into the soil from neigbouring plants. The main purposes of research on allelopathy include the application of the observed allelopathic effects to agricultural production, reduction of the input of chemical pesticides and consequent environmental pollution and provision of effective methods for the sustainable development of agricultural production and ecological systems (Macias *et al*., 2003; Li *et al*., 2010; Han *et al*., 2013; Jabran *et al*., 2015). Competition is one of the main modes of interaction between cultivated crops and their neighbouring plants (He *et al*., 2012; An *et al*., 2013). The ability of the plant to suppress weeds thus determine by crop allelopathy and competiveness.

Generally, leaves are the most potent source of allelochemicals; however, the toxic metabolites are distributed in all other plant parts in various concentrations. Important secondary metabolites identified as allelochemicals which possess inhibitory effects are phenolics, alkaloids, flavonoids, terpenoids, momilactone, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates, carbohydrates and amino acids (Kruse *et al*., 2000; Jabran and Farooq, 2012). Ravi *et al*. (2008) also found that the leaf litter leachates of *Ailanthus excelsa* registered maximum inhibition on germination, shoot length, root length and total dry weight of black gram, cowpea, green gram and red gram than fresh leaf and root leachates.

Woody perennial legumes are proved to be important in maintaining soil fertility by conserving soil moisture and its ability to fixed atmospheric nitrogen. These species had gained importance as a component in agroforestry systems in alley cropping in sloping areas for soil and water conservation. However, little efforts have been done on incorporation of leguminous shrubs like *Flemingia semialata* in agricultural lands. The species is exotic to the state; it's multifarious used have not been fully exploited for sustainable income to farmers. The species have a deep root system capable of soil nutrient conservation and it is an important species for lac cultivation. Therefore, in order to know the multiple importance of this species in rehabilitation of degraded agricultural lands and to promote marginal farmers income, the present study aims at understanding the decomposition dynamics of *Flemingia semialata* leaf litter, its mulching and allleopathic effects on the growth of two agricultural crops *viz*., maize and rice. The study was also designed to gather information on these important ecological processes in alley cropping with regard to soil organic matter and nutrient budgeting and also its allelopathic influence with the following hypotheses:

• *Flemingia* leaf litter capture a significant amount of nutrients in its biomass.

• *Flemingia* leaf litter decomposes faster and subsequently release nutrients at faster rate.

• *Flemingia* leaf litter plays a significant role in fast nutrient recovery in soil, and therefore be eventually used for mulching.

• *Flemingia* leaf litter does not show any allelopathic effect on agricultural crops such as rice and maize.

These hypotheses were tested with the following objectives:

1. To study the decomposition and nutrient release patterns of foliage of *Flemingia semialata* Roxb.
2. To evaluate leaf litter of *F*. *semialata* as a source of mulch on *Zea mays* and *Oryza sativa*.
3. To study the allelopathic effect of leaf litter on the growth and development of *Zea mays* and *Oryza sativa*.

The outcome of the investigation is expected to fill in the existing knowledge gap on nutrient cycling in leguminous crops in agroforestry systems which is pivotal in formulation of appropriate action plan for sustainable management of shifting cultivation lands. The present study can also provide information on the suitability of *Flemingia* species for eco-restoration of anthropogenic degraded sites that may affect the soil and overall nutrient cycling process in agroecosystems.

Chapter 2
Review of Literature

The study on decomposition and nutrient mineralization of leaf litter has gained much importance in forests ecosystem. Literatures on decomposition and nutrient release of litter in the forest floor have been studied by several researchers in India and abroad. Much of the studies on litter decomposition are mostly done on woody tree species of tropical and temperate regions. Limited research has been conducted on the decomposition of perennial legumes in India and abroad and information on the suitability of leguminous leaf litter in nutrients supply in agricultural systems and its decomposition dynamics is also limited. Application of inorganic mulch has also been widely used to improve crop productivity in water deficient areas. Mulch application on the soil surface increase or decrease soil temperature during cold and hot seasons. It conserves soil moisture and maintains soil microbial biomass and soil enzymes activity which are important in maintaining soil fertility. However, the use of organic mulch like leaf litter is very scarce and use of leguminous litters are also limited besides being these crops maintain soil fertility by fixing atmospheric nitrogen. Several researchers in India and abroad have also studied the allelopathic effect of different trees/shrubs species including weeds to know its compatibility with different agricultural crops and also to develop bio-pesticide from the extracted parts of the donor plants. Most of the research findings highlight the importance of the study on allelopathy in agriculture and forestry sector. Even though the available literature related to the present study on the test crops viz. maize and rice is limited. Therefore, several research articles are reviewed in order to obtain more information on decomposition, mulching and allelopathic effect of *Flemingia semialata* leaf litter on agricultural crops which have been outlined herewith:

2.1 Decomposition and nutrient mineralization

In the study conducted by Rojas *et al*. (2017) residual loss weight (%) on *Theobroma cocoa*, *Gliricidia sepium*, *Gossypium arboretum* and *Chromolaena odorata* varied significantly in time during decomposition. The leaves of *Gliricidia sepium* decomposed much faster compared to others due to its high N content and low amount of lignin.

Ventura *et al*. (2010) in their study on nutrient release and decomposition of *Prunus persica* L. leaf litter found a gradual decrease on the dry matter and C concentration. Nutrient contents such as N, P, K, Ca and Mg in the leaf litter decreased with days of incubation. Duarte *et al*. (2013) studied decomposition and nutrient release pattern of the tree species used in agroforestry systems and found that all the tree species in the study had higher N content and lower C/N ratio which could lead to high decomposition rate.

Partey *et al*. (2011) evaluated the decomposition and nutrient release patterns of *Tithonia diversifolia* and four other leguminous agroforestry species. *Tithonia diversifolia* having higher N, P, K content, lower C/N (13) recorded the highest decomposition and nutrient release rates which differed significantly ($p<0.05$) from rates of the four leguminous species. Among the nutrients, K element had the fastest release rates among species and Mg immobilization was recorded in *Acacia auriculiformis*, *Leucaena leucocephala* and *Gliricidia sepium* which were at later stage mineralized at a relatively faster rate.

Matos *et al*. (2011) in their study on decomposition and nutrient release of *Arachis pintoi*, *Calopogonium mucunoides*, *Stizolobium aterrimum* and *Stylosanthes guianensis* in coffee-based agroforestry systems found that decomposition rate constant (k) was between 0.002-0.007 day^{-1}. The k_N varied from 0.003-0.009 and k_P from 0.01-0.03 day^{-1} respectively. Among the nutrients K was found to have the highest release rates (k_K = 0.0076-0.0145 day^{-1}) and P was the most rapidly released nutrient. Okoh and Edu (2019) in their study on nutrient dynamics in decomposing litter from four selected tree species found that the rate of decomposition was faster during wet season when compared to dry season. The mean decomposition rate (*k*) was 0.0030 g day^{-1} during wet season and 0.0022 g day^{-1} during dry season. The carbon and nitrogen content in the leaf litter were generally higher in dry season than in wet season which revealed negative relationship ($p<0.01$) between periods of decomposition (days) in both the seasons.

Jeong *et al*. (2015) studied nutrient dynamics from decomposing leaf litter for three years from three dominant tree species (*Quercus serrata*, *Carpinus laxiflora* and *Carpinus cordata*) in a broadleaved deciduous forest of Mt. Geumsan. They found that the mass loss rate from decomposing leaf litter were significantly lower in *Quercusserrata* leaf litter than *Carpinus laxiflora* and *Carpinus cordata*. The nitrogen, phosphorous, calcium and magnesium concentration in the remaining stocks from decomposing leaf litter were also higher in *Carpinus laxiflora* and *Carpinus cordata* than in *Quercus serrata* indicating that *Carpinus spp* leaf litter was significant and easily decomposed source of nutrients among the dominant tree species of broadleaved deciduous forest.

Decomposition and nutrient mineralization dynamics on *Ochlandra setigera* was studied by Thomas *et al*. (2014) and concluded that the mass loss during litter decomposition showed an initial rapid loss followed by a slower loss rate towards the later part of decomposition. The decomposition rate constant (*k*) was found to be 0.24 day^{-1} which indicates faster rate of decomposition. The faster rate of decomposition could be due to higher N concentration and lower C/N ratio (22.62) of leaf litter. The declining concentrations of N, K, Ca and Mg were also observed in the initial stages of decomposition indicating nutrient release.

Seta *et al*. (2016) conducted an experiment on nutrient release pattern during leaf litter decomposition in Boter - Becho forest and found no significant difference between initial litter chemistry and nutrient release except for K. A significant difference was observed ($p<0.01$) in C and nutrient release pattern between wet and dry season in both the study sites with greater release in the wet season. They also concluded that, C and nutrient release pattern in the study area mainly depends on the climatic factors rather than the initial litter chemistry.

Upadhyaya *et al*. (2012) in their study on decomposition and nutrient mineralization of *Phyllostachys bambusoides* and *Arundinaria racemosa* leaf and sheath litter found that litter of *Phyllostachus bambusoides* decomposed at a faster rate than *Arundinaria racemosa* due to high significant ($p<0.01$) N concentration and N/P ratio in the leaf litter. The weight loss on both leaf and sheath were also strongly positively correlated with N and N/P ratio, and significantly negatively correlated ($p<0.01$) with C/N ratio. The Lignin/N of the leaf litter also showed a negative correlation with decay rate.

Pinos *et al*. (2017) evaluated leaf litter fall and decomposition of *Polylepis reticulate* in the tree-line of Ecuadorian Andes and found the decay constant (*k*) of leaf litter as 0.38 $year^{-1}$ and the leaf in the litter bag lost only 13% of their original dry weight after one year of decomposition. The decomposition rate for their study was quite low when compared to *k* values in tropical and sub-tropical regions having higher temperature and rainfall. The lower value of *k* could be the result of lower temperature and rainfall in the study area.

Bargali *et al*. (2015) studied the leaf litter decomposition and nutrient dynamics of four species viz., *Shorea robusta*, *Madhuca indica*, *Diospyros melanoxylon* and *Schleichera oleosa* in dry deciduous forest. They found that *Shorea robusta* containing higher N concentration experienced the highest weight loss and *Madhuca indica* having the lowest concentration of N showed the lowest weight loss. The monthly weight loss was also found to be positively correlated ($p<0.05$) with climatic factors (rainfall, temperature and relative humidity). The nutrient content in the leaf litter decreased continuously with time for all the species except for P in *Shorea robusta* and *Diospyros melanoxylon* which showed immobilization at later stage of decomposition and among all the nutrients, K showed initial rapid loss during decomposition.

Zhou *et al*. (2018) in their study on the relationship of rainfall with mass loss and nutrient release rate in evergreen broad-leaved forest in western China found that mass loss and nutrient release were faster on the site having higher precipitation. The concentration of C decreased from 431±9 to 356±25 g/kg at the end of the experiment however, the amount of P increased during the first 4-8 months which indicated immobilization and then decreased at later stage.

In the study conducted by Triadiati *et al*. (2011) on litter production and decomposition at natural forest and cocoa agroforestry in Central Sulawesi, Indonesia found that mass loss and nutrient (C and N) loss was more pronounced in natural forest than in cocoa agroforestry. Natural forest had the maximum decomposition rate (k = 3.07) during March-June and minimum decomposition (k = 1.85) during September-December. The lowest decay rate recorded range between 1.23 and 1.14 respectively in a planted forest. The C and N released were also found higher in natural forest compared to other land use systems.

Effect of litter quality and quantity on chemical changes on *Eucalyptus* litter decomposition was studied in *Eucalyptus* dominated forest of subtropical Australia by Wang *et al*. (2019), they found that good quality litter having higher C and N concentration with lower C/N ratio decomposed at a faster rate compared to low quality litter. The high-quality litter showed a decomposition rate of k = 0.53 and low-quality litter with k = 0.33.

Pei *et al*. (2019) conducted an experiment on N, lignin and C/N ratio as regulators of gross nitrogen release and immobilization during *Quercus mongolica* and *Pinus koraiensis* litter and twig decomposition. They found that the gross N release rate was positively correlated with initial N concentration and initial C/N ratio but negatively correlated with initial lignin concentration. *Quercus mongolica* leaf litter with N (2.18%), C/N (20.28) and lignin (18.63%) decomposed with much faster rate than twigs and litter of *Pinus koraiensis* having lower N, higher C/N ratio and lignin content.

Setiawan *et al*. (2016) studied the mixing effect on litter decomposition rates in a young tree diversity experiment and concluded that, high quality litter species with high N concentration, low C/N ratio, high P concentration and moderate to high Ca concentration such as *Tilia cordata* and *Betula pendulla* decomposed faster than low quality litter species of *Fagus sylvatica* and *Quercus robur* having lower N concentration, high C/N ratio, low P concentration and moderate to low Ca in the leaf litter.

Decomposition and nutrient release with respect to climate and litter quality was studied on *Quercus serrata*, *Schima wallichi* and *Lithocarpus dealbata* by Devi and Yadav (2010). They found that the initial C and N concentration in the leaf litter of *Lithocarpus dealbata* was the highest followed by *Quercus serrata* and *Schima wallichi*. The high rate of decomposition (k = 0.54) was found in *Lithocarpus dealbata*, while low rate of decomposition was observed in *Schima wallichi* (k = 0.33) having lower value of initial C and N. The remaining biomass during different months were also positively correlated with lignin, C, C/N ratio and cellulose but negatively correlated with initial N concentration.

Xu *et al*. (2016) in their study on decomposition of *Picea asperata*, *Betula albosinensis* and *Abies faxoniana* showed that the initial N, P and

Ca concentration was the highest in *Betula albosinensis* followed by *Abies faxoniana* and *Picea asperata*. *Betula albosinensis* also had the lowest C/N, C/P and Lignin/N ratio compared to other two species. Due to all these litter characteristics, *Betula albosinensis* had the highest mean decomposition rate (k=0.50) indicating faster decomposition than the other species.

Naik *et al*. (2017) studied the decomposition and nutrient mineralization of leaf litter from mango, guava and litchi from different orchards under hot and dry sub-humid climate. Among the three species, mango had higher concentration of C and N with lower content of lignin and Lignin/N ratio when compared to guava and litchi. Due to this parameter, mango might have released N and K at a faster rate with a mineralization rate of k = 4.06 and k = 4.66 respectively.

2.2 Mulching effect on growth parameters of test crops and soil characteristics

Ni *et al*. (2016) studied on effects of mulching on soil properties and growth of tea olive. Three mulch materials were used: round gravel, wood chips and manila turf grass living mulch. They found that, mulching with round gravel and wood chips improved plant growth by increasing root activity, soluble sugar, chlorophyll a content, as well as providing suitable moisture conditions and nutrients in the root zone.

Jourgholami *et al*. (2019) in their study on the effect of litter and straw mulch amendments on soil properties and Caucasian alder (*Alnus subcordata*) growth subjected to machine operating trials of low, medium and low traffic intensity showed that, after three years of mulch application, recovery values of soil physical and chemical properties were significantly higher in litter mulch than in straw mulch when compared to control. Significantly higher seed germination percentage was recorded in litter mulch with low traffic intensity.

Hou *et al*. (2010) conducted an experiment to examine the effect on duration of plastic mulching on soil temperature, evapo-transpiration, growth and yield of potato and water use efficiency under drip irrigation in arid region for two years. They found that daily mean soil temperature under plastic mulch was 2-9°C higher than for non mulch conditions. Mulch cover for 60 days favoured potato production compared to potatoes grown without mulch in both years.

Farrag *et al*. (2016) observed the effect of applying different irrigation levels and soil mulches on vegetative growth, yield and water use efficiency of *Solanum tuberosum* L. The experiment was conducted for two seasons, and in both the seasons they found that application of different levels of irrigation and mulch treatments significantly affected potato vegetative growth, tuber yield and nutrients content (N, P and K). The highest WUE was obtained under black polythene film mulch with 75% irrigation requirement followed by rice straw when compared to transparent polythene films and bare soil. Black polythene film in combination with 100% irrigation requirement produced the highest vegetative and tuber yield.

Gao *et al*. (2014) conducted a field experiment to access the soil water status and root distribution across the rooting zone in maize with plastic film mulching. They found that maize in full-film mulching had significantly greater root weight density, root length density and root diameter compared to half-film mulch or without mulch treatment. Compared to control, full-film mulch significantly improved soil water content and subsequently increase maize grain yield by 81% in the first year and 92% in the second year.

In the study conducted by Rahman *et al*. (2016) on the effect of different mulch materials on the growth and yield of tomato. Black polythene sheet, clear polythene sheet and rice straw were used as mulch materials which are compared with no mulch control. Results of their findings revealed that, plant height, number of leaves, number of branches, number of flowers, number of fruits, average fruit weight and yield per hectare were higher in black polythene sheets when compared to clear sheet and control.

Yaseen *et al*. (2014) conducted a field experiment on the effect of deficit irrigation and mulch on soil physical properties, growth and yield of maize. They found that, irrigation level with irrigation depth of 711.2 mm with mulch applied at the rate of 15 Mg ha^{-1} showed maximum increased in plant height, biological yield and grain yield when compared to other treatments and control. Highest SOC, nitrogen, phosphorus and potassium with values 0.55 g kg^{-1}, 0.64 g kg^{-1}, 15.48 ppm and 144.67 ppm respectively are found in treatment combination of mulch with 711.2 mm irrigation depth when compared to control.

Awal *et al*. (2016) observed the effect of mulch on microclimatic manipulation, weed suppression and growth and yield of *Pisum sativum* L. They found that soil temperature was increased in black and transparent polythene while rice straw decreased the soil moisture when compared to control. Soil moisture was also found higher in mulch treatments and weed growth was also suppressed by all the mulch treatments. Plant height, leaf area index, dry matter accumulation, seed yield, seed weights were influenced by different mulches. The highest seed yield was obtained from the crops grown with black (5.66 t/ha) and lowest in rice straw mulch (4.38 t ha^{-1}) when compared to control.

Zhao *et al*. (2014) in their study on the effects of straw mulch and buried straw on soil moisture and salinity in relation to sunflower growth and yield found that, combination of straw mulch and burying of maize straw layer (12 t ha^{-1}) at a depth of 40 cm promoted sunflower growth which is indicated by taller plant and greater leaf area index. The highest sunflower shoot biomass was obtained from straw mulch and maize straw layer. During the course of the study for three years, the average shoot biomass was increased by 4.8% compared to straw mulch alone and 20.8% compared to control treatment.

Zhang *et al*. (2019) conducted an experiment on a five-year-old commercial greenhouse located in Helan county, Ningxia, China with the mean air temperature of about 32°C and 31°C during summer season. They found that plastic film mulch increased soil moisture, soil temperature, pH, EC and decrease available P resulting in the reduction of plant growth (root length and diameter, relative growth ratio of plant height and leaf area and shoot and root biomass) and fruit yield. However, biodegradable paper mulch not only decreased soil temperature, it increased soil moisture as a result it showed several advantages such as decreasing soil EC, increasing soil enzyme activities, improving plant growth and increasing fruit yield when compared to other mulch treatments and control.

Zhang *et al*. (2018) measured the yield and WUE of maize with drip irrigation using film mulch and non-mulch. They found that the yield of maize increased by 5.9-8.8% and the water use efficiency increased by 10.7-13.1% in the field with mulch treatments when compared to treatment without mulch.

Zhang *et al*. (2017) investigated the soil water content, soil temperature, WUE, growth and grain yield of proso millet in 2014 and 2015 and found that, the highest gain yields appeared in ridging treatment with hills and furrows plastic film mulch in both the years. Due to its beneficial effects on soil water content, WUE and leaf area index, this treatment improved the growth of proso millet and increased its yield by 31.3%-35.3% during the experimental year when compared to control treatment with no mulch material.

Wu *et al*. (2018) in their study on the potential of rice straw mulching for mitigating N_2O emissions and increasing crop production of maize found that, straw mulching increased the yield of maize by 16.5 and 29.6% with 5000 kg/ha and 10,000 kg/ha straw mulch respectively. The higher quantity of mulch also increased the SOC, available N and available K of the experimental soil.

Wang *et al*. (2014) investigated the effect of plastic mulch on soil biochemical properties and nutrient uptake by maize in semi-aid environment for three years. They found that full mulch increased maize grain yield by 50% in the first year when compared to treatments with half mulch and control. Mulch treatments also increased above ground nitrogen uptake by 21-3% and phosphorus uptake by 21-42% in the first year of treatment. Soil microbial biomass and activities of urease, β-glucosidase and phosphatase at the 0-15 cm depth were generally higher during vegetative growth stage under mulch treatments than no mulch.

Thankamani *et al*. (2016) studied the effect of mulches on weed suppression and yield of ginger under rainfed condition. They found that maximum height (43.2 cm) and weed control efficiency (72%) was recorded in treatment application of old paddy straw along with green leaf mulch when compared to treatments with no mulch (control).

Sidhu *et al*. (2007) observed the effect of wheat straw mulch on soil temperature and growth and yield of maize in sandy loam soil for four years. They concluded that, application of mulch lowers the soil temperature, improved leaf area index by 0.42, plant height by 14 cm, grain yield by 0.24 t/ha and biomass by 1.57 t/ha respectively when compared to control.

Eifediyi *et al*. (2016) in their experiment to assess the response of sesame to mulch and inorganic fertilizer found that the combination of grass mulch with fertilizer @ 300 kg/ha increases the plant height, number of leaves and branches when compared with other treatments with wood chip mulch and control.

Qiu *et al*. (2014) studied the effect of gravel-sand mulch on soil physicochemical properties, microbial biomass and enzyme activities for 16 years. The changed in parameters was examined after 7, 11 and 16 years. They found that, total C, N and soil enzyme activities increased significantly 11 years of mulching; however, the positive effect shows a decline after 16 years of mulching.

Lu *et al*. (2014) conducted an experiment to assess the effect of maize straw mulch on yield of maize, soil moisture, soil temperature and WUE. They found that straw mulch caused decline in soil temperature and increased soil moisture in the early growing season. However, mulching with straw mulch reduced the maize yield by 18% in the first year to 26% in the following year. The WUE of the crop was also found to be decreased from 16% to 21% in the next year.

Kosterna (2014) studied the effect of plant covering and the type of straw used for soil mulching on soil temperature, yield and development of plant. It was found that, the application of covers in the form of mulch resulted in higher above ground biomass and leaf area compared to cultivation without covers. Irrespective of the types of straw, the experiment caused the acceleration of growth and development of tomato plants when compared to control.

Awopegba *et al*. (2017) carried out field experiment to evaluate the effect of shrub and herb mulch with NPK fertilizer on soil properties and nutrient status of maize. They found that, herbaceous mulch type and NPK fertilizer significantly increased the number of leaves, plant height and leaf area when compared to control. Soil organic carbon, total nitrogen, potassium and exchangeable cations were also found to be positively stimulated by herbaceous mulch.

Adak *et al*. (2014) in their study evaluated the changes in soil organic carbon, dehydrogenase activity, nutrient availability and leaf nutrient concentration in a mango orchard soil. They found that soil and leaf nutrient concentrations were significantly increased in organic and inorganic amended soil as compared to control. They also observed that dehydrogenase activity was the highest in treatments with organic amend soil when compared to control.

Idrissa *et al*. (2018) conducted an experiment to access the impact of deficit irrigation, straw mulch and nitrogen fertilizer application on vegetative growth of maize. They found that, application of mulch reduced the amount of water needed for irrigation and also significantly ($p<0.05$) affected plant height, leaf number, leaf area and shoot biomass.

Agbede *et al*. (2013) studied the effect of *Chromolaena* and *Tithonia* mulches on soil properties, leaf nutrient content, growth and yield of yam crop. They found that *Chromolaena* and *Tithonia* mulch reduced soil bulk density and temperature; it also increased the concentration of organic matter, N, P, K, Ca and Mg in soil and the leaves. Application of mulch also increased the growth and yield of yam when compared to control, and the values of soil organic matter, N and K in soil and N, P and K in leaf increased with increasing mulch rate.

2.3 Allelopathic effects on different crops

Tadele (2014) reported that the aqueous leaf extracts of *Lantana camara* L. in bioassay inhibited the root and shoot length of Tef where the highest inhibitory effect on the root length was observed at 75% aqueous concentration. The inhibitory effect on the root and shoot length increased with increase in concentration of leaf extracts. However, stimulatory effect on the root and shoot length was observed when compared to control in Finger millet, the highest stimulatory effect was found in 25% concentration for root and shoot length.

Debnath *et al*. (2016) studied the effect of aqueous and methanol leaf extracts on *Hevea brasiliensis* on four common legumes viz. *Cicer* *arietinum*, *Lens culinaris, Vigna radiata* and *Vigna mungois*. They found that both the leaf extracts showed inhibitory effect on the germination, radical and plumule length and biomass of the test crops.

Enyew and Raja (2015) showed that the leaf powder of *Lantana camara* L. mixed with 1000 g of soil in plastic container in different quantities inhibited the root and shoot length, stem thickness and biomass of wheat. The inhibitory effect increased with increase in the quantity of leaf powder added to the soil.

Musyimi *et al*. (2015) in their study on the allelopathic potential of shoot aqueous extracts of *Tithonia diversifolia* on the germination and growth of cowpea seedlings. They found that plumule length and radical length were reduced with increase in concentration of extracts. However, the leaf area, number of leaves, dry weight of roots and shoots and total chlorophyll content showed stimulatory effect after three weeks of plantation.

