PHENOLOGICAL DIVERSITY AND LEAF DYNAMICS OF MAJOR TREE SPECIES AND SOIL NUTRIENTS IN A SUBTROPICAL FOREST STAND OF MIZORAM

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CERTIFICATE

This is to certify that the thesis entitled "*Phenological diversity and leaf dynamics of major tree species and soil nutrients in a subtropical forest stand of Mizoram*" submitted to Mizoram University, Aizawl for the award of the degree of Doctor of Philosophy in Forestry is the original work carried out by Mr. R. Lalruatfela (Regd. No. MZU/Ph.D/907 of 13.04.2016) under my supervision. I further certify that the thesis is the result of his original investigation and neither the thesis as a whole nor any part of it was submitted earlier to any University or Institute for the award of any degree. The candidate has fulfilled all the requirements laid down in the Ph.D. regulations of the Mizoram University.

His passion oriented hard work for the completion of the research is to be duly appreciated.

Date: (Prof. S. K.Tripathi)
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DECLARATION

I, R. Lalruatfela, hereby declare that the subject matter of this thesis entitled "*Phenological diversity and leaf dynamics of major tree species and soil nutrients in a subtropical forest stand of Mizoram*" is the work done by me, that the contents of the thesis did not form basis of the award of any previous degree to me or anybody else to the best of my knowledge, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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

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et al.,	*et alii.* : and others
pH	power of hydrogen
N	nitrogen
P_2O_5	available phosphorus
K	potassium
C	carbon
Ca	calcium
Fe	iron
Mg	magnesium
Na	sodium
LSI	leaf strategy index
LMA	leaf mass area
SLA	specific leaf area
SWD	stem wood density
%	percentage
$cm^2\ g^{-1}$	centimeter square per gram
LUE	light use efficiency
ca.	circa (=about)
GPP	gross primary productivity
$degree^{-1}$	per degree
NReff	nitrogen resorption efficiency
SWD	stem wood density
km^2	square kilometres
ISFR	Indian state of forest report
spp.	species
°C	degree celcius
Rh	relative humidity
mm	millimeter
dbh	diameter at breast height
WMC	wood moisture content
WHC	water holding capacity
OM	organic matter
SMC	soil moisture content
SI	synchrony index
SE	standard error
LDMC	leaf dry matter content
LWCa	leaf water content per unit area
$g\ g^{-1}$	grams per gram
$g\ H_2Ocm^{-2}$	grams of water per square centimetre
RLGR	relative leaf growth rate
gm^{-2}	square grams
LMC	leaf moisture content

CHAPTER 1
INTRODUCTION

Phenology

Phenology has been principally concerned with the dates of first occurrence of biological events in the life cycle of plants annually, and is the science of recurring events in nature. A working group of the International Biological Program proposed the definition: 'Phenology is the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species (Lieth, 1974). The term, phenology was for the first time introduced in 1853 by Charles Morren, a Belgian botanist, who documented the changes in periodic life cycle events of trees and assessed the role of habitat factors and seasonal and interannual variations in the climate on phenological events. Life cycle events of the trees are known as phenophases, which includes budding, leaf unfolding, changes in leaf shape and color, leaf fall, flowering, fruiting and seed dispersal. These phenophases are characterized by vegetative phenology (i.e. the timing of vegetative bud break; leaf flush, leaf maturation; leaf senescence and leaf fall) and reproductive phenology (i.e. the timing of bud break of flowers, anthesis, floral senescence, fruiting, fruit maturation and seed production) (Singh and Kushwaha, 2005). In this thesis, efforts have been made to understand tree phenology (i.e. vegetative and reproductive) along with many tree intrinsic factors as well as abiotic environmental factors that are operating in sub tropical montane forest of Hmuifang, Mizoram, India. Variety of tree intrinsic factors assessed for all species studied were correlated with the timing of leaf flush, leaf fall, flowering, fruiting, duration of deciduousness. In depth study has been carried out for all the recorded observations like vegetative and reproductive phenophases for ascertaining the external and internal factors triggering these phenomena.

Phenological studies provide useful understanding on ecosystem processes, for example, plant growth pattern, biomass production, plant water stress (Reich *et al*., 1994; Kikuzawa and Lechowicz, 2011), plant responses to biotic and abiotic factors such as competition for light or pollinators (Negi and Singh, 1992), photoperiod (Wright and van Schaik, 1994), temperature (Arroyo *et al*., 1981) and precipitation (Opler *et al*., 1976). Plant phenology is determined by climatic factors like temperature and precipitation (Marques *et al.,* 2004). The timing of life history traits is central to lifetime fitness and the studies on the phenology of flowering in governing plant reproductive success are highly limited (Inouye, 2008). Phenological events in plants may be affected by various factors that can be classified as proximate or ultimate causes. Proximate causes principally include short-term environmental events that may trigger phenological patterns, while ultimate causes include evolutionary forces that are responsible for these patterns (Lobo *et al.*, 2003).

Temporal changes in phenological patterns

Based on its well-known variation with the annual course of weather elements, plant phenology might be expected to be one of the most responsive and easily observable traits in nature that change in response to climate (Badeck *et al.*, 2004). Trends in the timing of plant developmental phases that are brought about by the current anthropogenic global climate change can have major impacts on plant productivity, competition between plant species, and interactions with heterotrophe organisms, and can have consequences for goods and services of the ecosystems. The relationship between various response factors and climate would be important to select suitable bio-indicators for monitoring the landscape-ecological effects of climate change. The life cycles of most organisms are relatively fixed in time and are often strongly determined by climatological factors such as temperature and precipitation (water availability). Many phases in the life cycles of most plants and animals (i.e. the timing of (de)foliation, leaf-burst and flowering, the timing of seed-setting and ripening, the length of the growing or breeding season, growth and the timing of migration) are affected by these environmental conditions. Therefore, the changes in phenology may influence the competitive ability of the species. The responses of each species will vary individually and within its area of distribution, the changes in phenology will not be the same for each site as the changes in climate will differ for each region and therefore, many species behave differently at their phonological limits compared to the center of their distribution (de Groot and Ketner, 1995).

Seasonality in plant phenology is determined by climatic factors such as temperature and precipitation (Marques *et al.,* 2004). Understanding such patterns and mechanisms of plant phenotypic responses to environmental variability is an important step for predicting the influence of anthropogenic factors on plants and ecosystems (Dune *et al.,* 2003). The timing of tree vegetative phenology has been reported to strongly determine the flowering periods, and flowering on environmental periodicity (Rivera *et al.,* 2002). Rainfall has been found as a major governing factor for differences in patterns of leafing, flowering and fruiting in different ecosystems (Borchert *et al.,* 2004; Singh and Kushwaha, 2006; Boulter *et al.,* 2006). The timing of leaf fall and bud break was generally determined by tree water status, which in turn was a function of the interaction between the water status of the environment and the structural and functional state of the tree (Reich, 1995).

Photoperiod and availability of moisture mainly influenced the pattern of phenology and the nutrient uptake from the soil to leaves which is a season dependent process affected by the internal physiology and genetic makeup of the individual tree species. Phenological events (i.e. leaf budburst and first flower) have been reported to be sensitive to environment (Brochert, 1983). For instance, these phenophases may occur weeks earlier than usual in a particularly warm and dry spring, whereas in an exceptionally cool and wet spring they may be delayed for about a week (Lisa Gardiner, 2009). Such changes in a particular region of the globe level may have long lasting effects on the ecosystems and their services to the society. Therefore, in recent years, it has become an important area of research where effeorts are being made to track the effect of global warming and climate change on the species and make predictions about the future health of the environment and the species (Parmesan and Yohe, 2003).

The optimal adaptive strategy for leaf replacement depends on the combined effect of the relative intensities of cold and drought stress, where seasonality of temperature play major role, which can be evident from the leaf replacement strategy by avoiding cold stress in the cold season leaf fall and leaf flushing in warm season regardless of the availability of moisture. Jackson (1978) has several speculations, for example; if moisture is very seasonal leaf fall may occur in the dry season and flushing in the wet season, if moisture stress is not severe continuous leaf fall and flushing may be most advantageous, if moisture stress is moderate leaves may be dropped during the dry season but replaced nearly immediately, photosynthetic income being interrupted only enough to avoid a brief period of moisture stress. Under moderate temperature seasonality, dry season leaffall and wet season flushing may occur to avoid seasonal moisture stress. When moisture stress is never marked flushing may be most efficient during the warm season followed by leaf fall. Such a phenology is the best approximation to continuous leaf fall and flushing possible, given the unsuitability of a cool season for vegetative growth (Jackson, 1978).

The phenological changes in tropical trees are mainly regulated by the duration and intensity of seasonal drought and the changes in the date of onset of monsoon and the amount and distribution of rainfall during the annual cycle by affecting the soil-plant-atmosphere water continuum, which reflecting changes in asynchrony (Singh and Kushwaha, 2005). In tropical regions, periodical changes in mean temperature is considerable (i.e. very frequent) and changes in photoperiod are very small (Sakai, 2001).

In temperate areas, tree phenology is influenced by sever cold through a synchronized annual period of rest for both primary and secondary growth, which cases leaf shedding in deciduous species. Therefore, climatic conditions (long winter-induced rest period) are the primary factor controls tree growth dynamics and the leaves markers in the wood and stems (Morel *et al*., 2015). On the other hand, populations of tropical plants display complete intra- specific synchrony and asynchrony (van Schaik *et al.*, 1993), and the same also holds true for subtropical tree species. However, sub tropical forest, reproductive phenology is significantly governed by changes in the annual average temperature and precipitation. Further, the development of flowers and formation of fruits in a sub tropical forest are affected by timing and intensity of rainfall. Trees of most species in seasonal temperate and boreal forest biomes showed usually synchronized leaf phenologies, life spans (if deciduous), and demographies with seasonal patterns. Almost a similar linkage of tree species phenology with seasonality occur seasonal tropical forests and woodlands (Shukla and Ramakrishnan 1984, Reich 1995, Williams *et al.,* 1997). In relatively aseasonal environments, phenology, longevity, and demography may be relatively asynchronous within and among different species (Borchert, 1980) with varying degree of asynchrony (Reich *et al.*, 2004).

Existing hypothesizes reflect that under resopurce limited condition evergreen and deciduous species follow different ecological strategies for securing carbon profit during growth to avoid competition for resources. Both function groups have been reported share the resources with niche overlap when the resources are abundant and during the period resource depletion, these groups exhibit niche segregation and achieving growth by acquiring different strategies like deciduous species exhibited early and faster growth during the growing season and evergreen species continue to fix carbon during until late spring through winters when the resources are low (Devi and Garkoti, 2013).

Global warming and consequent increase in temperatures around the world has been speculated to shift spring and autumn phenologies with corresponding changes in the length of the growing season. However, our understanding of the spatial and interspecific variation of these changes is highly limited. Species growing in the same site with slight difference in elevation and aspect shows marked difference in their phenology, however, all species are not behaving similarly, and there is significant spatial variation occurred within species (Ibáñez *et al.,* 2010).

Leaf phenology and abiotic variables

Callado *et al.,* (2001) reported that leaf phenology is an important factor influencing the activity of the vascular cambium and leaf fall has a significant and direct effect on cambial activity. Therefore, cambial activity and leaf phenology offer a larger insight on the growth regulation within the growing plant and on the possible interactions with exogenous parameters like temperature or precipitation (Morel *et al.,* 2015).

Leaves are well known to produce carbohydrates during the process of photosynthesis which is important in sustaining the life on the earth through food web, and the capacity of the leaves to synthesis the amount of carbohydrate depends on the health of the soil as a medium to provide basic nutrients (like N, P, K, Ca and Na) along with minor nutrients and water for the plant growth and development (Daryanto *et al.,* 2016). In addition, soil pH is one of the most important soil properties that determine the availability of nutrients, e.g. decreased concentration of macronutrients under low pH and increased micronutrients in soils having high pH. Therefore, assessing the availability of soil nutrients and their interelations with leaf phenopases (the timing of vegetative and reproductive phenology) would be important.

Since leaves are essentially energy gaining organs, the arrangement of leaves in time (leaf phenology) and in space (canopy architecture) in both seasonal and non-seasonal environments can be viewed as a central to the plant strategies for carbon gain and interrelationships among leaf longevity, leaf habit and leaf emergence pattern together with shoot architecture that affect plant productivity. Leaf longevity is shown to maximize carbon gain through three parameters: leaf photosynthetic rate, the decrease in photosynthetic rate with leaf age, and the initial construction cost of the leaf (Kikuzawa, 1995). Leaflessness (deciduousness) in trees is important phonological events which have been ill defined and the precise information on leaflessness is not available (Singh and Kushwaha, 2005). Leaf Strategy Index (LSI) has been defined as the ratio of leaf fall duration to leaf flush duration which provides measure for comparing the deciduousness among the tree species. In general, leaf exchanging/semi-evergreen species show lower LSI values as compared to deciduous tree species, however, it is sometimes difficult to compute the LSI value for evergreen species becasue trees are always green throughout the year and so the peak period of senescence is considered as the days of leaflesness which does not extend beyond about half a month.

For the first time Hanson in 1917 has reported LMA (leaf mass area) for field measurements, which is defined as the ratio between the leaf dry mass and its area (gm^{-2}). It plays a significant role in inter-specific variation in relative growth rate (Garnier, 1992) and has been found to be positively related to leaf life span (which is reciprocal to deciduousness) and negatively to the photosynthetic rate per mass (Wright *et al*., 2004). LMA along with SWD (stem wood density) and LSI (leaf strategy indix i.e. resource use or photosynthesis rate) may significantly relate to deciduousness in tropical trees as they are closely related to leaf longevity (Reich *et al.*, 1997). These traits have a significant role in the accumulation of photosynthate during the leafing phenology (Kushwaha *et al.*, 2011). Flower initiation and subsequent fruiting mark the initiation of resource allocation from their own growth to reproduction (Roff, 2002) because both these events require a considerable expenditure of photosynthate accumulated during the leafing phenophase (Ashman and Schoen, 1997). The LMA of a species is, therefore, a good indicator of the position of that species along an axis based on resources acquisition (Leaf Economic Spectrum) (Wright *et al.*, 2004).

Analysis of variance (ln-transformation) indicates that 36% of the variation in LMA can be attributed to a general trend for LMA to increase from aquatic plants < ferns < herbs/grasses < deciduous shrubs and trees < evergreen shrubs and trees and succulents (Poorter *et al.*, 2009). The LMA is often used as it is easy to measure that provide a good foundation in growth theory; however, this does not imply that specific aspects is the best predictor of plant performance. In nature, LMA varies more than 100-fold among species. Part of the variation (ca. 35%) can be ascribed to differences between functional groups, with evergreen species having the highest LMA, but most of the variation is within groups or biomes. When grown in the same controlled environment, leaf succulents and woody evergreen, perennial or slow-growing species have inherently high LMA. Within most of the functional groups studied, high-LMA species show higher leaf tissue densities (Poorter *et al.,* 2009). However, differences between evergreen and deciduous species result from inherent thickness of leaves.

The ratio between leaf dry mass and leaf area (Leaf Mass per Area, LMA in gm^{-2}) can be understood as the leaf-level cost of light interception (Gutschick and Wiegel, 1988). The LMA is a key trait in plant growth (Lambers and Poorter, 1992) and an important indicator of plant strategies (Grime, 2001; Westoby *et al.,* 2002). Evergreen species generally have higher LMA values than deciduous species (Sobrado, 1991; Villar and Merino, 2001; Poorter *et al.,* 2009), both in the field and under controlled conditions. However, there is generally considerable overlap between the two groups of species (Castro-Diez *et al.,* 2000; Wright *et al.,* 2005; Poorter *et al.,* 2009). Evergreen species from a given family have been generally reported to have higher LMA than the deciduous species, but differences between families are as large as the differences between evergreen and deciduous species (Poorter *et al.,* 2009).

Older leaf of evergreen shrubs or trees generally reported to have similar or higher LMA values compared with younger leaves (Wright *et al.,* 2006). Shading of older foliage by younger leaves makes the separation of age and light effects difficult (Brooks *et al.,* 1994). For woody species, leaf longevity is always much shorter than plant longevity, and although an individual leaf will not necessarily increase in LMA with age, older plants almost invariably have leaves with higher LMA (Thomas and Winner, 2002; Niinemets, 2006; Poorter *et al.,* 2009). The LMA is part of a whole suite of interconnected traits that together shape the performance of plants. Species with low LMA tend to have a high concentration of proteins and minerals, a high water content, a low concentration of lignin and other secondary compounds, and a fast metabolism (high rates of photosynthesis and respiration per unit leaf dry mass) (Poorter *et al.,* 2009). Such species also show a high rate of photosynthesis per unit leaf nitrogen; they generally have leaves that require less force to tear apart or puncture and have a short life-span (Lambers and Poorter, 1992; Wright and Westoby, 2002).

Specific leaf area (SLA) is defined as the ratio between projected leaf area and leaf dry mass (cm^2 g^{-1}). SLA is important for estimating the leaf area of whole trees (Monserud and Marshall, 1999; Xiao *et al.,* 2006) and it is positively and linearly correlated to relative growth rate (Poorter *et al.,* 2009; Fellner *et al.,* 2016). Gulmon and Chu (1981) stated that the reduction in SLA is correlated with an increase in leaf nitrogen (N) per unit of external leaf area, leading to an overall increase in plant water-use efficiency (Field *et al.,* 1983). Specific leaf area (SLA) influences canopy expansion and growth through its effect on total leaf area per plant affecting light interception and light use efficiency (LUE) along with environmental changes (Kumar *et al*., 2012; Fitter and Hay, 2002). Light conditions are not the only reason for high or low SLA but it also depends on the longevity of leaves (Gholz *et al.,* 1976; Del Rio and Berg, 1979; Fellner, 2016) and differs between two functional groups (i.e. evergreen and deciduous) of trees (Gower and Richards, 1990; Withington *et al.*, 2006).

Reproductive phenology and abiotic variables

The pattern of flowering phenology varied widely among the species and the ecosysytems, however, the studusis are very less. The description of phenology patterns is one of the most intriguing and complex characteristics of reproductive phenology in tropical forests which reflect high diversity within and among forests (Sakai, 2001), whereas, in temperate forest period of reproductive and vegetative phenology are clearly marked. Seasonality of flower production is one of the well-known mechanisms of phenological diversification that reflect the complementarity in the resourse use and adapation of various species tom avoid interspecific completion. In both tropical and temperate regions, many plant produce flowers at a characteristic time of year and closely related species may flower at different times of year making seasonality not only an effective isolating mechanism but also a means of diversification through time with respect to a pollinator resource (Gentry, 1974). Significant competition for pollinators and its apparent effect on flowering times has been documented in a temperate community of flowering plants (Mosquin, 1971). Although competition for pollinators between tropical plants has not been so conclusively proven, it seems evident that this phenomenon also exists in tropical communities (Frankie *et al.*, 1974).

The phenology of reproduction is an important life history trait that influences fitness in a variety of ways. Reproducing at the wrong time, either in advance or delayed, may lead to failure in finding mates because of changing seasons and may lead to failure in match demands of growing offspring with temporal peaks of food resources (e.g. Visser *et al.*, 1998), or failure by a pollinator to find pollen and nectar, or failure of a flower to be pollinated. Because of these potentially severe consequences, it has been found in many cases that the phenology of reproduction evolved to rely on environmental cues that have proven to be reliable indicators of appropriate timing of reproductive effort (Inouye, 2008). The species within a community with different characteristics may help us to enhance our understanding on the effects of these characteristics on flowering phenology (Sakai, 2001). In addition, biotic factors such as pollinator and predator abundance may determine flowering synchrony as well (Auspurger 1980, 1981).

It has previously been hypothesized that flowering phenologies may be subject to natural selection. Flowering phenology is a multivariate trait that can be measured in different ways (e.g. flowering onset, duration, end of flowering), not all of which may be subject to the same selection (Rosas *et al.*, 2011). In some species flowering may occur twice a year while in many temperate species, flowering or good seed year may occur once in two years or more. In a study of flowering time in Indian dry tropical forest, large fraction of species produces flowers during the dry period (from December to June) when vegetative growth is at its minimum, reflecting the strategy to avoid intense completion for water required by growing organs (Kushwaha *et al.,* 2011). The authors stated that since environmental characteristics affect flowering and fruiting either directly (e.g. through conditions in the habitat) or indirectly (e.g. through deciduousness, LMA, SWD and LSI), and therefore, the impact of probable global climatic change may have long implications on reproductive phenology in dry tropical trees (Kushwaha *et al.,* 2011). Lasso *et al*., 2003 further stated that timing of flowering was correlated with light, which affect photosynthetic rate and thus carbon gain that can be invested in reproduction. Reproductive events usually deter mine population and community dynamics in future generations, which are affecting evolutionary processes (Sherry *et al.,*2007). Flowering and fruiting phenology of plants are very sensitive to environmental variables such as temperature, moisture, and photoperiod (Rathcke and Lacey, 1985; Sherry *et al.,* 2007), it is imperative to understand the impact of climate change on reproductive phenology (Sherry *et al.,* 2007). Flowering at the end of rainy season is also of adaptive value as it allows greater accumulation of biomass and so a larger plant size that are capable of producing more seeds (Kigel *et al.,* 2011).

Element concentrations in plant tissues

Plant growth is the process of controling carbon (C) input to terrestrial ecosystems (Liu *et al.,* 2018) requiring various elements (~16) in differing proportions (Agren, 2008), which are strongly linked with C-sequestration processes i.e. production and respiration in plants (Agren, 2008), Elser *et al.,* 2000). Among all elements, C, nitrogen (N), and phosphorus (P) are the most important limiting elements for plant production and C sequestration potential of the ecosystems (Ågren *et al.,* 2012). Carbon is the basic structural elements of the plants that accounts for ca. 50% of plant biomass, and N is an essential component of enzymes; and P is the basis element of nucleic acids and membrane lipids (Elser *et al.,* 2000; Liu *et al.,* 2018, Mani and Cao, 2019). The concentrations these elements basically (N and P) in plant tissues are also critical in controlling ecological processes like grazing, parasitism, and decomposition (Sterner and Elser, 2002). The potential for forest C sequestration and its storage can be presicely eastimated by determining the C in live tissues of the trees. In general C constitutes about 50% of tree biomass at different local, regional and global scales. In analyses of tissue-specific C content values, all tissues with the exception of leaves showed statistically significant linear relationships with stem wood C content (Thomas and martin, 2012; Tashi, 2017; Nakano *et al*., 2018), which reflect that there is a monthly C content fluctuation in tree leaves. The concentration major nutrients particularly, N and P in plant tissues determine the ability of the ecosystems to fix C and the productiovity and their C sequestration potential. N and P content in plant tissues and their relationship with photosynthetic capacity are critical to predicting future ecosystem C sequestration under global climate change (Tian *et al.*, 2018). As the plant leaves are the most dynalic compeont of the ecosystems therefore periodical changes in leaf C and nutrient (N and P) are important to study in different species and ecosystems.

Foliar chemistry among various populations may be affected by age differences among leaves. Altitudinal varians in the populations tend to occur at different phenological stages at any given time, and therefore, the collections made at one time either summer, rainy or winter growing season may not accurately represent differences in foliar chemistry as nutrients are diluted by growth and resorbed throughout the lifetime of the leaf (Bowman *et al*., 1999). Leaf nitrogen (N) concentrations tend to increase with increasing altitude (Körner, 1989). Photosynthesis is also phosphorus (P)-demanding process and P should also increase with altitude and increase photosynthetic capacity along with N (Körner, 1989). Generally, N concentration and mass decreased after an initial peak, then stabilized or fluctuated as leaves matured, and declined during senescence and leaf life exhibited a positive correlation with peak nitrogen mass (Athokpam and Garkoti, 2015). Although resorption of nutrients takes place throughout the leaf life span (Ackerly and Bazzaz, 1995), a major proportion of resorption normally occurs before abscission with in a short period of time (Wright andWestoby, 2003; Ares and Gleason, 2007). Evergreen species reduce N losses by synthesising leaves of low N concentrations and longer life spans, and so are better adapted through their higher N concentrations and longer life spans, and so are better adapted through their higher NReff (Athokpam and Garkoti, 2015). Deciduous species have adapted themselves by combining a greater dry mass loss with a relatively higher N, while their higher N concentrations during leaf initiation further render them less dependent on the supply of N from the soil during their initial (pre-monsoon) growth phase which enables them to coexist in largely evergreen forests (Athokpam and Garkoti, 2015).

Potassium enhances cell hydration and its deficiency causes tissue dehydration (Mengel and Kirkby, 2001). The main osmotic solute in plants is Potassium (Jones *et al.*, 1979) and it promotes stomatal opening (Fischer and Hsiao, 1968). Magnesium is the powerhouse behind photosynthesis in plants, which facilitates the capture of chlorophyll through sun energy needed for photosynthesis and give leaves their green color and magnesium in plants is located in the enzymes, in the heart of the chlorophyll molecule and it is also is also used by plants for the metabolism of carbohydrates and in the cell membrane stabilization (Patterson, 2020).

Calcium holds the cell walls of plants together in the form of Ca Pectate, and activates specific plant enzymes, which send signals to the plant cells that coordinate certain growth activities but it is an immobile nutrient in plants (Tajer, 2017). Sodium can be used by plants in small quantities, similar to micronutrients, to aid in metabolism and synthesis of chlorophyll. In some plants such as salt tolerating mangrove species, it can be used as a partial replacement for potassium and it also aids in the opening and closing of stomata, which helps regulate internal water balance (Bloodnick, 2018). Iron is involved when a plant produces chlorophyll, which gives the plant oxygen as well as its healthy green color and iron deficiency causes chlorosis in which plants show a sickly yellow color to their leaves. Iron is also necessary for some enzyme functions in many plants.

The state of Mizoram was endowed with rich biodiversity in the past due to favorable climatic conditions, whereas, in recent years the diversity of the region is badly affected due to anthropogenic activities primarily because of the age old shifting cultivation practice (Grogan *et al.*, 2012, Singh *et al.*, 2015, Tripathi *et al.*, 2016). Such changes along with the seasonal fluctuations in the temperature and precipitation patterns may lead to change in the diversity of tree phenophases due to altered soil nutrient conditions. This may also lead to change in the intrinsic chemical quality of the vegetative and reproductive parts that may have profound effects on vegetation dynamics. Recently study on phenology of 5 tree species has shown that the significant phenological changes are occurring in different tree species on seasonal and annual basis (Kumar, 2016). However, detailed scientific study on tree phenology in the forests of Mizoram is not available for far.

Objectives of the study

This study will enable us to understand how different tree species function with changing seasons and how they sustain the continuity of life inside the forest ecosystem. The study is designed to achieve the following major objectives:

1. To assess periodic changes in vegetative and reproductive phenology of major tree species in sub-tropical forest.
2. To determine periodic changes in leaf dry mass and leaf nutrients in major tree species.
3. To measure periodic changes in soil nutrients and to understand the critical factors determining the vegetative and reproductive phenology of major tree species.

CHAPTER 2
REVIEW OF LITERATURE

Plants have been reported to exhibit various vegetative and reproductive phenological changes in their life as result of changing abiotic and biotic variables (Lieth, 1974; Shackleton, 1999; Singh and Kushwaha 2005; Aono and Kazui, 2007; Kushwaha *et al.*, 2010, Kushwaha *et al.*, 2011a and 2011b). As plants reach the various developmental stages of their annual life cycle, phenological events, such as leafing, flowering, and fruiting, occur. The timing of a phenological event fluctuates under the influence of integrated climatic conditions during the period of growth and development (Aono and Kazui, 2007, Sundarapandian *et al.,* 2005). Analysis of community phenology provides information regarding the abiotic and biotic variables that determine the seasonal development and senescence of plant tissues and organs (Shackleton, 2001). Since the initiation and termination of growth phases represent the boundaries of periods of growth and productivity, an understanding of the triggers and controlling variables can contribute to an understanding of plant productivity, and hence resource availability (Shackleton, 2001). Phenological variations in the species are the result of genetic differentiation between populations and/or effect of environmental factors (i.e. rainfall, temperature and day length) along with tree intrinsic traits (Vitasse *et al*., 2010). Such informations are important for better understanding of ecological functioning and sustainable management of natural tropical forests (Sundarapandian *et al.,* 2005). Variaous tree intrinsic traits (i.e. leaf moisture content, leaf mass area, specific leaf area, stem wood density and stem wood moisture content) have also been reported to affect the plant phenophases (Singh and Kushwaha 2005; Kushwaha *et al*., 2010, Kushwaha *et al*., 2011a and 2011b).

Leaf Moisture Content (LMC)

Baraloto *et al.,* 2010 have stated that cross-species analyses of plant functional traits have shed light on factors contributing to differences in performance and distribution, but to date most studies have focused on either leaves or stems. Tognetti *et al.,* (2004) have observed a proportional decrease in maximum daily leaf conductance with increasing vapour pressure deficit, while mean daytime canopy stomatal conductance decreased with the season. As a result, plant water use was limited and excessive drought stress prevented. Olive tree typically experience reductions in transpiration, stomatal conductance and net photosynthesis during periods of water stress (Giorio *et al.,* 1999).

Kozlowski and Clausen, 1965, found that the increase in moisture content was traceable primarily to rapid translocation of moisture into the buds. Moisture contents of angiosperm leaves decreased rapidly in the early part of the growing season and slowly after midsummer. The seasonal decrease was traceable primarily to greater increase in leaf dry weight than to decrease in actual water content. In fact, moisture content, as % dry weight, decreased rapidly in early season while the actual amount of water in the expanding leaves increased. The rate of increase in leaf dry weight exceeded the rate of water uptake for the same period. In most angiosperms the actual amount of water in the foliage changed little from mid-June to the end of the season (Kozlowski and Clausen, 1965).

The seasonal trend in moisture content of gymnosperm leaves varied with age. In current-year needles the moisture content declined progressively, while in 1-year-old needles it increased at first and then tended to level off. These differences were caused largely by dry weight changes resulting from rapid carbohydrate translocation into current-year needles and some translocation out of the older needles. These experiments emphasized that changes in moisture content (% oven-dry weight) often occur without appreciable changes in actual water content of tissues (Kozlowski and Clausen, 1965).

Leaf Mass Area (LMA)

Leaf mass area (LMA) is the ratio between the leaf dry mass and leaf area (gm^{-2}), which plays a significant role in inter-specific variation in relative growth rate (Garnier, 1992). It has been found to be positively related to leaf life span (which is reciprocal to deciduousness) and negatively to the photosynthetic rate per mass (Wright *et al*., 2004). LMA along with SWD and LSI (resource use or photosynthesis rate) may significantly relate to deciduousness in tropical trees because all these characteristics are closely related to leaf longevity (Reich *et al.,* 1997). These traits have a significant role in the accumulation of photosynthate during the leafing phenology (Kushwaha *et al.,* 2011). Flower initiation and subsequent fruiting mark the initiation of resource allocation from their own growth to reproduction (Roff, 2002) because both these events require a considerable expenditure of photosynthate accumulated during the leafing phenophase (Ashman and Schoen, 1997). The LMA of a species is, therefore, a good indicator of the position of that species along an axis based on resources acquisition (Leaf Economic Spectrum) (Wright *et al.,* 2004).

The LMA is often used because it is one of the easy to measure parameters, with a good foundation in growth theory. However, this does not imply that for specific aspects it is always the best predictor of plant performance. In nature, LMA varies more than 100-fold among species. Part of the variation (ca.35%) can be ascribed to differences between functional groups with evergreen species having the highest LMA, but most of the variation is within groups or biomes. When grown in the same controlled environment, leaf succulents and woody evergreen, perennial or slow-growing species have inherently high LMA. Within most of the functional groups studied, high-LMA species show higher leaf tissue densities. However, differences between evergreen and deciduous species result from leaf thickness (Poorter *et al.,* 2009). The ratio between leaf dry mass and leaf area ('Leaf Mass per Area', LMA in gm^{-2}) can be understood as the leaf-level cost of light interception (Gutschick and Wiegel, 1988), be it that respiratory costs for construction and maintenance are not included. The LMA is a key trait in plant growth (Lambers and Poorter, 1992) and an important indicator of plant strategies (Grime, 2001; Westoby *et al.*, 2002).

Evergreen species have been reported to exhibit higher LMA values than deciduous ones (Sobrado, 1991; Villarand Merino, 2001), both in the field and under controlled conditions, though there is generally considerable overlap between the two groups of species (Diez *et al.*, 2000; Wright *et al.*, 2005). Evergreen species from a given family generally have a higher LMA than the deciduous species, but differences between families are as large as the differences between evergreen and deciduous species (Poorter *et al*., 2009).

Older leaf cohorts within evergreen shrubs or trees may have similar or higher LMA values compared with younger leaves (Wright *et al.*, 2006). Shading of older foliage by younger leaves makes the separation of age and light effects difficult (Brooks *et al*., 1994). For woody species, leaf longevity is always much shorter than plant longevity, and although an individual leaf will not necessarily increase in LMA with age, older plants almost invariably have leaves with higher LMA (Thomas and Winner, 2002; Niinemets, 2006). The LMA is part of a whole suite of interconnected traits that together shape the performance of plants. Species with low LMA tend to have a high concentration of proteins and minerals, a high water content, a low concentration of lignin and other secondary compounds, and a fast metabolism (high rates of photosynthesis and respiration per unit leaf dry mass) (Poorter *et al*., 2009). Such species also show a high rate of photosynthesis per unit leaf nitrogen; they generally have leaves that require less force to tear apart or puncture and have a short life-span (Lambers and Poorter, 1992 and references therein; Wright and Westoby, 2002).

Specific Leaf Area (SLA)

SLA is important for estimating the leaf area of whole trees (Monserud and Marshall, 1999; Xiao *et al*., 2006) and it is linearly and positively correlated to relative growth rate (Poorter *et al*., 2009). Marshal and Monserud, 2003 stated that SLA describes the efficiency with which the leaf captures light relative to the biomass invested in the leaf and it increases from top to bottom of a canopy. Gulmon and Chu (1981) stated that the reduction in SLA is correlated with an increase in leaf nitrogen (N) per unit of external leaf area, leading to an overall increase in plant water-use efficiency (Field *et al*., 1983). Marenco *et al*., (2009) also found a significant relationship ($p<0.05$) between SLA and LWC. Poorter *et al*., (2009) stated that reducing specific leaf area under prolonged drought conditions seems to be consistent across species and studies. Greenwood *et al*., (2017) also provided evidence that tree species with high specific leaf area can be more susceptible to drought-induced mortality than species with lower specific leaf area, although the nature of the relationship varied with drought severity. Deciduous species have invested less in the production of non-photosynthetic leaf tissues and produced leaves with higher SLA and maintained higher water use efficiency, as a result they compensated for their shorter leaf payback period by maintaining higher potentialpayback capacity (higher values of *A*mass) and lower leaf construction costs (higher SLA). Their short leafless period and the capacity to flush by the end of the dry season may also contribute to offset the longer payback period of evergreen species, although it may involve the higher costof maintaining a deep-root system or a tight control of plant water balance in the shallow-rooted ones (Franco *et al*., 2005).

Wright *et al*., 2001, found that species from drier sites had higher N and P concentrations for a given SLA than species from wetter sites. Light conditions are not the only reason for high or low SLA; it also depends on the longevity of leaves (Gholz *et al*., 1976; Del Rio and Berg, 1979) and differs between evergreen and deciduous trees (Gower and Richards, 1990; Withington *et al*., 2006). Hoffmann *et al*., (2005) stated that leaf traits are commonly associated with the life history, distribution and resource requirements of a species, they compare the differences in specific leaf area between congeneric savanna and forest trees and found that forest species had 52% greater SLA on average than savanna species, which accounts for the higher foliar nutrient concentrations of these species and observed that leaves of forest species had 17% higher N concentration, 32% higher P concentration and 37% higher K concentration than leaves of savanna species. In dry tropical forests, species with high wood density and low specific leaf area are associated with high growth rates and carbon storage, precisely because they can continue to function during drought (Prado-Junior *et al.*, 2016). On the other hand Wilson *et al.*, (2002) stated that specific leaf area is found to suffer from a number of drawbacks because of both variations between replicates and influenced by leaf thickness.

Stem wood Density (SWD) and Wood Moisture Content (WMC)

The density of wood depends on the specific gravity and moisture content of the species which been reported to be related to vegetative and reproductive phenogy of trees (Kushwaha *et al.*, 2010, Kushwaha *et al.*, 2011a and 2011b). Growth-quality studies are designed to determine the influences of conditions of growth and wood structures upon wood quality, where "quality" is expressed in terms of wood density or specific gravity (Smith, 1954). Due to the possible unequal shrinkage behavior of wood in drying from the green to the ovendry condition, specific gravity on the basis of ovendry weight and green volume is usually preferred in growth quality studies. The specific gravity of wood, determined by the water-displacement method, varies between 1.50 and 1.56 with an average value of 1.53 (Smith, 1954). Mean stand-level wood specific gravity on a per stem basis, is higher in forests due to the higher diversity and abundance of taxa with high specific gravity values and the variation in specific gravity is important because it determines the regional scale, spatial pattern of above ground biomass (Baker *et al.,* 2004).

King *et al.*, (2006) suggested that wood density can be used as an indicator of support costs due to the strong correspondence between wood density and the estimated stem biomass of a tree of specified height and crown area and stated that growth rates may increase with decreasing wood density because (a) species with low-density wood tend to be less shade-tolerant and are therefore restricted to brighter-than-average microsites; (b) the thickness of the peripheral shell of stem wood corresponding to a given biomass increment is inversely proportional to wood density, so that diameter growth rates vary inversely with wood density, all else being equal (Burslem, 2003); and/or (c) light-wooded species require less biomass to support their crowns, i.e. they have lower support costs, and are therefore able to achieve greater crown extension per unit of synthesized biomass, which enhances future light interception and growth.

Relative Leaf Growth Rate (RLGR)

Plant species may differ considerably in biomass production which can be caused by differences in seed weight, in the length of the growing period or may be related to environmental conditions. In addition, the maximum relative growth rate (RGR), the dry weight increase per unit of biomass and per unit of time under optimal conditions, may vary between species (Poorter and Remkes, 1990). A study by Duncan and Hesketh, 1968, on 22 races of maize grown at eight temperatures have found differences among temperatures and races in net photosynthetic rates, relative leaf growth rates, and leaf numbers. At low temperatures, high altitude races had relatively higher leaf growth rates and dry weights at harvest. At high temperatures high altitude races had relatively lower net photosynthetic rates and also found that leaf numbers increased with increasing temperatures.

The relation between interspecific variation in relative growth rate and carbon and nitrogen economy was investigated by Poorter *et al*., (1990) on twenty four wild species grown in a growth chamber with a nonlimiting nutrient supply and growth. A positive correlation was found with the rate of photosynthesis expressed per unit leaf dry weight and due to a higher ratio between leaf area and plant weight (leaf area ratio) fast growing species were able to fix relatively more C per unit plant weight and used proportionally less of the total amount of assimilates in respiration. Authors also found that fast growing species had a higher total organic nitrogen concentration per unit plant weight, allocated more nitrogen to the leaves and had a higher photosynthetic nitrogen-use efficiency, *i.e.* a higher rate of photosynthesis per unit organic nitrogen in the leaves, as a result, their nitrogen productivity, the growth rate per unit organic nitrogen in the plant per day was higher compared with that of slow growing species.

Poorter and Bergkotte (1992) examined chemical composition of 24 plant species which showed a three-fold range in potential growth rate and found that the carbon content of whole plants was lower for fast-growing species than for slow-growing ones. Fast-growing species accumulated more organic N-compounds, organic acids and minerals, whereas slow-growing species accumulated more (hemi) cellulose, insoluble sugars and lignin.

Climatic variables affecting phenology

Rainfall

It is well known variation with the annual course of weather elements, plant phenology might be expected to be one of the most responsive and easily observable traits in nature that change in response to climate (Badeck *et al*., 2004). Phenological data series of plants can be used as a proxy for climate change if the seasonal timing of a phenological event can be closely related to specific climatic conditions during plant development. Although phenological data series, acquired from historical records, enable climatic reconstruction on a shorter time scale than other proxies, the phenological data are accompanied by concrete dates, allowing precise reconstruction without requiring the use of an external dating procedure (Aono and Kazui, 2008). Water is needed for plant growth. It is required for both leaf and floral bud expansion, as well as for leaf and flower turgor maintenance under evapotranspirational demand (Galen *et al*., 1999). Plant water stress within the drought not only suppressed plant leaf production but also caused excessive leaf fall (Nomura *et al*., 2003).

Seasonality and physiognomy of tropical forests are mainly determined by the amount of annual rainfall and its seasonal distribution. Climatic change scenarios predict that global warming will result in reduced annual rainfall and longer dry seasons for some, but not all, tropical rainforests. Correlations between climate and responses of tropical trees are therefore poor and the responses of tropical rainforests to climatic changes are hard to predict. As the limits of drought tolerance of tropical rainforests are not known, rate and extent of future changes cannot be predicted andseasonal variation in rainfall synchronizes tree phenology within forests to some degree (Borchert, 1998). Climate change scenarios predict that global warming is unlikely to alter the climate of aseasonal tropical rainforests significantly, but will result in declining annual rainfall and prolonged seasonal drought in parts of the equatorial tropics covered by seasonal rainforests, especially in Amazonia (Hulme and Viner, 1998). As long as the ecophysiological mechanisms linking climatic inputs and tree responses are not well understood, predictions must be based on observed correlations between climatic variation and plant responses (Woodward, 1987).

Ecologists have formulated a global measure of seasonality, which captures the effects of both magnitude and concentration of the rainy season, and use it to identify regions across the tropics with highly seasonal rainfall regimes. They further decompose rainfall seasonality into its magnitude, timing and duration components and found an increase in the interannual variability of seasonality over many parts of the dry tropics, implying increasing uncertainty in the intensity, arrival and duration of seasonal rainfall over the past century. They also illustrated that such increases in rainfall variability were accompanied by shifts in its seasonal magnitude, timing and duration, thus underscoring the importance of analysing seasonal rainfall regimes in a context that is most relevant to local ecological and social processes (Feng *et al*., 2013).

Climatic warming produces significant gradual alterations in the timing of life-cycle events and experimental, historical and geographical changes in rainfall produced significant, complex and strongly species-specific, as well as spatially and temporally variable, phenological effects. Changes in rainfall and water availability, an important driver of climate change, can cause complex phenological changes with likely far-reaching consequences for ecosystem and biosphere functioning and structure (Peñuelas *et al*., 2004).

Phenology and cambium growth are progressively uncoupled from climatic seasonality in brevideciduous and evergreen trees growing at microsites with large soil water reserves which buffer trees against seasonal drought and thus may prevent the formation of distinct annual rings (Borchert, 1999). Broadhead *et al*., (2003) examined phenological patterns in relation to climatic conditions in the bimodal rainfall regions of Kenya to identify factors which dictate the intensity of competition between trees and crops and have founded that although essentially evergreen (as in many of the tree species studied in my research), leaf cover in *Croton megalocarpus* decreased during the dry season and increased rapidly during periods of high rainfall. Shackelton (2001) projected that rainfall zone appeared to influence: (1) the onset and magnitude of leaf emergence, (2) the onset and duration of mature leaves, and (3) the proportion of leafless trees. Generally, leaf growth was initiated earlier at the moist locality than at the semi-arid or arid localities. Emergent and mature leaves were recorded earlier, and in the case of mature leaves, retained longer. Overall, there is a low proportion of leafless trees at the moist site, followed by the semi-arid and the arid areas (Shackelton, 2001).

Temperature

Temperature is a main driver of many developmental processes in biology. The rates of chemical reactions are temperature dependent and generally increase with increasing temperature (Walther *et al*., 2010). In living systems this is especially true for enzyme-catalysed reactions. Temperature-sensitive biological processes include denaturation of enzymes at high temperatures, enzyme kinetics, the fluidity of membranes, and freezing and formation of ice crystals and consequent destruction of cellular structures (Johnson and Thornley, 1985).

Global warming is expected to have major impact on plant distributions, an issue of key importance in biological conservation. However, very few models are able to predict species distribution accurately except few know species which respond individually to climate change (Chuine and Beaubien, 2001). Temperature is a main driver of many plant developmental processes, and in many cases higher temperatures have been shown to speed up plant development and lead to earlier switching to the next ontogenetic stage. The documented advance in spring leaf bud burst and flowering dates in middle and higher latitudes could well be an effect of concurrent anthropogenic climate change and associated increasing temperatures (Badeck *et al*., 2004).

Vitasse *et al*., (2010) stated that phenotypic plasticity allows large shifts in the timing of phenology within one single generation and drives phenotypic variability under environmental changes, and thus enhances the inherent adaptive capacities of plants against future changes of climate. They observed that the magnitude of plasticity for leaf unfolding timing was high for both species following linear clinal trends with an advance of more than 5 days degree^{-1} of increase. In their observation of sessil oak and European beech in Gave valley in Pyrénées Mountains (south-western France), the growing season lengthened with increasing temperature up to a certain low to mid-elevation. In a study of cherry tree flowering in Kyoto by Aono and Kazui, 2008, full-flowering dates were closely related to the March mean temperature by means of a temperature accumulation index, in which plant growth is considered to be an exponential function of temperature, which also hold true for leaf flush timing of many tree species in a sub tropical forest.

Photoperiod

Effects of photoperiod and temperature on legume cover and green manure crops have studied by Keatinge *et al*., (1998). Authors showed that for all tropical and subtropical species, the warmest temperature combined with the shortest photoperiod hastened flowering and fruit maturity. Wayand Yamori, (2014) stated that trees are expected to migrate polewards as the climate warms, but this geographic movement will induce a mismatch between the thermal environment and the day length signals of the new site in comparison with the site of origin depending on the degree of phenotypic plasticity exhibited in response to temperature and photoperiod, and the extent to which a species relies on day length cues for determining phenology, trees may not be able to migrate as far as is currently predicted under a climate-envelope model approach. Increasing temperatures should facilitate the poleward movement of species distributions through a variety of processes, including increasing the growing season length and found that in temperate and boreal latitudes, temperature is not the only cue used by trees to determine seasonality, as changes in photoperiod provide a more consistent, reliable annual signal of seasonality than temperature. Authors also mentioned that in seasonally cold climates, plant developmental systems have evolved to match a seasonal climate cycle that shifts annually from favourable to unfavourable periods for growth and survival.

Way and Montgomery, (2015) stated that woody plants with perennial aboveground structures must enter dormancy prior to the onset of temperatures that are lethal to active buds and other tissues. In addition, trees have evolved to resume growth at a time that minimizes the risk of frost damage but maximizes growing season length. However, temperature is a fickle cue: variation in the onset and cessation of frost risk from year to year varies considerably and while many studies suggest that photoperiod may not be the dominant cue in spring, these results could be due to the fact that under current conditions, trees are robust to some variation in vernal cues: the control system has ‘built-in’ flexibility to cope with the inevitable vagaries of inter-annual climate fluctuations (Way and Montgomery, 2015). Improving our knowledge of the mechanisms underlying photoperiodic control of tree phenology and physiology is critical for predicting how trees will respond to novel combinations of day length and temperature, especially when evolution is unlikely to keep pace with the rapidly changing climate.

Hänninen and Tanino (2011) also stated that temperature is not the only seasonal cue for organisms: photoperiod, or day length, is another critical signal that indicates the progression of the seasons in a given location. Photoperiod will not change as the climate warms, leading to potential asynchrony in these functionally paired cues. Condit *et al*., 2005, found that in tropical rainforests, 30–65% of tree species grow at densities of less than one individual per hectare. At these low population densities, successful cross-pollination relies on synchronous flowering. In rainforests with low climatic seasonality, photoperiodic control is the only reliable mechanism for inducing synchronous flowering (Thomas and Vince-Prue, 1997; Rivera *et al*., 2002; Borchert *et al*., 2005). Günter *et al*., (2008) have investigated the effect of seasonality on tree phenology in the tropical montane rain forest of southern Ecuador and analysed possible triggering factors. Authors selected two nearby study sites with contrasting precipitation patterns at the same altitude east and west of the western Cordillera and found that there is strong evidence that flowering is induced not by one factor alone but with photoperiodic control, radiation and precipitation as possible proximate causes for both sites. Futher, they tested two hypotheses: (1) Interspecific synchronization of flowering and fruiting phenology is higher at study sites with pronounced rainfall seasonality compared with sites within perhumid forests. (2) Proximate causes for flowering in closely situated seasonal and perhumid sites are either photoperiodicity or climatic factors.

Effect of abiotic factors on vegetative phenology

Leaf phenology, which is described as the biological periodicity of leaf production, represents a plant strategy for maximizing net primary production under the temporal variation of limiting environmental factors (Kikuzawa, 1995). First, in a habitat with seasonal water stress, plants concentrate their leaf production in the wet season when water supply for leaf activity is available. Second, in a habitat with a permanent and sufficient water supply, plants concentrate their leaf production in the sunny (dry) season when photosynthetic productivity increases with high irradiance (van Schaik *et al.*, 1993).

Nomura *et al.*, (2003) in their studies in Sub-Alpine regions found that an increase in the irradiance within the drought coincided with a decrease in the soil water potential and a decrease in leaf flushing. They stated that excluding the period when the soil water potential decreased below the critical value, leaf flushing at the Sub-Alpine site was always observed and reduced initiation of new flushing events and the high proportion of flushing itself indicate the successive leaf flushing at the Sub-Alpine site and stated that successive leaf flushing is adaptive in such an environment of frequent periodic stress because it disperses the impact of the stress. For these reasons, plants endowed with successive leaf flushing have the capability to dominating at the Sub-Alpine site. Though the soil water potential equally recovered at the Lower Montane and Upper Montanesites, the initiation of leaf flushing was not synchronized. This asynchrony is similar to the asynchrony of the soil nutrient release. One possible explanation for the relationship between the leaf phenology and soil nutrient condition is the immediate utilization of acquired nutrients (Nomura *et al.*, 2003). They also found three characteristics of leaf phenology in the tropical montane forests which is the result of a one-year observation during a drought event. First, plant water stress primarily suppresses leaf flushing. Second, in a habitat of frequent water and light stress, successive leaf flushing is dominant. Third, in a habitat with a sufficient water supply, plants produce new leaves in response to soil nutrient release.

In a study of leaf functional traits of neo-tropical savanna trees, the timing of bud break was variable among evergreen species, while all deciduous species flushed by the end of the dry season. Evergreen leaf-exchangers simultaneously shed the leaves and produced new ones, while the briefly deciduous species remained leafless for short periods of time of <3 weeks. The other deciduous species remained leafless for periods of about 3–6 weeks. Evergreens may be greatly constrained in terms of producing leaves with a long life-span, because of accrued leaf damage by herbivores and pathogens and substantial reductions in stomatal conductance and partial leaf loss to stabilise water balance during the dry season (Franco *et al*., 2005). Borchert and Rivera, 2001, have shown that leaf buds remain dormant during the dry season in many tree species of semi-deciduous tropical forests, and bud-break is induced by an increasing photoperiod after the spring equinox. Bud-break is highly synchronous in conspecifics of these 'spring-flushing' trees, although some within species differences occurred. One likely explanation for the latter is the amount of stem, soil or rain water available to the tree. Whether leaf flush is triggered by photo- period or other factors, sufficient water supply is a prerequisite. The sizes of trees of (or functional groups) may affect the pattern of leafing phenology through differing water use and rooting depths and in this way explain both within species and between species differences in the timing of leaf flush. Tree size plays an important role in the pattern of leaf flush in these species, with large trees flushing leaves earlier than small ones (Sayer and Newbery, 2003).