Babu *et al*. (2014) observed that the aqueous weed extracts of *Parthenium hysterophorus*, *Tridax procumbens* and *Hyptis saveolens* in bioassay and pot culture produced allelopathic effect on *Vigna mungo* L. Inhibitory effect on germination, root and shoot length was observed in *Vigna mungo* on aqueous leaf extracts in both bioassay and pot culture. However, stimulatory effect on germination, root and shoot length was recorded in *Vigna mungo* when treated with aqueous leaf extracts of *Tridax procumbens* and *Hyptis saveolens*.

A pot experiment was conducted by Elisante *et al*. (2013) to determine the allelopathic effects of *Datura stramonium* on leaf chlorophyll content, root and shoot elongation, fresh and dry weight of *Cenchrus ciliaris* and *Neonotonia wightii*. They found that the leaf chlorophyll content, root and shoot elongation, fresh and dry weight of

Cenchrus ciliaris and *Neonotonia wightii* were significantly inhibited by seed and leaf aqueous extracts of *Datura stramonium*.

Parmar *et al*. (2018) had undertaken a study to analyse *Melia dubia* Cav. leaf litter and aqueous leaf extracts on germination and early growth and biomass of chilli and egg-plant in laboratory and pot culture. They found that, the leaf extracts in laboratory bioassay and leaf litter pot experiment showed inhibitory effect on the root/shoot ratio, root and shoot length and biomass of both the crops. The highest inhibitory effect in laboratory bioassay was shown in 100% extract concentrations and highest inhibitory effect on leaf litter polypot experiment was recorded in treatments with highest quantity of leaf litter.

Laxman *et al*. (2019) studied the effect of aqueous leaf extract and leaf litter leachate extracts from *Chromolaena odorata* L. on the growth of *Salvadora persica* in petri dishes under different concentrations (20, 40, 60 and 80%). They found that higher concentration of extract (60 and 80%) significantly reduced germination percentage, radicle length, plumule length and dry matter accumulation of *Salvadora persica* seedlings as compared to control.

Shankar *et al*. (2014) observed that leaf leachates of *Gmelina arborea* inhibited the germination percentage, seedling length, vigor index, seedling fresh and dry weight and relative water content of *Vigna mungo* (Green gram), *Vigna radiata* (Black gram), *Cajanas cajan* (Red gram) and *Cicer arietinum* (Chicken pea) in laboratory bioassay.

Chopra *et al*. (2017) undertook to assess the allelopathic effect of *Echinochloa colona* L. and *Cyperus iria* L. on germination and growth of *Glycine max* L. (soyabean). The results of their findings suggest that *Echinochloa colona* had good allelopathic potential which reduces the germination and growth of *Glycine max*. With increase in extract concentration from 1 to 100 mg/mL, a gradual decreased in seed germination and seedling length occurred.

Juma *et al*. (2019) conducted an experiment on allelopathic effect of *Dicranopteris dichotoma* on invasive species *Bidens pilosa* and *Eupatorium catarium* in laboratory bioassay. They concluded that, increasing extracts concentration of leaves, stem and root of *Dicranopterisdichotoma* decreased the root length, shoot length and dry weight of *E. catarium* as well as *B. pilosa*.

Nishimuta *et al*. (2019) studied the leaf and root allelopathic potential of *Vernonanthura brasiliana* on *Lactuca sativa*. Fresh and dry leaves and fresh and dry root extracts were used in the experiment. They found that the root length of *L. sativa* decreased with increase in the concentration of fresh and dry leaf extracts. However, stimulatory effect on the aerial length was observed for fresh leaf extracts but not for dry leaves when compared to control. The root length also decreased with increase in concentration of fresh and dry root extracts; however, the fresh root extracts showed a stimulatory effect on the shoot length of *L. sativa*.

Carvalho *et al*. (2015) evaluated the effect of various concentrations of an aqueous extracts of *Eucalyptus urograndis* on *Urochloa decumbens* and *Panicum maximum* seeds. The bioassay results showed that 50% and 100% concentration of leaf extracts most strongly inhibited the germination, vigor and seedling growth of the forage seeds.

Wang *et al*. (2020) studied the chemical composition and allelopathic potential of essential oils from *Eupatorium maculatum* on *Lolium perenne* L. and *Echinochloa crusgalli* L. It was found that the oils extracted from flowers, stems and leaves inhibited seed germination and seedling growth of *L. perenne* and *E. crusgalli*.

Alqarawi *et al*. (2018) investigated the allelopathic effect of *Rhazya stricta* leaf extracts on the germination, early seedling growth and metabolism of *Salsola villosa*. They found that the leaf extract of *R. stricta* inhibited root and shoot length of *Salsola villosa* and the inhibitory effect was concentration dependent. Aqueous extracts from the leaves of *R. stricta* restricted the growth and metabolism of *S. villosa* by hampering membranes functioning and photosynthetic capacity.

Hachani *et al*. (2019) evaluated the effect of three aqueous extracts (leaves, roots and litter) of *Casuarina glauca* and *Populus nigra* on germination and seedling growth of *Triticum durum* under laboratory conditions. They found that exposure to different extracts of *Casuarina glauca* and *Popolus nigra* significantly reduced dry mass production, root & shoot length, and chlorophyll & protein concentrations in *T. durum* seedlings.

Joshi *et al*. (2015) studied the effect of aqueous leaf extracts of *Hyptis sauveolens*, *Ricinus communis, Alternanthera sessilis*, *Ipomea carnea*, *Malachra capitata* and *Cymbopogon citrutus* on *Vigna radiata*. It was found that the root and shoot length and biomass of *Vigna radiata* were significantly inhibited at higher concentration of extracts.

Mendez and Glaxy (2017) investigated the effect of *Artocarpus heterophyllus* and *Artocarpus altilis* leaf extracts on *Vigna radiata*. They found that the aqueous leaf extracts of *Artocarpus heterophyllus* and *Artocarpus altilis* inhibited the germination rate, radicle elongation and plumule growth of *Vigna radiata* at higher concentration of extracts when compared to control.

Zhang *et al*. (2018) showed that root, stem and leaf aqueous extracts of *Koelreuteria bipinnata* var. *integrifoliola* inhibited the root and shoot length of *Agrostis tenuis*, *Festuca arundinacea* and *Lolium* *perenne*. The higher concentration of extracts showed inhibitory effect when compared to lower concentration and control.

Chu *et al*. (2014) conducted an allelopathy experiment in *Eucalyptus urophylla* plantation on *Acmena acuminatissima*, *Cryptocarya concinna* and *Pterospermum lanceaefolium*. It was found that the root length of the three tree species was significantly inhibited by *Eucalyptus urophylla* plantation. It was also found that fresh and dry weight of *Cryptocarya concinna* was significantly reduced in *Eucalyptus urophylla* plantation.

Liu *et al*. (2015) evaluated the allelopathic potential of *Rhus chinensis* on seedling growth of *Raphanus sativus*, *Cassia obtusifolia* and *Glycine max* under laboratory conditions. They found that the water extracts of seed, leaf and bark of *Raphanus chinensis* inhibited the germination, root and shoot length of radish, semen cassia and black soyabean. Significant reductions in the germination and growth of roots and shoots were observed as the concentration of water extract increased in all bioassays.

Song *et al*. (2018) conducted a green house experiment to assess the allelopathic effects of leaf and litter leachates of *Eucalyptus urophylla* on *Leucaena leucocephala*, *Pterospermum lanceaefolium*, *Schefflera octophylla* and *Albezia lebbeck*. They found that the leaf and litter leachates significantly inhibited seedling germination of *Leucaena leucocephala*, *Pterospermum lanceaefolium* and *Schefflera octophylla*. However, stimulatory effect on the biomass, root length and shoot length were observed in *Leucaena leucocephala* and *Schefflera octophylla*.

Ahmed *et al*. (2016) tested the allelopathic effect of *Eucalyptus camaldulensis* by incorporating the leaf litter in nursery bed. The growth of three agricultural crops (*Vigna unguiculata*, *Cicer arietinum* and *Cajanus cajan*) along with two tree species (*Albizia procera* and

Leucaena leucocephala) were recorded in the experiment. The result showed an inhibitory effect on germination, shoot and root growth, leaf number, collar diameter as well as a reduction of nodulation by legume crops.

El Id *et al*. (2015) evaluated the allelopathic effect of *Sesbania virgata* on the germination and development of *Enterolobium contortisiliquum*, *Sapindus saponaria*, *Oryza sativa* and *Solanum lycopersicum* in the laboratoryand greenhouse assays with seed and leaf extracts. It was concluded that the germination, root and shoot length and biomass of the crops were inhibited by the extracts.

Sahoo *et al*. (2010) investigated the aqueous leaf extracts of different concentration of *Mangifera indica* in bioassay and pot culture. They found that germination, root and shoot length and dry matter yield of soyabean, okra and chilli were inhibited and the inhibitory effect increases with increased in the concentration of the extracts.

2.4 Allelopathic effects on maize and rice

Enyew and Raja (2015) conducted a pot culture experiment to test the allelopathic effects of *Lantana camara* leaf powder on germination and growth behavior of maize. Different treatments were made by mixing 25, 50 and 75 g of leaf powder mixed with 1000 g of soil kept in plastic container and were compared with soil without leaf powder used as control. They concluded that the root length, shoot length, fresh and dry biomass were inhibited by leaf powder. With increase in the quantity of leaf powder added, the inhibitory effect on growth parameters increased.

Ogbu *et al*. (2019) investigated the aqueous leaf extracts of *Pentaclethra macrophylla* on germination and seedling growth of maize and okra in bioassay and in nursery condition. They found that stimulatory effect on germination of maize; however seedling sprout length and dry weight showed inhibitory effect with increase in the concentration of extracts in bioassay. The seedling plant height and seedling dry weight of maize showed a stimulatory effect on the extracts but the root length exhibited inhibitory effect with increase in the concentration of extracts in nursery condition.

Chopra *et al*. (2017) assessed the allelopathic effect of *Echinochloa colona* and *Cyperus iria* in relation to germination and primary growth of rice and soybeanin laboratory bioassay. They found that germination and mean length of rice were highly inhibited by the shoot and root extracts. With increase in extract concentration from 1 to 100 mg/mL, a gradual decrease in seed germination and seedling length occurred.

Tanveer *et al*. (2015) investigated the allelopathic effect of *Marsilea minuta* against the germination and seedling growth of rice and wheat in bioassay and soil cultures in laboratory conditions. They found that in bioassay and soil culture experiment, the root lengths, shoot lengths, seedling lengths, root dry weights, shoot dry weights, seedling biomass and seedling vigor indices of both the rice and wheat were inhibited by the aqueous extracts of the whole plant.

Bharath *et al*. (2014) made an attempt to investigate the allelopathic effects of aqueous leaf, stem and rhizome of *Zingiber officinale* on early seed growth parameters of maize. The root and shoot lengths were significantly decreased when treated with different concentration of ginger stem, leaf and rhizome extracts. The root and shoot lengths decreased with increase in the concentration of extracts. However, the dry weight of maize increased with increase in the concentration of ginger aqueous extracts.

Geethambigai *et al*. (2014) evaluated the allelopathic effects of aqueous leaf extracts of *Croton bonplandianum* on growth and development of two cultivars of rice in earthen pot containing 3 kg of normal garden soil. Different extract concentrations were irrigated in alternate days up to 13 days after sowing and distilled water used as control. They found that the germination percentage, root and shoot lengths of both rice cultivars gradually declined with increasing the concentrations of plant extracts.

Oyun (2006) studied the allelopathic potential of leaf leachates of *Gliricidia sepium* and *Acacia auriculiformis* on germination and seedling vigour of maize in bioassay. He found that the leaf leachates of both *Gliricidia sepium* and *Acacia auriculiformis* both affected all the growth parameters by inhibiting the germination, root and shoot length, fresh and dry weight of root and shoot and seedling vigour. The inhibitory effect on these growth parameters increases with increased in the concentration of leaf extracts.

Chukwuka *et al*. (2014a) conducted a green house experiment to examine the effects of aqueous leaf extracts of *Tithonia diversifolia* and *Vernonia amygdalina* on germination and growth development of maize. They found that both the radicle and plumule length were inhibited by the aqueous extracts of *Tithonia diversifolia* and *Vernonia amygdalina* and is concentration dependent. The plant height however showed a stimulatory effect for *Tithonia diversifolia* leaf extracts but the plant height decreased in the case of *Vernonia amygdalina*.

Navaey *et al*. (2013) tested the allelopathic effect of water extracts of *Glycyrrhiza glabra* on germination and chlorophyll content of maize in petri dishes and plastic pot. They concluded that seed germination, radicle length, shoot length, plant height, dry weight and chlorophyll content of maize were inhibited with increase in the concentration of leaf extracts.

Arora (2013) evaluated the allelopathic effect of foliar and flower extracts of *Cassia occidentalis* on seed germination and seedling growth of maize under laboratory condition. He found that germination and dry weight of maize was inhibited significantly by flower and leaf extracts. A dose dependent reduction was observed on the growth parameters with higher inhibitory effect found in higher concentration of extracts.

Babik and Jalali (2016) assessed the allelopathic potential of aqueous leaf extracts of *Cynodon dactylon* on seed germination and radicle length of maize. The results showed that seed germination and plant growth were delayed at higher concentration in both laboratory and greenhouse experiment.

A field experiment was conducted in a field by Vijayan (2015) to evaluate the allelopathic effects of *Acacia auriculiformis* on seed germination and seedling growth of rice. The field soil mulched with dry leaves of *Acacia* and field soil irrigated with cold extracts of fresh leaves of *Acacia* showed stimulatory effect on the shoot length and dry biomass but it caused inhibitory effect on the root length of maize.

Khan *et al*. (2016) studied the effect of *Populus nigra* bark aqueous extracts on maize under laboratory condition. They found that germination, plumule length, radicle length, fresh and dry biomass of maize was inhibited by aqueous bark extracts of *Populusnigra*. The inhibitory effect on the growth parameters were concentration dependent.

Boaprem (2019) conducted an experiment to study the allelopathic effects of *Leucaena leucocephala* leaf extracts on rice, wrinkle duck-bean and mungbean. He found that the shoot length, root length, dry weight and fresh weight were decreased by increasing concentration of the *Leucaena* leaves extract. It was also found that the inhibition was higher in the root length than shoot length in rice and wrinkle duck-bean.

Sahoo *et al*. (2010) investigated the allelopathic effect of leaf leachates of *Mangifera indica* on initaial growth parameters of few homegarden food crops in bioassay and pot experiment. They found a stimulatory effect on the shoot length of maize in leachates extracts when compared to control but inhibitory effect was observed on the shoot length and root length of maize and rice in bioassay. In pot experiment stimulatory effects are found on the shoot length of rice and root length of maize but inhibitory effect on the shoot length of maize and root length of paddy. The leaf leachates also showed an inhibitory effect on the dry weight of both the test crops.

Pacanoski *et al*. (2014) evaluated the allelopathic potential of *Datura stramonium* for root and shoot aqueous extracts in laboratory and glasshouse experiment on early growth of maize and sunflower. They found that the root and shoot extracts of *Datura stramonium* inhibited the root and shoot length of maize for both the extracts but stimulatory effect was observed on the shoot length for shoot leachates in laboratory experiment. In glasshouse experiment they found that fresh weight and height of maize were inhibited by the root and shoot leachates of *Datura stramonium*.

Karkanis *et al*. (2019) conducted a field experiment to assess the allelopathic effect of *Mentha spicata* and *Mentha piperita* on the growth, yield and photosynthetic rate of maize in crop rotation system. They found that the plant height, biomass and photosynthetic rate were lower in case of rotation system in the presence of *Mentha spicata* and *Mentha piperita*. The yield for all the growth parameters was higher in case of rotation system without incorporation of *Mentha spicata* and *Mentha piperita*.

Lalremsang *et al*. (2017a) studied the allelopathic effect of aqueous leaf extracts of *Trevesia palmata* on seedling growth of maize and french bean in bioassay. They found that the aqueous leaf extracts caused inhibitory effect on the root and shoot length at higher concentration of extracts. Stimulatory effect on the root and shoot length was observed in 40% extract concentration. For, fresh and dry biomass of maize, stimulatory effect was observed in all the concentration except in 100% concentration. Stimulatory effect on the fresh and dry biomass was observed more in 40% extract concentration.

The above literature survey clearly reveals limited information on decomposition dynamics of *Flemingia* leaf litter in north-eastern region in general and Mizoram in particular. Depletion of soil fertility due to shifting cultivation, the knowledge of *in-situ* replenishment pattern through decomposition is a vital process for proper management of woody perennial crops to obtain sustained production. Limited research on the use of leaf litter mulch in the literature survey also highlight the need for leaf mulch in conserving soil nutrients and moisture during post rainy season. The present study is thus proposed to investigate the status of nutrient release pattern on legume residues and its allelopathic potential when grown in agricultural fields. The study is significant not only with respect to fill in the knowledge gap in existing knowledge on the role of leaf litter on soil management and nutrient cycling but would also help in developing ecorestoration strategies for degraded forested areas in different land use systems in Mizoram.

Chapter 3
Study sites and species description

3.1 Study site

The study was conducted in Department of Forestry, Mizoram Univeristy (23°42` to 23°46` N Latitude and 92°38` to 92°42`E Longitude) with an elevation of 950 meter above sea level **(Figure 3.1)**.Mizoram University is located in Aizawl distict and it is about 20 kms from the heart of the city capital. The state is characterized by slopes ranging from 4% to more than 60%.

3.1.1 Geology

The rocks of Mizoram are sedimentary comprising of sandstone, shale and siltstones. Their intercalation constitutes the hilly terrain in and around Aizawl. These soft rocks ultimately converted into soil, giving rise to possibility of growing crops and vegetables. Rocks belonging to Middle Bhuban formation occupy the core of the anticline and the overlying upper Bhuban formation flanks the anticline on both sides (Anon, 2005).

The Middle Bhuban formation is overlain by younger arenaceous rocks of Upper Bhuban formation consisting of medium grained, moderately hard, sandstone with subordinate shale/siltstone. This formation is exposed along the Zokhawsang ridge in the eastern part; on the western side, this formation is represented from Luangmual towards Tanhril (study site); and on the northern part, it is exposed from Durtlang Vengthar towards Sihphir ridge.

Figure 3.1 Map showing study site.

3.1.2 Soil characteristics

The soils of Mizoram are dominated mainly by loose sedimentary formation. They are young, immature and sandy (Pachuau, 1994). Analysis of soil samples from different places of Mizoram indicates that magnesium, copper and iron are adequately available except zinc. The pH and organic content mostly decrease with depth (**Table 3.1)**.

Based on rainfall and humidity, the soil moisture regime of the study area is classified as Udic. The soil moisture regime refers to the presence or absence of water in the soil by periods of the years. A soil may be continuously moist in some or all horizons throughout the year or some part of the year. The soil may be saturated or the amount of water is enough to cause leaching and non-leaching regimes. The Udic moisture regime is common to the soils of humid climates that have well distributed rainfall or that has enough rainfall in summer that the amount of stored moisture plus rainfall is approximately equal to or exceed the amount of evapotranspiration.

Table 3.1. Soil physico-chemical properties of the study site.

Depth (cm)	pH	Organic C (g/kg)	Available K (mg/kg)	Available P (mg/kg)	Available N (mg/kg)	Soil moisture (%)
0-10	5.5	4.3	230	6.2	109.4	37.7
10-20	5.5	4	231	5.7	90	33.1
20-30	5	4.1	205	6.1	118.3	31.6

3.1.3 Climate

The climate is extremely warm in summer and moderately cold and dry during winter. The annual mean temperature ranges between 5˚C to 28˚C in winter and 20˚C to 39˚C in summer whereas the average annual rainfall is 2422 mm. Pre-monsoon rain starts from late April with heavy rain during May to starting July and continues till September. The entire state comes under the direct influence of south west monsoon (Tiwari, 2006). **(Figure 3.2)**

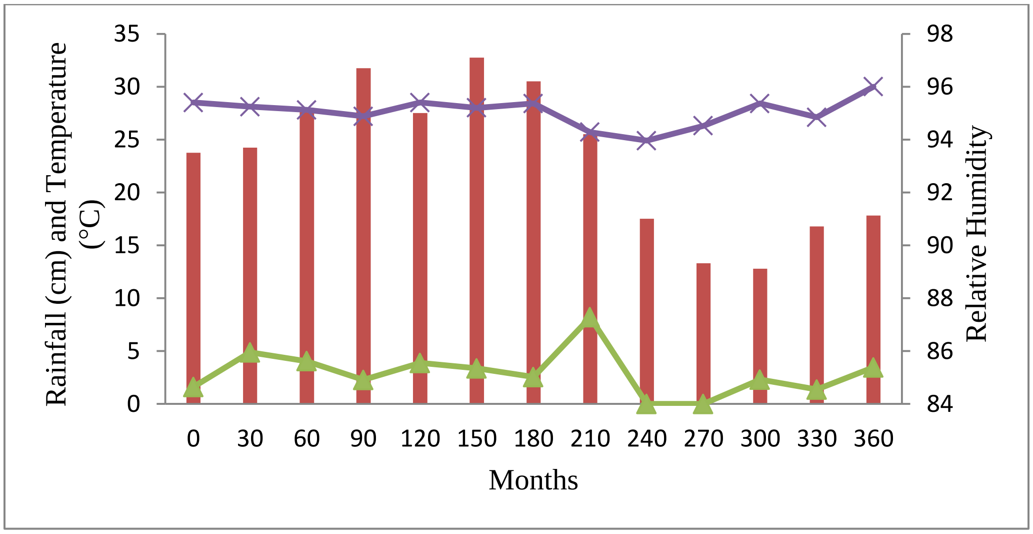


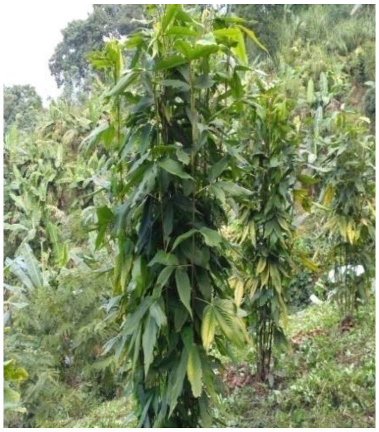
Figure 3.2 Climatograph of the study site (Green line represent Rainfall; Blue line represent temperature and Bar chart represent Relative humidity).

3.1.4 Vegetation and land use

Mizoram belongs to sub-tropical vegetation showing mixed pine forest. The common species of these forests are *Castanopsis purpurella*, *Duabanga grandiflora*, *Myristica spp*, *Phoebe goalparensis*, *Pinus kesiya*, *Podocarpus neriifolia*, *Prunus cerasoides*, *Quercus acutissima*, *Quercus semiserrata*, *Schima wallichi* etc. The major land use/land cover within the study area can be classified into built-up land; agriculture land (horticulture and shifting cultivation); primary/dense forest; secondary/open forest; bamboo forest and scrub land/abandoned shifting cultivation. Built-up land includes the settlement area, stone quarries and recreational areas like playground etc. which is concentrated in the central part and in few pockets towards the periphery of the study area. Agricultural land comprises of those areas where cultivation of crops is practiced under horticulture and shifting cultivation. Even though the same technique of shifting cultivation has been applied where trees and bamboos are felled and burnt for preparing the land for cultivation, the same land has been used continuously over again and again instead of shifting from one place to another due to limited availability of land.

Primary/dense forest refers to forest, which are not disturbed by biotic factors like shifting cultivation or any other human activities. Secondary/open forest includes forest, once distributed and affected by shifting cultivation and other human activities. Those lands which have been used for shifting cultivation are left fellow for over a year and new vegetation started growing and forest has generated again. Bamboo forests are mostly secondary growth since they grow in areas once used for shifting cultivation in the past. In the abandoned jhum fields of about one-year, young bamboo shoots start coming up if not distributed, when it attains maturity again forms a bamboo forest. They are mostly found in low lying areas near streams and on the hill slopes. Scrub land/abandoned shifting cultivation includes abandoned land of shifting cultivation and areas where shrubs, herbs and grasses grow.

3.2 Species description

Phylum – Tracheophyta

Class – Magnoliospida

Order – Fabales

Family – Fabaceae

Genus – *Flemingia* Roxb.ex W.T.Aiton

Species – *semialata* Roxb.ex W.T.Aiton

Flemingia semialata Roxb. (winged-stalk *Flemingia*) is a perennial woody shrub belonging to family Fabaceae closely resembling *Flemingia congesta* but much taller, petiole shorter and narrowly winged towards the upper end, glandular dots often absent, the racemes longer (3-6 in) and laxer and the calyx-teeth narrower. It flowers during the month of August-September and seeds are matured in the month of February-March the following year. This perennial herb can reach up to a height of 2-3.3 meters.

Chapter 4
Decomposition and nutrient release potential of *Flemingia semialata* Roxb. leaf litter

4.1 Introduction

Litter decomposition is modulated by both biotic and abiotic factors including temperature and humidity (Parton *et al*., 2007) as well as soil decomposing organisms (Berg *et al*., 2010; Garcia-Palacios *et al*., 2016). Litter characteristics also determine decomposition processes including nutrient concentrations as well as physical characteristics (Garcia-Palacios *et al*., 2016). Species type had a large influence on decomposition rate (*k*), most probably through its influence on leaf litter quality and its morphology (Salinas *et al*., 2011).