Greater leaf mass duration in evergreen species in the region seems to have higher returns of carbon compared to cost of leaf production annually, which may explain, in part, why evergreen species are favoured in the region compared to deciduous species. Greater leaf dry mass at the time of leaf initiation, and greater LMA, indicate the higher cost of leaf production in evergreen species, which they seem to compensate for by achieving greater carbon through longer leaf dry mass increase and steady state period, longer LL and gradual and slow loss of leaf dry mass. On the other hand, deciduous species have lower dry mass at the time of full leaf expansion, and lower LMA. They produce efficient leaves to achieve faster growth, then reabsorb a larger proportion of leaf dry mass at a faster rate from the senescing leaves with shorter LL. Completion of leaf growth earlier than the evergreen species, faster and larger decline of leaf dry mass from senescing leaves, and shedding leaves during unfavourable dry winter season seem to be growth strategies of deciduous species to reduce competition (Athokpam and Garkoti, 2013).

Effect of abiotic factors on reproductive phenology

Studies have emphasized the adaptive importance of flowering at a particular time relative to other individuals in the population, or other species in the community. An alternative view, however, is that flowering phenology is a trait that may not be under strong selection, and this may have allowed some variation to appear in populations by chance. Flowering phenology has normally been viewed as fundamental to a plant species' reproductive ecology (Ollerton and Lack, 1992). Studies of flowering phenology often focus on variation across years, but the reproductive success of plants can vary within populations depending on when they bloom (e.g. Augspurger, 1981; Schmitt, 1983; Dieringer, 1991; Ehrlen and Munzbergova, 2009). Reproductive rates in plants can be affected by various factors, such as water stress, light intensity, nutrient availability (McKenna and Houle, 2000), seed fertilization (Stephenson, 1981, Mamood *et al.*, 1990, Cabrera and Dieringer, 1992; Ehlers, 1999; Roitman, 1999) and pre-dispersal predation of the seeds (Janzen, 1971; Louda, 1982; Greig, 1993; Sheppard *et al.*, 1994; Louda and Potvin 1995; Ehrlén, 1996; Luna, 1999).

It has been reported that the timing of tree vegetative phenology strongly determines the flowering periods, and thus flowering at least depends indirectly on environmental periodicity (Rivera *et al.*, 2002). The timing of leafing, flowering, and fruiting are highly correlated and their relative importance as cues for habitat selection are difficult to discern from observational data alone (McGrath *et al*., 2008). A study conducted on change in flowering phenology and climate warming in southwestern Ohio found a significant relationship between warming temperatures and first flowering time for some species, and reported that 60% of the species in their study flowered earlier over the sampling interval and the remaining species exhibited no statistically detectable change (Ewan *et al*., 2010). Authors further stated that this variation is presumably associated with among-species variation in the role of climate cues in plant development.

Research on phenological behavior of tree species in tropical forests in the Western Ghats reflected that evergreen species showed no concentrated leaf fall during the study period and stated that most species bloomed once a year and flowering activity (starting from bud inception to full-bloom phase) in these species was seasonal (Sundarapandian *et al*., 2005). Authors also stated that some species produced flowers for several months, covering more than one season (extended flowering). Increase in temperature during warm and dry periods induces the leaf flushing and flowering in most of the species (Kikim and Yadava, 2001).

The average inter-plant distance for reproductive individuals may be reduced for dioecious species, while maintaining the same optimal inter-plant distance betweenseed-bearing individuals as for less closely aggregated hermaphroditic taxa (Janzen, 1971). A comparison of flower size of confamilial dioecious and hermaphroditic taxa within the study area indicated that the former usually have smaller flowers than the latter. In particular, these trees have small generalized flowers adapted for visitation and pollination by small insects of several orders, especially small bees (Bawa and Opler, 1975).

Clark *et al*., (2004) stated that quantification of seed rain patterns is an initial step towards explaining variation in plant recruitment, and consequently, organization of forest communities and mentioned that spatially contagious patterns of seed deposition, where seeds are patchily dispersed with some sites receiving relatively high densities and others receiving low densities of seeds may be a common trend. Non-conspecific seeds deposited in high densities may experience increased seed mortality even far from parent trees if predators are generalists. Alternatively, in the absence of complete density-dependent mortality, contagious seed dispersal could result in associations among species dispersed by the same dispersal agent and clades with fleshy fruits are significantly more diverse than sister clades with dry fruits (Smith, 2001). Visser *et al*., (2011) stated that masting, the production of large seed crops at intervals of several years, is a reproductive adaptation displayed by many tree species. Authors have mentioned the predator satiation hypothesis which predicts that starvation of seed predators between mast years and satiation during mast years decreases seed predation and thus enhances tree regeneration and strict masting strongly increases fitness compared with fruiting annually. Further, they also modelled and depicted that the demographic costs of mast fruiting are very low compared to the demographic losses due to seed predation in a scenario of annual fruiting.

CHAPTER 3

MATERIALS AND METHOD

3.1 Description of study site

Geography of the study area

Mizoram is a landlocked State in North East India whose southern part shares international borders with Myanmar and Bangladesh, and northern part shares domestic borders with Manipur, Assam and Tripura. The State encompasses an area of 21,087 km^2. It extends from 21°56'N to 24°31'N latitude and 92°16'E to 93°26'E longitude. Aizawl, the capital city of the state, is the most populous district of the state. Mizoram is a part of the Indo-Burma biodiversity hotspot. The topography is mostly hilly with hills running in the north to south direction. The average height of the hills to the west of the state is about 1,000 metres. These gradually rise up to 1,300 metres to the east. Mizoram has the most variegated hilly terrain in the eastern part of India with average altitude ranging from 500 to 800 metres. Phawngpui Tlang is the highest peak with 1950 m altitudes in Mizoram. The longest river in Mizoram is Chhimtuipui; it is also known as Kaladan.

The study site was located in Hmuifang reserve Forest (23°.45'N and 92°.7'E) of Aizawl district of Mizoram, India. It is about 50 km away from Aizawl with an elevation of 1619 meters; the mountain is still covered with virgin forests reserved since the Mizo Chief's time. Hmuifang is ideal to the nature lovers and the hill forest is one of the major catchment for Tuirial River. The vegetation of Hmuifang forest belongs to Northern Sub-Tropical Broad Leaved Hill Forest type (sub-group 8-B of Champion and Seth, 1968). The surrounding forests near Hmuifang Mountain abound with fascinating varieties of flora and fauna including rare orchids and wildlife especially avifauna. The mountain also has beautiful cliffs and offers great views of the surrounding hills. The topography is undulating but the hills have a gentle slope. Trees growing at the edge of the hills on the windward side show crooked and stunted growth as well as those that are growing in open spaces. The study was conducted for two annual cycles ie. May 2016 to April 2018.

The forests of Mizoram

According to the ISFR 2019, the forest cover is 18,186 km^2 and tree cover is 467 km^2, the total forest and tree cover is 18,653 km^2 which makes up 88.48 % of the geographical area of the State which accounts for 2.33% of India's forest and tree cover. The per capita forest and tree cover is 1.77 hectares in the State.

Based on Champion and Seth Classification (1968), six (6) important types of forests have been reported to occur in the State of Mizoram (Forest Survey of India, 2011).

1. Cachar Tropical Semi-evergreen Forest (2B/C2): This is one of the dominant forest types found in almost all districts of the State with rich species diversity.

2. Secondary Moist Bamboo Brakes (2/2S1): This covers the maximum forest area of the State. Dominant species of bamboo like *Melocanna baccifera, Dendrocalamus hamiltonii, Bambusa tulda, Dendrocalamus longispathus, Schizostachyum dullooa* etc. are present in this type of forests.

3. Pioneer Euphorbiaceous Scrub (2B/2S1): It is generally found in degraded forests and on steep slopes. It has some fast growing species like *Macaranga spp., Mallotus spp.* etc.

4. East Himalayan Moist Mixed Deciduous Forest (3C/C3b): This forest type also covers a large area in the State. Major species found in this forest type are *Albizia procera, Artocarpus spp., Neolamarckia cadamba, Dillenia pentagyna, Lagerstroemia speciosa, Schima wallichii, Syzigium cumini, Terminalia bellirica, T. chebula, Sterculia spp., Bombax spp e*tc.

5. East Himalayan Subtropical Wet Hill Forest (8B/C1): The forest type is composed of major species such as *Albizzia spp., Castanopsis spp., Litsea spp., Machilus spp., Schima wallichii, Betula cylindrostachya, Lithocarpus spp., Quercus spp* are found in Kolasib district of the State.

6. Assam Subtropical Pine Forest (9/C2): It is mostly dominated by *Pinus kesiya* with other associates like *Quercus spp., Schima wallichii, Rhododendron spp., Castanopsis spp., Lyonia ovalifolia, Rhus spp., Myrica esculenta, Prunus spp.etc.* This forest type is found mainly in Champhai district of the State.

Climate of the state

The climate is characterized by three seasons namely summer (March-June), rainy (July-October) and winter (November-February) having a pattern of moist tropical to moist sub-tropical, with average state rainfall 2540 mm per annum. Mizoram has a moderate climate with hot-dry summer (20 to 29 ºC) and cool-dry winter (7 to 22 ºC). It is usually cool in summer and not very cold in winter. During winter, the temperature varies from 11 ºC to 21 ºC and in the summer it varies between 20 ºC to 29 ºC. The entire region is under the direct influence of the monsoon. It rains heavily from May to September and the average rainfall in Aizawl is 210 cm.

The upper reaches of the hills are cool during the summer, while the lower reaches are fairly warm and humid. The storms come in the middle of March-April to herald the beginning of the summer. The maximum average temperature in the summer is 30 degree ºC while in the winter the minimum average temperature is around 11 degree celcius. The months between November and February are winter in Mizoram which is followed by the spring. The climate as at its moderate best in the two autumnal months, September and October, when the temperature moves between 19 to 24 ºC, the study area comes under humid subtropical climate (Cwa) under the Koppen Climate Classification.

Climate and soil of the study site

The mean monthly maximum temperature varies from 25 ° C in January to 29 ° C in May and the mean minimum temperature varies from 5 °C in January to 24 °C in May. Long-term total annual rainfall varies between 2140 and 2563 mm. The study was carried out during two annual cycle i.e.May 2016 to April 2017 and May 2017 to April 2018. The total rainfall during the first annual cycle was 2166.1 mm and the mean temperature was 18.95 ° C. The total rainfall during the second annual cycle was 2563.5 mm and the mean temperature was 20.85 ° C. June and August were the peak months of rainfall in both the study years. Temperature and Rainfall data was collected from Mizoram Remote Sensing Application Centre (MIRSAC), Science & Technology New Capital Complex Road, Khatla and ENVIS Centre: Mizoram.

The soil of the study is sandy loam in texture, rich in organic matter having a good depth and water holding capacity. The soil pH is acidic in nature which varies from 4.4 to 4.8. As per USDA classification system, major soils orders in Mizoram are Inceptisols, Entisols, Ultisols and Alfisols.

Table 3.1 Rainfall, Temperature and Relative humidity of the study area (May 2016 to April 2017)

Month	Temperature (°C)		Rh(%)		Rainfall (mm)
	Max	Min	Max	Min	
May	28	13	93.7	87.9	351
June	27.8	14.1	95.2	90.4	402.3
July	28.5	12.2	96.8	93.2	264.2
August	28.5	12.8	95	90	322.7
September	28	12.3	97.1	92.9	380.6
October	28.3	12	96.2	89.3	186
November	25.6	8.2	94.6	85.3	2.9
December	24.9	7	91	81.4	0
January	26.3	5.7	89.3	79.6	0
February	28.4	8.2	79.8	89.1	18.7
March	27.1	8.5	90.7	82	95.2
April	30	10.6	91.1	84.5	142.5
Period mean/total*	**14:48**	**9:12**	**13:00**	**3:12**	**2166.1***

***Rainfall is total and the other values are mean (**Courtesy**: ENVIS Centre: Mizoram)

Table 3.2 Rainfall, Temperature and Relative humidity of the study area (May 2017 to April 2018)

Month	Temperature (°C)		Rh (%)		Rainfall (mm)
	Max	Min	Max	Min	
May	30.3	13.8	92.7	86.4	216.5
June	28.4	12.2	96.5	93.6	688.6
July	29.1	12.6	97.45	95.1	374.5
August	28.6	13	98	96.7	447
September	29.9	14.1	97.5	95.8	239
October	28.2	14.7	95	94.3	329
November	28.8	13.9	92.1	85.33	0.3
December	25.7	11.9	87.9	79.6	3.4
January	25.5	7.2	94	86.5	1
February	28.6	11.4	93.4	81.1	1.4
March	30.1	14.4	91.7	79.8	3.8
April	30.5	11.9	92	86.3	259
Period mean/total*	**28.6417**	**12.5917**	**94.0208**	**88.3775**	**2563.5***

*Rainfall is total and the other values are mean (**Courtesy:** ENVIS Centre: Mizoram)

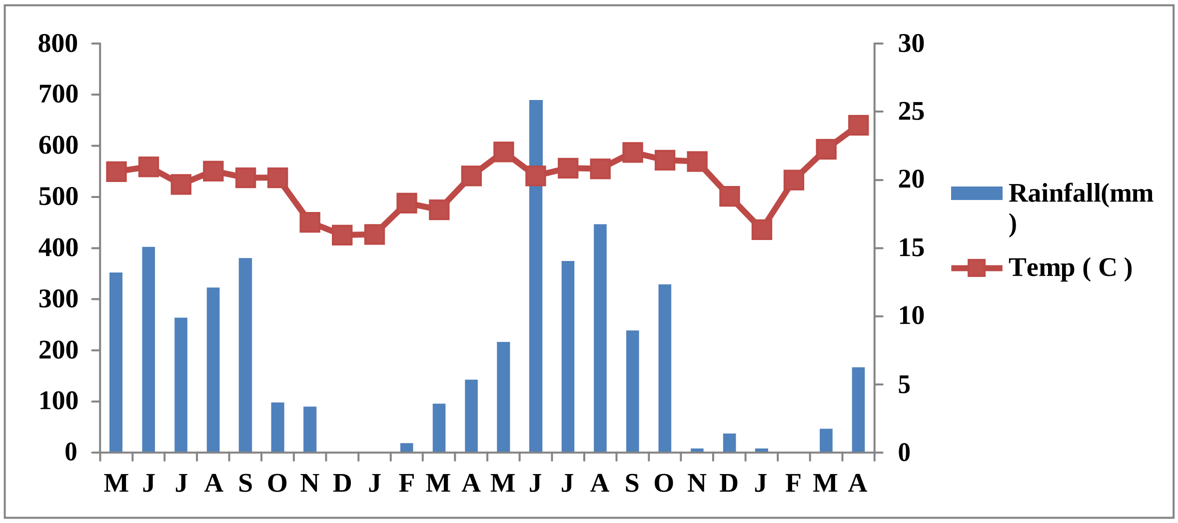

Figure 3.1 Monthly rainfall and mean monthly temperature of the study area (May 2016-April 2018)

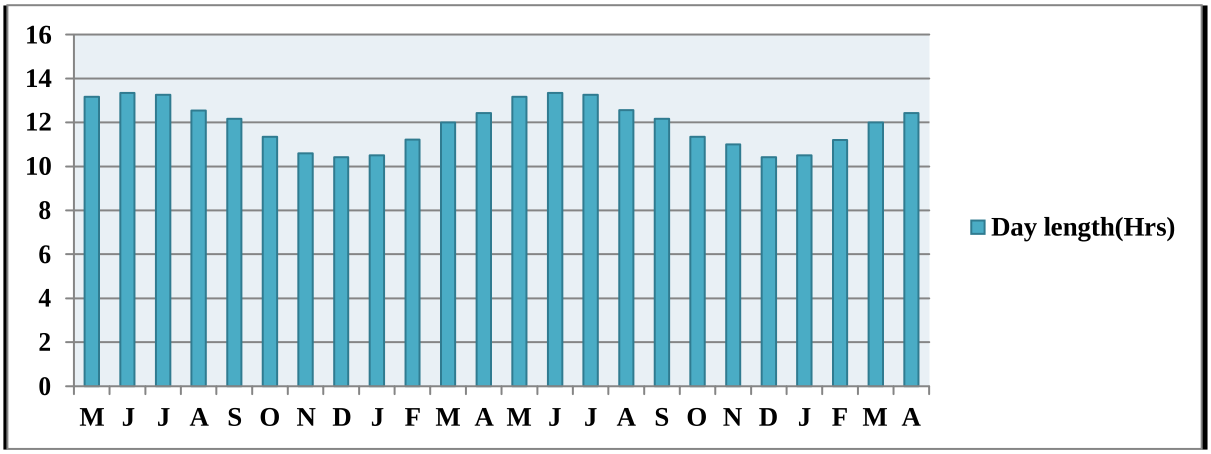

Figure 3.2 Monthly variations in photoperiod (day lengths) (May 2016-April 2018)

Description of the Species at the study site

Quercus floribunda (Lindl. ex A. Camus)

Class - Magnoliopsida

Order - Fagales

Family - Fagaceae

Genus - *Quercus*
Species - *floribunda*

Common Name - Moru oak
Vernacular Name - Thal (Mizo)

Natural range of distribution of the species is the temperate region of the western Himalayas from Nepal westwards at altitudes of 2100-2700 m, descending to about 1700 m in cool moist areas. Although found on all aspects, it avoids very dry situations and favours moist, cool locations on northerly aspects with deep and fertile soil but on shallow gravelly soils, the tree is stunted. It tends to regenerate in dense pure patches, and to grow gregariously in crops of varying extent. It is frequently found scattered in mixtures with coniferous and broad-leaved trees. It is frost-hardy but does not tolerate drought. It is the tallest oak in Western Himalaya, trunk 2-3 m in diameter. Leaves of the species are 3-7 x 2.5-4 cm; semi-evergreen; glabrous and lustrous grey green above; oboval or oblong lanceolate; pointed, base rounded or cordate; leathery; margin dentate, with 4-9 bristle-tipped teeth each side, sometimes entire; 8-12 veins pairs, thin, forked and reticulate; petiole 0.5-1 cm. The species flowers in April-May; fruits 16-18 months later, in winter; male flowers on 4-8 cm catkins, drooping and loose. Fruitsare acorns, 2-2.5 cm long, 1.6-1.8 cm in diameter; subsessile; pointed and mucronate; glabrous, brown at maturity; enclosed 1/3 or 1/2 by cup; cup with appressed, pubescent scales. maturing in 2 years; Bark, twigs andbuds bark dark grey brown, furrowed, exfoliating into longitudinal scales; branchlets and buds pubescent at first, becoming glabrous; bud ovoid, pointed, small.Sapwood is thin, grey while heartwood is russet to pale greyish brown with darker streaks, very hard, strong and heavy (wood weighs about 970 kg/cu. m). It has a straight grain but uneven texture, is difficult to season and work. In the western Himalayas, it is used for structural building construction, railway sleepers, dunnage pallets, tool handles, heavy-duty flooring, agricultural implements and door and window frames as well as for fuel and charcoal. It is a good fuelwood and is used for making charcoal (Orwa *et al*., 2009).

***Syzigium claviforum* (Roxb.) syn: *Acmenosperma claviflorum* (Roxb.)**

Class - Rosids

Order - Myrtales

Family - Myrtaceae

Genus - *Syzigium*

Species - *claviforum*

Common Name - Trumpet Satinash
Vernacular Name -Hmuifarial (Mizo)

Trumpet satinash is small tree upto 6-17 m tall and 91 cm diameter, hardly buttressed, bark smooth with persisting oblique leaf scars to slightly patchily cracked and flaky; inner bark greyish purple. Outer bark is often rather pale. Leaves are arranged in opposite pairs, narrowly oblong to elliptic, measuring 8-20 cm long and 3-8 cm wide. Flowers white-yellowish, sessile, grouped in terminal cymes with short peduncle, calyx cup long funnel shaped. Fruit is a berry, smooth, glabrous, greenish with reddish tip. Fruits are oblong-ellipsoid, measuring up to 2 cm in diameter, purplish-red when ripe and is 1-2 seeded, attaining about 11-14 x 9-10 mm; calyx lobes not obvious, pericarp succulent, cells radiating from the endocarp to the exocarp. Seeds are 7-8 x 7-8 mm in diameter and testa apparently absent.

It is distributed in northeast India and southern China to New Guinea and Australia. In undisturbed but sometimes rather open vegetation types including mixed dipterocarp, coastal, keranga and peat-swamp forests up to 1500 m altitude, often on alluvial sites, but also on the hillsides and ridges. This species produces a useful structural timber which is marketed as Grey Satinash. The edible fruits are locally conserved as a pickle (Tropical Plants Database, 2020).

***Dipterocarpus retusus* (Blume.)**

Class - Rosids

Order - Malvales

Family - Dipterocarpaceae

Genus - *Dipterocarpus*
Species - *retusus*

Vernacular Name -Thingsen (Mizo)

Dipterocarpus retusus is a large tree and one of the best known species in the genus *Dipterocarpus*. It is native to China, Vietnam, Philippines, Laos, Cambodia, Malaysia, Indonesia, Myanmar, and India and it is still locally abundant in the E Himalayan regions, its distribution is affected by habitat loss. The tree reaches 20-45m tall. Its habitat is moist evergreen, sometimes semi-deciduous, montane forest moist evergreen mid-mountain forests, at elevations of 800 - 1,300 metres, descending to lower elevations in seasonal areas, and as low as 100 metres in Assam.It has racemose inflorescence with 2-5-flowers. Calyx segments are rather long, linear and triangular. Flowers are reddish and sweetly scented. The fruit is a yellowish gray nut, ovoid and densely packed. Flowers during May to June and fruiting commences during December to January of following year. The wood is heavy and is used for building houses. The tree is a source of a balsam used for caulking boats. It is famed for its timber and resin. In Cambodia, the resin is collected by people in the mountainous regions, in order to make torches and candles, while the wood is used in construction to make columns and boards. Two varieties of *D. retusus* can be recognized in China, and they may co-occur in the same stand (Flora of China).

Rapanea capitellata **(Wall.)**

Class - Magnoliopsida

Order - Primulales

Family - Myrsinaceae

Genus - *Rapanea*
Species - *capitellata*
Vernacular Name - Neihlaia thing (Mizo)

It is a medium sized tree up to 6-15m, leaves are alternate below and opposite above, elliptic to lanceolate, flowers in umbellate fascicles axilliary/around branchlets, calyx lobes-5 having white corolla. It has medium sized lanceolated leaves which turns dark green when mature.

The fruit is a drupe, globose, dry/sub fleshy, brownish black and one seeded, it turns violet dark when ripe. The tree is found in India, Nepal and Bhutan upto 1400 m on the slopes (Henry *et al.*, 1987). Year round fruiting is a common phenomenon for this species.

Callophylum polyanthum **(Wall. ex Choisy)**

Class - Rosids

Order - Malpighiales

Family - Calophyllaceae

Genus - *Callophylum*
Species - *polyanthum*

Common Name -Sirpoon tree

Vernacular Name -Sentezel (Mizo)

It is commonly called Poonspar tree or Sirpoon tree. This plant grows in abundance in the Western Ghats in India (Assam (Barak Valley), Kerala) Indochina and Indomalaysia; in the Central Sahyadris. It is also found in Andaman & Nicobar Island, Bangladesh, Bhutan, Laos, Myanmar, Thailand and Vietnam. It is a tall tree, up to 35 m tall. Outer bark yellowish, with strong boat shape fissures; inner bark fibrous; blaze reddish. Branchlets quadrangular, leaves are glabrous. Leaves simple, opposite, decussate; petiole 0.8-2.5 cm long, planoconvex in cross section, glabrescent; lamina 5-9 x 2-4 cm, elliptic-lanceolate, apex acute to acuminate, base usually attenuate, sometimes acute, coriaceous; secondary nerves many, close, parallel, nearly right angle to midrib, terminating at thick margin. Flowers are white, fragrant and in panicles. Fruit an indehiscent drupe, obovoid-globose, about 2.5-3 x 1.8-2 cm across, with thin smooth exocarp, dry mesocarp and stony or spongy endocarp, dark purple when ripe. It is single seeded, ovoid-globose.The wood is antitermitic, used to furnish poonspars of commerce, ceiling boards, rafters, planking, cheap furniture, ship building, bridge building, general construction and paper pulp, it is also used for making tea chests, tent poles, mathematical instruments, construction of roads particularly leading to the sea coast. Seed oil used for illuminating purpose. Fruits are preffered by squirrels (Sharma, 1984).

***Beilschmiedia roxburghiana* (Nees)**

Class - Magnoliids

Order - Laurales

Family - Lauraceae

Genus - *Beilschmiedia*

Species - *roxburghiana*

Common Name - Thulo Tarshing

Vernacular Name - Khuanghlang (Mizo)

Thulo Tarshing is a tree up to 10-15 m tall. Branchlets are blackish brown, compressed, prominently angled, sparsely velvety or smooth. Terminal buds are small, densely gray-brown velvety. Leaves are opposite or alternate, carried on 1.5-2 cm long, slender stalks. Leaves are elliptic, narrowly elliptic, or elliptic-lanceshaped, 9-14 × 3.5-5 cm, papery or somewhat leathery, minutely gland-dotted on both surfaces. The base is broadly wedge-shaped or round, tip blunt or pointed acute or round. Flowers are borne in cyme-like panicles or racemes, in leaf axils or at branch ends, which is wholly densely yellow velvety. Flower-stalks are about 1 mm. Flowers are small. Tepals are ovate, about 1.5 mm. Fertile stamens are 9. Fruit is ellipsoid, 4-5 × 2-3 cm, smooth, rounded at both ends, tip mucronate. Fruiting stalks are robust, 5-20 mm, up to 7 mm in diameter, always brown maculate. Thulo Tarshing is found in Nepal, Sikkim, Assam, Malaysia, Thailand, Indo-China and Burma at an altitude of 250-2100 m. It is a tree of evergreen broad-leaved forests on mountain slopes (Flora of China).

***Lithocarpus xylocarpus* (Kurz)**

Class - Magnoliopsida

Order - Fagales

Family - Fagaceae

Genus - *Lithocarpus*
Species - *xylocarpus*
Vernacular Name - Then (Mizo)

Lithocarpus trees are evergreen tree up to 30 m tall, with leathery alternate leaves, which may be either entire or toothed.Young branchlets are sulcate and tawny tomentose. Leaf margin are entire, apex acute and midvein is flat to slightly raised on both surfaces and usually pubescent. Male inflorescence is often partly androgynous, solitary, 5-10 cm rachis tomentose. Female inflorescence is also rachis 5-8 cm, cupules in clusters of 3. Cupule subglobose but apically slightly narrowed, 3-4.5 cm in diam., completely enclosing nut, wall 3-5 mm thick; bracts linear, 2-3 mm, curved inward, densely and completely covered by minute hairs. The seed is a nut very similar to an oak acorn, but with a very hard, woody nut shell and subglobose to broadly ellipsoid, 2-3 cm in diam.; scar covering 4/5-5/6 of nut, convex. Flower during May-Jun, fruiting during Sep-Oct of following year.Its habitat is dry mixed mesophytic forests at an altitudinal range of 1500-2300 m. It is mainly distributed in NE India, N Laos, NE Myanmar and Vietnam (Flora of China).

Ixora walichii **(Wight ex Hook.f.)**

Class - Asterids

Order - Gentianales

Family - Rubiaceae

Genus - *Ixora*
Species - *walichii*
Vernacular Name - Saphut (Mizo)

It is an evergreen tree growing up to 10 metres, it grows commonly in subtropical climates with ample soil moisture. The leaves are lanceolated and soft which turns dark green and leathery when mature ranging from to 6 to 8 inches in length. Flowers are whitish green and produces fruit which is a drupe. The fruit is locally used for fish poison.

Styrax polysperma **(C.B. Clarke)**

Class - Magnoliopsida

Order - Ericales

Family - Styraceae

Genus - *Styrax*
Species - *polysperma*
Vernacular Name - Theipalingkawh (Mizo)

Trees grow upto 25m in height inside dense forest. Diameter at breast height (DBH) can reach >70 cm. The branches are smooth and cylindrical in shape. The winter buds are covered with hairs and stellate and naked. Petiole is smooth, sulcate, ~1.3 cm in size. The leaf blade is oblong-elliptic, greenish when dry, subglabrous, and thinly leathery, the base is cuneate, the margin is entire or mildly serrated, the apex is acuminate, there are 5–8 pairs of secondary veins, tertiary veins are reticulate and abaxially conspicuously raised. The corolla is white, lobes are ovate-oblong, ~1.5mm and pubescent on both sides. Filaments are 1.5–3mm in size, slightly flattened, glabrous or shortly pubescent on the inside on margin. Fruit is ellipsoid-oblong, 10–12 x 7–9mm in size, the apex is rostrate, exocarp is pulpy, pericarp is attached with bony endocarp. The seeds are oblong, strongly rugose and pointed at both the ends. Flowering takes place from April to July and fruiting from October–December (Hassler, 2018).

***Symplocos racemosa* (Roxb.)**

Class - Asterids

Order - Ericales

Family - Symplocaceae

Genus - *Symplocos*
Species - *racemosa*
Vernacular Name - Hau (Mizo)

It is a small tree upto 9 m high having grayish bark and lenticellate; blaze creamy yellow. The young branchlets are terete, glabrous, lenticellate. The leaves are simple, alternate, spiral; petiole up to 1.5 cm long, planoconvex in cross section, glabrous; lamina 6.5-12.5 x 3-4.3 cm, oblanceolate to narrow elliptic, apex narrowly acuminate, base acute to attenuate, margin serrate and slightly recurved, glabrous; midrib canaliculate above; secondary nerves 6-12 pairs; tertiary nerves obliquley distantly percurrent. Inflorescence is an axillary raceme, up to 14 cm long, tomentose. Fruit is a drupe, ellipsoid or oblong, ca. 1.5 cm long; seeds 1-2 (Ramesh *et al*., 2004)

***Eriobotrya bengalensis* (Roxb.)**

Class - Magnoliopsida

Order - Rosales

Family - Rosaceae

Genus - *Eriobotrya*

Species - *bengalensis*

Vernacular Name - Nghalchhun (Mizo)

It is a medium sized tree upto 27 m, rarely buttressed, with spreading branches having flat foliage ('terminalian' branching), bark rough and lenticellate, white or grey. Its large leaves are oblong to oblong-lanceolate, 6-17 by 2-6.5 cm, having a serrated edges, almost glabrous when mature but with a woolly indumentum on midrib and nerves when young, red when young and also when old. Inflorescence is a terminal compound raceme, the lowermost of those in the axils of (reduced) leaves, upper ones in axils of bracts, the panicle up to 14 cm long, peduncle very short, lower laterals up to 12 cm, pedicels 2-3(-5) mm long, densely hairy as are all other axes in the panicle. Flowers are fragrant and sepals triangular densely hairy outside. Petals ovate to broadly obovate, reflexed in anthesis, with hairs at base inside, otherwise glabrous, white. Fruits are globular, 10-15 by 9-15 mm (in dry state), exocarp more or less hairy, grey-green when young, reddish when ripe, mesocarp hard and gritty, endocarps firm-membranous. Fruits have 1 or 2 seeds per fruit, within a papery testa. The species is distributed mainly in Assam, Meghalaya, and Mizoram and in China (Prance and Whitmore, 1973).

Schima wallichii (DC. Korthals)

Class - Magnoliopsida

Order - Ericales

Family - Theaceae

Genus - *Schima*

Species - *wallichii*

Common Name - Needle wood tree
Vernacular Name - Khiang (Mizo)

Schima is a medium evergreen tree that generally reches a height of up to 10-20 m tall. The bole is cylindrical having a diameter up to 1 m, with steep buttresses rarely up to 1.8 m high; bark surface ruggedly cracked into small, thick, angular pieces, red-brown to dark grey; inner bark possesses skin-irritating fibres, bright red in colour. Leaves are elliptic-oblong in shape. Leaf margins are entire or slightly toothed. Flowers are white, fragrant, 3-4 cm across. Sepals rounded. Five white petals are broadly ovate and rounded. Fruit is a woody subglobose capsule, 2-3 cm in diameter, silky, opening by 5 valves; seeds winged all around. It is a tree of moist and dry evergreen as well as in mixed deciduous forests. Fair growth can be obtained even under infertile soil conditions. The tree usually flowers and fruit after 4 years. Flowering and fruiting occur all through the year, but flowers are usually more abundant around the time when seasons change. Generally, in India, trees bear flowers in April-June and the first fruits are observed from May to July. The seeds are shed in next January to March of the following year. Wood is suitable for paper pulp. *S. wallichii* yields a medium-weight to heavy hardwood. It is easy to work with hand and machine tools and polishes satisfactorily. The wood is relatively resistant to dry-wood termites. Used for medium-heavy construction that is under cover, such as columns and beams and good-quality plywood can be manufactured from the wood, and it is suitable for the production of wood-wool boards. Seeds of *S. wallichii* contain oil in India. The bark contains an alkaloid which is used as a fish poison. The astringent corollas are used to treat uterine disorders and hysteria. The crude drug is called ‘buah cangkok’ in Indonesia, and ‘changkoh’ in peninsular Malaysia (Orwa *et al*., 2009).

3.2.13. *Engelhardtia spicata* (Leschenault ex Blume)

Class - Rosids

Order - Fagales

Family - Juglandaceae

Genus - *Engelhardtia*
Species - *spicata*

Common Name - Mauwa
Vernacular Name - Hnum (Mizo)

Engelhardtia spicata is an evergreen to briefly deciduous tree with a dense, rounded crowm; it can grow up to 40 metres tall, though is usually much smaller. Mauwa is a tree identified by fissured bark, compound leaves with leaflets opposite, and winged nut. It is a deciduous tree up to 20 m tall. Bole is straight. Bark is grey or grey-brown, deeply fissured. Leaves are compound, alternate and spiral, impar- or paripinnate, leaflets are narrowly ovate or elliptic, with yellow glandular dots, margin entire. Primary vein is single. Flowers are arranged in a many-flowered inflorescence, in leaf axils, on small leafless twigs, unisexual, on the same tree, on stalks up to 3 mm long. Fruit is up to 3.5 cm long, 1-seeded, 3-winged nutlet, not splitting open. Mauwa is found in the Himalayas, till NE India, at altitudes of 1000-3000 m. Flowers during December to February (Fern, 2021).

***Embelia ribes* (*Burm.f.*)**

Class - Asterids

Order - Ericales

Family - Myrsinaceae

Genus - *Embelia*
Species - *ribes*

Common Name - white-flowered embelia
Vernacular Name - Rahsen (Mizo)

It is a small tree found in hilly parts of India up to 1500 m elevation from outer Himalayas to Western Ghats.It has long branches, slender, flexible, terete and long internodes. The bark is studded with lenticels. Leaves are coriacous, 5x2-4 cm long, elliptic or ellipticlanceolate, shortly and obtusely acuminate, entire, glabrous on both side, shining above, pales and somewhat silvery beneath, base rounded or acute and main nerves numerous. Petioles are more or less margined and glabrous. Flowers are small, greenish-yellow, numerous in lax panicled racemes. Calyx is minute, sepals connate, broadly triangular, ovate and ciliate. Petals are 5 and free and stamens are 5, but shorter than the petals. Fruits are 2.4-4.0 mm in diameter and globular with warty surface, smooth and succulent. The colour of fruit is bright red and becomes dull when it further ripens.

***Quercus spicata* (Bonpl.)**

Class - Magnoliopsida

Order - Fagales

Family - Fagaceae

Genus - *Quercus*
Species - *spicata*

Common Name - Spike oak, Sunda oak
Vernacular Name - Thingpuithing (Mizo)

It is an upper canopy tree up to 42 m tall and 81 cm dbh. Stipules are small. Leaves are alternate, simple, penni-veined and glabrous. Flowers are yellowish and placed in racemes. Fruits are greenish nut with basal cupule.Bark is deeply fissured or lenticellate, greyish brown; inner bark granular, reddish or brownish. Sapwood is yellowish or brownish. Twigs are sparsely tomentose, late-glabrescent, sparsely to densely large-lenticellate. Leaves coriaceous, rarely thick-coriaceous, glabrous on both surfaces; narrowly to broadly obovate or elliptic, base acute or cuneate, margin revolute, apex bluntly acute or acuminate, midrib raised on both surfaces; lateral veins thin, slightly raised or flat or sometimes impressed above, raised below, faintly joining near the leaf margin, forming an angle of 40-60 degrees with the midrib. Inflorescences may be male, androgynous or mixed. Male inflorescences are solitary but closely arranged along the rachis, androgynous or mixed inflorescences ~12-20 cm long; bracts and bracteoles broadly ovate. Female flowers are in cluster along the rachis. Acorns are ovoid or depressed ovoid to subglobose, glabrous, brownish; base flat, apex rounded; scar flat or concave, 1-1.5 cm diameter; wall woody, thin, most part free from the cupule (Soepadmo *et al.,* 2007).

Symplocos theaefolia **(D. Don)**

Class - Asterids

Order - Ericales

Family - Symplocaceae

Genus - *Symplocos*

Species - *theaefolia*
Vernacular Name – Musau (Mizo)

Small evergreen trees or shrubs, to 15 m high. Twigs green, glabrous, ridged. Petioles 6–12(–16) mm long; leaf blades leathery, 8–12×2–3 cm long, glabrous on both sides, base cuneate, margin subentire or serrated, apex long acuminate; midvein adaxially prominent, lateral veins 8–12 per side. Inflorescences simple or basally branched, axillary spikes, 0.8–2.5 cm long, axis puberulent; bracts and bracteoles persistent, broadly obovate, 1–3 mm long, often glabrous. Calyx glabrous or puberulent, margin ciliolate, lobes orbicular. Corolla white, 3–5 mm long, deeply 5-lobed. Stamens 15–50, pentadelphous or inconspicuous pentadelphous. Disc soft pilose. Drupes ellipsoidal, 6–15 × 4–7 mm, apex with erect or spread persistent calyx lobes, 3 loculed, 1 or 2 locules often fertile, mesocarp woody, endocarp surface smooth (Qin, 2013).

Ostodes paniculata **(Blume)**

Class - Rosids

Order - Malpighiales

Family - Euphorbiaceae

Genus - *Ostodes*
Species - *paniculata*

Common Name - Panicled Bone-Tree
Vernacular Name - Beltur (Mizo)

It is a small tree, up to 15 m tall, dioecious; bark gray-brown; branches and leaves glabrous. Leaves usually apically clustered; stipules caduceus. Leaf blade ovate-lanceolate to oblong-lanceolate, 10-24 × 5-10 cm, thinly leathery. Flowers are white: Male flowers: sepals 5 (3 wider, 2 narrower), 3-3.5 mm; petals 5, ovate-elliptic, ca. 5 mm, white; disk glands free; stamens 20-35. Female flowers are ca. 12 mm; sepals and petals as in male; disk annular; ovary hirsute; styles 3, bifid to below middle, apex densely longitudinally grooved. The fruit is a capsule tomentulose and densely elevated-verrucose; mesocarp hard, woody. Seeds are ellipsoidal. Flowering occurs during March to May and fruiting begins from August to September.

It is found in montane evergreen forests at an elevation of 400-1400 m. The tree is distributed in Bhutan, Cambodia, India, Indonesia, Malaysia (peninsular), Myanmar, Nepal, and Vietnam. The tree is planted as a pioneer species in northern Thailand in reforestation projects to restore native woodland - it is planted in degraded woodland and open areas mix with various other species that all have the ability to grow fast; produce dense, weed-suppressing crowns; and attract seed-dispersing wildlife, particularly birds and bats (Pakkad, 2002).

Diospyros lanceifolia **(Roxb.)**

Class - Asterids

Order - Ericales

Family - Ebenaceae

Genus - *Diospyros*

Species - *lanceifolia*

Common Name - Common Malayan Ebony
Vernacular Name - Zothinghang (Mizo)

It is an evergreen tree in the Ebenaceae family. It grows up to 27 metres (90 ft) tall. Twigs are reddish brown when young and senesced leaves are blackish or dark brown. Male flowers are found in dense clusters in the leaf axils, while the female flowers are found singly or 2–3 together. Its sweet-scented flowers are ochre-yellow and up to 1.3 cm wide. Fruits are fleshy (Non-Accessory Fruit: Berry) round, up to 2.5 cm (1 inch) in diameter. The specific *Epithet lanceifolia* is from the Latin meaning "lance-shaped leaves". It is comnly found in lowland forests (Francis, 2002). The fruit is subglobose or ovoid. The seeds are used as a fish poison in some communities. The principles involved here might be their content of naphthoquinone derivatives such as biplumbagin and chitranone, which are known to be ichthyotoxic (Wiart C, 2006). In general *Diospyros* species are dioecious and require both male and female forms to be grown if fruit and seed are required (Soepadmo *et al.*, 2002).

Helicia excelsa (Roxb.) Syn: *Alseodaphne crassipes* (Hook.f.)

Class - Eudicots

Order - Proteales

Family - Proteaceae

Genus - *Helicia*

Species - *excelsa*

Vernacular Name - Sialhma (Mizo)

It is a sub-canopy tree up to 20 metres (70 ft) tall, with a trunk diameter of up to 25 centimetres (10 inches). The bark is dark grey to blackish. Inflorescences bear up to three reddish brown flowers. Fruit is a drupe, black, ellipsoid, up to 3 centimetres (~1 inch) long. The specific *Epithet excelsa* is from the Latin meaning "lofty", referring to the tree’s growth. It is found in undisturbed mixed dipterocarp, swamp, sub-montane and montane forests up to 2200 m altitude on ridges, but also common on alluvial sites and along rivers and streams. In secondary forests it is usually present as a pre-disturbance remnant. *H. excelsa* is distributed in India, Burma, Indo-China, Thailand, Peninsular Malaysia, Sumatra and Borneo. The wood is locally used for house construction and in mines (Soepadmo *et al.,* 2002).

Syzigium zeylanicum (L.) DC.

Class - Magnoliopsida

Order - Myrtales

Family - Myrtaaceae

Genus - *Syzigium*
Species –*zeylanicum*

Common Name - Kelat
Vernacular Name - Thingchhunghul (Mizo)

Syzygium zeylanicum is an evergreen tree that can grow upto 12 metres tall. The wood is used in the region extensively for house pillars and beams. The bark is grayish white and smooth. Leaves are simple, opposite, petiole 3-8 mm long, stout, grooved above, glabrous; lamina 2.4-9.5 x 0.8-5.5 cm, elliptic-lanceolate, linear-lanceolate, ovate, ovate-lanceolate or oblong, base obtuse, round or acute, apex acute or acuminate, margin entire, pellucid dotted, glabrous, glossy, coriaceous; lateral nerves many, parallel, looped near the margin forming intramarginal nerve, prominent, intercostae reticulate, slender, faint. Flowers bisexual, in axillary and terminal cymes, small, white; peduncle 4-6 mm long; pedicel 3-4 mm long, slender; petals 5, 1.5-2 mm long, free, deciduous, white; stamens many, free, bent inwards at the middle when in bud; filament 4-6 mm long; no thickened staminal disc; ovary inferior, 2-celled, ovules many; style 1, 4-6 mm long; stigma simple. Fruit a berry, 6-12 mm long, white, gland-dotted, crowned with calyx segments (Sasidharan, 2017).

Methodology

Experimental Design

A total of twenty major tree species were selected to study changes in phenological diversity, leaf dynamics and soil nutrients in Hmuifang subtropical forest. For each species, 5 individuals were marked for periodical assessment of various phenological characterists. Duration of leafing, flowering and fruiting were recorded. Leaves of each species were collected in order to measure the Leaf mass area, Specific leaf area, Relative leaf growth rate, Leaf moisture content, Leaf dry matter content and Leaf water content per unit area. For nutrient analysis, the leaf samples were powdered and content of carbon, nitrogen, potassium, calcium, sodium, magnesium and iron were calculated. Percentage retranslocation of nutrients from senescing leaves to the perennial tissues and Nutrient mass for leaves was calculated. Soil sampling and analysis was done and various soil properties like organic carbon content, total nitrogen, pH, bulk density, texture and moisture content were calculated.

Recording of Leafing, Flowering and Fruiting Phenology

-To record the phenological observations, adult trees of a desired size having girth at breast height (dbh>30cm) were selected.

-A total of 20 tree species were selected for observation and 5 trees from each species of the desired size were first marked with spray paint. This way a total of 100 trees were marked.

-On each tree, four major branches facing different direction (East, West, South and North) were selected and four twigs (currently growing shoots of last-order branches) on each of four major branches (one in each direction) were marked with metal tags.

-Monthly collection of leaves was made from each species, taking 20 leaves per species with a total of 240 leaves per year for each species.

-Leaves were oven dried at 70° C for 48 hours to measure the moisture content, leaf mass area and specific leaf area.

-Leaf area was measured manually using a graph book.

-The following phenological events were recorded from all conspecific trees from the monthly counts of leaves, flowers and fruits: leaf flush initiation; leaf flush completion; leaf fall initiation; leaf fall completion; leafless period; initiation of flowering; completion of flowering; time lag between start of vegetative (first-leaf flush) and reproductive (first visible flower) phases; initiation of fruiting; completion of fruiting; fruit-fall initiation; and completion of fruit fall.

-Leaf flush was counted as the period (days) of an individual from the first leaf flush to the last one.

-Leaf fall period (days) of an individual was the time duration from the estimated first leaf fall to the last individual.

-Fruiting period of a species was the duration (days) from the first fruit formation to the last amongst its individuals.

-The fruit-fall period of a species was represented as the time duration from the first fruit fall amongst individuals to the last.

-The synchrony index for flowering, fruiting and fruit-fall phenophases of each species was calculated as the ratio between the individual's mean duration of a phenological phase and the overall duration of the phase (Devineau, 1999).

-Wood samples were collected and oven dried at 105 °C for 48 hours and wood moisture content was measured as: WMC = initial weight - oven dry weight/oven dry weight x 100.

Leaf dry mass analysis

-For each species, periodical changes in leaf dry mass was estimated by collecting leaf samples on the day of marking (i.e. at leaf expansion initiation time) and continued at weekly intervals until the time of full expansion of leaves.

-After full expansion of leaves, they were collected at monthly intervals until leaf senescence.

-On each sampling date, 30 marked leaves for each of the species were plucked. The samples were divided into three sets of ten leaves each. The area of these leaves were measured and samples were oven dried at 70° C to constant mass and weighed in an electric balance to derive the average dry mass per leaf or per cm^2.

-On the basis of leaf dry mass, the RLGR of leaf (Evans, 1972) and leaf dry mass per area of mature leaf (LMA) was calculated using the following expressions:

$$\text{RLGR } (g\ g^{-1}\ day^{-1}) = \frac{\log W_2 - \log W_1}{T_2 - T_1}$$

Where W_1 and W_2 = dry weight at time T_1 and T_2 respectively and $T_2 - T_1$ = number of days in the sampling interval.

-Leaf mass area (LMA) = LW/A ($g\ m^{-2}$)

Where A = leaf area (m^2) and LW = leaf dry weight (g)

-Specific leaf area (SLA) = leaf area/leaf weight ($cm^2 g^{-1}$)

- Leaf dry matter content ($g\ g^{-1}$) was calculated by dividing leaf dry mass (g) by leaf fresh mass (g)

- Leaf water content per unit area ($g\ H_2O\ cm^{-2}$) = leaf fresh mass - dry mass / leaf area

Leaf nutrient analysis

-The leaf samples were powdered and used for further chemical analysis.

-Carbon and nitrogen contents were determined by CHN analyzer (CHNS-O Elemental Analyzer EUROEA, 3000).

-Leaf material was digested using a wet ash nitric-perchloric acid procedure (Jackson, 1958).

- Calcium, Potassium, Sodium, Magnesium and Iron were determined with a flame photometry (Jackson, 1958).

-The nutrient mass for the leaves was computed as the product obtained by multiplying dry mass of leaves by their mean nutrient concentration.

-Percentage retranslocation of nutrients from senescing leaves to the perennial tissues was calculated using the formula: 100 × (nutrient mass in leaf at steady state - nutrient mass in leaf at abscission) ÷ (nutrient mass in leaf at steady state).

Soil sampling and analysis

-Soil sample of the study site was collected from five soil cores 30 cm depth twice for two years in order to analyze the physiochemical properties of the soil.

-Soil bulk density was measured once by inserting the known volume of steel tube in the soil. The soil from the tube was collected and oven dried, and the dry weight of soil was divided by the volume of the tube.

-Soil texture was also determined only once through hydrometer method. Water holding capacity was also measure only once during the study period.

-Gravimetric soil moisture was measured on every collection.

- Soil pH was measured using a pH meter and organic carbon by Walkley and Black’s rapid titration method (Allen, 1989).

-Total N was determined using Kjeldahl digestion method.

Statistical analysis

Data obtained from field and laboratory observations were subjected to statistical analysis on PC using Microsoft excel and SPSS software. Correlation of vegetative, reproductive and tree intrinsic parameters were worked out and results were interpreted.

CHAPTER 4
RESULTS AND DISCUSSION

Leaf persistence, Leaf area, Specific Leaf Area, Leaf Moisture Content

The leaves of the major (20) tree species were classified based on their leaf area as per the leaf classification proposed by Raunkaiers (1934) into three classes namely microphyll (2.25 to 20.25 cm^2), mesophyll (20.25 to 182.25 cm^2) and macrophyll (182.25 to 1640.25 cm^2). Among the tree species studied, *Ostodes paniculata* falls under the macrophyll category with highest leaf area (~186.86 cm^2) while *Embelia tsjeriam* falls under the microphyll category with smallest leaf area (~18.67 cm^2). Evergreen and deciduous species did not show any variation in leaf size but the variations were mainly because of morphological trait of the species.

The specific leaf area (SLA) value ranged from 236 to 93 among the species with *Ostodes paniculata* has the highest value (236.27±20.8) and the *Eriobotrya bengalensis* has the lowest value of SLA (93.25±6.1). In general, deciduous species have higher values of SLA compared to evergreen species (Table 4.1). SLA increased with decreasing light conditions and the depth of the canopy. *Eriobotrya bengalensis,* a deciduous species, show low SLA as it prefers open ground with full sunlight. Stand structure has a similar influence on the light conditions, and therefore also affects SLA (Del Rio and Berg 1979; Abrams and Kubiske 1990; Chen and Klinka 1998; Tardieu *et al*., 1999; Bond et al. 1999; Nagel and O'Hara 2001; Poorter *et al*., 2006), which holds true for *Ostodes paniculata and Syzigium zeylanicum*; a tree of lower height and blinded on the side and top for most of the season among the species studied. It is found that in the entire deciduous tree species observed, the month of maximum specific leaf area (SLA) coincides with the month of leaf production. The Specific Leaf Area tends to increase during leaf formation and decreases slowly at the time of leaf senescence.