Litter quality indexes include nitrogen concentration, C/N ratio, lignin concentration and Lignin/N ratio. Litter quality affects not only the rate mass loss, but also the patterns and rates of nutrient mineralization (Santa Regina, 2001).

High cost of fertilizers for marginal farmers and its adverse effect in the long run make it unsuitable for use in agricultural fields; the incorporation of woody perennials in cropping systems through agroforestry can help sustain agricultural production (George *et al*., 2001). Several leguminous species such as *Stizolobium aterrimum*, *Arachis pintio*, *Calopogonium mucunoides* and *Stylosanthes guianensis* are found to have outstanding capacity to produce high amounts of biomass and accumulate high nutrient concentrations which become available to crops after litter/residue decomposition (Matos *et al*., 2008). Decomposition in agroforestry systems differs from that of in the natural forest and in agricultural system because of differences in the types and quality of organic inputs (Mafongoya *et al*., 1998).

Trees grown naturally or plantation in agricultural fields have formed important traditional agroforestry systems in the arid and semi-arid regions of India. Fast growing woody perennials provide almost permanent litter cover, and the decomposing leaf litters are being replenished by freshly fallen materials. Although intensive studies on litter dynamics in forest ecosystems have been carried out worldwide, multipurpose trees especially those grown in farm fields have only received serious attention in recent years. Understanding the decomposition and nutrient release patterns of plant biomass is crucial in manipulating their incorporation into cropping systems to improve nutrient synchronization. Therefore, the present chapter aims at understanding the decomposition and nutrient release patter of leaf litter of *Flemingia semialata*, a potential multipurpose woody perennial species for agroforestry systems.

4.2 Materials and method

4.2.1 Litter sampling

Freshly fallen leaf litter was collected during April, 2016. Nylon litter bag technique (1mm, 20 cm x 20cm) was used for decomposition study (Mason, 1977). Air dried samples equivalent to 15 g of oven dried weight were placed in each litter bag. Seventy nylon bags were prepared and randomly distributed in five clusters on the experimental site in the month of May, 2016 and bags were buried in the top 0-5 cm soil layer and decomposition was monitored till April, 2017. Each cluster contained fourteen bags and five bags were retrieved every 30 days interval.

The retrieved samples from each litter bag was cleaned from adhering plant and soil particles in running tap water, the cleaned samples were again oven dried at 105°C for 24 hrs and the oven dried weight was recorded. The oven dried litter samples were ground in Willeymill and were again sieve with a mesh sieve of size 0.5 mm, the sieved samples were kept in a nylon zip pouch for chemical analysis. The rainfall and temperature data were collected from Department of Geography and Resource Management, Mizoram University and Directorate of Science and Technology, Government of Mizoram.

4.2.2 Chemical analysis of leaf litter

Carbon and total nitrogen content of the leaf litter were determined using CHNS analyzer (Euroea 3000). Total phosphorous was estimated using tri-acid digestion method (HNO_3, H_2SO_4, $HClO_4$ at 9:4:1 ratio) and the phosphorous content of the solution was estimated using UV-VIS spectrophotometer (Specord 200 plus, Analytikjena, Germany). Calcium, magnesium and potassium contents were determined using MPAES-Agilent 4100. Lignin, cellulose and hemicelluloses were estimated by VanSoest *et al*. (1991) and total phenol content of the leaf litter was estimated according to the method describe by Malick and Singh (1980). Ash content of litter was determined by igniting grounded samples in a Muffle furnace at 550°C for 6 hrs.

4.2.3 Computation and statistics

The decay constants of leaf litter were calculated using negative exponential decay model of Olson (1963): $k = - \ln (X/X_0)/t$, where, X_0 is the initial dry weight, X is the dry weight remaining at the end of investigation, k is the decay rate coefficient and t is the time period. The time require for 50 % (t_{50}) and 99% (t_{99}) weight loss was calculated as $t_{50}= 0.693/k$ and $t_{99}=5/k$. The nutrient (N and P) release constants ($k_N$and k_P) were also computed using the decay model. The nutrient content of decomposing leaf litter was derived by: % Nutrient remaining = (C/C_0) x (DM/DM_0) x 100, where C is the concentration of nutrient in litter at the time of sampling, C_0 is the concentration in initial leaf samples, DM is the mass of litter at the time of sampling and DM_0 is the initial mass of litter kept for decomposition (Bockheim *et al*., 1991). The correlation between the climatic variables and initial litter chemistry on the rate of decomposition was assessed using simple linear regression function, y=a+ bx. The data were subjected to analysis of variance and analysis was done using MS-Excel 2007. RBD experimental design was used for determining the decomposition pattern in the study site and Correlation between rainfall and mean mass loss of leaf litter was done using MS-Excel 2007.

4.3. Results

4.3.1 Initial litter chemistry

The mean nutrient content of leaf litter showed high concentration of C (51%), N (2.38%) and P (0.09%). Lignin content of leaf litter was 9.6%, total ash content was (5.3%), cellulose and hemi-cellulose contents were 8.2% and 0.41% respectively. Total phenol and crude fiber in the leaf samples were found to be 42.8 mg/g and 5.7% respectively. Other macro-nutrients in the litter had a concentration of 3.2%, 1.7% and 1.5% for K, Ca and Mg respectively. The C/N ratio was 21.5 while Lignin/N, N/P, C/P and Lignin/P ratios were 4.1, 26.39, 566.2 and 106.1 respectively (**Table 4.1**).

4.3.2 Decomposition and nutrient release

4.3.2.1 Decay pattern

Litter decomposition is expressed as loss of dry mass at the end of each month and it was observed that 80% of the total dry mass lost during the first four months of incubation **(Figure 4.1).** As incubation proceeded, the loss in dry mass also decreased with 92.6% at the final stage of incubation (365 days). The annual decomposition rate constant (*k*) for dry matter was 0.01 day^{-1} (3.65 $year^{-1}$) with t_{50} and t_{99} values were 96.43 and 695.73 days respectively **(Table 4.2).**

Mass loss of *Flemingia semialata* leaf litter during the first 30 days was slow **(Figure 4.1)**. This was followed by a rapid decay phase (19.1%

weight loss day^{-1}) upto150 days and thereafter a steady decay of 12.3% - 7.4% weight loss day^{-1} was observed till the end of the study period of 360 days, thus showing a three-phased decay pattern. The mass loss rate during decomposition of leaf litter showed a positive significant correlation with incubation time ($r=0.86$, $p<0.01$).

4.3.2.2 Nutrient release

4.3.2.2.1 N dynamics

The concentration of N decreased at a faster rate during 0-240 days, thereafter it slowed down during 300-360 days which could be due to N immobilization at later stage of decomposition. In general, until 150 days of incubation, there was a tendency of N immobilization and then a rapid mineralization occurred which continued throughout the study period **(Figure 4.2a)**.

4.3.2.2.2 P dynamics

In the initial stages of decomposition (0-180 days), P immobilization occured thereafter mineralization takes placed till the end of incubation. Upto 240 days of incubation P immobilization occured and then rapid mineralization upto 300 days. P immobilization occurred again after 300 days upto the end of incubation period (360 days). The loss of P occurred rapidly in successive phases and also with immobilization after four months of decomposition thereafter mineralization occurs at later stage **(Figure 4.2a)**.

4.3.2.2.3 K dynamics

Among all the nutrients, K concentration decreased rapidly after 30 days of incubation, thereafter the K immobilization occurs from 30-240 days. At 270 days, the concentration of K was 0.29% and the concentration decreased upto 0.23% during the final stage of incubation indicating mineralization at later stage of incubation **(Figure 4.2b)**.

4.3.2.2.4 C dynamics

Litter C loss represented almost all mass loss and therefore the magnitude and pattern of mass loss in litter was almost the same as C loss **(Figure 4.2c).** The dry mass and concentration of nutrients decreased during litter decomposition. Immobilization was observed during 150-180 days of incubation, thereafter a rapid mineralization was observed from 270 days upto the final stage of incubation.

4.3.2.2.5 Ca dynamics

After 30 days of decomposition, concentration of Ca increased with fluctuations thereafter it shows a rapid decreased in its concentration in the last month of decomposition **(Figure 4.2d)**. The concentration of Ca was higher after 30 days of incubation and it slowly decreased from 150 days showing nutrient immobilization.

4.3.2.2.6 Mg dynamics

Magnesium concentration tends to decreased slowly over the study period **(Figure 4.2e)** because magnesium is generally mobile in litter and vulnerable to leaching with the loss of dry matter. Mg immobilization was observed during 150-180 days of incubation thereafter mineralization occured upto the final stage of incubation.

Table 4.1.Initial litter chemistry of *Flemingia semialata*.

Parameters	Values	Parameters	Values
C (%)	50.96±9.9	Cellulose (%)	8.18±0.16
N (%)	2.38±0.14	Hemicellulose (%)	0.41±0.01
P (%)	0.09±0.0	Crude fiber (%)	5.7±0.6
K (%)	3.22±0.32	C/N	21.53±4.2
Mg (%)	1.51±0.11	Lignin/N	4.05±0.25
Ca (%)	1.67±0.23	C/P	566.2±109.8
Total phenols (mg/g)	42.75±1.94	N/P	26.39±1.43
Lignin (%)	9.55±0.05	Lignin/P	106.13±0.89
Total ash (%)	5.3±0.13		

Table 4.2. Daily decay/ mineralization constants (N, P& C) of *Flemingia semialata* leaf litter.

Decay parameter	Values	Decay parameter	Values	Decay parameter	Values	Decay parameter	Values
Dry matter decay		N *mineralization*		P *mineralization*		C *mineralization*	
% mass loss per day	0.25	% mass loss per day	0.11	% mass loss per day	0.16	% mass loss per day	0.11
k (day^{-1})	0.01	k_N(day^{-1})	0.002	k_P(day^{-1})	0.006	k_C(day^{-1})	0.001
t_{50} (days)	96.43	t_{50} (days)	449.16	t_{50} (days)	408.21	t_{50} (days)	507.85
t_{99} (days)	695.73	t_{99} (days)	3240.71	t_{99} (days)	2945.23	t_{99} (days)	3664.18

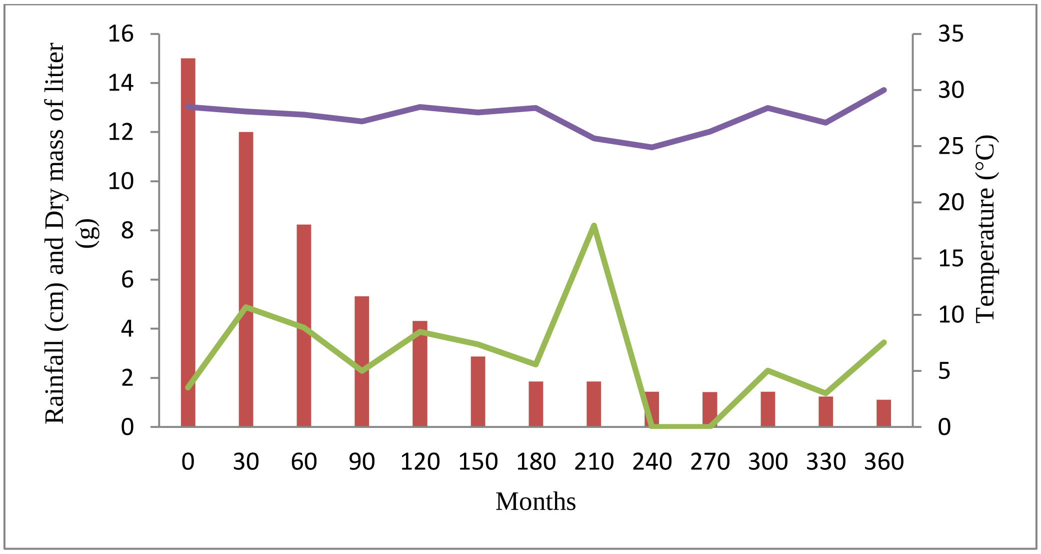


Figure 4.1 Monthly variations of rainfall and temperature with weight loss from May 2016 to April 2017 (Bar chart represent mass loss; Blue line represent temperature and Green line represent rainfall).

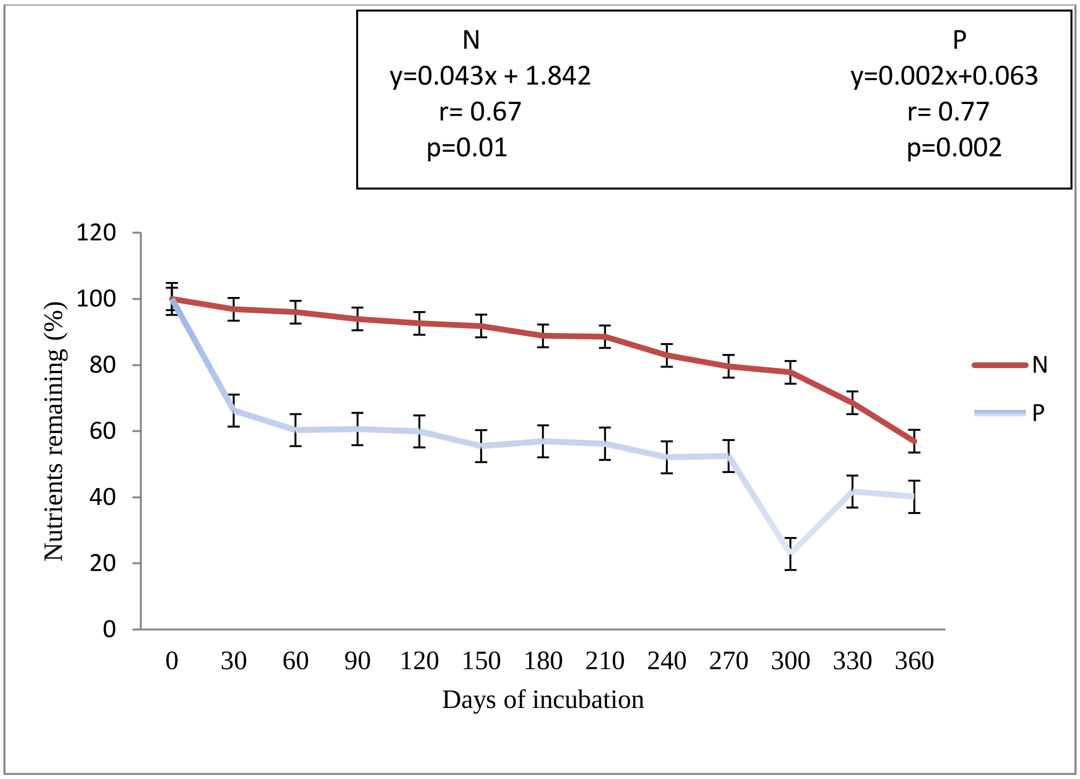


Figure 4.2 (a) Percentage of N and P remaining during litter decomposition of *Flemingia semialata*.

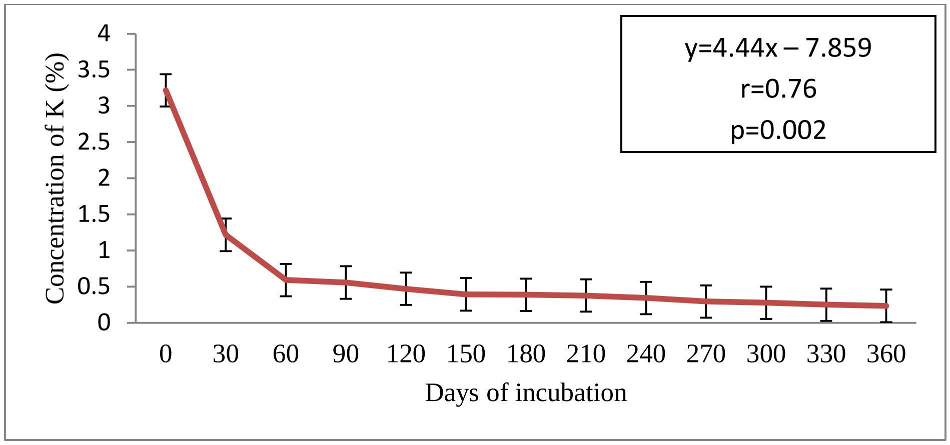


Figure 4.2 (b) Changes in Potassium concentration during litter decompositionof *Flemingia semialata*. Vertical lines represent standard error from three replicates.

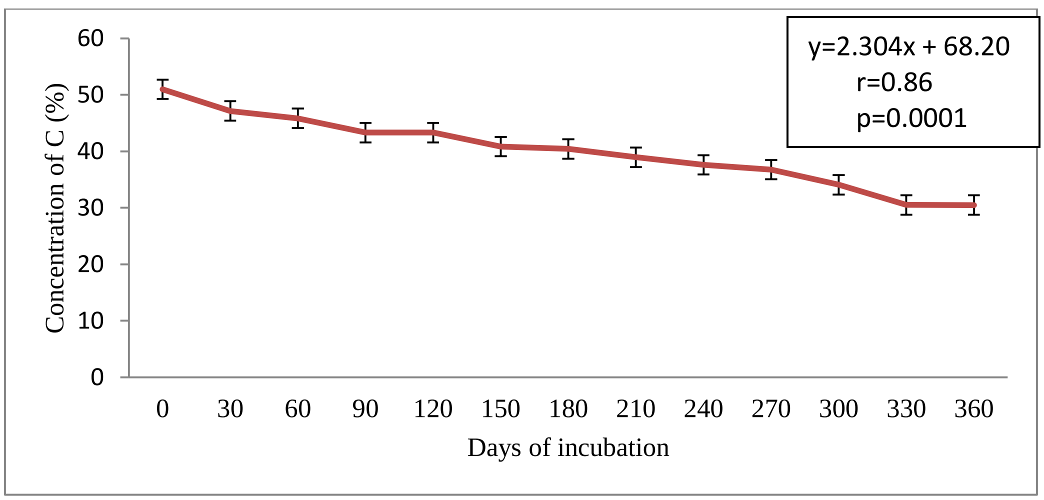


Figure 4.2(c) Changes in Carbon concentration during litter decomposition of *Flemingia semialata*. Vertical lines represent standard error from three replicates.

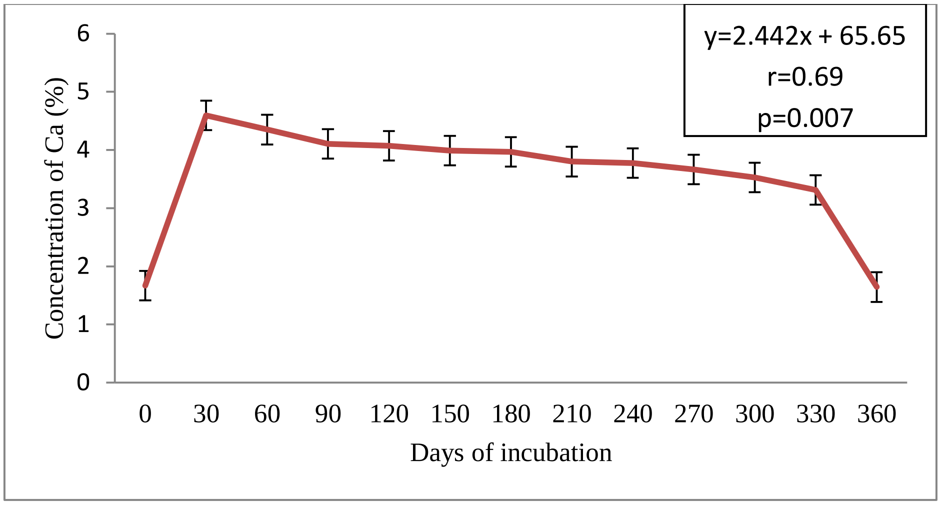


Figure 4.2 (d) Changes in Calcium concentration during litter decomposition of *Flemingia semialata*. Vertical lines represent standard error from three replicates.

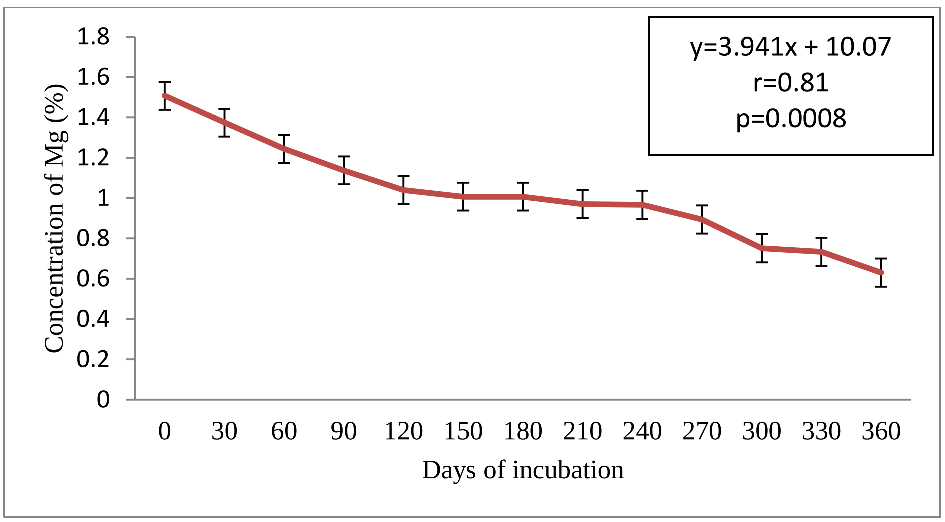


Figure 4.2 (e) Changes in Magnesium concentration during litter decomposition of *Flemingia semialata*. Vertical lines represent standard error from three replicates.

4.4 Discussion

The high mass loss in leaf litter could be attributed to rising temperature and increase in rainfall with lower lignin content favours higher decomposers activity. Lignin content in leaves has been widely used as an index of organic matter quality. For example, lignin content alone, or lignin/N in leaves could explain the rate of decomposition and negative correlations have been reported between lignin concentrations and decomposition rates. Lower lignin content favours decomposition rather than leaf litter with higher lignin concentration. The lignin content in the present study was 9.55% which was low thus favouring rapid decomposition. Sharma *et al*. (2018) also showed in their study that lower lignin concentration in *Perilla* foliage regulate decomposition. The quality of leaves also determines the rate of decomposition in tropical and sub-tropical forests, the C/N, Lignin/N, C/P ratio in the leaf litter appears to be a good indicator of decay rates.

Butenschoen *et al*. (2014) also reported that decomposition rates of leaf litter for six tropical rain forests species were negatively correlated with initial lignin concentration. Initial C/N and N/P ratios were also found be important factor in regulating litter decomposition rate (Zhou *et al*., 2008). The C/N ratio of leaf determines the litter quality, it is reported that the C/N (<25) are of high-quality litter tends to release N at a faster rate than C/N (>25) with lower quality litter (Myers *et al*., 1994). The C/N ratio of the present study proves to be a good indicator for fast N mineralization during decomposition. The C/N ratio of the present study was 21.53 which is lower than 25 which indicates faster rate of decomposition.

Vivanco and Austin (2008) also reported a negative correlation between hemicelluloses and lignin content in leaf with decomposition. Bunt (1988) also reported that cellulose play an important role in N immobilization since it breaks down rapidly thereby increases the C/N ratio. Das and Mondal (2016) reported that *Shorea robusta* litter having higher cellulose content (53.76%) decomposed less rapidly than *Tectona grandis* litter with lower cellulose content (51.60%). However, the cellulose content of the present study was 8.18% which is very low and could not be a reliable indicator for decomposition rate. Canhoto and Graca (1996) observed a strong negative correlation between the phenol content of different native litter types and litter decomposition rates in streams. Lin *et al*. (2006) also observed a negative correlation between total phenolics and N concentration for *Kandelia candel* and *Bruguiera gymnorrhiza* leaf litter at various stages of decomposition. Phenols may influence the rate of decomposition as they bind to N in leaves forming compounds resistant to decomposition (Palm and Sanchez, 1991). Total phenols in litter also act as a crucial indicator of changes in litter quality as they inhibit microbial activity and precipitate protein from litter (Palm and Sanchez, 1990; Schofield *et al*., 1998).

Several works also showed that lignin and lignin/N ratios in plant litter are also a good predictor for litter decomposition (Meentemeyer, 1978; Milillo *et al*., 1982). All these factors and their effects on decomposing leaf litter depend on soil characteristics and plant species. Leaf litter of nitrogen fixing genus alder (*Alnus*) has higher N concentration (often above 3%), in contrast to pine needle litter with poor N (frequently under 0.4%). Therefore, plant species appears to be prevailing features in defining the litter value (Berg and McClaugherty, 2003). The concentration of Phosphorous and C/P ratio of leaf litter are also appearing to be good predictors of decay rates (Vitousk *et al*., 1994). The N, Lignin/N, P and C/P values in the present study were 2.38%, 4.05, 0.09% and 566.2 respectively which could have an influenced on the rate of decomposition.