Species	**Family**	**Leaf persistence**	**Raunkiers classification**	**LA(cm2)**	**SLA (cm2 g)**	**LMC (%)**
Belschmeidia roxburghiana	Lauraceae	Leaf-exchanging	Mesophyll	34.42 ± 1.2	107.47 ± 6.11	54.882 ± 1
Callophylum polyanthum	Calophyllaceae	Leaf-exchanging	Mesophyll	31.37 ± 0.9	120.34 ± 8.41	60.472 ± 1.8
Diospyros lanceifolia	Ebenaceae	Leaf-exchanging	Mesophyll	34.23 ± 0.9	105.7 ± 5.1	60.819 ± 1
Ixora walichii	Rubiaceae	Leaf-exchanging	Mesophyll	72.5 ± 2.8	136.81 ± 5.7	64.37 ± 1.2
Lithocarpus xylocarpus	Fagaceae	Evergreen	Mesophyll	43.95 ± 2.4	117.86 ± 5.8	52.303 ± 1.4
Quercus spicata	Fagaceae	Evergreen	Mesophyll	64.78 ± 2.4	124.02 ± 7.2	52.484 ± 1
Symplocos racemosa	Symplocaceae	Evergreen	Mesophyll	84.35 ± 2.7	121.82 ± 9.5	63.99 ± 2
Symplocos theaefolia	Symplocaceae	Evergreen	Mesophyll	24.18 ± 1.03	111.2 ± 7.6	59.332 ± 0.9
Syzigium claviforum	Myrtaceae	Evergreen	Mesophyll	40.06 ± 1.7	101.282 ± 8.9	55.354 ± 1.3
Syzigium zeylanicum	Myrtaceae	Evergreen	Microphyll	16.23 ± 0.5	184.25 ± 15	62.356 ± 1.5
Schima walichii	Theaceae	Evergreen	Mesophyll	62.47 ± 2.2	154.984 ± 4.8	63.554 ± 2.3
Dipterocarpus retusus	Dipterocarpaceae	Deciduous	Mesophyll	21.5 ± 0.8	107.41 ± 10.3	55.618 ± 1.1
Engelhardtia spicata	Juglandaceae	Deciduous	Mesophyll	50.89 ± 1.4	156.1 ± 12.8	64.349 ± 2
Eriobotrya bengalensis	Rosaceae	Deciduous	Mesophyll	125.05 ± 4.3	93.25 ± 6.1	57.012 ± 1.4
Helicia excelsa	Proteaceae	Deciduous	Mesophyll	45.93 ± 1.5	122.27 ± 7.3	61.946 ± 0.6
Quercus floribunda	Fagaceae	Deciduous	Mesophyll	44.57 ± 2.06	119.415 ± 9.7	48.734 ± 2.9
Rapanea capitellata	Myrsinaceae	Deciduous	Mesophyll	29.63 ± 1.4	110.07 ± 8.7	64.966 ± 0.8
Ostodes paniculata	Euphorbiaceae	Deciduous	Macrophyll	186.86 ± 7	236.27 ± 20.8	70.394 ± 0.9
Styrax polysperma	Styracaceae	Deciduous	Mesophyll	65.65 ± 1.9	130.5 ± 4.4	63.653 ± 1.2
Embelia tsjeriam	Primulaceae	Deciduous	Microphyll	18.67 ± 0.9	111.55 ± 8.3	64.37 ± 2.7
Values are mean±*SE*						

Table 4.1 Leaf persistence, Leaf area (cm^2), SLA (cm^{2}g^{-1}), LMC (%)

Further, it is found that in 90% of the species the months of maximum specific leaf area (SLA) coincide with the months of minimum leaf mass area (LMA) and vice versa ($r = -0.911$, $P < 0.01$, $n=20$), which refelected an inverse relation between LMA and SLA. Whereas, the correlation between specific leaf area (SLA) with stem wood density (SWD) is significantly positive ($r=0.529$, $P < 0.05$, $n=20$) and the same is significantly negatively correlated with leaf moisture content (LMC) ($r= -0.619$, $P < 0.01$, $n=20$) exhibiting that water use efficiency of the species increases with decreasing specific leaf area, which holds true for the average SLA values obtained from the evergreen species compared to the deciduous species. There is a significantly negative correlation between specific leaf area (SLA) and wood moisture content (WMC) ($r= -0.454$, $P < 0.05$, $n=20$). For majority of the species, the monthly minimum value of SLA is observed in the transition between winter and summer (February to May) when precipitation and soil moisture is low, proving that moisture resources are efficiently stored in the plant tissues.

The overall leaf moisture content (LMC) of all the species studied comes to an average of 60±5%, *Ostodes paniculata* possesses the highest leaf moisture content (70.4±0.9%) while *Quercus floribunda* has the lowest LMC (48.8±2.9%). On an average, LMC is higher in deciduous species than evergreen species and strategy of leaf moisture conservation and resilience to water stress is more pronounced in evergreen species. The monthly difference in LMC is on an average lower for evergreen species, affirming that throughout the year, leaf moisture regime is more constant for evergreen/leaf exchanging species. The overall LMC is highest during the months of April and May when the monthly precipitation began to go above 120 mm and drops to its lowest during November to February when the monthly precipitation drops to lower than 90 mm. Months of maximum LMC also depended on the season of leaf flush as fully expanded young leaves contain the highest amount of moisture.

Species	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Leaf exchanging															
Belschmeidia roxburghiana		▒	═	═	═	═	═	═	═	═	═	▒		═	═
Callophylum polyanthum	═	═	═	═	═	■	═	═	▒	▒	═	═	═	═	═
Diospyros lanceifolia	▒	═	═	═	■	═	═	═	═	═	▒	═	═	═	═
Ixora walichii	═	═	■	═	═	═	═	═	▒	▒	═	═	═	═	■
Evergreen															
Lithocarpus xylocarpus	═	═	═	═	═	═	═	═	═		▒	▒	═	═	═
Quercus spicata	▒	═	═	═	═	═	═	═	═	■	═	═	▒	═	═
Symplocos racemosa	■	═	═	═	═	▒	═	═	═	═	■	═	═	═	═
Symplocos theaefolia	═	═	═	═	═	═	═	■	═	═	▒	▒	═	═	═
Syzigium claviforum	■	═	═	═	═	═	═	═	═	═	═	▒	■	═	═
Syzigium zeylanicum	▒	═	═	═	═	═	═	═	═	■		▒	▒	═	═
Schima walichii	▒	═	═	═	═	■	■	═	═	═	▒	▒	▒	═	═
<2 months deciduous															
Dipterocarpus retusus	▒	═	═	═	═	■	═	═	═	═	═	▒	▒	═	═
Eriobotrya bengalensis	▒	═	═	═	═	═	═	■	■	■	▦	▒	▒	═	═
Helicia excelsa	▒	═	═	═	═	■	■	═	═	═	═	▒	▒	═	═
Rapanea capitellata		■	═	═	═	═	═	═	═	═	═	▒	═	■	═
Ostodes paniculata	═	═	■	▦	▒	▒	═	═	═	═	═	═	═	═	■
2-3 months deciduous															
Styrax polysperma	═	═	■	■	▦	▦	▒	▒	▒	═	═	═	═	═	■
Embelia tsjeriam	▒	═	═	═	═	═	■	▦	▦	▒	▒	▒	▒	═	═
Quercus floribunda	▒	▒	═	═	═	═	═	═	■	▦	▦	▒	▒	▒	═
Engelhardtia spicata					■	▦	▦	▒	▒	▒					

■ Leaf fall ▒ Leaf flush ═ Mature leaf ▦ Leafless Coinciding leaf flush and fall

Figure 4.1 Leaf Phenology

Species	**SWD**	**LMA**	**LSI**	**Deciduousness**	**Leaf flush**	**Flowering**	**Fruiting**
Leaf exchanging	**(g cm^{-3})**	**(gm m^{-2})**		**(Days)**	**(Days)**	**(Days)**	**(Days)**
Belschmeidia roxburghiana	0.545 ± 0.020	95.417 ± 6.32	0.481 ± 0.0031	10 ± 2	22±6	84±12	90±21
Callophylum polyanthum	0.604 ± 0.056	88.732 ± 5.41	0.525 ± 0.0022	11 ± 2	21±5	43±7	86±27
Diospyroslanceifolia	0.643 ± 0.022	97.182 ± 4.73	0.422 ± 0.0017	6 ± 2	14±9	42±8	124±17
Ixora walichii	0.715 ± 0.011	73.096 ± 2.96	0.473 ± 0.0021	13 ± 3	28±9	53±8	116±26
Evergreen							
Lithocarpus xylocarpus	0.673 ± 0.014	87.879 ± 4.7	0.411 ± 0.0041	8 ± 2	20±5	47±9	60±11
Quercus spicata	0.59 ± 0.011	83.041 ± 5.14	0.506 ± 0.0026	14 ± 2	28±2	57±8	92±24
Symplocos racemosa	0.719 ± 0.020	87.919 ± 6.37	0.484 ± 0.0011	7 ± 3	15±6	64±14	77±21
Symplocos theaefolia	0.669 ± 0.038	95.366 ± 6.78	0.385 ± 0.0011	6 ± 2	16±8	148±18	157±29
Syzigium claviforum	0.839 ± 0.020	104.846 ± 9.03	0.487 ± 0.0018	9 ± 3	19±3	66±8	71±11
Syzigium zeylanicum	0.721 ± 0.036	60.262 ± 6.31	0.532 ± 0.0021	14 ± 2	26±8	53±14	61±8
Schima walichii	0.689 ± 0.012	64.728 ± 2.19	0.569 ± 0.0015	20 ± 5	35±13	72±16	93±19
<2months deciduous							
Dipterocarpus retusus	0.666 ± 0.016	98.871 ± 6.96	0.657 ± 0.0069	26 ± 2	40±7	74±15	78±13
Eriobotrya bengalensis	0.783 ± 0.047	110.671 ± 8.75	0.702 ± 0.0036	58 ± 2	83±25	53±9	123±22
Helicia excelsa	0.685 ± 0.041	87.716 ± 6.15	0.678 ± 0.0010	33 ± 4	19±14	45±14	156±25
Rapanea capitellata	0.59 ± 0.031	91.285 ± 8.94	0.641 ± 0.0033	39 ± 3	61±12	96±21	103±27
Ostodes paniculata	0.424 ± 0.012	46.79 ± 4.86	0.54 ± 0.0033	27 ± 4	50±15	43±6	117±22
2-3months deciduous							
Styrax polysperma	0.546 ± 0.022	77.871 ± 2.94	0.769 ± 0.0095	75 ± 4	97±26	95±29	117±23
Embelia tsjeriam	0.771 ± 0.014	93.762 ± 6.54	0.852 ± 0.0031	88 ± 3	103±14	76±12	133±25
Quercus floribunda	0.793 ± 0.059	89.932 ± 7.86	0.743 ± 0.0033	63 ± 5	85±7	72±5	95±14
Engelhardtia spicata	0.511 ± 0.005	67.077 ± 4.67	0.726 ± 0.0015	65 ± 7	90±10	93±14	93±14
Values are mean ± SE							

Table 4.2 Stem Wood Density, Leaf Mass Area, Leaf Strategy Index, Deciduousness, Leaf Flush, Flowering and Fruiting

Stem Wood Density, Leaf Mass Area, Leaf Strategy Index, Deciduousness, Leaf Flush, Flowering and Fruiting

The Stem wood density (SWD) was expressed in grams per cubic centimeter (g cm^{-3}). Among the trees observed, the SWD ranged between 0.42 g cm^{-3} and 0.84 g cm^{-3}, *Syzigium claviforum* has the highest SWD (0.839±0.020) while *Ostodes paniculata* has the lowest SWD (0.424±0.012). There is no significant difference in wood density between evergreen and deciduous tree species.

There is a significant variation in Leaf Mass Area (LMA) values between evergreen and deciduous species in which the value is generally higher for evergreen species but it cannot be exactly true for all species. The overall monthly difference i.e. maximum and minimum LMA on an average is also higher for evergreen species.

The value of Leaf Strategy Index (LSI) i.e. the ratio of leaf fall duration to leaf flush duration increases with increase in the duration of deciduousness. Duration of flowering was more or less similar between evergreen and deciduous species while overall the duration of fruiting for deciduous species was longer by more than half a month among the species studied.

Most of the deciduous species (viz. *Quercus floribunda, Dipterocarpus retusus, Styrax polysperma, Eriobotrya bengalensis, Engelhardtia spicata, Embelia tsjeriam and Helicia excelsa)* in the present study exhibited leaf flush in the beginning of the growing season which stayed until autumn. This phenomenon of leaf growth was corresponded with the increase in leaf mass area (LMA) during leaf maturity. Jurik (1986) observed the same trend in Northern Hardwood forest of America and explained that it may be because of the buildup of cell wall material and chloroplast. However, in leaf exchanging species (i.e. *Callophylum polyanthum* and *Ixora walichii*) the LMA drops at the time of leaf exchange and the leaf resources are quickly replenished by the time of leaf maturity. In some species like *Syzigium claviforum, Rapanea capitellata*, *Eriobotrya bengalensis*, *Ostodes paniculata and Helicia excelsa*, the LMA increases considerably (>60%) from the monthly average values which coincided with leaf fall and leaf nutrient retranslocation during senescence.

The correlation between deciduousness (days) and leaf strategy index (LSI) was significantly positive (r= 0.94, P <0.01, n = 20). The relationship between leaf area and wood moisture content (WMC) was significantly positive (r= 0.57, P<0.01, n = 20). The correlation between leaf moisture content (LMC) with stem wood density (SWD) was also significantly negative (r= -0.405, P <0.01, n=20). It is found that months of maximum leaf moisture content (LMC) coincided with months of leaf flush which is considered to be a general trend. Further, it is also found that the maximum monthly leaf mass area (LMA) values were negatively correlated (r= -0.453, P <0.05, n=20) to monthly leaf moisture content. The SWD and LMA were positively correlated (r= 0.53, P <0.01, n=20). The leaf moisture content (LMC) was significantly positively correlated with the wood moisture content (WMC) (r= 0.63, P <0.01, n=20).

The wood moisture content (WMC) was significantly negatively correlated with stem wood density (SWD) (r= -0.49, P <0.05, n = 20). The wood moisture content (WMC) was species specific, among the trees observed, *Quercus floribunda* has the minimum WMC (45.5%) whereas *Ostodes paniculata* has the maximum WMC (142%).

Majority of flowering occurred during the summer months just before the onset of monsoon and when the photoperiod exceeds 13 hours. The duration of flowering and fruiting durations were longest for *Symplocos theaefolia* spanning for almost five months for this species. *Diospyros lanceifolia* has the shortest duration of flowering phenophase spanning about a month which proves the findings of Fantinato *et al*., (2016), the authors stated that subordinate species showed shorter flowering length than the common species and a mostly specialized pollination system. Duration of fruiting was shortest in *Lithocarpus xylocarpus,* the growth of the fruit which is a nut surrounded by a spiny covering reduces the neccessity of the fruit for a longer duration as it was well protected from predation by birds and arboreal mammals. Besides, prolonged fruiting species like *Symplocos thaefolia*, *Helicia excelsa* and *Embelia ribes* tend to produce abundant and fleshy pulp. Erratic rainfall and stormwinds during flowering was very harmful as they negatively affected the setting of fruits and also lead to greater mortality of smaller and more fragile flowers. In species like *Symplocos theaefolia, Helicia excelsa* and *Rapanea capitellata*, fruits can be seen attached to the tree for almost throughout the year, and for these species, flowering occurred during winter and proved that tree species flowering after the rains or during winter months have a greater chance of fruit formation having higher density of fruits which may also link to better chance of propagation and survival inside the forest.

		Synchrony index (SI)			**Time lag**
	Species	**Flowering**	**Fruiting**	**Fruit fall**	**Days**
1	*Quercus floribunda*	0.31	0.4	0.28	15
2	*Syzigium claviforum*	0.35	0.38	0.26	0
3	*Dipterocarpus retusus*	0.38	0.4	0.21	89
4	*Rapanea capitellata*	0.35	0.38	0.26	98
5	*Callophylum polyanthum*	0.19	0.38	0.42	186
6	*Belschmeidia roxburghiana*	0.32	0.35	0.32	20
7	*Lithocarpus xylocarpus*	0.31	0.39	0.29	156
8	*Ixora walichii*	0.23	0.51	0.25	158
9	*Styrax polysperma*	0.31	0.38	0.29	125
10	*Symplocos racemosa*	0.3	0.36	0.33	122
11	*Eriobotrya bengalensis*	0.18	0.42	0.39	94
12	*Schima walichii*	0.29	0.38	0.32	63
13	*Engelhardtia spicata*	0.38	0.38	0.23	0
14	*Embelia tsjeriam*	0.29	0.5	0.2	95
15	*Quercus spicata*	0.25	0.4	0.34	105
16	*Symplocos theaefolia*	0.39	0.42	0.18	81
17	*Ostodes paniculata*	0.16	0.44	0.39	130
18	*Diospyros lanceifolia*	0.17	0.51	0.31	59
19	*Helicia excelsa*	0.13	0.47	0.38	35
20	*Syzigium zeylanicum*	0.32	0.37	0.3	18

Table 4.3 Synchrony Index for Flowering, Fruiting, Fruit Fall and Time Lag

Synchrony Index for Flowering, Fruiting, Fruit Fall and Time Lag

The synchrony index for flowering, fruting and fruitfall was calculated for each species and variation was found for intra-species as well as within members of similar species. In majority of the species studied, flowering commences when the monthly average precipitation exceeds 150 mm. Synchrony of plant reproductive phases for each species is essential for continuity of species, colonization of available spaces, establishment, and maintenance of wider gene pool and for overall survival of the species.

The synchrony index for flowering was highest for *Symplocos theaefolia* and it was lowest for *Helicia excelsa,* high synchrony in flowering in *Symplocos theaefolia* resulted in higher frequency of pollination and in production of sufficient quantity of fruits and this trend was in line with the findings of Ausperger (1983). Synchrony index for fruiting was highest in *Diospyros lanceifolia* and *Ixora walichii* and asynchrony was highest for *Belschmeidia roxburghiana,* however, marked difference among the species in synchrony regarding fruiting was not observed. In majority of the species, fruit fall occur during the months when the precipitation drops lower than 40 mm. Synchrony index for fruit fall was highest in *Callophylum polyanthum* and asynchrony in fruit fall was highest in *Symplocos theaefolia*, therefore, abundant fruits can be seen in this species through the year.

Time lag i.e. number of days between start of vegetative (first-leaf flush) and reproductive (first visible flower) phases was greatest for *Callophylum polyanthum* and it was nil for *Engelhardtia spicata* and *Syzigium claviforum* meaning there is an instantaneous development of leaves as well as flowers at the same time. It was observed that species having higher time lag like *Callophylum polyanthum, Lithocarpus xylocarpus, Ixora walichii and Ostodes paniculata* produce abundant fruits. On the other hand, in majority of the species studied, the increase in time lag can be attributed to the inherent tendency of trees to first accumulate photosynthate through leaf production and eventually prepare for reproductive phase.

It is observed that during fruiting, the fruit bearing shoots have lesser leaves as compared to non fruit bearing shoots; this can be seen as a strategy for specific resource allocation for specific purpose in different part of the tree.

Sl no.	Species / Months	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	Average
1	*Quercus floribunda*	66.1	61.0	71.0	89.3	61.4	117.5	100.2	90.4	88.0	137.6	132.1	64.5	89.9
2	*Syzigium claviforum*	81.2	112.4	104.4	108.6	111.6	55.6	64.6	95.3	95.2	119.3	172.5	137.6	104.8
3	*Dipterocarpus retusus*	81.5	67.2	47.9	103.8	99.4	94.1	97.7	104.7	112.8	129.6	121.2	126.5	98.9
4	*Rapanea capitellata*	56.6	62.5	62.6	87.6	95.7	85.7	84.8	88.1	79.3	119.2	101.2	172.3	91.3
5	*Callophylum polyanthum*	82.7	104.6	79.7	80.7	85.9	80.8	87.7	94.4	79.0	52.7	109.4	127.5	88.7
6	*Belschmeidia roxburghiana*	82.3	85.7	89.0	85.8	79.3	82.5	77.5	73.2	114.4	112.1	145.2	118.1	95.4
7	*Lithocarpus xylocarpus*	76.9	70.5	86.3	75.6	82.6	69.2	78.4	96.2	88.8	112.2	121.8	95.9	87.9
8	*Ixora walichii*	70.2	65.4	95.9	70.5	83.5	71.3	75.3	76.6	72.3	53.8	65.9	76.5	73.1
9	*Styrax polysperma*	74.3	81.0	67.9	76.4	72.4	75.9	79.9	64.5	74.5	96.7	98.3	72.6	77.9
10	*Symplocos racemosa*	101.9	96.4	76.1	110.0	62.8	56.4	64.6	70.5	79.1	111.5	105.5	120.3	87.9
11	*Eriobotrya bengalensis*	97.1	98.2	73.5	113.3	90.0	103.7	110.3	112.0	109.0	197.3	98.1	125.5	110.7
12	*Schima walichii*	59.4	72.4	82.8	64.2	56.6	66.0	61.3	57.7	65.7	57.5	62.5	70.7	64.7
13	*Engelhardtia spicata*	90.4	81.4	69.0	78.7	72.7	67.8	41.3	37.0	63.2	79.3	71.6	52.7	67.1
14	*Embelia tsjeriam*	85.4	86.1	76.7	76.4	87.6	83.2	92.6	107.4	113.4	136.1	124.7	55.7	93.8
15	*Quercus spicata*	79.3	66.2	78.3	73.3	59.1	67.9	75.5	80.3	87.6	114.8	110.3	103.9	83.0
16	*Symplocos theaefolia*	99.0	128.7	83.5	85.6	60.9	74.7	77.3	82.8	92.3	116.0	141.4	102.1	95.4
17	*Ostodes paniculata*	67.9	64.1	32.5	33.2	27.8	43.2	42.6	38.6	34.2	48.7	83.7	45.0	46.8
18	*Diospyros lanceifolia*	79.8	90.1	89.1	108.7	100.2	87.2	83.2	81.4	91.9	106.2	135.9	112.6	97.2
19	*Helicia excelsa*	66.8	77.3	64.8	86.7	77.7	86.2	87.6	97.4	75.5	109.7	142.8	80.2	87.7
20	*Syzigium zeylanicum*	35.2	49.0	43.3	55.4	48.6	56.0	55.0	53.2	53.7	101.4	107.4	64.9	60.3

Table 4.4 Monthly variations in Leaf Mass Area (gm^{-2})

Monthly variations in Leaf Mass Area

Monthly values of Leaf Mass Area was recorded and it was found that LMA values were higher during the beginning of the growing season (February to May) for majority of the species and it is a morphological trait widely used as a good indicator of plant functioning (i.e. photosynthetic and respiratory rates, chemical composition, resistance to herbivory, etc.) (Riva *et al.*,2016).

On an average, evergreen tree species have a higher value of LMA as compared to deciduous tree species, but the variation in LMA is much wider among deciduous species studied. On the other hand, vegetative phenological activity is more active or pronounced in deciduous tree species as they shed and renew their leaves annually while evergreen leaves exchange their leaves slowly and in an inconsistent manner. *Eriobotrya bengalensis* have the highest average value of LMA while *Ostodes paniculata* has the lowest value.

The overall values of monthly LMA tends to increase during or just before flowering (mostly during the months of February to April) and drops at the time of fruiting which is an important prerequisite in the life cycle of trees. It is also found that tree height is directly proportional to LMA values in which tree having greater height have higher LMA values and vice-versa, this holds true for most of the species studied, however, tree density and spacing can also alter the relationship between LMA and height.

The value of Specific Leaf Area on the other hand was higher during the rainy season while majority of the species are flowering and fruiting which can be correlated to higher consumption of photosynthate and minerals needed for reproductive phenophases.

Sl no.	Species / Months	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	Average
1	*Quercus floribunda*	151.04	163.67	135.69	111.97	163.08	85.17	94.61	110.70	113.59	72.66	75.69	155.09	119.41
2	*Syzigium claviforum*	123.14	88.91	95.71	92.12	89.60	180.17	121.00	105.22	105.04	83.83	57.98	72.67	101.28
3	*Dipterocarpus retusus*	122.67	132.00	208.82	96.65	100.91	106.42	98.32	95.79	88.63	77.17	82.51	79.03	107.41
4	*Rapanea capitellata*	104.03	160.00	159.74	114.29	104.57	116.93	77.32	117.15	126.16	83.91	98.79	58.04	110.08
5	*Callophylum polyanthum*	120.99	95.53	152.21	124.16	116.44	124.11	118.37	105.95	126.60	189.84	91.43	78.46	120.34
6	*Belschmeidia roxburghiana*	121.48	113.00	112.39	116.82	126.14	121.25	119.00	136.69	87.40	81.92	68.87	84.67	107.47
7	*Lithocarpus xylocarpus*	128.02	141.79	118.51	131.93	121.17	144.62	136.58	103.69	112.58	89.09	82.09	104.26	117.86
8	*Ixora walichii*	142.45	152.90	104.26	141.89	119.72	140.24	128.69	130.57	138.33	185.99	151.86	130.75	138.97
9	*Styrax polysperma*	134.64	123.44	147.17	130.90	138.13	131.79	128.00	154.93	134.15	103.43	101.76	137.70	130.50
10	*Symplocos racemosa*	98.11	103.69	131.38	90.89	159.23	177.32	165.33	141.83	126.48	89.70	94.82	83.15	121.83
11	*Eriobotrya bengalensis*	103.00	101.75	135.91	88.49	111.16	96.44	69.00	89.25	91.77	50.67	101.95	79.67	93.26
12	*Schima walichii*	168.28	137.95	120.70	155.93	176.62	151.83	147.58	173.16	152.19	173.99	160.05	141.53	154.98
13	*Engelhardtia spicata*	110.66	122.75	144.89	127.26	137.69	147.95	197.64	270.55	158.28	126.12	139.59	189.84	156.10
14	*Embelia tsjeriam*	117.07	116.11	130.35	130.87	114.20	120.44	95.00	93.14	88.20	73.50	80.17	179.61	111.55
15	*Quercus spicata*	126.17	150.98	127.67	136.35	169.20	147.38	118.00	124.54	114.20	87.10	90.65	96.02	124.02
16	*Symplocos theaefolia*	101.00	77.67	119.69	116.85	164.11	134.22	131.59	126.20	108.38	86.17	70.69	97.94	111.21
17	*Ostodes paniculata*	147.30	155.80	307.47	301.52	359.32	231.60	234.00	259.17	292.33	205.26	119.46	222.11	236.28
18	*Diospyros lanceifolia*	125.39	110.90	112.24	92.04	100.00	114.63	132.00	122.94	108.87	94.19	73.60	81.54	105.69
19	*Helicia excelsa*	149.73	129.34	158.20	115.40	128.72	116.20	148.61	102.69	132.49	91.19	70.04	124.64	122.27
20	*Syzigium zeylanicum*	283.72	200.92	231.03	180.23	207.08	179.13	208.95	187.80	186.38	98.64	93.14	154.02	184.25

Table 4.5 Monthly variations in Specific Leaf Area (cm^2g^{-1})

Species / Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Quercus floribunda	43.5	45.2	50.6	75.5	49.3	44.2	59.2	47.3	48.8	45.7	34.4	41.2	48.7
Syzigium claviforum	59.0	56.1	55.1	54.9	60.9	51.5	58.1	57.2	55.7	58.3	42.5	55.0	55.4
Dipterocarpus retusus	51.0	54.1	55.6	63.4	60.2	60.1	58.7	55.4	53.6	52.7	49.8	52.7	55.6
Rapanea capitellata	65.1	60.4	66.0	63.6	71.3	67.0	66.3	66.6	64.1	63.8	61.6	63.8	65.0
Callophylum polyanthum	58.1	76.0	62.6	59.2	67.7	53.9	61.4	59.5	59.2	58.8	52.6	56.6	60.5
Belschmeidia roxburghiana	57.0	55.5	53.3	49.1	61.1	57.4	52.4	56.3	56.7	51.9	50.3	57.6	54.9
Lithocarpus xylocarpus	51.4	46.0	51.8	61.3	52.2	61.3	55.5	51.5	47.1	51.6	49.6	48.3	52.3
Ixora walichii	60.7	72.3	71.8	67.2	64.9	61.4	57.8	63.6	61.0	62.4	56.7	62.6	63.5
Styrax polysperma	65.2	61.2	67.4	67.0	63.3	52.6	68.5	62.9	67.4	65.9	64.9	66.3	64.4
Symplocos racemosa	68.0	61.7	68.6	50.0	61.3	62.2	69.6	51.9	68.9	72.7	62.2	70.9	64.0
Eriobotrya bengalensis	57.8	52.1	55.5	46.6	64.2	61.3	59.7	50.2	61.8	58.7	57.3	59.0	57.0
Schima walichii	55.3	73.5	76.4	64.0	75.3	61.8	58.9	69.5	55.3	58.3	55.1	59.4	63.6
Engelhardtia spicata	63.6	63.4	61.4	60.3	75.2	59.7	60.5	58.9	60.3	57.4	75.2	76.4	64.3
Embelia tsjeriam	59.7	53.9	60.5	74.2	89.6	50.0	66.1	63.9	62.7	63.8	58.1	59.9	63.5
Quercus spicata	51.6	47.7	51.7	48.6	57.5	57.0	49.6	52.3	57.7	54.9	47.9	54.7	52.6
Symplocos theaefolia	52.1	61.9	63.3	61.3	57.2	60.9	59.9	61.4	60.2	57.8	54.6	61.4	59.3
Ostodes paniculata	71.7	66.8	68.3	71.2	66.3	69.7	68.9	76.1	76.2	68.6	68.1	73.0	70.4
Diospyros lanceifolia	62.5	59.7	60.3	62.5	67.4	59.2	61.0	52.3	63.0	61.6	57.5	62.8	60.8
Helicia excelsa	60.1	63.2	60.3	60.8	65.4	63.4	65.4	58.3	61.1	60.2	61.9	63.2	61.9
Syzigium zeylanicum	62.1	51.6	58.0	62.3	73.5	61.8	66.9	64.1	64.2	61.0	58.1	64.6	62.4

Table 4.6 Monthly variations in Leaf Moisture content (%)

Leaf mass(green)																				
Months/Species no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
May	0.58	0.93	0.60	0.50	0.75	0.66	0.53	1.41	1.60	2.14	3.27	1.25	1.48	1.18	0.89	0.44	3.85	0.58	1.17	0.16
June	0.46	1.32	0.23	0.54	0.68	0.73	0.72	1.53	1.42	1.99	3.02	0.99	1.03	0.38	1.24	0.70	3.40	0.65	0.90	0.13
July	0.68	0.87	0.19	0.49	0.69	0.50	0.90	1.77	1.43	2.14	2.56	1.12	0.97	0.70	1.07	0.54	2.40	0.80	1.09	0.20
August	0.86	1.17	0.53	0.64	0.83	0.67	1.05	1.89	1.31	2.37	3.42	1.13	1.33	0.49	1.13	0.43	3.19	1.06	1.05	0.22
September	0.77	0.93	0.47	0.61	0.79	0.76	0.68	1.68	1.90	1.83	3.40	1.04	0.98	0.44	1.09	0.62	2.86	0.98	0.98	0.32
October	1.22	0.56	0.56	1.06	0.69	0.76	0.77	1.53	1.64	2.47	3.19	1.18	0.81	0.50	1.14	0.62	3.06	1.07	0.98	0.30
November	1.10	0.75	0.54	0.67	0.65	0.68	0.73	0.46	0.37	1.93	2.78	1.63	0.58	0.51	0.77	0.52	1.79	0.27	0.67	0.24
December	0.49	0.38	0.21	0.27	0.31	0.33	0.37	0.51	0.39	0.64	1.38	0.41	0.23	0.17	0.49	0.20	0.79	0.30	0.48	0.10
January	0.65	1.35	0.57	1.09	0.74	0.92	1.19	1.76	1.45	2.19	3.66	1.20	0.94	0.44	1.37	0.49	2.52	1.02	0.81	0.21
February	0.84	1.37	0.56	0.75	0.61	0.92	0.54	0.86	1.47	2.04	3.09	0.91	0.96	0.38	1.16	0.51	2.55	0.89	0.85	0.28
March	0.56	0.77	0.38	0.57	0.51	0.61	0.46	0.92	1.12	1.57	2.82	1.00	0.70	0.33	0.96	0.43	1.88	0.79	1.01	0.33
April	0.44	0.53	0.41	0.63	0.69	0.46	0.47	1.11	1.04	1.27	2.08	0.99	0.61	0.28	0.89	0.54	1.84	0.89	0.68	0.23
Average	0.72	0.91	0.44	0.65	0.66	0.67	0.70	1.29	1.26	1.88	2.89	1.07	0.88	0.48	1.02	0.50	2.51	0.77	0.89	0.23

Table 4.7 Leaf green mass (g) corresponding to different months during the study period

Leaf mass(dry)																				
Months/Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
May	0.29	0.36	0.24	0.14	0.24	0.26	0.34	0.52	0.59	0.79	1.20	0.31	0.37	0.12	0.39	0.20	1.30	0.19	0.38	0.04
June	0.26	0.64	0.21	0.19	0.31	0.31	0.28	0.59	0.55	0.81	1.20	0.39	0.40	0.15	0.61	0.30	1.11	0.27	0.35	0.07
July	0.35	0.37	0.10	0.15	0.27	0.23	0.39	0.75	0.46	0.68	1.11	0.49	0.37	0.26	0.48	0.19	0.64	0.29	0.40	0.06
August	0.47	0.50	0.24	0.24	0.33	0.32	0.55	0.71	0.58	1.11	1.67	0.48	0.58	0.15	0.58	0.18	0.73	0.45	0.49	0.09
September	0.41	0.40	0.22	0.22	0.32	0.33	0.36	0.65	0.62	0.57	1.30	0.46	0.39	0.16	0.46	0.25	0.68	0.36	0.38	0.11
October	0.66	0.23	0.27	0.38	0.28	0.37	0.37	0.57	0.56	0.68	1.32	0.49	0.34	0.18	0.52	0.26	0.96	0.41	0.39	0.12
November	0.40	0.42	0.20	0.24	0.27	0.28	0.37	0.53	0.50	0.71	1.34	0.40	0.35	0.16	0.52	0.22	0.81	0.34	0.38	0.09
December	0.49	0.38	0.21	0.27	0.31	0.33	0.37	0.51	0.39	0.64	1.38	0.41	0.23	0.17	0.49	0.20	0.79	0.30	0.48	0.10
January	0.37	0.55	0.28	0.38	0.31	0.40	0.58	0.69	0.51	0.70	1.54	0.54	0.34	0.18	0.66	0.23	0.71	0.38	0.32	0.08
February	0.46	0.60	0.26	0.30	0.15	0.41	0.29	0.24	0.57	0.78	1.48	0.24	0.35	0.18	0.61	0.19	0.85	0.36	0.31	0.14
March	0.28	0.35	0.17	0.19	0.19	0.29	0.22	0.26	0.37	0.49	1.25	0.24	0.27	0.13	0.46	0.16	0.60	0.31	0.40	0.14
April	0.11	0.24	0.15	0.23	0.28	0.24	0.18	0.36	0.34	0.64	1.11	0.36	0.24	0.07	0.46	0.21	0.53	0.33	0.27	0.09
Average	0.38	0.42	0.21	0.25	0.27	0.31	0.36	0.53	0.50	0.72	1.33	0.40	0.35	0.16	0.52	0.22	0.81	0.33	0.38	0.09

Table 4.8 Leaf dry mass (g) corresponding to different months during the study period

Species	**LDMC (g g^{-1})**	**LWCa (g H_2Ocm^{-2})**
Quercus floribunda	0.686	0.0381
Syzigium claviforum	0.669	0.0874
Dipterocarpus retusus	0.656	0.1302
Rapanea capitellata	0.566	0.1316
Callophylum polyanthum	0.68	0.0414
Belschmeidia roxburghiana	0.671	0.0320
Lithocarpus xylocarpus	0.643	0.1433
Ixora walichii	0.599	0.0359
Styrax polysperma	0.597	0.0518
Symplocos racemosa	0.631	0.0427
Eriobotrya bengalensis	0.558	0.0248
Schima walichii	0.587	0.0544
Engelhardtia spicata	0.509	0.1552
Embelia tsjeriam	0.546	0.1660
Quercus spicata	0.6	0.0432
Symplocos theaefolia	0.487	0.2233
Ostodes paniculata	0.415	0.0348
Diospyros lanceifolia	0.568	0.1198
Helicia excelsa	0.528	0.0871
Syzigium zeylanicum	0.627	0.1664

Table 4.9 Leaf dry matter content (LDMC) and Leaf water content per unit area (LWCa)

Green and Dry mass of Leaves, Leaf dry matter content and Leaf water content per unit area

The green and dry mass of leaves (g/cm^2) was highest for *Eriobotrya bengalensis* and was lowest for *Syzigium zeylanicum.* On an average, deciduous tree species have higher leaf mass as well as leaf area compared to evergreen tree species; which can be linked to shorter leaf lifespan in deciduous species and more efficient utilization of resources for fixing greater amount of organic matter through photosynthesis within a shorter span of time. The monthly leaf mass is at its lowest during leaf flush and it increases as the leaf mature and reached its final size thereby acculmulating more and more nutrients and minerals.

The growth and mass of leaves were higher and are comparatively constant during May to October when the photoperiod exceeded 12 hours and it can be attributed to the fact that during this period, nutrients and minerals are luxuriously synthesized and accumulated in the vegetative regions.

Species	**C (%)**	**N (%)**	**K (ppm)**	**Ca (ppm)**	**Na (ppm)**	**Mg (ppm)**	**Fe (ppm)**
Quercus floribunda	45.77	2.48	5.9	6.23	1.06	1.82	0.38
Syzigium claviforum	43.62	1.8	3.73	5.96	1.42	1.99	0.22
Dipterocarpus retusus	54.47	1.87	4.21	9	1.76	1.61	0.37
Rapanea capitellata	58.83	2.35	5.77	7.15	1.53	1.58	0.32
Callophylum polyanthum	48.1	1.84	4.14	6.5	1.4	1.6	0.55
Belschmeidia roxburghiana	55.15	2.02	4.56	8.7	1.19	1.81	0.34
Lithocarpus xylocarpus	57.73	2.17	3.5	4.42	1.37	1.41	0.31
Ixora walichii	55.21	2.15	4.94	6.24	1.05	1.88	0.24
Styrax polysperma	55.17	2.19	3.67	6.1	2.68	2.84	0.38
Symplocos racemosa	56.43	1.87	3.12	5.05	0.86	1.26	0.26
Eriobotrya bengalensis	49.27	2.05	5.95	6.32	1.47	2.19	0.26
Schima walichii	46.37	2.18	3.23	2.32	1.87	1.64	0.18
Engelhardtia spicata	46.44	3	5.37	5.36	1.12	5.57	0.28
Embelia tsjeriam	43.45	2	8.28	6.17	1.79	2.7	0.29
Quercus spicata	57.8	2.6	4.3	4.4	1.24	1.37	0.26
Symplocos theaefolia	54.62	2.9	3.19	4.98	0.98	0.97	0.2
Ostodes paniculata	47.74	3.6	7.32	6.42	0.87	2.35	0.24
Diospyros lanceifolia	58.13	2.9	5.16	7	1.78	2.28	0.25
Helicia excelsa	57.31	2.52	2.33	5.53	1.24	1.97	0.29
Syzigium zeylanicum	46.93	2.12	6.97	7.13	1.64	2.82	0.4

Table 4.10 Average nutrient content of leaves

Analysis of Nutrient Content of Leaves

The element content of normal and senesced leaves (Carbon, Nitrogen, Potassium, Calcium, Sodium, Magnesium and Iron) were compared for each species on a trimonthly basis. The carbon content in evergreen trees was slightly higher than deciduous and brevi-deciduous species and the periodic carbon content for majority of the species was higher during monsoon as compared to dry season (Table 4.10). The monthly variations of carbon in the leaves do not exceed 5% for both evergreen and deciduous species and the variation was slightly higher for deciduous species. Carbon content in the senesced leaves was higher on evergreen species as compared to deciduous species. Since Carbon is a structural component, the variations in the carbon content have not been reported in the literature (Tripathi and Singh 1992a, Tripathi and Singh 1994, 1996).

There is no significant difference in N content of evergreen and deciduous tree species, however, the monthly N content was higher during the wet season. Average values of retranslocation of N from senesced leaves to perennial tissue was much higher in deciduous species (31%) as compared to evergreen species (22%), round the year fruiting species like *Rapanea capitellata, Ostodes paniculata* and *Belschmeidia roxburghiana* have a very high percentage of retranslocation (Table 4.12). The N retranslocation efficiency (NReff), however, was on an average higher in evergreen species (67.61%) as compared to deciduous species (55.53%), this indicated higher additional nitrogen requirement from soil for deciduous species. Leaf nutrients are efficiently conserved in case of deciduous species which exchange and renew their leaves on a yearly basis and require higher rates of photosynthesis for vigorous leaf growth and development within a shorter span of time. On an average, the additional Nitrogen requirement for soil was higher in deciduous species (44.37%) as compared to evergreen species (32.39%). The CN ratio ranges from 13.01 to 30.18 and it was higher in evergreen species but the range is wider in deciduous species. In nature, larger proportion of species with a high CN ratio enabled communities to inhabit more N-limited conditions (Zhang *et al.,* 2019).

The concentration of K in leaves and retranslocation from senescing leaves to perennial tissues was on an average slightly higher in deciduous tree species and mainly in the months of new leaf formation and during fruit formation. Higher concentration of potassium during months of new leaf and fruit formation can be attributed to its role in translocation of water and nutrients which facilitates protein and starch synthesis in leaves and fruits.

The concentration of Ca in leaves was slightly higher for deciduous species as compared to evergreens, this can be ascribed to the functional role of calcium in formation of cell wall and in the formation of young leaves and shoots which occur more frequently in deciduous species compared to evergreen species.

There was no significant difference between evergreen species and deciduous species regarding sodium, magnesium and iron content in leaves.

Table 4.11 Nutrient Mass for leaves and Relative Leaf Growth Rate

Species	**C**	**N**	**K**	**Ca**	**Na**	**Mg**	**Fe**	**RLGR (g g^{-1} day^{-1})**
Quercus floribunda	29.4	1.61	3.43	4.06	0.56	1.12	0.21	0.28
Syzigium claviforum	38.22	1.55	3.27	5.18	1.18	1.63	0.18	0.11
Dipterocarpus retusus	20.98	0.73	1.62	3.51	0.63	0.6	0.14	0.21
Rapanea capitellata	36.4	1.36	3.44	4.61	0.91	0.91	0.19	0.19
Callophylum polyanthum	27.77	1.04	2.33	3.85	0.85	0.98	0.32	0.21
Belschmeidia roxburghiana	35.87	1.24	2.75	5.37	0.77	1.11	0.19	0.13
Lithocarpus xylocarpus	39.58	1.47	2.37	2.84	0.92	0.95	0.21	0.098
Ixora walichii	69.54	2.56	5.93	7.61	1.28	2.33	0.28	0.25
Styrax polysperma	66	2.62	4.31	7.38	3.06	3.22	0.42	0.3
Symplocos racemosa	102.9	3.44	5.52	9.45	1.54	2.32	0.48	0.31
Eriobotrya bengalensis	132.9	5.49	16.5	17.62	4.04	6.06	0.57	0.37
Schima walichii	47.54	2.26	3.28	2.26	1.82	1.62	0.18	0.1
Engelhardtia spicata	38.49	2.5	4.01	4.49	0.88	4.26	0.24	0.14
Embelia tsjeriam	19.13	0.91	3.89	2.74	0.75	1.16	0.13	0.04
Quercus spicata	57.54	2.53	3.92	4	1.31	0.26	0.26	0.089
Symplocos theaefolia	26.35	1.4	1.55	2.2	0.45	0.4	0.05	0.14
Ostodes paniculata	110	8.35	16.3	15.64	15.6	5.5	0.57	0.46
Diospyros lanceifolia	43.71	2.2	3.67	5.4	1.29	1.72	0.18	0.087
Helicia excelsa	48.06	1.95	1.95	4.62	0.97	1.69	0.17	0.09
Syzigium zeylanicum	10.46	0.46	1.37	1.53	0.35	0.58	0.09	0.46

Relative Leaf Growth Rate and Leaf Nutrient Mass

The RLGR was calculated for each tree species and among them, *Ostodes paniculata* had the fastest leaf growth rate while *Lithocarpus xylocarpus* had the slowest leaf growth. In general, deciduous trees showed higher RLGR as compared to evergreen species which can be attributed to the fact that when favourable biotic and abiotic conditions arise for leaf production, faster leaf growth will enable the tree to capture more photosynthate and compensate for the leafless months.

Among all the species observed, the element mass for leaves was positively and significantly correlated to the relative leaf growth rate (RLGR): ($r= 0.519$, $P <0.05$, $n=20$) for nitrogen, ($r= 0.474$, $P <0.05$, $n=20$) for carbon, ($r= 0.561$, $P <0.05$, $n=20$) for Potassium, ($r= 0.582$, $P <0.01$, $n=20$) for Calcium, ($r= 0.539$, $P <0.05$, $n=20$) for Sodium, ($r= 0.492$, $P <0.05$, $n=20$) for Magnesium and ($r= 0.583$, $P <0.01$, $n=20$) for Iron. On an average, leaf nutrient mass for all the measured nutrients was much higher for deciduous species as compared to evergreen species.

	Species	**C**	**N**	**K**	**Ca**	**Na**	**Mg**	**Fe**
1	*Quercus floribunda*	32%	27%	52%	25%	51%	35%	3%
2	*Syzigium claviforum*	14%	11%	9%	21%	20%	33%	9%
3	*Dipterocarpus retusus*	18%	7%	21%	15%	48%	30%	5%
4	*Rapanea capitellata*	20%	45%	38%	3%	28%	46%	9%
5	*Callophylum polyanthum*	19%	26%	31%	8%	18%	14%	7%
6	*Belschmeidia roxburghiana*	15%	42%	49%	42%	14%	41%	6%
7	*Lithocarpus xylocarpus*	10%	15%	19%	40%	20%	16%	6%
8	*Ixora walichii*	12%	39%	35%	27%	27%	21%	8%
9	*Styrax polysperma*	25%	25%	34%	11%	47%	50%	18%
10	*Symplocos racemosa*	15%	10%	29%	2%	23%	10%	12%
11	*Eriobotrya bengalensis*	31%	33%	18%	15%	13%	11%	12%
12	*Schima walichii*	21%	16%	26%	44%	44%	36%	17%
13	*Engelhardtia spicata*	29%	26%	56%	25%	54%	66%	14%
14	*Embelia tsjeriam*	33%	46%	20%	30%	51%	40%	17%
15	*Quercus spicata*	12%	25%	54%	45%	18%	33%	8%
16	*Symplocos theaefolia*	10%	32%	10%	52%	36%	65%	5%
17	*Ostodes paniculata*	41%	47%	57%	15%	76%	33%	21%
18	*Diospyros lanceifolia*	9%	8%	38%	2%	29%	10%	12%
19	*Helicia excelsa*	20%	22%	9%	22%	32%	19%	7%
20	*Syzigium zeylanicum*	15%	22%	57%	33%	37%	50%	3%

Table 4.12 Percentage retranslocation of nutrients from senescing leaves to the perennial tissues

Percent retranslocation of nutrients from senescing leaves

Percent retranslocation of nutrients from senescing leaves to other perennial tissues was recorded for all the species with inter-specific and intra-specific variations. Retranslocation of elements like nitrogen, sodium and magnesium from senescing leaves to perennial tissues was highest in deciduous species indicating efficient nutrient retranslocation in deciduous species from leaves to other tissues before leaf senescence as strategy to make the tree independent for these nutrients from the soil in summer and these nutrients are remobilsed by the plants for the formation of new leaves in dry season when the nutrient supply from the soil is not possible (Tripathi and Singh, 1994). The lesser extent of nutrient retranslocation in evergreen species can be attributed to the fact that their leaves have a longer life span and prolonged nutrient retention time and do not necessarily retranslocate it to perennial tissues (Table 4.12). Retranslocation of nitrogen, sodium, potassium and iron was highest in *Ostodes paniculata.* Retranslocation of magnesium was highest in *Engelhardtia spicata.* On an overall, percentage retranslocation of nutrients like sodium, potassium and magnesium were high while it was lowest for iron the reason being its immobility in plant tissues.

Soil nutrient status also played an important role in retranslocation and it is highly related with fertility gradient. The soil carbon status of hmuifang is at an optimum which results in lower retranslocation from leaves to other tissue; on the other hand the soil is poor in nitrogen which resulted in higher retranslocation. Lal *et al.,* 2001, tested the hypothesis that the nutrients withdrawn from the senescing leave support the emergence and expansion of leaves in dry tropical woody species to a significant extent.

Relationship between the Soil Bulk Density and Soil Organic Carbon

The mean soil bulk density of the forest floor was 0.65 g/cm^3 which increases to 1.00 g/cm3 on topmost soil layer (0-10 cm) with a maximum of 1.35 g/cm^3 in 30-40cm soil depth. The Bulk density is gradually increasing with respect to soil depth and the difference in the bulk density implies that the organic matter present in forest floor and 0-10 cm was more as compared to the deeper soil (Fig 4.2). Soil organic carbon was inversely correlated to the soil bulk density.

The SOC content differs according to the depth. The total SOC of the forest soil is 41.85 t C ha^{-1} upto 40 cm soil depth.The topsoil 0-10 cm contributes maximum SOC i.e.18.28 t C ha^{-1} and 30-40 cm soil contributes the least amount of SOC i.e. 6.09 t C ha^{-1} (Sharma *et al.*, 2018).

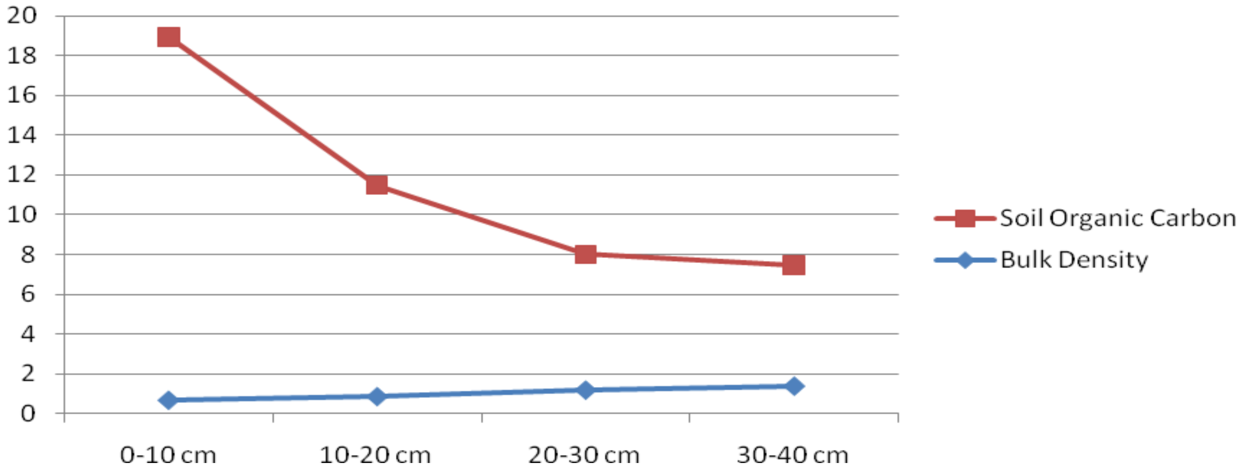

Figure 4.2 Relationship between the Soil Bulk Density and Soil Organic Carbon

Soil	**pH**	**SMC (%)**	**WHC (ml/L)**	**OM (%)**	**N (%)**	**P_2O_5(kgha^{-1})**	**Carbon (%)**
Summer	4.76±0.07	33.77±11	450	7.03±0.91	0.31±0.08	117.98±0.54	3.76±0.08
Rainy	4.43±0.09	41.22±4		7.13±0.66			
Autumn	4.79±0.04	24.62±2		6.93±0.48			

Table 4.13 Soil parameters

SMC-Soil Moisture content, WHC-Water holding capacity, OM-Organic matter, N-Nitrogen, P_2O_5-Available phosphorus, C-Carbon

CHAPTER 5

SUMMARIZATION AND CONCLUSION

The research aims at finding the various biotic and abiotic environmental influences on tree phenology of sub-tropical montane forest of Mizoram. Detailed in-depth research on the vegetative and reproductive phenology of major tree species of Hmuifang forest has shed light on various environmental cues that trigger these events and the constrain that hamper their normal physiological functioning. Monitoring of various temporal phenological events indicated that evergreen, leaf exchanging and deciduous tree species varied with their various intrinsic and extrinsic qualities in relation to abiotic variables, which together regulate the vegetative and reproductive phenophases of the trees in the region.