The annual decomposition rate constant (*k*) for dry matter in the present study was 0.01 day^{-1} (3.65 $year^{-1}$) with t_{50} and t_{99} values of 96.43 and 695.73 days respectively. Wang *et al*. (2019) found the annual decomposition rate constant (*k*) of 0.54 and 0.33 $year^{-1}$ for high quality and low-quality litter of *Eucalyptus spp* corresponding to t_{50} of 1.28 and 2.10 years, and t_{95} of 5.56 and 9.09 years respectively. Rave-Oviedo *et al*. (2013) found the *k* values of 1.74 and 1.76 $year^{-1}$ for Andean forests in Colombia. Krishna and Mohan (2017) showed that the *k* values in forest were larger than 1. The environments with *k* value lower than 1 shows slow decomposition rate and low surface litter deposition. Our findings in the present study confirm to the above findings where the *k* value of *Flemingia semialata* litter was 0.01 (3.65 $year^{-1}$), higher than 1 which showed faster rate of decomposition. It is believed that the higher value of *k* in the present study compared to the above is a result of low lignin content, C/N ratio, higher temperature and precipitation in the study area. The litter remaining after one year of decomposition in the present study was only 7.4% and a period of 0.26 years (3.12 months) was needed to decompose half of the initial litter mass (t_{50}). Very high value of *k* (4) was observed in African tropical forests (Olson, 1963) indicating rapid nutrient cycling. The present finding is also very much similar to the findings by Upadhyaya *et al*. (2012) for *Phyllostachys bambusoides* where decomposition was fast due to high N concentration, low C/N ratio and low N/P ratio in *Flemingia semialata* leaf litter.

The rapid rate of decomposition upto 150 days of incubation may be due to high rainfall which might have favoured greater microbial activity thereby causing higher decay rate. The litter decomposition in the present study was observed to be more dependent on rainfall rather than temperature because faster rate of decomposition was observed during monsoons as sufficient moisture during monsoon might have influenced for soil microbial decomposition.

This positive correlation of rainfall with weight loss in the present study (**Figure 4.3**) confirms the other findings by Singh and Singh (1999) who also observed 50% decomposition in leaf litter of *Dendrocalamus strictus* plantations in seven months under hot and dry sub-humid conditions. In the studies conducted across geographical gradients, precipitation significantly enhanced litter decomposition, demonstrating faster litter decomposition rates in wet than in dry areas (Monroy *et al*., 2016; Huang and Li, 2017). Santonja *et al*. (2015) also found that lower precipitation results in slower mass loss rates and a strong shift in litter mixture effects, with fewer facultative and more inhibitory interactions. Reduction in precipitation also likely to reduced the activity and composition of soil microorganisms (Kardol *et al*., 2011; Xu *et al*., 2012) which detrimentally effects decomposition (Santonja *et al*., 2017). Thomas *et al*. (2014) also showed a positive relationship of litter decomposition with rainfall ($r = 0.647$). The lower lignin (9.55%) and Lignin/N (4.05) of leaf litter the present study was supported by the findings of Cornelissen (1996), who observed that lignin and Lignin/N were both negatively correlated with leaf litter weight loss in a wide range of temperate plant species.

The decreasing trend in the N concentration from its initial level of decomposing litter may be attributed to leaching. In the present study, the C/N ratio of leaf litter is 21.5 and N release from the leaf litter started during the first stage of decomposition. A rapid decreased in N concentration in the later part of decomposition may be attributed to higher demand for nitrogen during intense microbial activity. Slow decrease in N concentration during 300-360 days of incubation may be attributed to microbial immobilization (Arunachalam *et al*., 1996) and throughfall input of atmospheric N (Peterson and Rolfe, 1982). The faster release of N during incubation may also be due to lower C/N ratio (21.5) which might prevent immobilization.

The immediate N release or immobilization may be directly linked to the chemical structure of litter types which was also observed by Semwal *et al*. (2003) in multipurpose tree species of central Himalaya, India. Legume residues generally have lower C/N ratio compared to other tree species, low C/N ratio is generally associated with higher mineralization rates (Brunetto *et al*., 2011). The rapid release of N in the present study might also be due to lower initial N (2.38%) content of the leaf litter. The lignin content of leaf litter also plays an important role in N mineralization, low lignin content in leaf litter results in faster decomposition thereby also releases N at a faster rate.

Berg and McClaugherty (1987) found that N release can start at C/N ratio between 29 and 80, and concluded that C/N ratio is not a good predictor for N release on the onset of decomposition. Parton *et al*. (2007) also reported that net N release from litter only occurred when the C/N ratio of the litter was less than between 31 and 40. Wang *et al*. (2019) showed the C/N ratio of *Eucalyptu*s litter as 1.98 with lower N content (0.26%) where he observed N immobilization during the whole decomposition period. Naik *et al*. (2017) in their study concluded that in spite of greater N content in litchi leaf litter, the decay was slower due to higher lignin level (33%) when compare to fast decomposing leaf litter with lignin content of 17.2%. This indicates that decomposition in leaf litter may be governed mostly by the initial lignin content rather than N content in the leaf litter. The initial lignin content in the present study was 9.55% which was lower than the lignin content of leaf litter showing slower decomposition. The faster decomposition rate in the present study might be due the lower lignin content in the litter which confirmed that lignin plays an important role in the process of decomposition rather than other litter characteristics. Initial N content of litter also plays an important role in decomposition rate. In the study conducted by Jeong *et al*. (2015), the initial lower nitrogen concentration of *Quercus serrata* leaf litter (0.75%) decomposed at slower rate compare to *Carpinus* *laxiflora* and *Carpinus cordata* with initial nitrogen concentration of 1.23 and 1.35% respectively.

The increase or decrease in P mineralization during decomposition in the present study may depend upon the initial P content of litter. Several authors have also suggested the role of critical P content in non-woody litters, above which P is, released (Rustad and Cronan, 1988; Eason and Newman, 1990). The shorter or longer P immobilization periods have also been reported by Stohlgren (1988) and Prescott *et al*. (1993) for different variety of leaf litter. The classic pattern of nutrient immobilization followed by release in this case was conspicuous for fast decomposing litter than for litter decaying more slowly (Presscot *et al*., 1993).

Loss in P during initial stages of decomposition might be attributed to leaching of soluble P containing compounds (Isaac and Nair, 2005). Besides this, the P content in the experimental soil was very low and thus it appeared to be P limited, so if any additions of P are made, it is consumed readily by soil micro-organisms and caused immobilization in four months of decomposition **(Table 4.1)**. Similar to C/N ratio, the C/P ratio provides information on whether P will be mineralized or immobilized (Blair, 1988; Manzoni *et al*., 2010; Mooshammer *et al*., 2012). Elser *et al*. (2000) concluded that if the C/P ratio is higher than 375, P will be immobilized in litter. In the present study, the C/P ratio was 566, and the P immobilization upto four months during decomposition fits the above findings.

In addition, due to the strong P immobilization in decomposition compared to those of N, it is likely that P is more deficient than N and an important control of decomposition in the studies leaf litter. The relatively low content of P (0.09%) in the litter might also lead to immobilization or reduced rate of mineralization despite the high level of N which according to Palm *et al*. (2001) suggested that high N (>2.5%)

and P (>0.25%) favours mineralization during decomposition. The k_N and $k_P$value of four legume tree species viz. *Prosopis cineraria*, *Dalbergia sissoo*, *Acacia leucophloea* and *Acacia nilotica* studied by Yadav *et al*. (2008) were in the range of 0.016-0.024 and 0.014-0.029 respectively. Our present findings on k_N (0.002) and k_P (0.006) values for *Flemingia semialata* leaf litter were below these range which indicates longer half life compared to other four legume tree species **(Table 4.2)**.

Carbon compounds have also been identified as drivers of litter decomposition in forest ecosystems (Hättenschwiler *et al*., 2011). The acceleration in C loss during decomposition may be partially driven by the increased supply of nutrients from the underlying soil because microbes decomposing fresh litter are frequently N-limited (Berg and McClaugherty, 2008). It is also observed that litter decomposition is slow due to low concentrations of easily accessible energy-rich C compounds leading to energy starvation for decomposers (Hättenschwiler and Bracht Jorgensen, 2010). The k_C value observed in the present finding confoms to the above findings where decomposition is slow due to low k_C value (0.001) **Table 4.2**. The initial rapid decrease in K concentration may be due to the loss of soluble form of nutrients at initial stages of decomposition (Mahmood *et al*., 2007) and a slower release at later stage is governed by microbial oxidation of refractory components and physical and biological fragmentation (Ortega and Marcos, 2000). The rapid dropped in K concentration was also observed by Jeong *et al*. (2015) during the initial months of decomposition. The initial fast leaching of K followed by a late phase of fluctuation in concentration in the present study is also in agreement with the findings by Chhetri *et al*. (2012) in decomposition of chir pine and oak. Among all the nutrients K had the fastest nutrient release rate with k_K (0.01) **Table 4.3**. The faster release may be due to the high mobility of K which indicates that it is easily leached (Tian *et al*., 1992; Bargali *et al*., 1993)

The increase in concentration of Ca **(Figure 4.2c)** after one month of decomposition could be due to the inherent characteristics of calcium as a structural component in leaf cell walls (Ribeiro *et al*., 2002). The initial immobilization in the present study was also observed by Ventura *et al*. (2010) during litter decomposition of *Prunus persica*. The release rate of Ca after 30 days of incubation was slow, a rapid decline in Ca concentration was observed after 330 days. The slow released or mineralization of Ca could be due to low value of k_{Ca} (0.003) **Table 4.3**. Mg immobilization was observed during 150-180 days of incubation, thereafter a slow declined on the concentration was observed indicating mineralization. The slow release of Mg could be due to low value of k_{Mg} (0.005), moreover Mg help make up the middle lamella of plant cell wall, thereby becoming one of the most recalcitrant compounds in plant cell which could favoured Mg release at slower rate compared to other nutrients (Vitti *et al*., 2006; Marschmer, 2012).

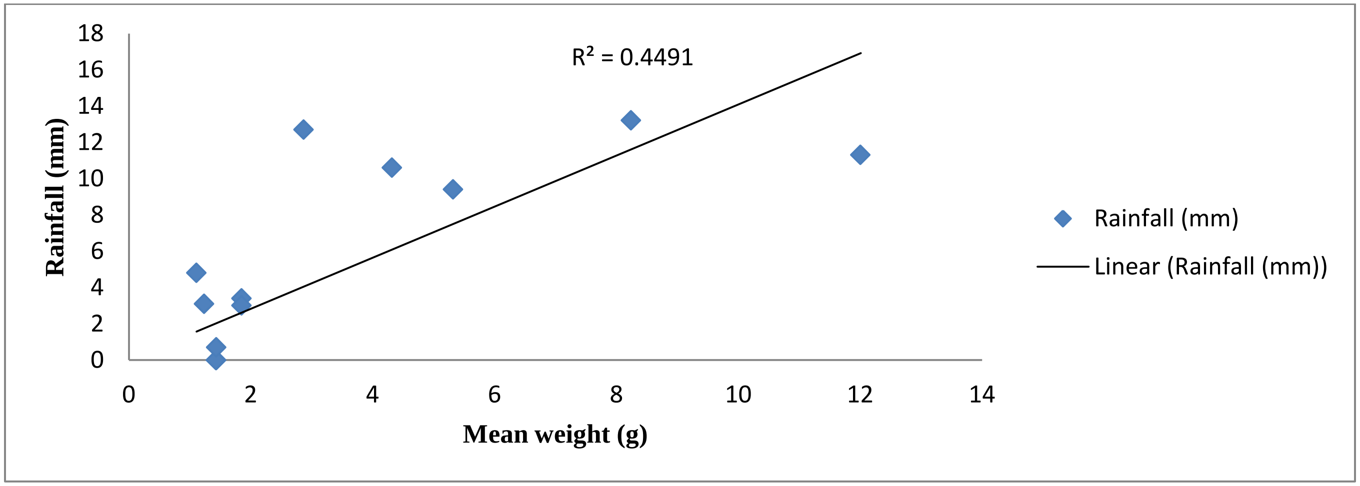


Figure 4.3 Correlation between rainfall and mean mass loss during incubation.

Table 4.3. Daily decay/ mineralization constants (K, Ca & Mg) of *Flemingia semialata* leaf litter.

Decay parameter	Values	Decay parameter	Values	Decay parameter	Values
K *mineralization*		Ca *mineralization*		Mg *mineralization*	
% mass loss per day	0.27	% mass loss per day	0.18	% mass loss per day	0.24
k_K(day^{-1})	0.010	k_{Ca}(day^{-1})	0.003	k_{Mg}(day^{-1})	0.005
t_{50} (days)	67.89	t_{50} (days)	228.16	t_{50} (days)	128.37
t_{99} (days)	489.84	t_{99} (days)	1646.2	t_{99} (days)	926.22

Chapter 5
Mulching potential of *Flemingia semialata* leaf litter

5.1 Introduction

Mulching is considered an effective method of manipulating the growing environment to increase crops yield, controlling soil temperature for improve product quality, soil moisture retention and reducing soil evaporation (Chakraborty *et al*., 2008). Mulches improve soil moisture retention capacity as well as soil structure and suppress weed growth (Mutetwa and Mtaita, 2014). The choice of selection of an appropriate mulching material depends on local, climate and feasibility for the crop. Yin *et al*. (2016) reported a double mulching of plastic film and straw mulch for intercropping of wheat and maize production in northwestern China.

Application of straw mulch at 4-6 t ha^{-1} has been found effective in improving soil physical conditions (Lal, 1974). The plastic mulch was found to be effective in reducing soil evaporation, improving crop water use efficiency (Almeida *et al*., 2015) and minimizing salt build up in the crops root zone (Dong *et al*., 2009; Yuan *et al*., 2009).McMillen (2013) reported that application of mulch with wheat straw, grass clippings and leaf debris of 5-10 cm depth increased soil moisture by 10% compared to bare soil.

Besides, moderating soil moisture and temperature, mulch residues also affect soil organic matter (Huang *et al*., 2008) that can augment dissolved organic carbon and nitrogen by plant material decomposition (Chantigny, 2003). Subramaniyan *et al*. (2006) reported up to 12% increased population of soil bacteria, fungi, actinomycetes under plastic mulch when compared to non-mulch treatments. Komariah *et al*. (2011) also reported a rise in earthworm population at 5 cm depth soil in the combination of rice bran and transparent plastic mulch. Above all, mulching alters the structure of soil microbiology and diversity due to changes in soil moisture and soil temperature, therefore addition of organic matter as mulch is very important in maintaining soil microbial status.

The increased rate of mulch applied increases soil porosity, improves soil aggregates stability and organic matter content and reduces soil bulk density. Soil physical properties are also influence by soil environment that are greatly related to soil moisture and temperature. Despite the importance of all mulch materials in conserving soil and increasing crop yield, limited research has been done towards the use of leaf litter as mulch in crop production. Therefore, the present chapter aims to understand the effect of *Flemingia semialata* leaf litter as mulch on growth and yield of crops, WUE, physicochemical and biological properties of soil under mulch application.

5.2 Materials and method

5.2.1 Experimental setup

A polypot experiment was conducted to evaluate the mulching potential of *Flemingia semialata* leaf litter. For this purpose, freshly fallen leaves of *Flemingia semialata* were collected from the plantation site and sufficient amount collected was stored in a gunny bag for future use. The leaf was cut into smaller pieces with scissors to the size enough to apply in a poly pot as mulch. Soil was collected from Botanical garden, Mizoram University and sieved using 2 mm mesh sieve. The sieved soil was filled in poly pots having a capacity of 15 kg soil. The experiment consisted of eight treatments with three replications and CRD experimental design was used for the study. Soils for each treatment in poly pots was mixed with NPK fertilizer (6:4:4) except for control. The treatments for the experiments are denoted as given below:

T_0 = Control (soil); **T_1** = soil+ fertilizer; **T_2**= mulch (dose 1) + fertilizer; **T_3** = mulch (dose 1) + without fertilizer; **T_4**= mulch (dose 2) + fertilizer; **T_5** = mulch (dose 2) + without fertilizer; **T_6** = mulch (dose 3) + fertilizer; **T_7** = mulch (dose 3) + without fertilizer respectively. Dose 1 mulch was applied @ 5 t/ha; dose 2 of mulch applied @ 8 t/ha and dose 3 of mulch was used @ 10 t/ha in polypot for each treatment except for **T_0** and **T_1**.

Seeds of maize and rice were soaked in 0.5% sodium hypochlorite solution to prevent from fungus infection on seeds. The seeds were again rinsed with running tap water before sowing in a poly pot. Five seeds each of maize and rice were sown in each poly-pot and observed for germination. The germinated seeds after obtaining two leaf stages were thinned out to single seedling per ploy-pot and were monitored for different growth parameters till the yield stage for rice and up to six months for maize from the date of germination. Monitoring of maize up to yield stage was not possible due to the incidence of Fall armyworm which attacked the tender leaves of maize that resulted into death of the crops or stunted growth. Poly pots were kept in mist chamber and 500ml of water was applied to each poly pot on alternate days. At two leaf stage of the crop, mulch was applied at different doses in different treatments mentioned above.

5.2.2 Estimation of chlorophyll content and WUE

Chlorophyll extraction was done using the method given by Arnon (1949). Leaf samples were collected from different treatments for chlorophyll determination during peak vegetative phase at the initiation of first flowering. One gram of finely cut fresh leaves were taken and ground with 20-40 ml of 80% acetone. It was then centrifuged at 5000-10000 rpm for five minutes. The supernatant was transferred and the procedure was repeated till the residue became colourless. The absorbance of the solution was read at 645 nm and 663 nm against the solvent (acetone) blank. The total chlorophyll content was calculated using the equation:

$$\text{Total chlorophyll} = 20.2\ (A_{645}) + 8.02\ (A_{663})$$

For WUE determination, the biomass (roots and shoots) of the crops was kept in the oven at 60°C for 24 hrs. The dry mass of roots and shoots were measured using a digital balance. The quantity of water applied for irrigation till the harvest was also recorded and computed to determined the water used. Water use efficiency (WUE) of the crop was calculated based on total biomass basis (Siddique *et al*., 2001) using the formula:

$$\text{WUE} = \text{total biomass (g)/water use (L) for irrigation}$$

5.2.3 Soil analysis

At the time of harvest, soils from each poly pot in different treatments were collected and following soil parameters were analyzed accordingly. Soil moisture content was determined by Gravimetric method and soil pH was measured at 1:2.5 soil water suspension using pH meter. For soil moisture determination, soil samples were kept in oven at 60°C for 24 hrs. The collected soil samples were air dried at room temperature and the air-dried samples were sieved with 2 mm mesh sieve for soil organic carbon, available nitrogen, available phosphorus, available potassium, calcium and magnesium content of the soil.

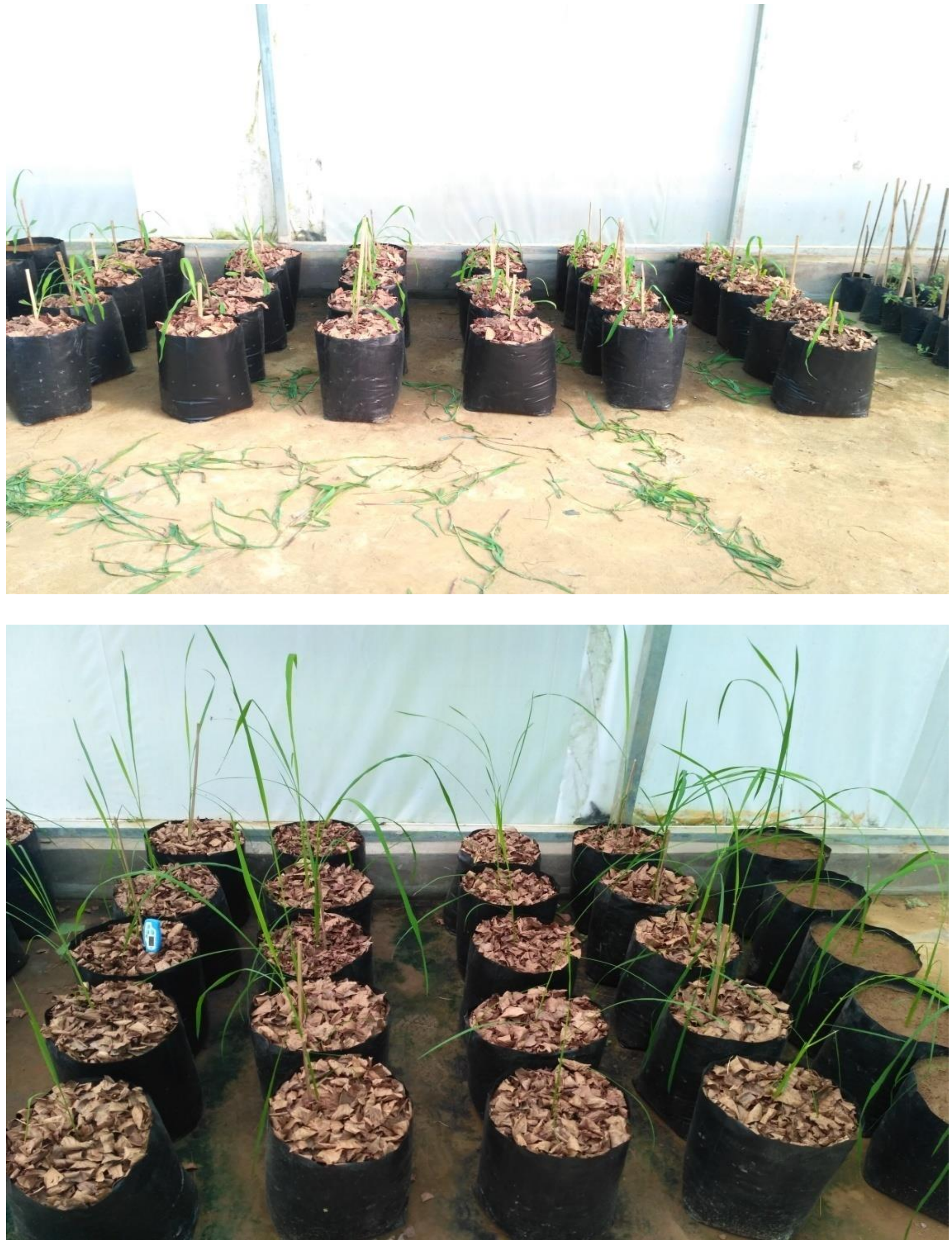
Soil organic carbon was determined by K_2Cr_2O wet oxidation method by Walkley and Black (1934). Available nitrogen was determined with permanganate oxidation method according to Subbiah and Asija (1956). Available potassium was determined by extraction with ammonium acetate solution (Jackson, 1973) using flame photometer (ESICO-1384, India). Available phosphorus was determined by Bray II method (Bray and Kurtz, 1945). Calcium and magnesium were estimated by complexometric titration using EDTA (Jackson, 1973).

Microbial biomass carbon (MBC) was determined by chloroform fumigation extraction method where fresh soil was extracted with 0.5 M K_2SO_4 (Jenkinson, 1988). Carbon content in the extract was determined by $K_2Cr_2O_7$ wet-oxidation method and total N by Kjeldahl method (Bremner and Mulvaney, 1982). The difference between fumigated and un-fumigated samples was determined and calculation of MBC and MBN were done using conversion factors (K_{EC}=0.38; Vance *et al*., 1987 and K_{EN}=0.5). Microbial biomass phosphorus (MBP) was determined using modified fumigation and $NaHCO_3$ extraction technique (Brookes *et al*., 1982).

Acid phosphatase activities (ACP) were estimated using modified universal buffer (MUB, pH6.5 and 11) and p–nitrophenyl phosphate disodium salt (0.025M) as a substrate (Tabatabai and Bremmer, 1969).

Soil dehydrogenase activity (DHY) was determined by the reduction of triphenyl tetrazolium chloride (TTC) to triphenyl formazan (TPF) during soil incubation of 37°C for 24h and expressed as μg TPF g^{-1} (dw) soil h^{-1} (Casida Jr. *et al*., 1964).

Urease activity (URE) was estimated by urea remaining method and expressed as μg Urea hydrolysed g^{-1} (dw) soil h^{-1} (Tabatabai, 1994). All the enzyme activities were measured using UV- VIS spectrophotometer (Specord 200 plus, Analytikjena, Germany).



Photograph 5.1 Mulching of maize and rice with *Flemingia semialata* leaf litter in poly-pot.

5.2.4 Statistical Analysis

Data were subjected to analysis of variance and the mean values were compared using Duncan's Multiple Range Test at 1% and 5% probability level. Statistical analysis including correlation analysis was done using SPSS version 20. DMRT analysis was made to know the statistical significant difference between each of the treatments used.

5.3 Results

5.3.1 Effect of *Flemingia semialata* leaf litter mulch on growth of maize

The root and shoot length of maize and dry weight of shoot showed significant effect ($p<0.01$) among different treatments when compared to control (**Table 5.1a**). Among all the treatments T_5 showed the highest root length when compared to other treatments and T_1 recorded the lowest root length (20.83 cm). Significant increase ($p<0.05$) on the root length was observed in T_5 (54.60 cm) when compared to T_1, T_2, T_4 and T_6, however its effect was not significant when compared to control. The shoot length was found significantly ($p<0.05$) higher in all the treatments when compared to control. Maximum shoot length was found in T_5 (61.17 cm) and T_3 (61.10 cm) followed by T_4, T_6, T_2, T_1 and T_7 respectively whereas it was minimum in T_0 (19.90 cm). Maximum root dry weight was found in T_3 (0.35 g) followed by T_5, T_6 and T_2 respectively. The root dry weight on treatments T_3 and T_5 was significantly higher ($p<0.05$) when compared to control treatments.