It is found that variation in leaf size does not determine the deciduousness of a tree rather it varies according to the genetic makeup and/or environment of the species. Among the tree species, value of specific leaf area (SLA) is higher for deciduous species as compared to evergreen species, and it is found that water use efficiency of the species increases with decreasing specific leaf area, which holds true for lower average values of SLA obtained from the evergreen species as compared to deciduous species. Leaf moisture content (LMC) and its periodic difference is found to be lower for evergreen species and leaf moisture regime is more constant for evergreen/leaf exchanging species. In general, for both deciduous and evergreen species, LMC drops during the dry months and is at peak during flush of new leaves. The overall value of Leaf strategy index (LSI) increases with the duration of leaflessness in all the tree species.

There is no significant difference in wood density between evergreen and deciduous tree species. The value of Leaf mass area (LMA) is generally higher for evergreen species but according to the research, it does not hold true for all species studied. The overall variation in LMA is much wider among deciduous species. In general, the values of LMA dropped during formation of new leaves due to the fact that cell wall material and chloroplast are not sufficiently developed. This finding is highly evident in leaf-exchanging species where LMA value drops suddenly during fall of old leaves and simultaneous development of new leaves. The average values of monthly LMA tends to increase during reproductive phase i.e. just before flowering (February to April) and further drops at the time of fruiting, which indicate the flow or allocation of nutrients from leaves to reproductive parts.

Majority of flowering among the species were observed before the onset of monsoon where the photoperiod exceeded 13 hours, the findings highlighted the importance of longer duration of photosynthesis prior to flowering; a resource exhaustive phenomena. The duration of flowering, fruiting and fruit fall varies considerably among the species irrespective of deciduousness. Several trees fruit almost throughout the year while annual fruiting is absent in some which is considered as important ecosystem attributes of the species to the ecosystem services. Synchronisation of fruiting between tree species and longer duration of fruiting in several tree species is essential for future propagation and survival of the tree species themselves; it also sustain the continuity of faunal diversity inside the forests especially for small herbivores, birds, bees and other insects; forming an important component of the food web.

Synchrony index for flowering, fruiting, fruit fall and time lag between vegetative and reproductive phases was calculated. Synchrony of plant reproductive phases for each species is necessary for continuity of species, colonization of available spaces, establishment, and maintenance of wider gene pool and for overall survival of the species. Higher synchrony in flowering resulted in higher frequency of pollination and in production of sufficient quantity of fruits and vice-versa. In majority of the species, fruit fall occur during the months when the precipitation drops to a considerable level, and asynchrony in fruit fall among species may have something to do with better seed dispersal throughout the year, however, there is no clear cut observation on the success of propagation and its relation to species survival. In species having longer time lag, there is a better development of flowers and fruit which can be attributed to better compartmentalization and allocation of nutrients for each phase i.e. vegetative and reproductive; there is a higher stress on nutrients when two phases occur simultaneously, thereby resulting in lower intensity of flowering and fruiting. Findings also reveal that fruiting intensity is higher in leafless branches or those having fewer leaves and vice-versa, an indicator of resource allocation within the tree itself.

It is observed that deciduous tree species have higher leaf mass as well as leaf area compared to evergreen tree species; which is correlated to shorter leaf lifespan in deciduous species which in turn require higher efficiency in accumulating resources and rapidly built up organic matter through photosynthesis within a shorter span of time. Relative leaf growth rate (RLGR) was much higher for deciduous tree species as compared to leaf-exchanging and evergreen species. Higher RLGR is compulsory for deciduous species as faster leaf growth enable the tree to capture more photosynthate and compensate for the absence of photosynthesis during leafless months.

The results obtained from measuring the element content of normal and senesced leaves revealed that carbon content in evergreen trees was slightly higher than deciduous and brevi-deciduous species and the periodic carbon content for majority of the species was higher during monsoon as compared to dry season. However, overall periodic variation in carbon content among both evergreen and deciduous species were quite negligible. There was no significant difference in Nitrogen content between evergreen and deciduous species, however, the overall monthly N content was higher during the wet season compared to dry season. The value of nitrogen retranslocation from senesced leaves to perennial tissues was significantly higher in deciduous species. Additionally, the species exhibit year round fruiting species reflected considerably high percentage of nitrogen retranslocation. The nitrogen retranslocation in trees make them independent for nitrogen supply from soil and the amount of nitrogen retranslocated to perennial parts are remobilized for the formation leaves and fruits as and when required, if the supply of nitrogen is not possible from the soil due to abiotic stress.

The Nitrogen retranslocation efficiency (NReff) was on an average higher in evergreen species, indicating higher additional nitrogen requirement from soil for deciduous species. The finding is backed up by higher CN ratio in evergreen species that enable them to inhabit more N-limited soil conditions as compared to deciduous species.

The concentration of potassium in leaves and retranslocation from senescing leaves to perennial tissues was on an average slightly higher in deciduous tree species and mainly in the months of new leaf and fruit formation validating its role in translocation of water and nutrients which facilitates protein and starch synthesis in leaves and fruits. The concentration of calcium in leaves was more pronounced for deciduous species, as formation of young leaves and shoots occur more frequently in deciduous species, its functional role in formation of cell wall and its abundance is more evident. There was no significant difference between evergreen and deciduous tree species regarding changes in sodium, magnesium and iron content in leaves.

The element mass for leaves i.e. nitrogen, carbon, calcium, potassium, sodium, magnesium and iron were positively and significantly correlated to the relative leaf growth rate. On an average, leaf nutrient mass for all the measured nutrients was much higher for deciduous species as compared to evergreen species. While the percent retranslocation of nitrogen was higher in evergreen species than the deciduous species, the reverse was observed in case of sodium and magnesium. Tripathi and Singh (1994) reported high nutrient translocation in tropical deciduous species and considered the phenomenon of retranslocation as strategy to make the tree independent for these nutrients from the soil in summer when abosorption from the soil is not possible due extremely dry soil (soil temperature < 1%). Authors further reported that these nutrients are remobilsed from the perennial plant parts for the formation of new leaves in dry season when the nutrient supply from the soil is not possible.

The mean soil bulk density of the forest floor was lowest followed by the topmost soil with a maximum in 30-40cm soil depth. The Bulk density gradually increases with soil depth and the difference in the bulk density implies that the organic matter present in forest floor and topsoil was more as compared to the deeper soil. Soil organic carbon was inversely correlated to the soil bulk density. The Soil Organic

Carbon (SOC) content varies according to the depth, the topsoil contributes maximum SOC and deeper soil contributes the least amount.

The present finding shed light on understanding of tree phenology of sub-tropical montane forest and findings have highlighted various vegetative and reproductive parameters of various functional groups of sub-tropical forest. It also showed that how these parameters affect plant life processes and overall functioning of forest ecosystems. The research was the first of its kind in Mizoram and it will pave the way for young scholars having research interest in tree phenology for the coming days. Extensive research, collaborative work and use of modern equipments and techniques will be crucial in order to fully understand the functioning of forest ecosystems.

References

Abrams MD, Kubiske ME (1990) Leaf structural characteristics of 31 hardwood and conifer tree species in central Wisconsin: Influence of light regime and shade-tolerance rank. Forest Ecology and Management 31(4): 245-253.

Ackerly DD, Bazzaz FA (1995) Plant growth and reproduction along CO_2 gradients:non-linear responses and implications for community change. Global change biology 1:199-207.

Ågren GI (2008) Stoichiometry and Nutrition of Plant Growth in Natural Communities.A nnual Review of Ecology, Evolution, and Systematics 39:153-170.

Ågren GI, Wetterstedt JAM, Billberger MFK (2012) Nutrient limitation on terrestrial plant growth – modeling the interaction between nitrogen and phosphorus. New phytologist (Ecological stoichiometry & global change 953-960.

Aono Y, Kazui K (2008) Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century. International Journal of Climatology 28:905-914.

Ares A, Gleason SM (2007) Foliar nutrient resorption in tree species. New Research on Forest Ecology Chapter 1.

Arroyo MTK, Armesto JJ, Villagran C (1981) Plant Phenological Patterns in the High Andean Cordillera of Central Chile. Journal of Ecology 69: 205-223.

Ashman TL, Schoen DJ (1997) The cost of floral longevity in Clarkia tembloriensis: an experimental investigation. EvolBiol 11:289–300 Biogeogr 13:409–425.

Athokpam FD, Garkoti SC (2013) Variation in evergreen and deciduous species leaf phenology in Assam, India. Trees 27: 985–997.

Athokpam FD, Garkoti SC (2015) Dynamics of foliar nitrogen of evergreen and deciduous plant species in a wet tropical forest, South Assam, India. Plant Ecology 216:117–1135.

Augspurger CK (1981) Reproductive Synchrony of a Tropical Shrub: Experimental Studies on Effects of Pollinators and Seed Predators in *Hybanthus prunifolius* (Violaceae). Ecology 62:775-788.

Augspurger CK (1983) Phenology, flowering synchrony, and fruit set of sixneotropical shrubs. Biotropica 15: 257–267.

Badeck FW, Bondeau A, Böttcher K, Doktor D, Lucht W, Schaber J, Sitch S (2004) Responses of Spring Phenology to Climate Change. The New Phytologist 162:295-309.

Baker TR, Phillips OL, Malhi Y, Almeida S, Arroyo L, Di Fiore A, Erwin T, Niro Higuchi, Killeen TJ, Laurance SG, Laurance WF, Lewis SL, Monteagudo A, Neil DA, Vargas PN, Pitman NCA, Silva JNM, Martínez RV (2004) Increasing biomass in Amazonian forest plots. Philosophical Transactions of The Royal Society B 359(1443).

Baraloto C, Paine CET, Patiño S, Bonal D, Hérault B, Chave J (2010) Functional trait variation and sampling strategies in species-rich plant communities. Functional Ecology 24(1):208-216.

Bawa KS, Opler PA (1975) Dioecism in tropical forest trees. Evolution 29:167-179.

Bond GC, Showers W, Elliot M, Evans M, Lotti R, Hajdas I, Bonani G, Johnson S (1999) The North Atlantic's 1–2 kyr climate rhythm: Relation to Heinrich events, Dansgaard/Oeschger cycles and the Little Ice Age, in Mechanisms of Global Climate Change at Millennial Time Scales. Geophys. Monogr 112:35– 58.

Borchert R (1980) Phenology and Ecophysiology of Tropical Trees: *Erythrina poeppigiana* (O. F. Cook). ECOLOGY (esa) :1065-1074.

Borchert R (1983) Phenology and control of flowering in Tropical trees. Biotropica 15:81-89.

Borchert R (1998) Responses of Tropical Trees to Rainfall Seasonality and Its Long-Term Changes. Potential Impacts of Climate Change on Tropical Forest Ecosystems : 241-253.

Borchert R (1999) Climatic Periodicity, Phenology, and Cambium Activity in Tropical Dry Forest Trees. IAWA 20 (3).

Borchert R, Rivera G (2001) Photoperiodic control of seasonal development and dormancy in tropical stem-succulent trees. Tree Physiology 21:213–221.

Borchert R, Meyer SA, Felger RS, Porter-Bolland L (2004) Environmental control offlowering periodicity in Costa Rican and Mexican tropical dry forests. Global Ecol 13: 409-425.

Borchert R, Renner SS, Calle Z, Navarrete D, Tye A, Gautier L, Spichiger R , von Hildebrand P (2005) Photoperiodic induction of synchronous flowering near the Equator. Nature 433:627–629 (10 February 2005).

Boulter SL, Kitching RL, Howlett BG (2006) Family, visitors and the weather: patterns of flowering in tropical rain forests of northern Australia. J Ecol 94:369–382.

Bowman WD, Keller A, Nelson M (1999) Altitudinal Variation in Leaf Gas Exchange, Nitrogen and Phosphorus Concentrations, and Leaf Mass per Area in Populations of *Frasera speciosa.* Arctic, Antarctic, and Alpine Research An Interdisciplinary Journal 31:191-195.

Broadhead JS, Ong CK, Black CR (2003) Tree phenology and water availability in semi-arid agroforestry systems. Forest Ecology and Management180(1–3):61-73.

Brooks JR, Hinckley TM, Sprugel DG (1994) Acclimation responses of mature *Abies amabilis* sun foliage to shading. Oecologia 100: 316-324.

Burslem DFRP, Whitmore TC (2003) Functional diversity and response to disturbance in lowland tropical rain forest on Kolombangara, Solomon Islands. In: Long term changes in composition and diversity as a result of natural and man made disturbances: case studies from the Guyana Shield, Africa, Borneo and Melanesia (ed. H. TerSteege), Tropenbos International, Wageningen, The Netherlands 61-77.

Cabrera RL, Dieringer G (1992) Reproductive Biology of a Population of Acourtiaruncinata (Asteraceae: Mutisieae: Mutisieae) at the Northeastern Limit of its Range. The American Midland Naturalist 128:83-88.

Callado C, da Silva NS, Scarano F, Costa C (2001) Periodicity of growth rings in some flood-prone trees of the Atlantic Rain Forest in Rio de Janeiro, Brazil.Trees, December 15: 492–497.

Calvo-irabien LM, Islas-luna A (1999) Predispersal predation of an understory rainforest herb *Aphelandra aurantiaca* (acanthaceae) in gaps and mature forest. American Journal of Botany 86(8): 1108–1113.

Castro-Diez P, Puyravaud JP, Cornelissen JHC (2000) Leaf structure and anatomy as related to leaf mass per area variation in seedlings of a wide range of woody plant species and types. Oecologia 124: 476-486.

Chen HYH, Klinka K (1998) Survival, growth, and allometry of planted *Larix occidentalis* seedlings in relation to light availability. Forest Ecology and Management 106:169-179.

Chuine I, Beaubien EG (2001) Phenology is a major determinant of tree species range. Ecology Letters 4:500-510.

Clark CJ, Poulsen JR, Connor EF, Parker VT (2004). Fruiting trees as dispersal foci in a semi-deciduous tropical forest. Oecologia 139:66–75.

Condit RS, Ashton MS, Balslev H, Brokaw NVL, Chuyong BS, George BCL, Dattaraja HS, Davies SJ,Esufali SE, Corneille EN, Foster RB, Gunatilleke N, Gunatilleke S, Hernandez C, Hubbell SP, John R, Kenfack D, Kiratiprayoon S, Hall P, Hart TH, Itoh A, LaFrankie JV, Liengola IL, Daniel L, Suzanne L, Elizabeth C, Magard E, Makana JR, Manokaran N, Navarrete H, Mohammed N, Supardi OT, Perez R, Samper CK, HuaSeng LH, Sukumar R, Svenning JC, Tan S, Thomas DW, Thompson JD, Vallejo MI, Villa Muñoz G, Valencia R, Yamakura T, Zimmerman JK (2005) Tropical Tree a-Diversity: Results From a Worldwide Network of Large Plots. BiologiskeSkrifter 55:565–582.

Craufurd PQ, Wheeler TR (2009) Climate change and the flowering time of annual crops. Journal of Experimental Botany 60:2529–2539.

Daryanto S, Wang L, Jacinthe PA (2016) Global Synthesis of Drought Effects on Maize and Wheat Production. PLoS ONE 11(5): e0156362.

de Groot RS, Ketner P (1994) Sensitivity of NW European species and ecosystems to climate change and some implications for nature conservation and management. Impacts of Climate Change on Ecosystems and Species: 29-53.

de la Riva EG, Olmo M, Poorter H, Ubera JL, Villar R (2016) Leaf Mass per Area (LMA) and Its Relationship with Leaf Structure and Anatomy in 34 Mediterranean Woody Species along a Water Availability Gradient. PLoS ONE 11(2): e0148788.

Del Rio E, Berg A (1979) Specific leaf area of Douglas-fir reproduction as affected by light and needle age. For Sci 25:183–186.

Dieringer G (1991) Variation in individual flowering time and reproductive success of agalinisstrictifolia (scrophulariaceae). American Journal of Botany 78:497-503.

Duncan WG, Hesketh JD (1968) Net Photosynthetic Rates, Relative Leaf Growth Rates, and Leaf Numbers of 22 Races of Maize Grown at Eight Temperatures. Crop Science 8:670-674.

Dunne JA, Harte J, Taylor KJ (2003) Subalpine Meadow Flowering Phenology Responses to Climate Change: Integrating Experimental and Gradient Methods. Ecological monographs 73: 69-86.

DW (2008) Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. ECOLOGY (esa) 89(20): 353-362.

Ehlers BK (1999) Variation in fruit set within and among natural populations of the self-incompatible herb Centaureascabiosa (Asteraceae). Nordic Journal of Botany 19:653-663.

Ehrlén J (1996) Spatiotemporal variation in predispersal seed predation intensity. Oecologia 108:708–713.

Ehrlén J, Münzbergová Z (2009) Timing of Flowering: Opposed Selection on Different Fitness Components and Trait Covariation. The American Naturalist 173(6).

Elser JJ, Fagan WF, Denno RF, Dobberfuhl DR, Folarin A, Huberty A, Interlandi S, Kilham SS, McCauley E, Schulz KL, Siemann EH,Sterner RW (2000) Nutritional constraints in terrestrial and freshwater food webs. Nature 408:578–580.

Fellner H, Dirnberger GF, Sterba H (2016) Specific leaf area of European Larch (*Larix decidua* MILL.). Trees 30:1237–1244.

Feng X, Porporato A, Rodriguez-Iturbe I (2013) Changes in rainfall seasonality in the tropics.Nature Climate Change 3:811–815.

Fern K (2021) Tropical Plants Database. tropical.theferns.info.

Field C, Merino J, Mooney HA (1983) Compromises between water-use efficiency and nitrogen-use efficiency in five species of California evergreens. Oecologia 60:384-389.

Fischer RA, Hsiao TC (1968) Stomatal Opening in Isolated Epidermal Strips of *Vicia faba*. II. Responses to KCl Concentration and the Role of Potassium Absorption. Plant physiology 43:1953-1958.

Fitter A, Hay R (2002) Energy and Carbon. Environmental Physiology of Plants (Third Edition) 23-73.

Flora of China 4:339.

Flora of China 7:235- 237.

Flora of China 13: 48- 49.

Franco AC, Bustamante M, Caldas LS, Goldstein G, Meinzer FC, Kozovits AR, Rundel P, Coradin VTR (2005) Leaf functional traits of Neotropical savanna trees in relation to seasonal water deficit. Trees19:326–335.

Frankie GW, Baker HG, Opler PA (1974) Comparative Phenological Studies of Trees in Tropical Wet and Dry Forests in the Lowlands of Costa Rica. Journal of Ecology 62: 881-919.

Garnier E (1992) Growth analysis of congeneric annual and perennial grass species. J Ecol 80:665–675.

Gentry AH (1974) Flowering Phenology and Diversity in Tropical Bignoniaceae. Biotropica 6:64-68.

Gholz HL, Fitz FK, Waring RH (1976) Leaf area differences associated with old-growth forest communities in the western Oregon Cascades. Can J For Res 6:49–57.

Giorio P, Sorrentino G, d’Andria R (1999) Stomatal behaviour, leaf water status and photosynthetic response in field-grown olive trees under water deficit. Environmental and Experimental Botany 42:95-104.

Gower ST, Richards JH (1990) Larches: deciduous conifers in an evergreen world—in their harsh environments, these unique conifers support a net carbon gain similar to evergreens. Bioscience 40:818–826.

Greenwood S, Ruiz-Benito P, Martínez-Vilalta J, Lloret F, Kitzberger T, Allen CD, Fensham R, Laughlin DC, Kattge J, Bönisch G, Kraft NJB, Jump AS (2017) Tree mortality across biomes is promoted by drought intensity, lower wood density and higher specific leaf area. Ecology Letters 20:539-553.

Greig N (1993) Predispersal seed predation on five *Piper* species in tropical rainforest. Oecologia 93:412–420.

Grime JP (2001) Plant strategies, vegetation processes and ecosystem properties, 2nd edn. Chichester: Wiley.

Grogan P, Lalnunmawia F, Tripathi SK (2012) Shifting cultivation in steeply sloped regions: a review of management options and research priorities for Mizoram state, Northeast India. Agroforestry Systems 84:163-177.

Gulmon SL, Chu CC (1981) The effects of light and nitrogen on photosynthesis, leaf characteristics, and dry matter allocation in the chaparral shrub, *Diplacus aurantiacus*. Oecologia 49:207-212.

Günter S, Stimm B, Cabrera M, Diaz ML, Lojan M, Ordoñez MLE, Richter M, Weber M (2008) Tree phenology in montane forests of southern Ecuador can be explained by precipitation, radiation and photoperiodic control. Journal of Tropical Ecology 24:247-258.

Gutschick VP, Wiegel FW (1988) Optimizing the canopy photosynthetic rate by patterns of investment in specific leaf mass. The American Naturalist 132: 67-86.

Hänninen H, Tanino K (2011) Tree seasonality in a warming climate. Trends in Plant Science 16:412-416.

Hassler M (2018) World Plants: Synonymic Checklists of the Vascular Plants of the World.

Haverd V, Cuntz M, Nieradzik LP, Harman I (2016) Improved representations of coupled soil–canopy processes in the CABLE land surface model. Geoscientific Model Development 9 (9):3111-3112.

Henry AN, Kumari GR, Chitra V (1987) Flora of Tamil Nadu India 1(2).

Hoffmann WA, Franco AC, Moreira MZ, Haridasan M (2005) Specific leaf area explains differences in leaf traits between congeneric savanna and forest trees. Functional ecology 19(6): 932-940.

Hulme M, Viner D (1998) A Climate Change Scenario for the Tropics.Potential Impacts of Climate Change on Tropical Forest Ecosystems :5-36.

Ibáñez I, Primack RB, Rushing AJM, Ellwood E, Higuchi H, Lee SD, Kobori H, Silander JA (2010) Forecasting phenology under global warming. Philosophical transactions of The Royal Society B 365(1555).

Inouye DW (2008) Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89: 353-362.

Jackson JF (1978) Seasonality of Flowering and Leaf-Fall in a Brazilian Subtropical Lower Montane Moist Forest. Biotropica 10: 38-42.

Janzen DH (1971) Seed Predation by Animals.Annual Review of Ecology and Systematics 2:465-492.

Johnson IR, Thornley JHM (1985) Temperature Dependence of Plant and Crop Process. Annals of Botany 55:1–24.

Keatinge JDH, Qi A, Wheeler TR, Hellis R, Summerfield RJ (1998) Effects of temperature and photoperiod on phenology as a guide to the selection of annual legume cover and green manure crops for hillside farming systems. Field Crops Research 57(2):139-152.

Kigel J, Konsens I, Rosen N, Rotem G, Kon A, Sapir F (2011) Relationships Between Flowering Time and Rainfall Gradients Across Mediterranean-Desert Transects. Israel Journal of Ecology and Evolution57(1-2).

Kikim A, Yadava PS (2001) Phenology of tree species in subtropical forests of Manipur in north eastern India. Tropical Ecology 42(2): 269-276.

Kikuzawa K (1995) The basis for variation in leaf longevity of plants. Vegetatio 121: 89–100.

Kikuzawa K, Lechowicz MJ (2011) Ecology of Leaf Longevity. Ecological Research Monographs.

King DA, Davies SJ, Tan S, Noor NSM (2006) The role of wood density and stem support costs in the growth and mortality of tropical trees. Journal of Ecology 94:670-680.

Körner C (1989) The nutritional status of plants from high altitudes: A worldwide comparison. Oecologia 81: 379–391.

Kozlowski TT, Clausen JJ (1965) Changes in Moisture Contents and Dry Weights of Buds and Leaves of Forest Trees. International Journal of Plant Sciences 126(1).

Kraft NJB, Rand V, Ackerly DA (2008) Functional Traits and Niche-Based Tree Community Assembly in an Amazonian Forest. Science 322: 580-582.

Kumar KS (2016) Reproductive phenology, pollen production and pollinator availability in some tropical trees of Aizawl, Mizoram. Ph.D. Thesis (unpublished), Digital Repository, Mizoram University, India.

Kumar U, Singh P, Boote KJ (2012) Effect of Climate Change Factors on Processes of Crop Growth and Development and Yield of Groundnut (*Arachis hypogaea* L.). Advances in Agronomy 116:41-69.

Kushwaha CP, Tripathi SK, Singh KP (2011) Tree specific traits affect flowering time in Indian dry tropical forest. Plant Ecol 212:985-998.

Lal CB, Annapurna C, Raghubanshi AS, Singh JS (2001) Foliar demand and resource economy of nutrients in dry tropical forest species. Journal of Vegetation Sciences 12(1):5-14

Lambers H, Poorter H (1992) Inherent variation in growth rate between higher plants: a search for physiological causes and ecological consequences. Advances in Ecological Research 23: 187.

Lasso E, Ackerman JD (2003) Flowering Phenology of *Werauhia sintenisii*, a Bromeliad from the Dwarf Montane Forest in Puerto Rico: an Indicator of Climate Change? Selbyana 24:95-104.

Lieth H (1974) Phenology and Seasonality Modeling. Berlin, Germany: Springer.