5.3.2 Effect of *Flemingia semialata* leaf litter mulch on growth of rice

Observable significant effect was seen in all the treatments on the shoot length, fresh weight of root and shoot, dry weight of shoot of rice when compared to control. Significant ($p<0.05$) increase in the shoot length of rice was observed in all the treatments when compared to control and the highest shoot length was found in T_1 (120.83 cm) and the lowest was in T_0 (70.67 cm) (**Table 5.1c**). Root fresh weight per plant was found the highest in T_7 (1.01 g) followed by T_4, T_1 and T_6 and the lowest root fresh weight was recorded in T_3 (0.23 g) but the treatments mean was not significantly different ($p<0.05$). Treatments T_1, T_2, T_4 and T_6 showed significant increased in the shoot fresh weight of rice when compared to control. The maximum fresh biomass was observed in T_1 (33.84 g) and the minimum was recorded in T_3 (5.99 g).

Significant increase ($p<0.01$) in dry shoot weight was observed in treatments T_1, T_2, T_4 and T_6; on the contrary, significant decrease ($p<0.01$) was shown by treatments T_3, T_5 and T_7 when compared to control. The highest dry biomass was recorded in T_1 (16.15 g) and the lowest in T_3 (2.41 g).

5.3.3 Effect of *Flemingia semialata* leaf litter mulch on chlorophyll content and WUE of maize

Significant increase ($p<0.01$) in total chlorophyll content was observed in T_1 and T_3 when compared to other treatments however, significant decrease ($p<0.01$) in the total chlorophyll content was observed in T_5, T_6 and T_7. The maximum significant ($p<0.01$) increase in total chlorophyll content was observed in T_1 when compared to other treatments and control (**Table 5.1b**). WUE do not showed any significant changed in all the treatments. However, increased in WUE was observed in all the treatments when compared to control. The maximum WUE was observed in T_6 (2.26) and lowest in T_1 (0.27).

5.3.4 Effect of *Flemingia semialata* leaf litter mulch on chlorophyll content and WUE of rice

Significant increase ($p<0.01$) in total chlorophyll content was observed in T_3 and T_5, however significant decrease ($p<0.01$) in total chlorophyll content was observed T_1, T_2 and T_6 when compared to control **(Table 5.1d)**. The maximum total chlorophyll content was observed in T_3 (0.88 mg/L) and minimum in T_1 (0.54 mg/L). Significant ($p<0.01$) increase in WUE was found in T_1, T_2, T_4 and T_6however, significant ($p<0.01$) decrease in WUE was observed in treatments T_3, T_5 and T_7 when compared to control. The maximum WUE was observed in T_1 (0.80) and minimum in T_3 (0.15).

Table 5.1 (a). Effect of *F. semialata* leaf litter mulch on the growth of maize.

Treatments	**Root length (cm)**	**Shoot length (cm)**	**Collar diameter (mm)**	**Fresh wt. of root (g/plant)**	**Fresh wt. of shoot (g/plant)**	**Dry wt. of root (g/plant)**	**Dry wt. of shoot (g/plant)**
T_0 (control)	36.30^{abc}	19.90^{a}	4.52	0.36	6.37	0.10^{a}	1.13
T_1 (nm+f)	20.83^{a}	45.20^{b}	4.39	0.57	10.47	0.16^{ab}	1.32
T_2 (1m+f)	28.37^{ab}	49.43^{b}	4.27	0.67	15.60	0.20^{abc}	7.43
T_3 (1m+wf)	44.50^{bc}	61.10^{b}	4.80	0.96	17.91	0.35^{c}	6.65
T_4 (2m+f)	25.83^{ab}	58.90^{b}	4.70	0.40	13.86	0.14^{ab}	5.94
T_5 (2m+wf)	54.60^{c}	61.17^{b}	4.93	0.74	20.63	0.30^{bc}	10.71
T_6 (3m+f)	43.50^{abc}	56.50^{b}	4.78	0.63	23.71	0.26^{abc}	12.20
T_7 (3m+wf)	23.43^{ab}	41.33^{b}	4.67	0.32	1.05	0.12^{ab}	4.60
SEM±	3.12*	3.32*	0.18(ns)	0.07(ns)	1.71(ns)	0.02*	1.26(ns)

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Table 5.1 (b).Effect of *F*. *semialata* leaf litter mulch on total chlorophyll content and WUE of maize.

Treatments	Total chlorophyll (mg/L)	WUE (g/L)
T_0 (control)	1.23[b]	0.22
T_1 (nm+f)	2.98[d]	0.27
T_2 (1m+f)	1.08[b]	1.39
T_3 (1m+wf)	1.64[c]	1.27
T_4 (2m+f)	1.27[b]	1.11
T_5 (2m+wf)	0.29[a]	2
T_6 (3m+f)	0.31[a]	2.26
T_7 (3m+wf)	0.12[a]	0.86
SEM±	0.18**	0.23(ns)

p< 0.05= significant at 5%*, p <0.01=significant at 1%**; same symbol in superscript do not differ significantly (p>0.05).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Table 5.1 (c). Effect of *F*. *semialata* leaf litter mulch on the growth of rice.

Treatments	**Root length (cm)**	**Shoot length (cm)**	**Collar diameter (mm)**	**Fresh wt. of root (g/plant)**	**Fresh wt. of shoot (g/plant)**	**Dry wt. of root (g/plant)**	**Dry wt. of shoot (g/plant)**
T_0 (control)	14.80	70.67[a]	4.03	0.49[ab]	8.51[a]	0.33	3.85[ab]
T_1 (nm+f)	21.50	120.83[c]	4.86	0.66[abc]	33.84[b]	0.46	16.15[d]
T_2 (1m+f)	22.70	11983[c]	4.92	0.42[ab]	27.98[b]	0.31	10.46[c]
T_3 (1m+wf)	21.83	87.33[ab]	3.53	0.23[a]	5.99[a]	0.20	2.41[a]
T_4 (2m+f)	23.83	108.50[c]	5.09	0.86[bc]	27.41[b]	0.36	7.55[bc]
T_5 (2m+wf)	21.50	101.33[ab]	4.38	0.29[a]	8.59[a]	0.20	3.89[ab]
T_6 (3m+f)	26.90	103.80[ab]	4.46	0.65[abc]	27.22[b]	0.33	7.28[bc]
T_7 (3m+wf)	20.17	91.83[ab]	3.48	1.01[c]	7.35[a]	0.44	2.75[a]
SEM±	0.95(ns)	4.48*	0.18(ns)	0.07*	2.60**	0.03(ns)	1**

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Table 5.1 (d). Effect of *F. semialata* leaf litter mulch on total chlorophyll content and WUE of rice.

Treatments	Total chlorophyll (mg/L)	WUE (g/L)
T_0 (control)	0.77[cd]	0.22[ab]
T_1 (nm+f)	0.54[a]	0.80[e]
T_2 (1m+f)	0.71b[cd]	0.54[d]
T_3 (1m+wf)	0.88[d]	0.15[a]
T_4 (2m+f)	0.77[cd]	0.40[cd]
T_5 (2m+wf)	0.86[cd]	0.21[ab]
T_6 (3m+f)	0.59[ab]	0.36[bc]
T_7 (3m+wf)	0.78[cd]	0.17[a]
SEM±	0.03**	0.05**

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

5.3.5 Effect of *Flemingia semialata* leaf litter mulch on physico-chemical properties of soil

5.3.5.1 Soil physico-chemical properties under maize

Application of mulch at different doses in different treatments showed a significant effect on soil temperature, soil moisture, available phosphorus and available potassium under maize. Significant increase ($p<0.01$) in soil moisture was obtained in T_1, T_4 and T_6 when compared to control and other treatments. The highest soil temperature was observed in T_6 (23.8°C) and the lowest in T_3 (23.4°C) when compared to control. Treatments T_2, T_3, T_5 and T_7 recorded significant ($p<0.01$) increased in soil moisture with the highest soil moisture content in T_7 (40.83%) and the lowest in T_6 (35.34%). Significant variation in the available P was also observed in all the treatments wherein significant increased ($p<0.01$) in P concentration was observed in treatments T_1, T_2, T_4 and T_6 respectively **(Table 5.2a)**. Maximum available P was observed in T_4 (35.15 mg/kg) and minimum was found in T_7 (1.90 mg/kg). Available K also increased significantly ($p<0.01$) in treatments T_1, T_2, T_4 and T_6 when compared to control. The highest value of available K was shown by treatment T_4 (228.42 mg/kg) and the lowest was recorded in T_3 (44.42 mg/kg). There was no significant variation on the pH, Ca and Mg content under different treatments. The maximum values on pH (5.83), Ca (0.97 meq/100g) and Mg (0.67 meq/100g) was obtained in T_7 when compared to other treatments. SOC was also found maximum in T_6 (16.53 g/kg) and minimum in T_0 (14.67 g/kg). Non significant increased in Available N was found in all the treatments when compared to control. The maximum available N was obtained in T_6 (140.45 mg/kg) and minimum in T_0 (86.45 mg/kg).

5.3.5.2 Soil physico-chemical properties under rice

In case of poly pot experiment for rice, significant change in soil pH, Ca, Mg, soil temperature and available P was observed among various treatments (**Table 5.2b**). Significant increase ($p<0.05$) in pH was observed in treatments T_5, T_6 and T_7 when compared to other treatments and control. The highest soil pH value was recorded in T_7 (5.17) and the lowest was found in T_2 (4.07). Significantly enhanced ($p<0.01$) in Ca content of the soil was observed in treatments T_2 to T_7 with the maximum highest Ca recorded in T_4 (1.10 meq/100g) and the minimum in T_1 (0.27 meq/100g). Magnesium content in soil also showed a significant change in all the treatments with the highest Mg was found in T_1 (1.17 meq/100g) and the lowest was estimated in T_4 (0.33 meq/100g). Soil temperature in all the treatments showed significant decrease when compared to control. Available P content in all the treatments increased significantly ($p<0.01$) when compared to control wherein the highest available P was shown by T_6 (8.86 mg/kg) and the lowest in control T_0 (0.04mg/kg). There was no significant variation on the SOC and soil moisture among different treatments, maximum SOC carbon was observed in T_4 (12.95 g/kg) and maximum soil moisture was observed in T_5 (35.42%). Available N and K showed variable changes in different treatments but not significant. The maximum available N and K was observed in T_1 (105.95 mg/kg) and T_6 (100.33 mg/kg).

5.3.6 Effect of *Flemingia semialata* leaf litter mulch on soil biological properties

5.3.6.1 Soil microbial biomass and enzyme activities under maize

Microbial biomass content in soil did not show any significant effect on the treatments; however, the highest MBC, MBN and MBP was observed in T_3 (1287.41 µg/g), T_5 (94.66 µg/g) and T_1 (7.34 µg/g) respectively and the lowest was recorded in T_2 (337.34 µg/g), T_2 (29.13 µg/g) and T_7 (1.18 µg/g) respectively. Significant change in soil urease activity was observed in poly-pot treatments for maize. In general, all the treatments showed a significant decrease ($p<0.5$) in the activity of urease when compared to control (**Table 5.2c**). The lowest urease activity was shown by T_2 (6.71 µg Urea $g^{-1}h^{-1}$) and the highest was in T_0 (29.74 µg Urea $g^{-1}h^{-1}$). The acid phosphatase and dehydrogenase enzymes were also found maximum in T_6 (140.45 µ pNP $g^{-1}h^{-1}$) and T_0 (0.45 µg TPF $g^{-1}h^{-1}$) respectively and the lowest in T_0 (86.45 µ pNP $g^{-1}h^{-1}$) and T_4 (0.18 µg TPF $g^{-1}h^{-1}$) respectively.

5.3.6.2 Soil microbial biomass and enzyme activities under rice

For poly-pot treatments in rice, significant change in MBP, MPN, soil dehydrogenase, acid phosphatase and urease were observed among the treatments. Significant increased ($p<0.01$) in MBP was recorded in all the treatments when compared to control (**Table 5.2d**). The highest MBP was shown by T_5 (8.94 µg/g) followed by T_7 (7.43 µg/g), T_4 (4.93 µg/g), T_6 (4.33 µg/g), T_1 (3.73 µg/g), T_3 (2.11 µg/g) and the lowest in T_0 (1.51 µg/g). Significantly enhanced ($p<0.01$) MBN was observed in T_2 (42.04 µg/g), however it decreased significantly in all the treatments when compared to control T_0 (11.05 µg/g) wherein the lowest MBN was shown by T_6 (7.67 µg/g). No significant difference was observed for MBC in all the treatments. The maximum MBC was observed in T_2 (536.21 µg/g) and the minimum was observed in T_6 (104.32 µg/g).

Significant increase ($p<0.05$) in acid phosphatase activity was shown by treatments T_7 (677.66 µ pNP $g^{-1}h^{-1}$), T_5 (612.24 µ pNP $g^{-1}h^{-1}$) and T_3 (567.79 µ pNP $g^{-1}h^{-1}$) whereas the lowest value of ACPwas found in T_2 (470.75 µ pNP $g^{-1}h^{-1}$). Dehydrogenase activity also showed a significant increased ($p<0.05$) in all the treatments except T_5 (0.35 µg TPF $g^{-1}h^{-1}$) when compared to control. The maximum dehydrogenase activity was observed in T_7 (0.91 µg TPF $g^{-1}h^{-1}$) followed by T_2 (0.87 µg TPF $g^{-1}h^{-1}$), T_4 (0.70 µg TPF $g^{-1}h^{-1}$), T_6 (0.70 µg TPF $g^{-1}h^{-1}$), T_1 (0.52 µg TPF $g^{-1}h^{-1}$) and T_3 (0.43 µg TPF $g^{-1}h^{-1}$). Among the treatments, significant increased ($P<0.01$) in urease activity was recorded in T_3, T_5 and T_7 however, it decreased significantly in T_1, T_2, T_4 and T_6 in comparison to control. The highest urease activity was observed in T_3 (35.62 µg Urea $g^{-1}h^{-1}$) and the lowest was in T_1 (2.39 µg Urea $g^{-1}h^{-1}$).

Table 5.2 (a). Soil physico-chemical properties as affected by *F. semialata* leaf litter mulching under maize.

Treatments	Soil moisture (%)	Soil temperature (°C)	pH	SOC (g/kg)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
T_0 (control)	36.49[ab]	23.5[b]	5.77	14.67	86.45	2.23[a]	74.58[a]	0.93	0.43
T_1 (nm+f)	35.97[ab]	23.2[a]	5.63	14.86	101.23	26.11[b]	188.67[b]	0.73	0.50
T_2 (1m+f)	37.72[b]	23.5[b]	5.57	15.23	120.94	30.93[b]	187.75[b]	0.83	0.33
T_3 (1m+wf)	39.71[c]	23.4[b]	5.73	15.23	91.99	2.39[a]	44.42[a]	0.80	0.60
T_4 (2m+f)	36.54[ab]	23.7[c]	5.33	15.42	120.12	35.15[b]	228.42[b]	0.83	0.27
T_5 (2m+wf)	40.50[c]	23.6[b]	5.77	15.42	90.55	2.50[a]	49.83[a]	0.80	0.47
T_6 (3m+f)	35.34[a]	23.8[c]	5.17	16.53	140.45	30.09[b]	211.25[ab]	0.83	0.47
T_7 (3m+wf)	40.83[c]	23.5[b]	5.83	16.16	95.69	1.90[a]	7.33[a]	0.97	0.67
SEM±	0.46**	0.04**	0.07(ns)	0.18(ns)	5.57(ns)	3.12**	15.57**	0.02(ns)	0.04(ns)

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Table 5.2 (b).Soil physico-chemical properties as affected by *F. semialata* leaf litter mulching under rice.

Treatments	**Soil moisture (%)**	**Soil temperature (°C)**	**pH**	**SOC (g/kg)**	**Available N (mg/kg)**	**Available P (mg/kg)**	**Available K (mg/kg)**	**Ca (meq/100g)**	**Mg (meq/100g)**
T_0 (control)	32.16	24.0^c	4.90^b	10.67	102.67	0.40^a	85.08	0.43^a	0.87^{bc}
T_1 (nm+f)	32.11	23.4^b	4.20^a	12.29	105.95	1.84^a	70.50	0.27^a	1.17^c
T_2 (1m+f)	31.41	23.1^b	4.07^a	12.38	102.26	2.01^a	79.08	1.03^b	0.57^{ab}
T_3 (1m+wf)	34.28	22.6^a	4.47^{ab}	12.67	95.48	0.48^a	75.42	1.00^b	0.43^a
T_4 (2m+f)	31.36	22.5^a	4.50^{ab}	12.95	98.97	0.86^a	88.42	1.10^b	0.33^a
T_5 (2m+wf)	35.41	22.2^a	4.97^b	12.10	94.45	1.35^a	80.50	0.97^b	0.67^{ab}
T_6 (3m+f)	31.00	22.6^a	4.97^b	10.57	99.59	8.86^b	100.33	0.97^b	0.57^{ab}
T_7 (3m+wf)	33.02	22.4^a	5.17^b	11.90	100.82	1.87^a	75.08	1.00^b	0.50^{ab}
SEM±	0.45(ns)	0.13**	0.10*	0.37(ns)	1.32(ns)	0.56**	2.55(ns)	0.06**	0.06**

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Table 5.2 (c). Soil microbial biomass and enzyme activities as affected by *F. semialata* leaf litter mulching under maize.

Treatments	**MBC (µg/g)**	**MBP (µg/g)**	**MBN (µg/g)**	**ACP (µg pNp $g^{-1}h^{-1}$)**	**DHY (µg TPF g^{-1} h^{-1})**	**URE (µg Urea g^{-1} h^{-1})**
T_0 (control)	914.53	2.56	65.56	86.45	0.45	29.74^{d}
T_1 (nm+f)	646.26	7.34	50.31	101.23	0.34	28.37^{cd}
T_2 (1m+f)	337.34	3.12	29.13	120.94	0.34	6.71^{a}
T_3 (1m+wf)	1287.41	3.20	85.83	91.99	0.30	12.07^{abc}
T_4 (2m+f)	650.75	5.24	59.23	120.12	0.18	15.35^{abcd}
T_5 (2m+wf)	1036.85	2.95	94.66	90.55	0.41	18.27^{abcd}
T_6 (3m+f)	833.43	632	69.56	140.45	0.44	9.79^{ab}
T_7 (3m+wf)	603.29	1.18	54.84	95.69	0.25	25.75^{bcd}
SEM±	90.93(ns)	0.56(ns)	6.99(ns)	5.57(ns)	0.04(ns)	2.29*

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p > 0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer

Table 5.2 (d). Soil microbial biomass and enzyme activities as affected by *F. semialata* leaf litter mulching under rice.

Treatments	MBC (µg/g)	MBP (µg/g)	MBN (µg/g)	ACP (µg pNp $g^{-1}h^{-1}$)	DHY (µg TPF g^{-1} h^{-1})	URE (µg Urea g^{-1} h^{-1})
T_0 (control)	135.15	1.51^{a}	11.97^{a}	494.77^{a}	0.35^{a}	11.05^{a}
T_1 (nm+f)	108.04	3.73^{ab}	16.45^{a}	466.95^{a}	0.52^{abc}	2.39^{a}
T_2 (1m+f)	536.21	3.09^{ab}	42.04^{b}	470.75^{a}	0.87^{bc}	9.37^{a}
T_3 (1m+wf)	155.94	2.11^{a}	12.99^{a}	567.79^{ab}	0.43^{ab}	35.62^{b}
T_4 (2m+f)	131.34	4.93^{abc}	12.54^{a}	497.92^{a}	0.70^{abc}	8.52^{a}
T_5 (2m+wf)	187.05	8.94^{c}	14.22^{a}	612.24^{ab}	0.35^{a}	31.55^{b}
T_6 (3m+f)	104.32	4.33^{ab}	7.67^{a}	481.68^{a}	0.70^{abc}	2.57^{a}
T_7 (3m+wf)	267.56	7.43^{bc}	18.27^{a}	677.66^{b}	0.91^{c}	33.52^{b}
SEM±	39.34(ns)	0.63**	2.9*	20.49*	0.06*	3.34**

$p < 0.05$= significant at 5%*, $p < 0.01$=significant at 1%**; same symbol in superscript do not differ significantly ($p>0.05$).

nm+f= no mulch with fertilizer; 1m+f= dose 1 mulch with fertilizer; 1m+wf= dose 1 mulch without fertilizer; 2m+f= dose 2 mulch with fertilizer; 2m+wf= dose 2 mulch without fertilizer; 3m+f= dose 3 mulch with fertilizer; 3m+wf= dose 3 mulch without fertilizer.

Photograph 5.2 Soil fumigation for soil microbial biomass C, N and P.

Photograph 5.3 Soil physico-chemical and biological analysis.

5.4 Discussion

Straw and plastic mulching was found to increase chlorophyll content of crops (Yang *et al*., 2006). Sekhon *et al*. (2005) also found an increase in chlorophyll content of soybean leaf under straw mulching which is in conformity with our findings in rice where the total chlorophyll content was found higher in treatments with mulch when compared to lower dose and no mulch. However, the above findings are in contrary to our findings in maize where lower dose of mulch favours the chlorophyll content in leaf when compared to other treatments. The decrease in total chlorophyll content with higher dose of mulch in maize could be due to the allelopathic effect caused by allelochemicals present in the leaf litter. These allelochemicals are received by crops in the form of leachates during the application of water for irrigation. The decrease in chlorophyll content was also observed in *Cenchrus ciliaris* and *Neonotonia wightii* due to aqueous leaf extracts of *Datura stramonium* (Elisante *et al*., 2013).

Mulching is also found to have proven effective in improving the yield and WUE (Zhou *et al*., 2009) particularly because it reduced soil evaporation and increases crops transpiration (Jia *et al*., 2006). Zribi *et al*. (2015) reported that increase in water use efficiency of 20-60% was found in plastic mulch due to reduced evaporation. Yaseen *et al*. (2014) also reported an increase in WUE on mulch treatment of maize when compared to control. Their findings also corroborate to our results where application of mulch with fertilizer increases the WUE in rice when compared to control.

The higher root and shoot length of maize in the present finding is at par with the findings by Rajput *et al*. (2014) where he found an increase in plant height, number of leaves per plant, dry biomass and yield in all the mulch treatments when compared to control. Abd El-Mageed *et al*. (2016) also found an increase in plant height, yield and

WUE in squash which is at par with our findings in maize where the dry biomass increased with the application of mulch. However, the above reports are in contrary for our results in rice where the root length, fresh and dry biomass decreased with the application of higher quantity of mulch. This could be due to antagonistic effect caused between higher doses of mulch with fertilizer or due to the allelopathic effects of leaf litter when applied as mulch material. Sidhu *et al*. (2007) also found an increase in plant height, yield and biomass in maize when compared to control. Eifediyi *et al*. (2016) also found a significant increased in the growth and yield parameters of sesame with the use of grass mulch and fertilizer application.

Plastic mulch treatment stored the highest amount of soil moisture compared to organic mulch treatments and the bare soil (Ogundare *et al*., 2015). The application of mulch also increased total porosity, aggregation and soil moisture content (Mulumba and Lal, 2008). These findings are also at par with our findings in maize poly-pot experiment where application of higher doses of mulch increased soil moisture. Contrary to this, Ashrafuzzaman *et al*. (2011) did not find any significant difference on soil moisture content among various mulch treatments, but the soil moisture content was always higher than the bare soil which also holds true for the present rice poly-pot experiment.

Higher soil temperature was found in treatments with higher doses of mulch when compared to control but no significant change on the soil temperature was observed in rice poly-pot treatments. Wang *et al*. (2016) reported higher soil temperature under plastic mulch which promoted soil microbial activity and speeds up decomposition of organic matter in the soil. Charkraborty *et al*. (2008) found that increased soil temperature under mulch did not improve the yield of wheat in India. In some regions, farmers need to lower soil temperature for higher yield, while in other regions, to obtain higher yield soil temperature is increased (Haapala *et* *al*., 2014). Mulches reduce soil temperature in summer and vice versa. Olasantan (1999) obtained higher soil temperature during colder weather and lower soil temperature during warmer weather under mulching compared to non-mulch soil.

The higher value of available N in mulch treatments compared to control in maize was observed in our study but mulching did not influence N availability in soil in case of rice poly-pot experiment. Ren *et al*. (2009) reported an increased in total soil nitrogen under mulching when compared to bare soil; the increase in nitrogen is probably due to an increased nitrogen metabolism by nitrogen-fixing of the organic mulch that stimulates protein production of bacterial community in nitrogen cycles.

Yan *et al*. (2013) reported that accumulation of more soil organic matter on surface soil increased the availability of P in P-fixing soils and that the humic substance increases the bioavailability of P applied in fertilizer. The present findings also showed higher value of available P in the treatments with higher doses of mulch in combination with NPK fertilizer when compared to treatments with lower dose of mulch without fertilizer application. Debicka *et al*. (2016) found that removing soil organic matter decreased the adsorption capacity for P in most of the top soil.

Less organic matter content in soil results in low enzyme activity (Blonska *et al*., 2017). They also reported the higher activity of dehydrogenase and urease in forest soil with high accumulation of soil organic matter and lower activity of dehydrogenase and urease in agriculturally cultivated soil characterized by less organic matter. Our results also confirm to this finding wherein the activities of soil enzymes were higher in treatment with mulch application when compared to treatments without mulch application and increase in enzyme activities was observed with application of higher doses of mulch in both maize and rice poly-pot treatments.