Liu L, Wallach D, Li J, Liu B, Xiang L, Tang ZL, Yu Zhang, Qiu X, Cao W, Zhu Y (2018) Uncertainty in wheat phenology simulation induced by cultivar parameterization under climate warming. European Journal of Agronomy 94:46-53.

Lobo JA, Quesada M, Stoner KE, Fuchs EJ, Herrerías Diego Y, Rojas J, Saborío G (2003) Factors affecting phenological patterns of bombacaceous trees in seasonal forests in Costa Rica and Mexico. American Journal of botany 90:I 1054-1063.

Louda SM (1982) Distribution Ecology: Variation in Plant Recruitment over a Gradient in Relation to Insect Seed Predation. Ecological monographs 52:25-41.

Louda SM, Potvin MA (1995) Effect of Inflorescence Feeding Insects on the Demography and Lifetime of a Native Plant. Ecology (esa) 76:229-245.

Mamood AN, Ray DT, Waller GD (1990) Seed set in Guayule (*Parthenium argentatum*, asteraceae) in relation to insect pollination. Economic Botany44:440–444.

Mani S, Cao M (2019) Nitrogen and Phosphorus Concentration in Leaf Litter and Soil in Xishuangbanna Tropical Forests: Does Precipitation Limitation Matter? Forests 10(3).

Marenco RA, Antezana-Vera SA, Nascimento HCS (2009) Relationship between specific leaf area, leaf thickness, leaf water content and *SPAD-502* readings in six Amazonian tree species.Photosynthetica 47:184–190.

Marques MCM, Roper JJ, Salvalaggio APB (2004) Phenological patterns among plant life-forms in a subtropical forest in southern Brazil. Plant Ecology173: 203–213.

Marshall JD, Monserud RA (2003) Foliage height influences specific leaf area of three conifer species. Canadian Journal of Forest Research 33: 164-170.

McEwan RW, Brecha RJ, Geiger DR, John GP (2011) Flowering phenology change and climate warming in southwestern Ohio. Plant Ecology212:55–61.

McGrath LJ, van Riper C III, Fontaine JJ (2009) Flower power: tree flowering phenology as a settlement cue for migrating birds. Journal of Animal Ecology 78:22-30.

McKenna MF, Houle G (2000) Why are annual plants rarely spring ephemerals? The New Phytologist 148:295-302.

Mengel K, Kirkby EA (2001) Principles of plant nutrition. Dordrecht: Kluwer Academic Publishers: 849.

Monserud RA, Marshall JD (1999) Allometric crown relations in three northern Idaho conifer species. Can J For Res 535:521–535.

Morel H, Mangenet T, Beauchêne J, Ruelle J, Nicolini E, Heuret P, Thibaut B (2015) Seasonal variations in phenological traits: leaf shedding and cambial activity in *Parkia nitida* Miq. And *Parkia velutina* Benoist (Fabaceae) in tropical rainforest. Trees 29: 973–984.

Mosquin T (1971) Competition for Pollinators as a Stimulus for the Evolution of Flowering Time.Oikos 22:398-402.

Munguía Rosas MA, Ollerton J, Parra Tabla V, De Nova JA (2011) Meta-analysis of phenotypic selection on flowering phenology suggests that early flowering plants are favoured. Ecology Letters14:511-521.

Nagel LM, O'Hara KA (2006) Functional Comparison of Productivity in Even-Aged and Multiaged Stands: A Synthesis for *Pinus ponderosa*. Forest Science 52(3):290-303.

Nakano K, Shibahara N, Nakai T, Shintani K, Komata H, Iwaoka M, Hattori N (2018) Greenhouse gas emissions from round wood production in Japan. Journal of Cleaner Production 170:1654-1664.

Negi JDS, Manhas RK, Chauhan PS (2003) Carbon allocation in different components of some tree species in India: A new approach for carbon estimation. Current Science 85(11): 1528-1531.

Negi GCS, Singh SP (1992) Leaf growth pattern in evergreen and deciduous species of the Central Himalaya, India. International Journal of Biometeorology 36:233–242.

Niinemets UD (2006) The controversy over traits conferring shade-tolerance in trees: ontogenetic changes revisited. Journal of Ecology 94: 464-470.

Nomura N, Kikuzawa K, Kitayama K (2003) Leaf Flushing Phenology of Tropical Montane Rain Forests: Relationship to Soil Moisture and Nutrients. TROPICS 12(4).

Ollerton J, Lack AJ (1992) Flowering phenology: An example of relaxation of natural selection? Trends in Ecology and Evolution 7:274-276.

Opler PA, Frankie GW, Baker HG (1976) Rainfall as a Factor in the Release, Timing, and Synchronization of Anthesis by Tropical Trees and Shrubs.Journal of Biogeography 3:231-23.

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A (2009) Agroforestree Database:a tree reference and selection guide version 4.0.

Pakkad G, Elliott S, Anusarnsunthorn V (2002) Proceedings of the Southeast Asian Moving Workshop on Conservation, Management and Utilization of Forest Genetic Resources No. 31.

Patterson S (2020) Fixing Magnesium Deficiency in Plants: How Magnesium Affects Plant Growth. Gardening Knowhow (www.gardeningknowhow.com).

Peñuelas J, Filella I, Zhang X, Llorens L, Ogaya R, Lloret F, Comas P, Estiarte M, Terradas J (2004) Complex spatiotemporal phenological shifts as a response to rainfall changes. New Phytologist161(3):837-846.

Poorter H, Niinemets Ü, Poorter L, Wright IJ, Villar R (2009) Causes and Consequences of Variation in Leaf Mass Per Area (LMA): A Meta-Analysis. New Phytologist 182:565-588.

Poorter H, Bergkotte M (1992) Chemical composition of 24 wild species differing in relative growth rate. Plant, Cell & Environment 15:221-229.

Poorter H, Remkes C, Lambers H (1990) Carbon and Nitrogen Economy of 24 Wild Species Differing in Relative Growth Rate. Plant physiology (ASPB) 94(2).

Poorter H, Remkes C (1990) Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. Oecologia83:553–559.

Poorter L, Bongers F (2006) Leaf traits are good predictors of plant performance across 53 rain forest species. Ecology 87(7):1733-43.

Prado-Junior JA, Schiavini I, Vale VS, Arantes CS, van der Sande MT, Lohbeck M, Poorter L (2016) Conservative species drive biomass productivity in tropical dry forests. Journal of Ecology 104:817–827.

Whitmore P (1973) Tree Flora of Malaya f. 2.

Qin BLHN (2013) Journal of Systematics and Evolution 51 (1): 94–114.

Quintero JM, Fournier JM, Benlloch M (1999) Water transport in sunflower root systems: effects of ABA, Ca^{2+} status and $HgCl_2$. Journal of Experimental Botany 50:1607-1612.

Ramesh BR, Ayyappan N, Grard P, Prosperi J, Aravajy S, Pascal JP (2004) Biodiversity documentation for Kerala- Flowering Plants 6: 275.

Rathcke B, Lacey EP (1985) Phenological Patterns of Terrestrial Plants.Annual Review of Ecology and Systematics 16:179-21.

Reich PB (1995) Phenology of tropical forests: patterns, causes and consequences. Canadian Journal of Botany 73: 164-174.

Reich PB, Borchert R (1984) Water stress and tree phenology in a tropical dry forest in the lowlands of Costa Rica. Journal of Ecology 72:61-74.

Reich PB, Uhl C, Walters MB, Prugh L, Ellsworth DS (2004) Leaf Demography and Phenology in Amazonian Rain Forest: A Census of 40 000 Leaves of 23 Tree Species. Ecological Monographs 74:3-23.

Reich PB, Walters MB, Ellsworth DS (1997) From tropics to tundra: global convergence in plant functioning. Proceedings of the National Academy of Sciences of the USA 94: 13730–13734.

Reich PB, Walters MB, Ellsworth DS, Uhl C (1994) Photosynthesis-nitrogen relations in Amazonian tree species.Oecologia 97: 62-7.

Rivera G, Elliott H, Caldas LS, Nicolossi G, CoradinVTR, Borchert R (2002) Increasing day-length induces spring flushing of tropical dry forest trees in the absence of rain. Trees 16:445-456.

Roff DA (2002) Life history evolution.Sinauer, Sunderland.

Roitman GG (1999) Pollination biology of *Grindelia covasii* (Asteraceae), a potential crop for arid lands. Journal of Arid Environments 43:103-110.

Sakai S (2001) Phenological diversity in tropical forests. Population Ecology 43: 77-86.

Sasidharan N (2017) Kerala Forest Research Institute, Peechi.

Sayer EJ, Newbery DM (2003) The role of tree size in the leafing phenology of a seasonally dry tropical forest in Belize, Central America. Journal of Tropical Ecology 19:539-548.

Schmitt J (1983) Individual flowering phenology, plant size, and reproductive success in *Linanthus androsaceus*, a California annual. Oecologia 59:135–140.

Schwartz MD (2003) Phenology: an integrative environmental science.

Shackleton CM (2001) Rainfall and topo-edaphic influences on woody community phenology in South African savannas. Global Ecology and Biogeography 8(2):125-136.

Sharma BD (1984) Biodiversity Documentation for Kerala 6: Flowering Plants.

Sharma SB, Singh NS, Lalruatfela R (2018) Tree diversity and carbon stocks of Hmuifang forest, Mizoram. International Journal of Research in BioSciences 7(1): 87-99.

Sheppard AW, Cullen JM, Aeschlimann JP (1994) Predispersal seed predation on *Carduus nutans* (Asteraceae) in southern Europe. ActaOecol 15:529–541.

Sherry RA, Zhou X, Gu S, Arnone III JA, Schimel DS, Verburg PS, Wallace LL, Luo Y(2007) Divergence of reproductive phenology under climate warming.PNAS 104 (1):198-202.

Shukla RP, Ramakrishnan PS (1984) Leaf dynamics of tropical trees related to successional status. New Phytologist 97:697-706.

Simpson WT (1993) Determination and use of moisture diffusion coefficient to characterize drying of northern red oak (*Quercus rubra*). Wood Science and Technology 27: 409–420.

Singh KP, Kushwaha CP (2005) Emerging paradigms of tree phenology in dry tropics.Current Science 89: 964-975.

Singh KP, Kushwaha CP (2006) Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Ann Bot 97:265–276.

Singh ShB, Mishra BP, Tripathi SK (2015) Recovery of plant diversity and soil nutrients during stand development in subtropical forests of Mizoram, Northeast India. Biodiversitas 16: 205-212.

Smith DM (1954) Maximum moisture content method for determining specific gravity of small wood samples. Madison, Wis. : U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory.

Smith JF (2001) High Species Diversity in Fleshy Fruited Tropical Understory Plants. The American Naturalist 157: 646-653.

Sobrado MA (1991) Cost-benefit relationships in deciduous and evergreen leaves of tropical dry forest species. Functional Ecology 5: 608-616.

Soepadmo E, Saw LG, Chung, Richard CK, Kiew R (2007). Tree Flora of Sabah and Sarawak 6:335.

Soepadmo E, Saw LG, Chung, Richard CK (2002) Tree Flora of Sabah and Sarawak 4: 388.

Soepadmo E, Saw LG, Chung, Richard CK (2002) Tree Flora of Sabah and Sarawak 4:174–175.

Stephenson AG (1981) Flower and Fruit Abortion: Proximate Causes and Ultimate Functions. Annual Review of Ecology and Systematics.

Sterner RW, Elser JJ (2002) Ecological stoichiometry: the biology of elements from molecules to the biosphere.

Sundarapandian SM, Chandrasekaran S, Swamy PS (2005) Phenological behaviour of selected tree species in tropical forests at Kodayar in the Western Ghats, Tamil Nadu, India. Current Science 88: 5, 10.

Tashi S (2017) Soil carbon stocks under different forest types in Bhutan, Eastern Himalayas. University of Sydney Faculty of Agriculture and Environment.

Thomas SC, Martin AR (2012) Carbon Content of Tree Tissues: A Synthesis. Forests 3(2): 332-352.

Thomas B, Vince-Prue D (1997) Photoperiodic control of flower initiation: Some general principles. Photoperiodism in plants. 2nd Ed. Academic Press.

Thomas SC, Winner WE (2002) Photosynthetic differences between saplings and adult trees: a meta-analysis. Tree Physiology 22: 117-127.

Tian D,Yan Z, Niklas KJ, Han W, Kattge J, Reich PB, Luo Y, Chen Y, Tang Z, Hu H, Wright IJ, Schmid B, Fang J (2018) Global leaf nitrogen and phosphorus stoichiometry and their scaling exponent. National Science Review 5:728-739

Tognetti R, d'Andria R, Morelli G, Calandrell D, Fragnito F (2004) Irrigation effects on daily and seasonal variations of trunk sap flow and leaf water relations in olive trees. Plant and Soil 263:249–264.

Tripathi SK, Roy A, Kushwaha D, Lalnunmawia F, Lalnundanga, Lalraminghlova H, Lalnunzira C (2016) Perspectives of Forest Biodiversity Conservation in Northeast India. J Biodivers Biopros Dev 3: 157.

Tripathi SK, Singh KP (1992a) Abiotic and litter quality control during the decomposition of different plant parts in a dry tropical bamboo savanna in India. Pedobiologia 36: 241- 256.

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

Tripathi SK, Singh KP (1994) Productivity and nutrient cycling in recently harvested and mature bamboo savannas in the dry tropics. Journal of Applied Ecology 31: 109-124.

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

Tropical Plants Database, Ken Fern. tropical.theferns.info.

Van Schaik CP, Terborgh JW, Wright SJ (1993) The Phenology of Tropical Forests: Adaptive Significance and Consequences for Primary Consumers. Annual Review of Ecology and Systematics 24:353-377.

Villar M, Merino JA (2001) Comparison of leaf construction cost in woody species with differing leaf life-spans in contrasting ecosystems. New Phytologist 151: 213-226.

Visser MD, Jongejans E, van Breugel M, Zuidema PA, Chen YY, Kassim AR, de Kroon H (2011) Strict mast fruiting for a tropical dipterocarp tree:a demographic cost–benefit analysis of delayedreproduction and seed predation. Journal of Ecology 99:1033–1044.

Visser ME, Van Noordwijk AJ, Tinbergen JM, Lessells CM (1998) Warmer springs lead to mistimed reproduction in great tits (Parus major). Proceedings of The Royal Society B 265(1408).

Vitasse Y, Bresson CC, Kremer A, Michalet R, Delzon S (2010) Quantifying phenological plasticity to temperature in two temperate tree species. Functional Ecology 24: 1211-1218.

Walther BD, Kingsford MJ, O'Callaghan MD, Mc Culloch MT (2010) Interactive effects of ontogeny, food ration and temperature on elemental incorporation in otoliths of a coral reef fish. Environmental Biology of Fishes 89:441–451.

Way DA, Montgomery RA (2015) Photoperiod constraints on tree phenology, performance and migration in a warming world. Plant, Cell and Environment 38:1725-1736.

Way DA, Yamori W (2014) Thermal acclimation of photosynthesis: on the importance of adjusting our definitions and accounting for thermal acclimation of respiration. Photosynthesis Research119(1–2):89–100.

Westoby M, Falster DS, Moles AT, Vesk PA, Wright IJ (2002) Plant ecological strategies: some leading dimensions of variation between species. Annual Review of Ecology & Systematics 33: 125-159.

Wiart C (2006) Medicinal Plant of Asia-Pacific-Drugs for the Future. World Scientific Publishing Co. Pte. Ltd., British Library Cataloguing-in-Publication 380.

Williams RJ, Myers BA, Muller WJ, Duff GA, Eamus D (1997) Leaf phenology of woody species in a north Australian tropical savanna. Ecology 78:2542-2558.

Withington JM, Reich PB, Oleksyn J, Eissenstat DM (2006) Comparisons of structure and life span in roots and leaves among temperate trees. EcolMonogr 76:381-397

Woodward FI (1987) Climate and Plant Distribution. Cambridge University Press**.**

Wright IJ, Leishman MR, Read C, Westoby M (2006) Gradients of light availability and leaf traits with leaf age and canopy position in 28 Australian shrubs and trees. Functional Plant Biology 33: 407-419.

Wright IJ, Westoby M (2003) Nutrient concentration, resorption and lifespan: leaf traits of Australian sclerophyll species. Functional ecology 17(1): 10-19.

Wright IJ, Reich PB, Cornelissen JHC, Falster DS, Gamier E, Hikosaka K, Lamont BB, Lee W, Oleksyn J, Osada N, Poorter H, Villar R, Warton DI, Westoby M (2005) Assesing the generality of global leaf trait relationships. New Phytologist 166: 485-496.

Wright IJ, Reich PB, Westoby M, Ackerly DD, Baruch Z, Bongers F, Bares JC, Chapin T, Cornelissen JHC, Diemer M, Flexas J, Garnier E, Groom PK, Gulias J , Hikosaka K , Lamont BB, Lee T, Lee W, Lusk C, Midgley JJ, Navas ML, Niinemets Ü, Oleksyn J, Osada N, Poorter H, Poot P, Prior L, Pyankov VI, Roumet C, Thomas SC, Tjoelker MG, Veneklaas EJ, Villar R (2004) The worldwide leaf economics spectrum. Nature 428: 821-827.

Wright IJ, Reich PR, Westoby M (2001) Strategy shifts in leaf physiology, structure and nutrient content between species of high and low rainfall and high and low nutrient habitats. Functional ecology 15(4): 423-434.

Wright IJ, Westoby M (2002) Leaves at low versus high rainfall: coordination of structure, lifespan and physiology. New Phytologist 155: 403-416.

Wright SJ, Van Schaik CP (1994) Light and the Phenology of Tropical Trees. The American Narturalist 143(1).

Wyn Jones RG, Brady CJ, Speirs J (1979) Ionic and osmotic relations in plant cells. Recent advances in cereal biochemistry: 63-103.

Xiao CW, Janssens IA, Yuste JC, Ceulemans R (2006) Variation of specific leaf area and upscaling to leaf area index in mature Scots pine. Trees-StructFunct 20:304-310.

Zhang J, He N, Liu C, Xu L, Chen Z, Li Y, Wang R, Yu G, Sun W, Xiao C, Chen HYH, Reich PB (2019) Variation and evolution of C:N ratio among different organs enable plants to adapt to N-limited environments. Global Change Biology 26 (4): 2534-2543.

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ABSTRACT

PHENOLOGICAL DIVERSITY AND LEAF DYNAMICS OF MAJOR TREE SPECIES AND SOIL NUTRIENTS IN A SUBTROPICAL FOREST STAND OF MIZORAM

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ABSTRACT

The research aims at finding the various biotic and abiotic environmental influences on tree phenology of sub-tropical montane forest of Mizoram. Detailed in-depth research on the vegetative and reproductive phenology of major tree species of Hmuifang forest has shed light on various environmental cues that trigger these events and the constrain that hamper their normal physiological functioning. Monitoring of various temporal phenological events indicated that evergreen, leaf exchanging and deciduous tree species varied with their various intrinsic and extrinsic qualities in relation to abiotic variables, which together regulate the vegetative and reproductive phenophases of the trees in the region.

It is found that variation in leaf size does not determine the deciduousness of a tree rather it varies according to the genetic makeup and/or environment of the species. Among the tree species, value of specific leaf area (SLA) is higher for deciduous species as compared to evergreen species, and it is found that water use efficiency of the species increases with decreasing specific leaf area, which holds true for lower average values of SLA obtained from the evergreen species as compared to deciduous species. Leaf moisture content (LMC) and its periodic difference is found to be lower for evergreen species and leaf moisture regime is more constant for evergreen/leaf exchanging species. In general, for both deciduous and evergreen species, LMC drops during the dry months and is at peak during flush of new leaves. The overall value of Leaf Strategy Index (LSI) increases with the duration of leaflessness in all the tree species.

There is no significant difference in wood density between evergreen and deciduous tree species. The value of Leaf mass area (LMA) is generally higher for evergreen species but according to the research, it does not hold true for all species studied. The overall variation in LMA is much wider among deciduous species. In general, the values of LMA dropped during formation of new leaves due to the fact that cell wall material and chloroplast are not sufficiently developed. This finding is highly evident in leaf-exchanging species where LMA value drops suddenly during fall of old leaves and simultaneous development of new leaves. The average values of monthly LMA tends to increase during reproductive phase i.e. just before

flowering (February to April) and further drops at the time of fruiting, which indicate the flow or allocation of nutrients from leaves to reproductive parts.

Majority of flowering among the species were observed before the onset of monsoon where the photoperiod exceeded 13 hours, the findings highlighted the importance of longer duration of photosynthesis prior to flowering; a resource exhaustive phenomena. The duration of flowering, fruiting and fruit fall varies considerably among the species irrespective of deciduousness. Several trees fruit almost throughout the year while annual fruiting is absent in some which is considered as important ecosystem attributes of the species to the ecosystem services. Synchronisation of fruiting between tree species and longer duration of fruiting in several tree species is essential for future propagation and survival of the tree species themselves; it also sustain the continuity of faunal diversity inside the forests especially for small herbivores, birds, bees and other insects; forming an important component of the food web.

Synchrony index for flowering, fruiting, fruit fall and time lag between vegetative and reproductive phases was calculated. Synchrony of plant reproductive phases for each species is necessary for continuity of species, colonization of available spaces, establishment, and maintenance of wider gene pool and for overall survival of the species. Higher synchrony in flowering resulted in higher frequency of pollination and in production of sufficient quantity of fruits and vice-versa. In majority of the species, fruit fall occur during the months when the precipitation drops to a considerable level, and asynchrony in fruit fall among species may have something to do with better seed dispersal throughout the year, however, there is no clear cut observation on the success of propagation and its relation to species survival. In species having longer time lag, there is a better development of flowers and fruit which can be attributed to better compartmentalization and allocation of nutrients for each phase i.e. vegetative and reproductive; there is a higher stress on nutrients when two phases occur simultaneously, thereby resulting in lower intensity of flowering and fruiting. Findings also reveal that fruiting intensity is higher in leafless branches or those having fewer leaves and vice-versa, an indicator of resource allocation within the tree itself.

It is observed that deciduous tree species have higher leaf mass as well as leaf area compared to evergreen tree species; which is correlated to shorter leaf lifespan in deciduous species which in turn require higher efficiency in accumulating resources and rapidly built up organic matter through photosynthesis within a shorter span of time. Relative leaf growth rate (RLGR) was much higher for deciduous tree species as compared to leaf-exchanging and evergreen species. Higher RLGR is compulsory for deciduous species as faster leaf growth enable the tree to capture more photosynthate and compensate for the absence of photosynthesis during leafless months.

The results obtained from measuring the element content of normal and senesced leaves revealed that carbon content in evergreen trees was slightly higher than deciduous and brevi-deciduous species and the periodic carbon content for majority of the species was higher during monsoon as compared to dry season. However, overall periodic variation in carbon content among both evergreen and deciduous species were quite negligible. There was no significant difference in Nitrogen content between evergreen and deciduous species, however, the overall monthly N content was higher during the wet season compared to dry season. The value of nitrogen retranslocation from senesced leaves to perennial tissues was significantly higher in deciduous species. Additionally, the species exhibit year round fruiting species reflected considerably high percentage of nitrogen retranslocation. The nitrogen retranslocation in trees make them independent for nitrogen supply from soil and the amount of nitrogen retranslocated to perennial parts are remobilized for the formation leaves and fruits as and when required, if the supply of nitrogen is not possible from the soil due to abiotic stress.

The Nitrogen retranslocation efficiency (NReff) was on an average higher in evergreen species, indicating higher additional nitrogen requirement from soil for deciduous species. The finding is backed up by higher CN ratio in evergreen species that enable them to inhabit more N-limited soil conditions as compared to deciduous species.

The concentration of potassium in leaves and retranslocation from senescing leaves to perennial tissues was on an average slightly higher in deciduous tree species and mainly in the months of new leaf and fruit formation validating its role in translocation of water and nutrients which facilitates protein and starch synthesis in leaves and fruits. The concentration of calcium in leaves was more pronounced for deciduous species, as formation of young leaves and shoots occur more frequently in deciduous species, its functional role in formation of cell wall and its abundance is more evident. There was no significant difference between evergreen and deciduous tree species regarding changes in sodium, magnesium and iron content in leaves.

The element mass for leaves i.e. nitrogen, carbon, calcium, potassium, sodium, magnesium and iron were positively and significantly correlated to the relative leaf growth rate. On an average, leaf nutrient mass for all the measured nutrients was much higher for deciduous species as compared to evergreen species. While the percent retranslocation of nitrogen was higher in evergreen species than the deciduous species, the reverse was observed in case of sodium and magnesium. Tripathi and Singh (1994) reported high nutrient translocation in tropical deciduous species and considered the phenomenon of retranslocation as strategy to make the tree independent for these nutrients from the soil in summer when abosorption from the soil is not possible due extremely dry soil (soil temperature < 1%). Authors further reported that these nutrients are remobilsed from the perennial plant parts for the formation of new leaves in dry season when the nutrient supply from the soil is not possible.

The mean soil bulk density of the forest floor was lowest followed by the topmost soil with a maximum in 30-40 cm soil depth. The Bulk density gradually increases with soil depth and the difference in the bulk density implies that the organic matter present in forest floor and topsoil was more as compared to the deeper soil. Soil organic carbon was inversely correlated to the soil bulk density. The Soil Organic Carbon (SOC) content varies according to the depth, the topsoil contributes maximum SOC and deeper soil contributes the least amount.

The present finding shed light on understanding of tree phenology of sub-tropical montane forest and findings have highlighted various vegetative and reproductive parameters of various functional groups of sub-tropical forest. It also showed that how these parameters affect plant life processes and overall functioning of forest ecosystems. The research was the first of its kind in Mizoram and it will pave the way for young scholars having research interest in tree phenology for the coming days. Extensive research, collaborative work and use of modern equipments and techniques will be crucial in order to fully understand the functioning of forest ecosystems.