Manjaiah and Singh (2001) also found an increase in dehydrogenase activity and microbial biomass was proportional to the addition of number and amount of nutrient added in the soil. The activities of dehydrogenase increased significantly following applications of N fertilizer and leaf mulch (Acosta-Martinez *et al*., 1999) but had no effect on the activity of acid phospahtase enzyme (Elfstrand *et al*., 2007) which confirm to our findings in maize. High nitrogen fertilizer application significantly increased dehydrogenase activity in surface and sub surface soil and urease activity in surface due to increased accumulation of enzymes stabilized by soil colloids in dry soils (Murugan and Ludwig, 2019).

The increase in acid phosphatase enzyme in higher dose of mulch in the present study is also in accordance with the findings by Giuaquiani *et al*. (1994) who reported that the activity of acid phosphatase enzyme increased with increase in the dose of compost. Martens *et al*. (1992) also found that addition of organic matter maintained high level of phosphatase activity in soil during long term study. Dodor and Tabatabai (2003) also found high phosphatase activity resulted from higher organic carbons in the soil.

Significant decrease in MBC might be due to the inhibition of microbial population because of inability to perform basic metabolic functions in poor availability of moisture regime (Kaur *et al*., 2018). No significant variation with control may be due to breakdown of litter thereby insufficient amount of nutrients were supplied for soil microorganism (Kaur *et al*., 2018). The maximum MBC under different treated soils indicates that microbes in the soil do not discriminate between the sources of nutrients i.e., whether it's from organic or inorganic source (Kaur *et al*., 2018) which is in conformity with the findings by Li *et al*. (2016) and Sall *et al*. (2016). N fertilization significantly decreased MBC under high N treatment when compared to control (He *et al*., 2013) however in contrary to this our findings showed an increase in MBC content in soil in treatments with higher dose of mulch with application of fertilizers. MBC and MBN were found to be positively correlated **(Table 5.3 a&b)** and the change (increase or decrease) in one might have caused the same change on the other with mulch or without mulch treatments when compared to control. Correlation matrix of different soil parameters have been presented in **Table 5.3 a&b** to know their relationship with the application of different doses of mulch in different treatments. Available N showed a positive significant correlation with available P (r = 0.528**) and with available K (r = 0.529**). The collar diameter of rice also showed a positive correlation with available N (r = 0.420*) **Table 5.4b**.The positive correlation among the major nutrients indicates the synergistic effects. Similar findings were also reported by Aneepu *et al*. (2017) who observed significant correlation of availalable N with phosphorus and potassium. The correlation matrix on different soil parameters on the growth attributes in maize and rice has also been presented in **Table 5.4 a&b**.

MBP values in maize pot experiment was lower in treatments with mulch without NPK fertilizer however, treatments with higher dose of mulch without fertilizer showed higher MBP in rice. The higher value of MBP in mulch and NPK combination may be due to the application of P in the form of NPK fertilizer and vice versa. MBP values obtained in the present findings are well within the range of 5-67 mg/kg for agriculture, grassland, orchard and wood land soils as reported by Brookes *et al*. (1984) and Dinesh *et al*. (2006). The non-significant influence in other treatments could perhaps be due to the low availability of P in soil for microbial immobilization.

The significant increase ($p<0.05$) in Ca was observed in mulch treatments under rice when compared to control. The increase concentration in Ca and Mg under mulch treatments was also observed by Awopegba *et al*. (2017) under leaf mulch treatments with *M. oleifera*, *G. sepium*, *T. diversifolia* and *C. mucunoides* for maize. These results conform to our present findings in which the concentration of Ca increased under mulch application. Significant increase ($p<0.05$) in Ca and Mg was also observed by Nzeyimana *et al*. (2018) under coffee farming systems using leaf litter mulch of *Cymbopogon* spp, *Panicum* spp and *Eucalyptus* spp, however in contrary to this, our findings showed a significant decrease ($p<0.01$) in Mg concentration with application of higher dosed of mulch when compared to control which could be due to low soil moisture content and low soil pH.

Table 5.3(a) Correlation matrix of soil parameters on maize poly-pot experiment

	ACP	DHY	URE	MBC	MBN	MBP	SM	ST	AP	AK	AN	Ca	Mg	SOC	pH
ACP	1	-.029	-.189	-.215	-.156	.184	-.356	.382	.528**	.529**	1.000**	.108	-.109	.114	-.355
DHY	-.029	1	.014	.065	.066	-.045	-.220	.116	-.150	-.061	-.029	-.341	.251	-.122	-.213
URE	-.189	.014	1	.205	.243	-.182	.075	-.282	-.295	-.241	-.189	.048	.113	-.455*	.212
MBC	-.215	.065	.205	1	.959**	-.158	.171	.024	-.406*	-.474*	-.215	-.046	.004	-.264	-.087
MBN	-.156	.066	.243	.959**	1	-.131	.198	.148	-.347	-.407*	-.156	-.016	-.071	-.219	-.098
MBP	.184	-.045	-.182	-.158	-.131	1	-.522**	-.032	.587**	.540**	.184	-.340	-.110	.138	-.258
SM	-.356	-.220	.075	.171	.198	-.522**	1	-.238	-.604**	-.688**	-.356	.174	.223	.228	.395
ST	.382	.116	-.282	.024	.148	-.032	-.238	1	.276	.301	.382	.146	-.288	.285	-.373
AP	.528**	-.150	-.295	-.406*	-.347	.587**	-.604**	.276	1	.945**	.528**	-.263	-.403	.112	-.487*
AK	.529**	-.061	-.241	-.474*	-.407*	.540**	-.688**	.301	.945**	1	.529**	-.202	-.363	.141	-.463*
AN	1.000**	-.029	-.189	-.215	-.156	.184	-.356	.382	.528**	.529**	1	.108	-.109	.114	-.355
Ca	.108	-.341	.048	-.046	-.016	-.340	.174	.146	-.263	-.202	.108	1	-.115	.222	.318
Mg	-.109	.251	.113	.004	-.071	-.110	.223	-.288	-.403	-.363	-.109	-.115	1	.129	.160
SOC	.114	-.122	-.455*	-.264	-.219	.138	.228	.285	.112	.141	.114	.222	.129	1	-.134
pH	-.355	-.213	.212	-.087	-.098	-.258	.395	-.373	-.487*	-.463*	-.355	.318	.160	-.134	1

* Correlation is significant at the 0.05 level (2-tailed), ****** Correlation is significant at the 0.01 level (2-tailed), ACP: Acid phosphatase, DHY: Dehydrogenase,

URE: Urease, MBC: Microbial biomass carbon, MBN: Microbial biomass nitrogen, MBP: Microbial biomass phosphorus, SM: Soil moisture, ST: Soil temperature, AP:Available P, AK: Available K, AN: Available N, Ca: Calcium, Mg: Magnesium, SOC: Soil organic carbon

Table 5.3(b) Correlation matrix of soil parameters on rice poly-pot experiment

	ACP	DHY	URE	MBC	MBN	MBP	SM	ST	AP	AK	AN	Ca	Mg	SOC	pH
ACP	1	-.042	.478*	.227	.107	.290	.598**	-.487*	-.124	-.305	-.196	.277	-.106	.073	.210
DHY	-.042	1	-.060	.145	.121	.287	-.198	-.119	.199	-.070	.147	.340	-.317	.172	-.014
URE	.478*	-.060	1	-.100	-.174	.253	.292	-.306	-.322	-.306	-.300	.291	-.237	.167	.362
MBC	.227	.145	-.100	1	.937**	.021	.047	-.004	-.024	-.027	.040	.159	-.072	.071	-.315
MBN	.107	.121	-.174	.937**	1	-.060	-.045	.131	-.099	-.091	.003	.009	-.008	.183	-.461*
MBP	.290	.287	.253	.021	-.060	1	.078	-.489*	.032	-.126	-.050	.284	-.166	.142	.438*
SM	.598**	-.198	.292	.047	-.045	.078	1	-.371	-.231	-.337	-.204	.149	.004	-.049	-.074
ST	-.487*	-.119	-.306	-.004	.131	-.489*	-.371	1	-.164	-.102	.429*	-.735**	.513*	-.053	-.220
AP	-.124	.199	-.322	-.024	-.099	.032	-.231	-.164	1	.467*	.163	.119	.037	-.284	.192
AK	-.305	-.070	-.306	-.027	-.091	-.126	-.337	-.102	.467*	1	-.200	.102	-.139	-.136	.306
AN	-.196	.147	-.300	.040	.003	-.050	-.204	.429*	.163	-.200	1	-.268	.302	-.063	.008
Ca	.277	.340	.291	.159	.009	.284	.149	-.735**	.119	.102	-.268	1	-.832**	.089	.112
Mg	-.106	-.317	-.237	-.072	-.008	-.166	.004	.513*	.037	-.139	.302	-.832**	1	-.050	-.142
SOC	.073	.172	.167	.071	.183	.142	-.049	-.053	-.284	-.136	-.063	.089	-.050	1	-.418*
pH	.210	-.014	.362	-.315	-.461*	.438*	-.074	-.220	.192	.306	.008	.112	-.142	-.418*	1

* Correlation is significant at the 0.05 level (2-tailed), ****** Correlation is significant at the 0.01 level (2-tailed), ACP: Acid phosphatase, DHY: Dehydrogenase,

URE: Urease, MBC: Microbial biomass carbon, MBN: Microbial biomass nitrogen, MBP: Microbial biomass phosphorus, SM: Soil moisture, ST: Soil temperature,,
AP:Available P, AK: Available K, AN: Available N, Ca: Calcium, Mg: Magnesium, SOC: Soil organic carbon

Table 5.4 (a). Correlation coefficient between soil parameters and growth in maize

	Root length	Shoot length	Collar diameter	Fresh wt. root	Dry wt. root	Fresh wt. shoot	Dry wt. shoot	Total Chlorophyll
Soil moisture	.189	.164	.107	.125	.194	.153	.095	-.420*
Soil temperature	.156	.177	.145	-.131	.033	.190	.342	-.602**
Available P	-.306	.196	-.029	.031	-.051	.090	.152	.227
Available K	-.305	.144	-.010	-.195	-.254	-.053	.056	.225
Available N	-.096	.014	-.447*	.095	.127	.460*	.618**	-.131
Ca	-.155	-.284	-.239	-.069	-.110	-.026	.125	-.365
Mg	.095	-.077	.037	.085	.176	.111	.123	-.102
pH	-.033	-.348	-.099	-.118	-.160	-.371	-.106	.014

* Correlation is significant at the 0.05 level (2-tailed), ****** Correlation is significant at the 0.01 level (2-tailed)

Table 5.4 (b). Correlation coefficient between soil parameters and growth in rice

	Root length	Shoot length	Collar diameter	Fresh wt. root	Dry wt. root	Fresh wt. shoot	Dry wt. shoot	Total Chlorophyll
Soil moisture	-.468*	-.386	-.518**	-.227	-.221	-.093	-.430*	.500*
Soil temperature	.005	.133	.309	.254	.139	-.149	-.356	-.374
Available P	.172	.342	.102	.130	.109	.178	.421*	-.523**
Available K	.120	.013	.008	-.064	.369	.085	.095	-.125
Available N	.287	.303	.420*	.342	.282	.083	-.190	-.485*
Ca	-.027	-.162	-.345	-.374	-.060	.098	.326	.409*
Mg	.078	.250	.357	.434*	-.053	.079	-.192	-.401
pH	.191	-.343	.060	-.482*	-.245	-.322	-.021	.231

* Correlation is significant at the 0.05 level (2-tailed), ****** Correlation is significant at the 0.01 level (2-tailed)

Chapter 6
Allelopathic potential of *Flemingia semialata* leaf litter

6.1 Introduction

Allelopathy is a natural ecological phenomenon. It has been known and used in agriculture from time immemorial (Zeng, 2014). The use of allelopathic crops in agriculture is currently being realized like as a component of crops rotations, for intercropping, as cover crops or as green manure (Wortman *et al*., 2013; Silva *et al*., 2014; Wezel *et al*., 2014; Haider *et al*. 2015). The released allelochemicals into the soil inhibits seed germination and establishment of certain crops. The allelochemicals responsible for inhibitory effects are tannins in *Acacia leucophloea*, *Acacia nilotica*, *Adina cordifolia* (Swaminathan *et al*., 1989; Bhatt and Todaria, 1990) and phytotoxins in *Eucalyptus* (Suresh and Rai, 1987). The germination, root length and dry matter production of sorghum, cowpea, cotton and sunflower were depressed due to allelopathic influence of *Ecucalyptus tereticornis*, *Casuarina equisetifolia* and *Leucaena leucocephala* (Divya *et al*. 2010).

Flemingia semialata Roxb. has potential symbiotic nitrogen fixing ability and tendency of soil and water conservation; therefore, it is used as hedge in improved fallow in Jhum and Alley cropping (Songachan and Kayang, 2012). The species has nutritive fodder and it is deep rooting, nitrogen fixing and can withstand long drought and submergence (Ghosh *et al*., 2017). Of late the species has become popular as Lac hosts due to its faster growth and therefore has tremendous potential to be used as important woody perennial species in lac-based agroforestry system (Entomo-forestry). Nevertheles, many multipurpose tree species used in agroforesty are found to inhibit the growth of agricultural crops and there is also limited information on the use of *Flemingia semialata* as MPTs in agricultural fields. *F. semialata* too, like other MPTs is expected to impart allelopathy and hence can influence the germination and growth of associated agricultural crops. Therefore, the present study aimed to determine the compatibility of *Flemingia semialata* with commonly grown field crops viz. maize (*Zea mays* L.) and rice (*Oryza sativa* L.) which might be affected through inhibitory or stimulatory action of various allelochemicals released from its decaying leaf litter.

6.2 Materials and method

6.2.1 Leaf litter collection

Freshly fallen litter was collected from the site where *Flemingia semialata* was cultivated. The litter was stored in gunny bags till sufficient amount needed for the experiment had been collected. Collection of litter was done during the month of January to March, 2016 and 2017. The leaf litters were air dried to minimum moisture and to avoid fungus infection before preparation of the leaf extracts for allelopathy experiment. The leaf litters were thoroughly cleaned from adhering soil and unwanted particles before grounded in grinding machine to be used for preparation of extracts.

6.2.2 Leaf extracts preparation

The air-dried leaf litters were cut into smaller pieces and grinded into fine powder using grinding machine. Leaf extracts were prepared by adding 100g powdered leaf in 1.0 L distilled water and soaked for 24 h at room temperature (25±2°C). The resultant extract was filtered using Whatman filter paper No. 1 and 25, 50, 75 and 100 % concentrations were made with distilled water from the stock solution. The distilled water was used as control for Lab. bioassay while tap water was used as control in pot experiment. The extracts were stored in 4°C in refrigerator until further use. The experiments included five treatments (0, 25, 50, 75 and 100%) including distilled/tap water as control (0%). The treatments were replicated thrice in completely randomized design (CRD).

6.2.3 GC-MS Analysis

For this analysis, freshly fallen leaves of *Flemingia semialata* were collected from the standing trees and air dried for one week. The dry leaves were chopped into small pieces and stored in air tight polythene bags till their extraction. The chopped leaves of 250g/500ml (w/v) were put inside thimble in Soxhlet apparatus. The solvents (Chloroform, Methanol and Petroleum ether) were poured inside the thimble up to the level of siphon tube to avoid flowing out of solvents into the receiving flask. Compounds present in the leaf samples were extracted by distillation using three different solvents mentioned above. The filtered supernatant was again condensed by rotary evaporation, then freeze dried and stored for GC-MS analysis. The aliquot samples were kept in plastic centrifuge tube vial and sent to *VIT-SIF Lab, SAS, Chemistry Division for GC-MS Analysis in VIT University, Vellore.*

6.2.4 Laboratory Bioassays

Test crop seeds (maize and rice) were surface sterilized with sodium hypochlorite (1%) to prevent fungus infection and then washed again in running tap water. Each petri dish of size 10cm X 1.5cm were sterilized in oven at 60 °C for 24 hours and lined with Whatman filter paper No. 1 and moistened with different concentrations of extract by adding 5ml each on alternate days as per treatments designed. Twenty seeds of maize or rice were sown equidistant on top of moistened filter paper and placed inside laboratory at 25±2 °C. Seed germination was monitored for 20 days and the number of germinated seeds was recorded each day. After 20 days, the shoot and root length, fresh and dry weight of test cops were measured and recorded. For dry weight, the fresh roots and shoots were wrapped in aluminum foil and dried in oven at 60°C for 24 hrs.

Germination percentage of the seeds was calculated using the formula:

GP (%) = Seeds germinated/Total seeds x 100

The percentage inhibition/stimulation effect on germination over control was calculated as under (Surendra and Pota, 1978).

$$I = 100 - (E_2 \times 100/E_1),$$

Where I: Percentage inhibition/stimulation, E_1: Response of control and E_2: Response of treatment.

Ratio of germination and elongation were calculated as suggested by Rho and Kil (1986).

$$RGR = GR_t/GR_c \times 100$$

Where, RGR: Relative germination ratio, GR_t: Germination ratio of tested crop and GR_c: Germination ratio of control.

$$RER = ML_t/ML_c \times 100$$

Where, RER: Relative elongation ratio of root and shoot, ML_t: Mean root and shoot length of tested crop and ML_c: Mean root and shoot length of control.

6.2.5 Pot Experiment

Ten sterilized seeds of rice and maize crops were sown 2-3 cm deep in poly-pots of size 26 cm x 20cm with 24cm depth and 8 kg of soil kept in mist chamber at 29±2 °C. The poly-pot was irrigated with 150 ml extract or distilled water as per treatments on alternate days till 90 days. At two leaf stage, thinning was done and one seedling was kept per pot. After 90 days, the seedlings were carefully uprooted from the poly-pots, washed with tap water to remove adhering soil. The shoot and root lengths and fresh weight were recorded. To determine dry weight, the plants were wrapped in aluminum foil and dried in oven at 60°C for 24 hrs.

The percentage inhibition/stimulation effects on germination over control in pot culture were calculated similarly using the formula given by Surendra and Pota (1978) as in case of laboratory bioassays.

6.2.6 Statistical Analysis

Data were subjected to one-way analysis of variance (ANOVA). Based on the outcome of ANOVA, LSD at 5% level of significance was performed to compare the treatment means. The statistical analysis was done using SAS version 9.2 software. DMRT analysis was made to know the statistical significant difference between each of the treatments used.

Photograph 6.1 Bioassays experiment of *F. semialata* leaf extracts on rice and maize.

Photograph 6.2 Poly-pot experiment of *F. semialata* leaf extracts on rice and maize.

6.3 Results

6.3.1 Laboratory Bioassays

The 75% concentration of extract was found to be most stimulatory on the root (+85.69) and shoot (+75.78) length of maize. Stimulatory effect was also observed in 25 and 50% extracts on the root and shoot length of maize when compared to control **(Table 6.1)**. The highest root (185.69%) and shoot (265.56%) elongation was observed in 75% extracts concentration and in control (0%) **Figure 6.1a**.

On the contrary, *F. semialata* aqueous leaf extracts showed inhibitory effect on the root and shoot length of rice and the inhibitory effect increased with increase in the concentration of extracts. The 100% extract concentration was found most inhibitory to root (-27.67%) and shoot length (-51.73%). The lowest root (72.33%) and shoot (42.27%) elongation was also observed in 100% extracts concentration **(Figure 6.1c)**.

The fresh and dry weight of root and shoot of maize was also found stimulated by *F. semialata* aqueous leaf extracts on maize and was concentration dependent **(Table 6.2)**. However, the aqueous leaf extracts inhibited the fresh and dry biomass production in rice, where inhibitory effect increased with increase in extracts concentration.

6.3.2 Pot culture

The higher concentration of extracts shows stimulatory effect when compared to control for maize **(Table 6.3)**. The maximum root (5.17 cm) and shoot (3.29 cm) length were recorded at 100% extract concentration. The increase in root and shoot length of maize was dependent on concentration of leaf extracts. The highest root (214.52 %) and shoot (114.63%) elongation ratio was observed at 100% concentration **(Figure 6.1b)**.

On the contrary, the aqueous extract did not influence the root and shoot length of rice when compared to control. Aqueous extract at 50% concentration significantly decreased the root length (41%) of rice compared to control. The inhibitory effects of *Flemingia semialata* aqueous leaf extracts on root length of rice were observed with increase in extract concentration. The root and shoot biomass of maize was concentration dependent of leaf extracts. The root and shoot biomass were maximum at 75% and 100% and minimum in 25% aqueous leaf extract **(Table 6.4)**. The lowest relative elongation ratio on root (59.26%) and shoot (95.93%) was observed in 50% and 100% extracts concentration when compared to control **(Figure 6.1d)**.

6.3.3 Allelochemicals from *Flemingia semialata* leaf litter

Using the gas chromatography mass-spectrometry (GCMS), 38-types of compounds were detected from methanol, chloroform and petroleum ether extract in leaf litter samples used for bioassay and pot culture experiments **(Table 6.5)**. These chemical compounds were from 7-Chemical classes: Terpenoids, Phenols, Alkaloids, Flavonoids, Saturated fatty Acids, Steroids, Esters and coumarin **(Table 6.6)**. Terpenoids were found in all three solvents leaf extracts and their concentration was higher than other bioactive compounds. Two terpenoids (Phytol and squalene) were also found in both methanol and petroleum ether extracts.

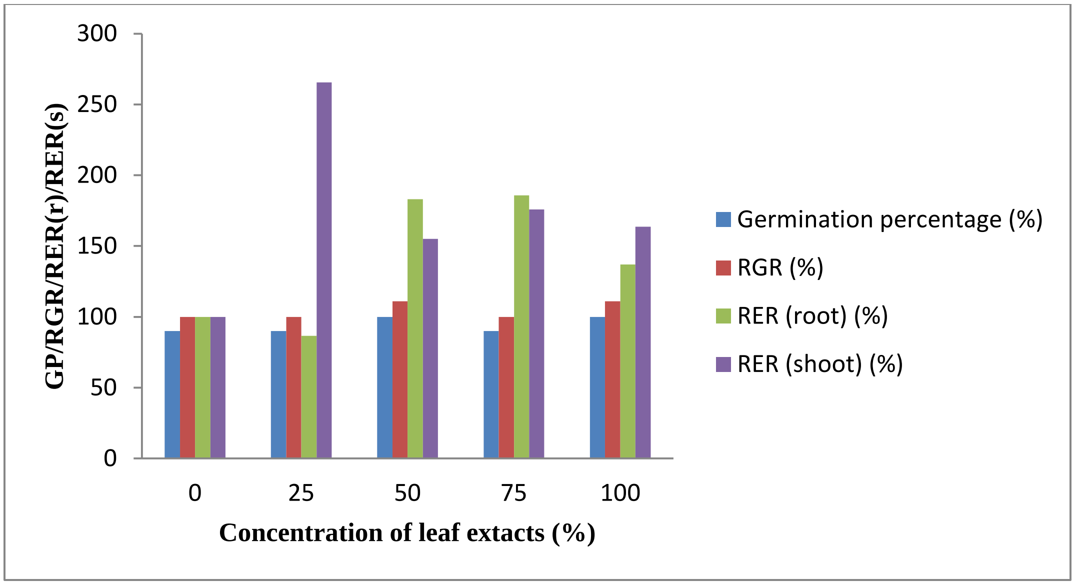


Figure 6.1(a). Germination percentage, Relative germination ratio (RGR), Relative elongation ratio (RER) roots and shoot of maize in laboratory bioassays.

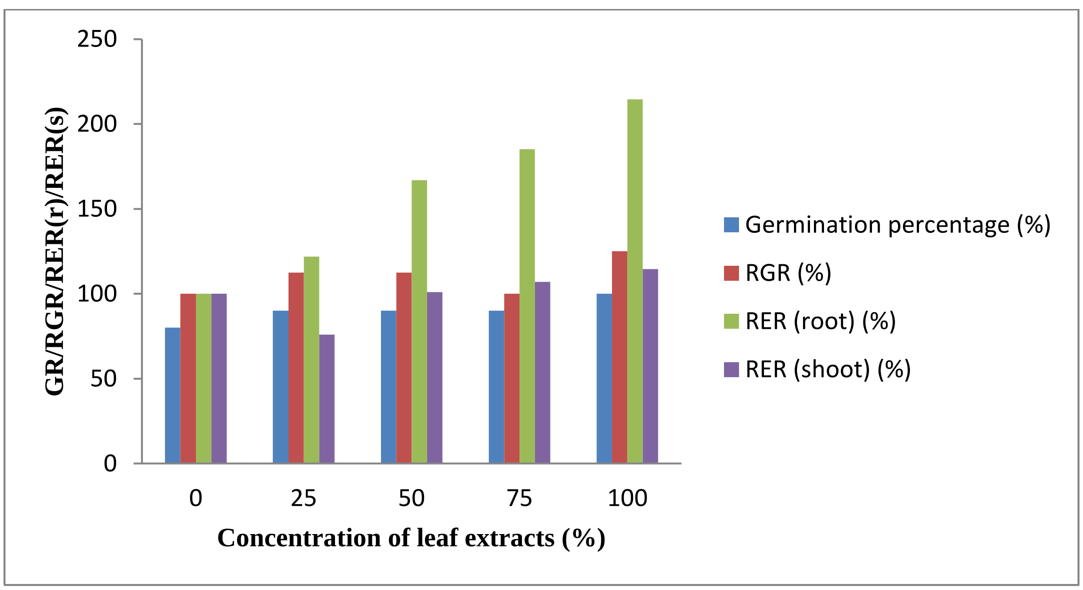


Figure 6.1(b). Germination percentage, Relative germination ratio (RGR), Relative elongation ratio (RER) root and shoot of maize in pot culture.

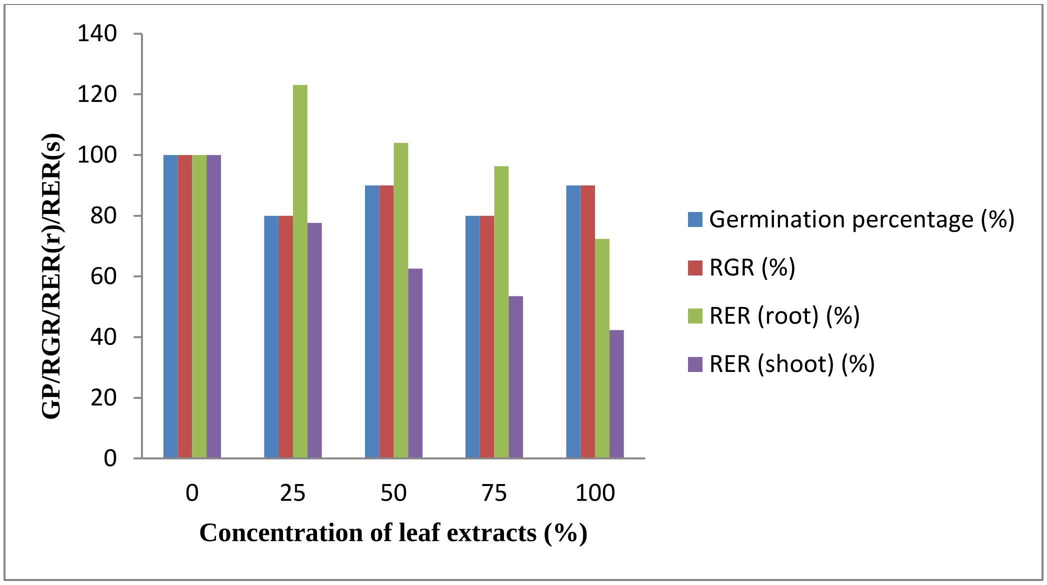


Figure 6.1(c). Germination percentage, Relative germination ratio (RGR), Relative elongation ratio (RER) roots and shoot of rice in laboratory bioassays.

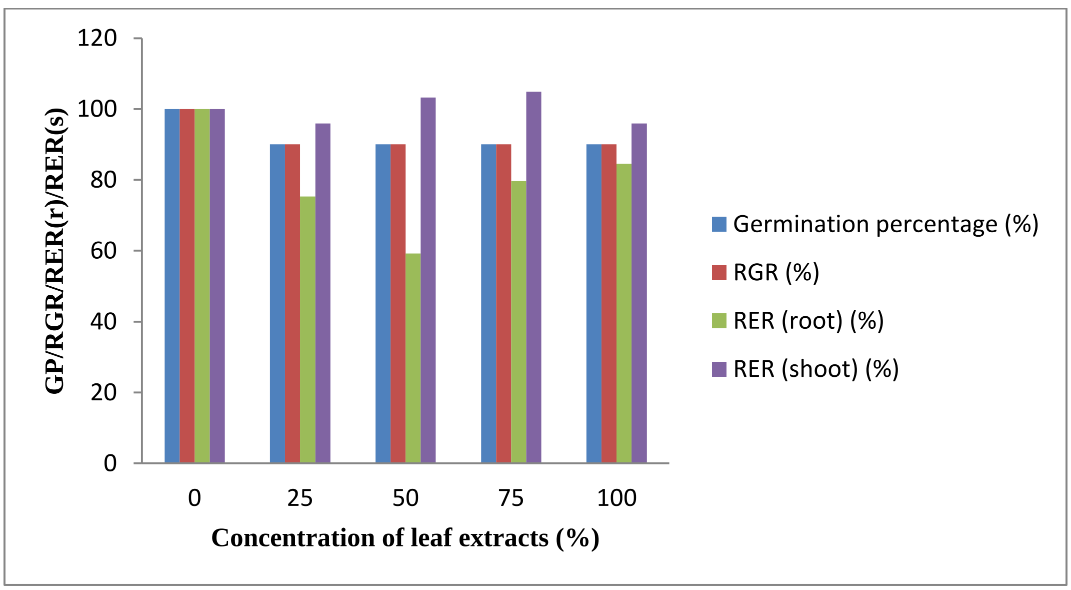


Figure 6.1(d). Germination percentage, Relative germination ratio (RGR), Relative elongation ratio (RER) root and shoot of rice in pot culture.

Table 6.1 Effect of aqueous leaf extracts of *F. semialata* on shoot length and root length of maize and rice in laboratory bioassay.

Concentrations	*Zea mays*			*Oryza sativa*		
	Root length (cm)	**Shoot length (cm)**	**Root:Shoot**	**Root length (cm)**	**Shoot length (cm)**	**Root:Shoot**
Control	9.65±0.40[bc]	4.50±0.28[b]	2.15±0.10[a]	6.94±0.38[b]	6.91±0.35[a]	1.01±0.09[b]
25%	8.36±2.34[c] (-13.26)	11.95±2.84[a] (+165.78)	0.96±0.55[b] (-67.76)	8.53±0.31[a] (+23.05)	5.37±0.46[b] (-22.39)	1.60±0.09[a] (+59.41)
50%	17.66±1.44[a] (+83.11)	6.97±0.32[b] (+55.11)	2.52±0.12[a] (+18.22)	7.21±0.78[ab] (+4.03)	4.14±0.59[c] (-40.17)	1.77±0.13[a] (+75.25)
75%	17.92±0.91[a] (+85.69)	7.91±0.51[ab] (+75.78)	2.27±0.04[a] (+6.07)	6.68±0.39[b] (-7.20)	3.70±0.17[c] (-46.53)	1.81±0.15[a] (+79.21)
100%	13.21±0.94[b] (+36.99)	7.36±0.45[b] (+63.56)	1.82±0.25[b] (-16.36)	5.02±0.37[c] (-27.67)	3.33±0.15[c] (-51.73)	1.50±0.07[a] (+49.50)

Values presented are means ±SE (Standard Error). Superscripts (a,b,c,ab,bc) indicates significant difference between the extract concentrations within same crop growth parameters. Values in the parenthesis indicate percentage inhibition (-) or stimulation (+) relative to control.

Table 6.2. Effect of aqueous leaf extracts of *F. semialata* on shoot and root biomass of maize and rice in laboratory bioassay.

Concentrations	*Zea mays*				*Oryza sativa*			
	Fresh wt.(g)		Dry wt.(g)		Fresh wt.(g)		Dry wt.(g)	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Control	5.683±0.45[b]	6.263±0.42[c]	0.810±0.05[b]	0.843±0.00[b]	0.360±0.01[a]	0.560±0.02[a]	0.050±0.00[a]	0.110±0.01[a]
25%	4.340±1.53[b] (-23.59)	7.390±0.84[c] (+18.05)	1.070±0.06[a] (+32.09)	0.973±0.03[ab] (+15.48)	0.286±0.01[b] (-22.22)	0.476±0.06[ab] (-14.29)	0.046±0.00[a] (0)	0.110±0.03[a] (0)
50%	8.863±0.59[a] (+55.99)	10.077±0.80[b] (+61.02)	1.000±0.07[ab] (+23.46)	1.043±0.08[ab] (+23.81)	0.226±0.03[b] (-36.11)	0.416±0.08[ab] (-25)	0.050±0.01[a] (0)	0.090±0.01[a] (-18.18)
75%	9.037±1.3[a] (+59.15)	12.683±0.94[a] (+102.56)	0.986±0.10[ab] (+20.99)	1.213±0.10[a] (+44.05)	0.233±0.03[b] (-36.11)	0.383±0.03[b] (-32.14)	0.043±0.00[ab] (-20)	0.080±0.01[a] (-33.33)
100%	8.347±0.24[a] (+47.01)	12.230±0.70[ab] (+95.37)	0.893±0.01[ab] (+9.88)	1.190±0.07[a] (+41.67)	0.136±0.01[c] (-61.11)	0.340±0.02[b] (-39.29)	0.030±0.00[b] (-40)	0.066±0.00[a] (-50)

Values presented are means ±SE (Standard Error). Superscripts (a,b,c,ab) indicates significant difference between the extract concentrations within same crop biomass parameters. Values in the parenthesis indicate percentage inhibition (-) or stimulation (+) relative to control.

Table 6.3. Effect of aqueous leaf extracts of *F. semialata* on shoot length and root length of maize and rice in pot culture.

Concentrations	*Zea mays*			*Oryza sativa*		
	Root length (cm)	**Shoot length (cm)**	**Root:Shoot**	**Root length (cm)**	**Shoot length (cm)**	**Root:Shoot**
Control	2.41±0.35[d]	2.87±0.21[b]	0.84±0.05[b]	1.63±0.04[a]	1.23±0.03[ab]	1.32±0.01[a]
25%	2.93±0.50[cd] (+21.58)	2.19±0.10[c] (-23.69)	1.36±0.26[a] (+1.33)	1.22±0.04[ab] (-25.15)	1.18±0.01[b] (-4.06)	1.03±0.02[ab] (-1.03)
50%	4.01±0.39[bc] (66.39)	2.90±0.11[b] (+1.05)	1.39±0.13[a] (+1.38)	0.96±0.33[b] (-41.10)	1.28±0.03[ab] (+4.06)	0.75±0.25[b] (-0.75)
75%	4.45±0.32[ab] (+84.65)	3.08±0.12[ab] (+7.32)	1.45±0.05[a] (+1.44)	1.29±0.08[ab] (-20.85)	1.29±0.04[a] (+4.87)	1±0.04[ab] (-1)
100%	5.17±0.12[a] (+114.52)	3.29±0.07[a] (+14.63)	1.57±0.05[a] (+1.57)	1.37±0.11[ab] (-15.95)	1.18±0.03[b] (-4.06)	0.16±0.08[a] (-1.16)

Values presented are means ±SE (Standard Error). Superscripts (a,b,c,d,ab,bc,cd) indicates significant difference between the extract concentrations within same crop growth parameters. Values in the parenthesis indicate percentage inhibition (-) or stimulation (+) relative to control.

Table 6.4. Effect of aqueous leaf extracts of *F. semialata* on shoot and root biomass of maize and rice in pot culture.

Concentrations	*Zea mays*				*Oryza sativa*			
	Fresh wt.(g)		Dry wt.(g)		Fresh wt.(g)		Dry wt.(g)	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Control	1.070±0.23[ab]	10.370±1.59[bc]	0.150±0.03[b]	0.923±0.15[b]	0.010±0.00[a]	0.356±0.05[b]	0.010±0.00[a]	0.076±0.01[b]
25%	0.693±0.17[b] (-35.51)	8.160±0.30[c] (-21.31)	0.136±0.02[b] (-13.33)	0.713±0.05[c] (-22.82)	0.023±0.00[a] (+100)	0.543±0.02[a] (+50)	0.010±0.00[a] (0)	0.140±0.00[a] (+75)
50%	0.960±0.07[ab] (-10.28)	9.593±0.46[bc] (-7.52)	0.160±0.00[b] (+6.67)	0.906±0.04[b] (-1.09)	0.020±0.00[a] (+100)	0.376±0.01[b] (+5.56)	0.006±0.00[a] (0)	0.073±0.02[b] (-12.5)
75%	1.493±0.39[a] (+39.25)	11.927±0.64[ab] (+15.04)	0.316±0.03[a] (+113.33)	1.180±0.08[a] (+28.26)	0.026±0.00[a] (+200)	0.456±0.04[ab] (+27.78)	0.013±0.00[a] (0)	0.103±0.03[ab] (+25)
100%	1.286±0.16[ab] (+20.56)	12.803±1.73[a] (+23.43)	0.313±0.00[a] (+106.67)	1.260±0.09[a] (+36.96)	0.020±0.00[a] (+100)	0.393±0.05[b] (+8.33)	0.013±0.00[a] (0)	0.110±0.00[ab] (+37.5)

Values presented are means ±SE (Standard Error). Superscripts (a,b,c,ab,bc) indicates significant difference between the extract concentrations within same crop biomass parameters. Values in the parenthesis indicate percentage inhibition (-) or stimulation (+) relative to control.

6.4 Discussion

6.4.1 Laboratory Bioassays

The stimulatory effect on the root and shoot length of maize in the present study confirms to the findings by Musyimi *et al*. (2015) who report the shoot length of cowpea was concentration dependent with *Tithonia diversifolia* aqueous shoot extracts. Mubeen *et al*. (2012) also found that allelochemicals from sunflower and sorghum stimulated the germination and seedling growth of rice which was also in accordance with the present findings. Stimulatory effect on plant height of maize and okra was observed by Ogbu *et al*. (2019) when treated with aqueous leaf extracts of *Pentaclethra macrophylla*.

On the contrary to our observation in maize, the root and shoot length of rice decreased with increase in the concentration of extracts. This finding is in accordance with the observation by Sahoo *et al*. (2015) where aqueous leaf extracts of *Citrus reticulate* was found to inhibit the root and shoot length of soyabean, maize, paddy, chilli and okra. Desai and Gaikwad (2015) also concluded that the litter leachates of *Exoecoria agallocha* inhibited the germination, root and shoot length, dry matter and vigour index of rice with increase in leachates concentration. The root and aerial part extracts from *Echinochloa colona* was also found to inhibit the seedling growth of rice and soyabean (Chopra *et al.*, 2017).

Higher concentrations of allelochemicals might inhibit the seed germination by suppressing the synthesis of gibberellins and indole acetic acid (Moradshahi *et al*., 2003). The highest inhibitory effect on rice fresh and dry biomass in the present study was observed in 100% extract concentration. This finding is in agreement with another finding, where the root and shoot biomass of maize decreases with increase in the concentration of *Schima wallichi* leaf extracts (Lalremsang *et al*., 2017b). The stimulatory effects on the biomass of maize is in conformity with another observation, where the neem leaf extracts significantly stimulated the root growth of wild oats (Bano *et al*., 2012) and the aqueous leaf extracts of *Parashorea macrophylla* increased the seedling dry weight of maize and okra (Ogbu *et al*., 2019). The leaf and stem extracts of *Ludwigia adscendens* reduced the fresh and dry weight of rice (Mukherjee and Barik, 2013), which may be due to the sensitivity of smaller seeds of rice to allelochemicals (Weidenhamer *et al*., 1987). The reduction in biomass might be because the leaf extract stunted and reduces the seedlings growth (Tripathi *et al*., 2000).

6.4.2 Pot culture

The present investigation also revealed a stimulatory effect on the root and shoots length, root and shoot biomass observed in maize however, inhibitory effect was observed in rice seedlings and was concentration dependent. The stimulatory effect on the root and shoot length of maize confirm to the observation by Dhole *et al*. (2011), where aqueous extracts of *Portulaca oleracea* was reported to stimulate seed germination and seedling growth of *Sorghum vulgare* Pers. The inhibitory effect of *Flemingia semialata* aqueous extracts on root length of rice in this study was also at par with the findings by Sahoo *et al*. (2007), where aqueous leaf extracts of *Tectona grandis* and *Leucaena leucocephala* were found to inhibit the radicle extension of maize. Arora (2013) also opined that the decreased in the root length of maize compared to shoot length, when treated with *Celtis occidentalis* extracts might be due to early exposure of radicle to plant extracts as compared to plumule during seed germination. The inhibitory effects on rice and stimulatory effects on maize in bioassay showed a positive correlation ($p<0.05$) with respective pot culture experiments.

Different fatty acids (hexadecanoic acid, formic acid, hexanodioic acid, octadecanoid acid) were also present in *Casuarina equisetifolia* which were found to be allelopathic (Xu *et al*., 2015). The inhibitory effects in this study could be correlated with presence of fatty acids in the leaf extracts. The inhibitory flavanoids 7-Hydroxy-3-(1,1-dimethylprop-2-enyl)Coumarin in leaf extract confirms to other study in which leaf extract of *Acacia auriculiformis* was found to inhibit the germination of some crops (Bora *et al*., 1999). The phenolic compounds present in the leaf extracts inhibits the root elongation, cell division, changes in ultra cell structure and interfere with the growth and development of whole plant (John and Sarada, 2012). The inhibitory compounds in *Flemingia semialata* leaf extracts were: 2-Isopropyl-5-methylcyclohexyl 3-(1-(4-chlorophenyl)-3-oxobutyl)-C, hexadecanoic acid, oleic acid and pentadecanoid acid, which were also found in leaf extracts of *Cassia alata* (Sujatha *et al*., 2019).

The inhibitory effects of *Flemingia semialata* aqueous leaf extracts on the crops in the present study might be due to the presence of Phenol 2,4-Bis(1,1-Dimethylethyl). This is in agreement with another finding, where the leaf extracts of *Dicranopteris dichotoma* showed inhibitory effect on *Bidens pilosa* and *Eupatorium catarium* due to the presence of same compound i.e. Phenol 2,4-Bis(1,1-Dimethylethyl) (Gul *et al*., 2019). Similar inhibitory effects of Phenol 2,4-Bis (1,1-Dimethylethyl)were reported in rice, lettuce and barnyard grass, where rice showed the highest inhibition (Qin *et al*.,2011). The presence of Phenol 2,4-Bis (1,1-Dimethylethyl) was also reported in *Rehmannia glutinosa* and *Casuarina equisetifolia* that affected the *Sesamum indicum*, *Vatica mangachapoi*, *Thespesia lampas* and *Calophyllum inophyllum* (Wang *et al*., 2009; Lin, 2007 and Xu *et al*., 2015).

The presence of high amountof coumarin compounds [2-Isopropyl-5-methylcyclohexyl 3-(1-(4-chlorophenyl)-3-oxobutyl)-C] in methanol extracts might have inhibited the growth of test crops. The high amount ofsesquiterpenoid 2R-acetoxymethyl-1, 3, 3- trimethyl-4T-(3-methyl-2-buten-1-yl)-1T cyclohexanol in Petroleum ether extract might have caused inhibitory effects in the present study. Alkaloids also have inhibitory effect effects on some agricultural crops (Hättenschwiler and Vitousek, 2000). Alkaloids 2, 6- Pyrazinediamine found in theleaf extracts inhibited the synthesis of ethylene in *Arabidopsis thaliana*, thereby, suppressing the growth and root hair development (Sun *et al*., 2017). It is clear from the results that the presence of different allelochemicals in the leaf extracts which might have been responsible for the inhibition of the growth and development of crops. The presence of phenols, although in lesser amount, might have also influenced the germination and growth performance of the two test crops.

Table 6.5 Chemical compounds, retention time, peak height, molecular weight, chemical formula and area under curve detected in (GC-MS) analysis of *Flemingia semialata* leaf litter using different solvent extracts.

S.No.	RT	Name of the compound	Peak Height	Area (%)	Mol. Weight	Chemical formula
		Solvent : Methanol				
1	17.489	Phytol	20,693,860	9.636	296	$C_{20}H_{40}O$
2	17.899	3,7,11,15-Tetramethyl-2-Hexadecene-1-ol	11,674,422	4.249	296	$C_{20}H_{40}O$
3	25.012	Oleic acid	6,920,550	1.603	282	$C_{18}H_{34}O_2$
4	25.512	Pentadecanoid acid	9,345,512	2.639	242	$C_{15}H_{30}O_2$
5	26.078	T-Butyl Cyclopentaneperoxycarboxylate	14,323,848	9.366	186	$C_{10}H_{18}O_3$
6	26.528	1,6;3,4-Dianhydro-2-Deoxy-Beta-D-Lyxo-	15,198,562	5.528	128	$C_6H_8O_3$
7	26.943	2,6-Pyrazinediamine	17,994,224	13.827	110	$C_4H_6N_4$
8	27.303	14-Heptadecenal	11,707,493	2.27	252	$C_{17}H_{32}O$
9	27.433	Pentanoic acid, 2-(Aminooxy)-	10,975,939	3.428	133	$C_5H_{11}O_3N$
10	27.853	7-Hydroxy-3-(1,1-Dimethylprop-2 Enyl)Coumarin	15,666,573	5.456	230	$C_{14}H_{14}O_3$
11	28.093	N-(5-Chloro-2-Hydroxyphenyl)Dodecanamide	8,931,113	1.854	325	$C_{18}H_{28}O_2NCl$
12	29.514	2-Isopropyl-5-Mehtylcyclohexyl 3-(1-(4-Chlorophenyl)-3-Oxobutyl)-C	53,121,816	38.36	524	$C_{30}H_{33}O_6Cl$
13	30.329	Stigmastan-6,22-Dien, 3,5-Dedihydro-	9,356,690	1.784	394	$C_{29}H_{46}$
	Solvent : Petrolem ether					
14	16.964	3,7,11,15-Tetramethyl-2-Hexadecene-1ol	56,250,304	3.693	296	$C_{20}H_{40}O$
15	24.077	Squalene	898,596,54	16.862	410	$C_{30}H_{50}$
16	24.442	Octadecanoic acid, 9,10-Epoxy-,Isopropyl ester	90,926,888	2.653	340	$C_{21}H_{40}O_3$
17	24.587	Cyclohexanol,4-Ethyl-4-Methyl-3-(1-Methylethyl),(1.Alpha.,3.Beta.,4.Alpha.)-	97,398,128	2.497	184	$C_{12}H_{24}O$
18	25.833	Sulfurous acid, Octadecyl 2-Propyl ester	122,770,224	1.588	376	$C_{21}H_{44}O_3S$
19	26.393	Vitamine E	369,778,832	23.551	430	$C_{29}H_{50}O_2$
20	28.284	4,4,6A,6B,8A,11,11,14B-Octamethyl 1,4,4A,5,6,6A,6B,7,8,8A,9,10,11,12,12A,14,14A,	171,778,832	5.685	424	$C_{30}H_{48}O$
21	28.689	2R-Acetoxymethyl-1,3,3-Trimethyl-4T-(3-Methyl-2-Buten-1-yl)-1T-Cyclohexanol	507,688,032	24.04	282	$C_{17}H_{30}O_3$
22	28.889	9,19-Cyclolanost-24-en-3-ol, Acetate, (3.Beta.)-	189,876,656	9.523	468	$C_{32}H_{52}O_2$
23	29.134	9,19-Cycloergost-24-(28)-en-3-ol,4,14-Dimethyl-,Acetate,(3.Beta.,4.Alpha.,5.Alpha.)-	56,440,372	3.397	468	$C_{32}H_{52}O_2$
24	29304	2,4,4-Trimethyl-3-Hydroxymethyl-5A-(3-Methyl-But-2-enyl)-Cyclohexene	49,038,372	2.373	222	$C_{15}H_{26}O$
25	30.364	7-Dehydrocholesteryl Isocaproate	52,383,040	4.138	482	$C_{33}H_{54}O_2$
	Solvent : chloroform					
26	14.698	Phenol,2,4-Bis(1,1-Dimethylethyl)-	16,535,517	2.244	206	$C_{14}H_{22}O$
27	15.323	4-Trifluoromethylbenzoic acid,Octadecyl ester	20,241,120	2.811	442	$C_{26}H_{41}O_2F_3$
28	16.739	Z-2-Octadecen-1-ol	261,607,456	36.739	268	$C_{18}H_{36}O$
29	17.064	3,7,11,15-Tetramethyl-2-Hexadecen-1-ol	102,491,672	10.923	296	$C_{20}H_{40}O$
30	17.299	Phytol	114,568,856	21.472	296	$C_{20}H_{40}O$
31	18.45	N-Tetracosanol-1	51,128,940	5.046	354	$C_{24}H_{50}O$
32	19.99	1-Eicosanol	52,637,084	4.376	298	$C_{20}H_{42}O$
33	21.426	1-Hexacosanol	53,467,209	2.92	382	$C_{26}H_{54}O$
34	22.821	1-Docosene	38,238,264	1.552	308	$C_{22}H_{44}$
35	24.267	Squalene	51,063,476	1.503	410	$C_{30}H_{50}$
36	26.528	Cholesta-8,24-Dien-3-ol,4-Methyl-,(3.Beta.,4.Alpha.)-	36,144,160	2.07	398	$C_{28}H_{46}O$
37	26.673	2,4-Dimethyl-7-oxo-4,7-Dihydro-Triazolo(3,2-C)Triazine	45,77,240	5.687	165	$C_6H_7ON_5$
38	30.464	2H-Ideno[1,2-B]Furan-2-one,3,3A,4,5,6,7,8,8B-Octahydro-8,8-Dimethyl	39,988,204	2.658	206	$C_{13}H_{18}O_2$

Table 6.6. Chemical classes of compounds detected in leaf litter of *Flemingia semialata* leaves using different solvent extracts.

Chemical Class	**Numbers**	**Chemical Compounds**
Terpenoids	9	(phytol, 3,7,11,15-tetramethyl-2-hexadecene-1-ol, stigmastan-6,22-dien,3,5-dedihydro-, squalene, 2R-acetoxymethyl-1,3,3-trimethyl-4T-(3-methyl-2-buten-1-yl)-1T-cyclohexanol, 9,19-cyclolanost-24-en-3-ol,Acetate,(3.Beta.)-, 9,19-cycloergost-24-(28)-en-3-ol,4,14-dimehtyl-acetate(3.Beta., 4.Alpha., 5.Alpha.), Z-2-Octadecen-1-ol and 2H-Idenol[1,2-B]Furan-2-one,3,3A,4,5,6,7,8,8B-Octahydro-8,8-dimethyl)
Phenols	6	(14-heptadecenal, 2,4,4-trimethyl-3-hydroxymethyl-5A-(3-methyl-but-2-enyl)-Cyclohexene, N-tetracosanol-1, 1-Eicosanol,1-Hexacosanol and Phenol2,4-Bis(1,1-Dimethylethyl)-)
Alkaloids	3	(2,6-Pyrazinediamine, Vitamin E and 2,4-Dimethyl-7-oxo-4,7-dihydro-triazolo(3,2-C)Triazine)
Flavonoids	1	(7-Hydroxy-3-(1,1-dimethylprop-2-enyl)
Saturated Fatty Acids	4	(Oleic acid, pentadecanoic acid, T-butylcyclopentaneperoxycarboxylate and pentanoic acid)
Steriods	2	(7-dehydrocholestryl Isocaproate and Cholesta-8,24-dien-3-ol,4-methyl-,(3.Beta.,4.Alpha.)
Esters	3	(Octadecanoic acid, 9,10-Epoxy-,Isopropyl ester, Sulfurous acid,Octadecyl 2-propyl ester and 4-trifluoromethylbenzoic acid, Octadecyl ester)
Coumarin	1	(2-Isopropyl-5-methylcyclohexyl 3-(1-(4-chlorophenyl)-3-oxobutyl)-C)

Chapter 7
General Discussion and Conclusion

Flemingia is a genus of flowering plants in the legume family Fabaceae. It is native to Asia and the species are distributed in Bhutan, Burma, China, India, Indonesia, Loas, Malaysia, Nepal, Pakistan, Papua New Guinea, Phillipines, Sri Lanka, Taiwan, Thailand and Vietnam. The number of known species is ambiguous due to taxonomic problems and is usually enumerated as more than 50. Myanmar and China have the highest record of *Flemingia* species with 16 each, followed by India (15 species), Thailand (11 species), Loas (10 species), Vietnam (8 species), Bhutan (1 species) and Nepal (5 species). Species of *Flemingia* are well known in traditional medicines in various Asian communities. This is attributed to their unique chemical properties especially those of flavonoids and sterols. *Flemingia semialata* is not native to Mizoram but other species *Flemingia macrophylla* and *Flemingia stricta* are found distributed in different parts of the area in patches (Anon, 2013). *F. semialata* has a deep root system and can fix atmospheric nitrogen and therefore is also recommended for soil and water conservation. The species is also known being used in Central and Eastern part of India as lac host. Because of its importance and multiple uses *F. semialata* can be a potential species to be planted in agroforestry system as a woody perennial in improved fallow system in abandoned jhum fallows in hedge row intercropping (Alley copping) as well as multipurpose woodlot in degraded sites.

Due to its faster growth, this species can meet a variety of socioeconomic and ethno-botanic human needs in the region when grown and maintain properly. However, the role of this species in soil nutrient cycling in degraded sites and its introduction has been less studied unlike other multipurpose tree species. Recycling nutrients from decomposing plant litter are one of the main nutrient sources for maintaining growth of forest vegetation. In the present study an attempt has been made to understand the decomposition dynamics of *Flemingia semialata* leaf litter which is an important ecological process in an ecosystem with regard to soil organic matter and nutrient budgeting. The overall observations of the study have been discussed herewith in relation to different objectives mentioned in chapter 1.

7.1 Decomposition dynamics

During the first stage of incubation, faster decomposition was observed. Up to 210 days of incubation, a rapid rate of decomposition was observed and thereafter decomposition rate slowed down till the end of incubation period. The faster rate of decomposition during the initial stage upto 210 days may be due to high C (51%), N (2.38%), low lignin (9.6%) low C/N (21) and Lignin/N (4) ratio. In this context, Duarte *et al*. (2013) reported faster decomposition and nutrient release rate in agroforestry tree species due to lower C/N ratio and higher N content in the leaf litter. The nutrient contents of the leaf litter also gradually decreased with days of incubation. The gradual decrease on nutrient content of leaf litter was also observed by Ventura *et al*. (2010) in *Prunus persica*. Among all the nutrients, K had the fastest release rate and Mg immobilization was observed at later stage of incubation. This is at par with findings by Partey *et al*. (2011) who observed that K had the fastest release rate among the species studied and Mg immobilization was observed at later stage in *Acacia auriculiformis* and *Gliricidia sepium* leaf litter decomposition.

In general, the rate of decomposition was faster during rainy and warm season. The high mass loss in leaf litter could be attributed to rising temperature and increase in rainfall with lower lignin content which might have favoured higher decomposers' activity. The rapid rate of decomposition upto 150 days of incubation may be due to high rainfall which favours greater microbial activity thereby causing higher decay rate. In this context, Maoyi *et al*. (1988) reported that higher temperatures and moisture conditions during monsoon favoured decomposition of bamboo litter in China which is in agreement with the present findings. The decay rate constant (*k*) of the present study was 3.65 which indicate faster decomposition. The decay rate constant (*k*) for *P*. *bambusoides* and *A*. *racemosa* were found to be 3.75 and 3.58 (Upadhyaya *et al*., 2012) respectively which is closed to the decay rate constant of the present study. The decay rate constant (*k*) of various species in different ecosystems are represented in **Table 7.1**.

7.2 Nutrient dynamics

The concentration of N decreased at faster rate upto 240 days after that it slowed down from 330 days which could be due to N immobilization at later stage of decomposition. However, P immobilization occurred upto 180 days from the initial stage of incubation, thereafter mineralization was observed at later stage. This increase or decrease in P mineralization during decomposition depends upon the initial P content of litter. Litters with initial N/P>15 are more likely to release N and retain P than those with N/P<15 more likely to retain N and release P. The present study had an N/P of 26 releases N at a greater rate than P. The initial C/P ratio in the present study was 566 which are below the critical C/P ratio of 574 for P release (Edmonds, 1980).

The rapid decrease in N concentration at initial stage may be due to high N (2.38%) content, low C/N (21) and Lignin/N (4) ratio. The faster rate of N mineralization in initial stage may be due high N content; low C/N and Lignin/N can be confirmed from the findings by Jeong *et al*., 2015; Myers *et al*., 1994 and Milillo *et al*., 1982. P immobilization during initial stage and mineralization at later stage of incubation in the present study was in accordance with the observation by Stohlgren

(1988) and Prescott *et al*. (1993). The higher value of *k* for P than N in the present study indicates longer availability of N in the soil for plant nutrient uptake. The nutrient released rates of different MPTs are represented in **Table 7.2**.

7.3 Mulching effect

In general, higher dose of mulch application with *Flemingia* leaf litter found to be better for collar diameter in maize when compared to control treatment. WUE was also found higher in treatments with mulch and fertilizer combination. In this context, Zhang *et al*. (2017) observed an increase of maize yield by 5.9-8.8% and water use efficiency by 10.7-13.1% with mulch treatments when compared to treatment without mulch application. The root and shoot length of rice was also found to be higher in treatments with mulch and fertilizer combination. Phosphatase and urease activities were also found higher in higher dose of mulch without fertilizer. Zhang *et al*. (2019) also found that application of paper mulch increased soil enzyme activities, improving plant growth and increasing fruit yield when compared to control which can corroborate to our findings. In the study conducted by Wang *et al*. (2014) found increase in soil microbial biomass, phosphatase, urease and β-glucosidase in mulch treatments than with no mulch. Significant changed on the root and shoot length, total chlorophyll content, WUE and dry biomass was observed in the treatments when compared to control. The significant changed on different growth and yield parameters on different crops with the application of different mulch materials are highlighted in **Table 7.3**.

The significant variation on different soil parameters like pH, soil temperature, soil moisture, available P, available K, Ca and Mg under mulch application observed in the present study can be corroborated with changed in different soil parameters highlighted in **Table 7.4** due to the application of different mulch materials.

7.4 Allelopathic effects

The root and shoot length, fresh and dry biomass of the test crops were significantly affected by the application of leaf extracts in different concentrations both in bioassays and pot experiment. Higher concentration of extracts stimulated the root and shoots length, fresh and dry biomass of maize; however inhibitory effect was observed in rice. The stimulatory effect on the rate of germination in maize in laboratory bioassay and pot-experiment was observed with increase in concentration of leaf extracts, however inhibitory effect was observed in rice when compared to control. The effect of concentrations on the growth parameters were concentration dependent which cause stimulatory/inhibitory effect on the test crops. Stimulatory effect observed in maize for all the growth parameters can be comparable with the findings by Lalremsang *et al*. (2017b) who observed that the leaf extract of *Schima wallichi* and *Mesua ferrea* produced stimulatory effect on the root and shoot length, fresh and dry biomass of crops in poly pot experiment. Similar findings on the inhibitory effect of rice was also observed by Sitthinoi *et al*. (2017) who reported that extracts of *Echinochloa colona* shoot and root inhibit the germination and seedling growth of rice. Similar observations on the inhibitory or stimulatory effect of leaf litter extracts on different test crops are highlighted in **Table 7.5** to confirm the results obtained in the present findings.

Table 7.1 Litter decay constants of different species.

Species	Ecosystem, country	k(y^{-1})	Reference
Acacia auriculiformis	Moist semi-deciduous	5.11	Partey *et al*. (2011)
Leucaena leucocephala	forest, Ghana	4.75	Partey *et al*. (2011)
Mangifera indica	Hot and dry sub-humid	3.22	Naik *et al*. (2017)
Psidium guajava	climate, India	1.33	Naik *et al*. (2017)
Litchi chinensis		0.62	Naik *et al*. (2017)
Tectona grandis	Sub-tropical forest,	2.70	Das & Mondal (2016)
Shorea robusta	India	2.41	Das & Mondal (2016)
Schima wallichi	Sub-tropical wet	0.328	Devi & Yadava (2010)
Quercus serrata	hill forest, India	0.463	Devi & Yadava (2010)
Lithocarpus dealbata		0.539	Devi & Yadava (2010)
Perilla frutescens	Tropical monsoon, India	2.79-3.93	Sharma *et al*. (2018)
Flemingia semialata	**Sub-tropical forest, India**	3.65	**Present study**

Table 7.2 Nutrient release rate of different species.

Species	Ecosystem, country	***k* (day^{-1})**	Reference
Acacia auriculiformis	**Moist semi-deciduous forest, Ghana**	k_N = 0.016 k_P = 0.020 k_K = 0.039 k_{Ca} = 0.014 k_{Mg} = 0.021	Partey *et al*. (2011)
Leucaena leucocephala		k_N = 0.014 k_P = 0.015 k_K = 0.034 k_{Ca} = 0.007 k_{Mg} = 0.014	
Gliricidia sepium		k_N = 0.029 k_P = 0.038 k_K = 0.051 k_{Ca} = 0.02 k_{Mg} = 0.033	
Gmelina arboria	**Tropical humid forest, Colombia**	k_N = 0.018 k_P = 0.022 k_K = 0.038 k_{Ca} = 0.029 k_{Mg} = 0.026	Rajos *et al*. (2017)
Theobroma cocoa		k_N = 0.011 k_P = 0.014 k_K = 0.022 k_{Ca} = 0.016 k_{Mg} = 0.019	
Prosopis cineraria	**Semi-arid region, India**	k_N = 0.0241 k_P = 0.0290 k_K = 0.0418	Yadav *et al*. (2008)
Dalbergia sissoo		k_N = 0.0201 k_P = 0.0258 k_K = 0.0337	
Acacia leucophloea		k_N = 0.0158 k_P = 0.0149 k_K = 0.0201	
Acacia nilotica		k_N = 0.0180	

		k_P = 0.0145 k_K = 0.0287	
Species	**Ecosystem, country**	***k* (day^{-1})**	**Reference**
Flemingia semialata	**Sub-tropical forest, India**	k_N = 0.002 k_P = 0.006 k_K = 0.010 k_C = 0.001 k_{Ca} = 0.003 k_{Mg} = 0.005	**Present study**

Table 7.3 Mulching effect on growth and yield of crops.

Mulch material	Test crops	Change in growth and yield attributes	Reference
Tithonia diversifolia *Vernonia amygdalina*	Maize	Plant height and collar diameter	Chukwuka *et al*. (2014b)
Barley residue	Pistachio	Shoot length and collar diameter	Namaghi *et al*. (2018)
Rice straw	Sweet corn	Plant height and biomass	Vial *et al*. (2015)
Rice straw	Mungbean	Root length, WUE and grain yield	Bunna *et al*. (2011)
Chromolaena odorata *Tithonia diversifolia*	Yam	Vine length and tuber yield	Agbede *et al*. (2013)
Moringa oleifera *Gliricidia sepium* *Tithonia diversifolia* *Calopogonium mucunoides*	Maize	Plant height, grain yield and biomass	Awopegba *et al*. (2017)

Table 7.4 Mulching effect on soil properties.

Mulching material used	Soil parameter analyzed	Impact on soil properties	Reference
Barley residue	Soil moisture and temperature	increase	Namaghi *et al*. (2018)
Leaf mulch of *Acacia crassicarpa* *Albezia adianthifolia* *Albizia zygia*	pH, Mg, N, P and K pH, Ca and K pH, Mg and K	increase increase increase	Adesuyi *et al*. (2018)
Cover crops of *Crotalaria juncea* *Mucuna pruriens* *Vigna unguiculata* *Sorghum bicolor* *Sorghum* x *drummondii*	SOC, Total N, MBC and MBN	increase	Wang *et al*. (2007)
Cover crops of *Trifolium repens* *Coronilla varia* *Lolium perenne*	SOC, Available P, Available K, URE and ACP	increase	Qian *et al*. (2015)
Leaf mulch of *Tithonia diversifolia* *Chromobena odorata*	Soil moisture, Total N, Available P, Ca, Mg and K	increase	Agbede *et al*. (2013)
Leaf mulch of *Moringa oleifera* *Gliricidia sepium* *Tithonia diversifolia* *Calopogonum mucunoides*	pH, Available P, Total N, Ca, Mg and K	increase	Awoprgba *et al*. (2017)

Table 7.5 Allelopathic effect on different crops.

Donor plant	**Test crops**	**Growth parameters studies**	**Inhibition/ Stimulation**	**Reference**
Glycyrrhiza glabra	Maize	Seed germination, root and shoot length and chlorophyll content	Inhibitory	Navaey *et al*. (2013)
Echinochola colona *Cyperus iria*	Rice and soybean	Seed germination and shoot length	Inhibitory	Chopra *et al*. (2017)
Casuarina glauca *Populus nigra*	Durum wheat	Root and shoot length and dry biomass	Inhibitory	Hachani *et al*. (2019)
Rhus chinensis	Radish, semen cassia and soybean	Seed germination, root and shoot length	Inhibitory	Liu *et al*. (2015)
Zingiber officinale	Maize	Seed germination, root and shoot length, root and shoot biomass	Inhibitory	Bharath *et al*. (2014)
Marsilea minuta	Rice and wheat	Seed germination and dry weight of root and shoot	Inhibitory	Tanveer *et al*. (2015)
Vernonanthura brasiliana	Lettuce	Shoot length	Stimulatory	Nishimuta *et al*. (2019)
Eucalyptus urophylla *Eucalyptus citriodora* *Eucalyptus camaldulensis*	Cucumber	Root and shoot length	Stimulatory	Zhang & Fu (2010)

Conclusions

Based on the observations through field and laboratory experiments, plant and soil sample analysis, the following conclusions have been made:

- ***Flemingia semialata* leaf litter could be useful in regulating soil nutrient pool through faster litter turnover.**

- **Initial litter chemistry plays an important role in decomposition and nutrient release pattern in *F. semialata* species.**

- **Lignin/N plays an important factor in influencing decomposition rate and nutrient mineralization compared to initial N and C/N ratio.**

- **The C/P and N/P also influenced the mineralization/immobilization of phosphorus in the leaf litter.**

- **Besides litter quality parameters, rainfall significantly influenced the decay process and the nutrient release from decomposing litter of *F. semialata*.**

- **Available N and P of soil also influence the biomass and collar diameter of both the test crop.**

- **Soil moisture, Ca and Mg content of soil also influenced the chlorophyll content and fresh biomass of root in rice.**

- **Higher dose of mulch application favours the growth of crops, WUE, Phosphatase and Urease activity in the soil.**

- **Higher dose of extract concentrations affects the root and shoot length, fresh and dry biomass of the test crops.**

Summary

A detailed study was carried out on the decomposition dynamics, nutrient release pattern, mulching efficacy and allelopathic potential of *Flemingia semialata* leaf litter in Mizoram. The study was conducted in Department of Forestry, Mizoram University (23°42` to 23°46` N Latitude and 92°38` to 92°42`E Longitude) with an elevation of 950 meter above sea level. The climate is humid and tropical characterized by short winter and long summer accompanied with heavy rainfall. The maximum temperature was observed during April and May and minimum during December and January. The average annual rainfall of the area is about 182 mm. The investigation on decomposition dynamics was conducted in order to understand decay and the nutrient release pattern from the leaf litter. Mulching with different doses of leaf litter was carried out to evaluate its suitability as mulching material for maize and rice cultivation. A laboratory bioassay and pot culture experiment was also conducted to assess allelopathic potential of *F. semialata* leaf litter in order to know its compatibility with maize and rice, two major food crops of Mizoram.

The major findings of the study have been summarized as below:

1. Due to high initial C (51%) concentration in the leaf litter, mass loss in the litter starts from the first month of decomposition and proceeds up to the final stage of decomposition.
2. The initial higher N (2.38%) concentration with low C/N (21) ratio may also be an important factor in faster rate of decomposition in the leaf litter. The initial higher concentration of C and N in the leaf litter signifies the captured amount of nutrients in its biomass.

3. The lower lignin (9.55%) content and Lignin/N (4.05) ratio of the initial leaf litter might have also favored faster decomposition of leaf litter in the present study.
4. The decomposition of *F. semialata* leaf litter followed a gradual pattern of weight loss with a decay constant of (k) = 3.65 $year^{-1}$. The decay rate above (k>3) signifies faster decomposition and subsequently release nutrients at a faster rate.
5. The P mineralization k_P (2.19) rate was higher than k_N (0.73) per year in the leaf litter indicating slower release rate of N during decomposition.
6. The weight loss during decomposition was positively correlated with rainfall (r = 0.42).
7. The weight loss was positively correlated with different nutrients during decomposition viz., N (p = 0.01), P (p = 0.0006), K (p = 0.002), C (p = 0.0001), Ca (p = 0.007) and Mg (p = 0.0008). The significant amount of nutrients present in the leaf litter *viz*., C (51%), N (2.38%), K (3.22%), Mg (1.51%) and Ca (1.67%) plays an important role in fast nutrient recovery in soil that could eventually be used for mulching.
8. Mulch with no fertilizer showed higher shoot length and root length of maize treatments.
9. Higher dose of mulch also increased collar diameter in maize compared to other treatments.
10. Significant ($p<0.01$) effect on chlorophyll content of maize was recorded with no mulch with fertilizer treatment (T_1).
11. WUE was found higher in treatments with mulch and fertilizer combined.
12. Lower dose of mulch with no fertilizer treatment improved soil phosphatase activity than other treatments under maize. However, application of mulch and fertilizer combine had no effect on dehydrogenase and urease activities.
13. Higher root and shoot length were found in treatments with mulch and fertilizer combination in rice compared to control. Collar diameter was also found higher for treatments with mulch and fertilizer.

14. Maximum chlorophyll content was observed in treatments with high dose of mulch with fertilizer.
15. WUE was found higher in lower dose of mulch and fertilizer combined.
16. Phosphatase activity was found higher at higher dose of mulch without fertilizer in rice but higher dose of mulch with fertilizer combine showed higher phosphatase activity in maize.
17. Dehydrogenase activity was more at lower dose of mulch with fertilizer.
18. Mulch without fertilizer showed highest urease activity in maize and rice.
19. Leaf extract of 75% concentration was found to produced stimulatory effect on root and shoot length, fresh and dry biomass of maize both in laboratory bioassays and pot culture.
20. Leaf extract with 75 and 100% concentrations produced inhibitory effect on the root and shoot length, fresh and dry biomass of rice.

It can be concluded from the above findings that leaf litter of *Flemingia semialata* could be useful in regulating soil nutrient pool through faster litter turnover. The results also contributed in understanding the dynamics, nutrient release and soil enrichment by the leaf litter of the leguminous species in plantations and traditionally managed sustainable land use systems on farmer's field. A decay constant of k= 3.65 year^{-1}revels that *F. semialata* through faster rate of leaf litter decomposition can effectively contribute to organic matter build up in degraded sites such as in abandoned jhum lands. The lower value of k_N indicates slower release rate which indicates longer availability of N in the soil for plants and can help in soil nutrient restorations. The overall decay rate and nutrient mineralization in the study also suggest that *Flemingia semialata* can be used as an important perennial crop to be incorporated along with agricultural crops for maintaining soil fertility and better productivity.

The difference in the level of response to mulch application in the two crops represents host specificity for growth requirements and soil microbial status in different treatments. The response on application of mulch and fertilizer are different for both the test crops so proper dose of mulch and fertilizer requirements need to be assessed first before its application. Besides bioassay and pot culture experiments on allelopathy also reveals synergic effect of *F. semialata* leaf litter on maize and contrarily antagonistic effect on rice causing inhibition of germination and growth behavior. The study also suggests that maize is more compatible than rice to *F. semialata*. Since, the present study is confined to only poly-pot experiment, the effect of mulch application in field condition is not known, and furthermore antagonistic effect due to application of higher dose of mulch with fertilizer also needs to be studied in detail which could be useful in plant management and soil nutrient status in different environmental conditions. Therefore, further research is needed to elucidate the role of litter mulch on the growth of agricultural crops and soil biology of the experimental site in field condition.

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BIO-DATA

1. **Name** : Paul Lalremsang
2. **Address** : H.NO. Y-58, Luangmual, Aizawl
3. **Father's Name** : Rosiama
4. **D.O.B** : 9th August 1981
5. **Nationality** : Indian
6. **Religion** : Christian
7. **Sex**: Male
8. **Marital Status** : Unmarried
9. **E – mail** : sangpuia107@gmail.com ; **Contact No** : 9774381944
10. **Educational Qualification** :
    (i) HSLC (X) : 1998
    (ii) HSSLC (XII) Science : 2000
    (iii) Bachelor of Science (Forestry) : NERIST, Arunachal Pradesh, 2005
    (iv) Master of Science (Forestry) : Mizoram University, 2015

Courses and Seminars Attended

- Participate in UGC-Sponsored Short Term Course on "One Week Course on Applied Statistics", 7-12th September, 2015 organized by Human Resource Development Centre, Mizoram University.
- Participate in two days training on "Mushroom Production Technology" organized by Department of Biotechnology, Mizoram University sponsored by ICAR-Directorate of Mushroom Research (ICAR-DMR), Himachal Pradesh, India from 21-22nd January, 2016.
- Participate in UGC-Sponsored Short Term Course on "Research Methodology for Research Scholars", 20-26th June, 2016 organized by Human Resource Development Centre, Mizoram University.
- Presented paper in National Seminar on Biodiversity, Conservation and Utilization of Natural Resources with reference to Northeast India (BCUNRNEI), 30-31 March, 2017, MZU, Mizoram, India.
- Presented paper in XIX Commonwealth Forestry Conference, 3-7 April, 2017, FRI, Dehradun, India.

- Presented paper in International Conference on Natural Resources Management for Sustainable Development and Rural Livelihoods, 26 -28th October, 2017, MZU, Mizoram University.
- Presented paper in 7th International Science Congress (ISC-2017), 8-9th December, 2017 held at Bhutan, Jointly organized by International Science Community Association and College of Science and Technology, Royal University of Bhutan.
- Presented paper on International Conference on Ecological Agriculture and Forestry (ICEAF-18), 14-15th October, 2018 held at Klang, Malaysia.

Awards

- **Gold Medallist** in MSc. Forestry, 2015
- Agricultural Scientist Recruitment Board (ASRB), ICAR NET Qualified (2016)
- Awarded **International Young Scientist Award for Best Oral Presentation** in 7th International Science Congress, 8-9th December, 2017.

APPENDICES

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE: **PAUL LALREMSANG**

DEGREE: **DOCTOR OF PHILOSOPHY**

DEPARTMENT: **FORESTRY**

TITLE OF THE THESIS: **DECOMPOSITION DYNAMICS, MULCHING EFFICACY AND ALLELOPATHIC POTENTIAL OF LEAF LITTER OF FLEMINGIA SEMIALATA ROXB**.

DATE OF ADMISSION: **12.08.2015**

APPROVAL OF RESEARCH PROPOSAL:

1. DRC: **04.04.2016**
2. BOS: **06.04.2016**
3. SCHOOL BOARD: **13.04.2016**

   MZU REGISTRATION NO.: **89 of 2014**

   Ph.D REGISTRATION NO. & DATE: **MZU/Ph.D/906 of 13.04.2016**

   EXTENSION (IF ANY): **NO EXTENSION**

Head

Department of Forestry