SOIL CARBON EFFLUX AND LITTER DECOMPOSITION IN NATURAL FORESTS OF KFRI PEECHI CAMPUS

By

NIRAJLAL K.

(2012 - 20 - 121)

THESIS

Submitted in partial fulfilment of the

Requirements for the degree of

B.Sc. – M.Sc. (Integrated) CLIMATE CHANGE ADAPTATION

FACULTY OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

2017

DECLARATION

I, Nirajlal K. (2012–20–121) hereby declare that this thesis entitled **“Soil carbon efflux and litter decomposition in natural forests of KFRI Peechi campus”** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellanikkara
19-03-2018

Nirajlal K
(2012-20-121)

CERTIFICATE

Certified that this thesis entitled **"Soil carbon efflux and litter decomposition in natural forests of KFRI Peechi campus"** is a record of research work done independently by Mr. Nirajlal K., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara
19-03-2018

Dr. K. A Sreejith
Scientist B, Department of Forest Ecology,
Kerala Forest Research Institute,
Peechi, Thrissur

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Nirajlal K., a candidate for the degree of **B.Sc. – M.Sc. (Integrated) Climate Change Adaptation** agree that the thesis entitled **"Soil carbon efflux and litter decomposition in natural forests of KFRI Peechi campus"** may be submitted by Mr. Nirajlal k. in partial fulfilment of the requirement for the degree.

19/03/2018
Dr. K. A Sreejith
(Chairman, Advisory Committee)
Scientist B,
Department of Forest Ecology,
Kerala Forest Research Institute,
Peechi, Thrissur

19/03/2018
Dr. T. K. Kunhamu
Special Officer and Head,
Academy of Climate Change Education
and Research (ACCER),
Kerala Agricultural University,
Vellanikkara

19/03/2018
Dr. S. Sandeep
Scientist-B,
Department of Soil Science,
Kerala Forest Research Institute,
Peechi, Thrissur

19/03/2018.
Prof. (Dr.) Betty Bastin
Dept. of Soil Science and
Agricultural Chemistry,
College of Horticulture,
Kerala Agricultural University,
Vellanikkara

(EXTERNAL EXAMINER)

Dr. C. BUVANESWARAN, Ph.D.,
SCIENTIST
INSTITUTE OF FOREST GENETICS
AND TREE BREEDING
COIMBATORE - 641 002

ACKNOWLEDGEMENT

First of all, I am grateful to 'The Almighty God' for his blessing which has helped me to complete my work successfully.

I owe my heartfelt and immense gratitude to **Dr. K.A Sreejith**, Scientist, Department of Forest Ecology, Kerala Forest Research Institute, Peechi, and Thrissur for his valuable guidance, consistent supervision, constant encouragement and friendly approach rendered during my study. My gratitude is boundless to him for guiding and helping me to overcome all hindrances in my work.

I am grateful to **Dr. S Pradeep Kumar,** Director, Kerala Forest Research Institute, and **Dr. M.P Sujatha**, PG attachment co-ordinator, KFRI, Peechi for providing me the permission and required facilities.

I express my sincere gratitude to **Dr. S. Sandeep**, Scientist and **Dr. MP Sujatha**, Scientist E2, Department of Soil Science, KFRI, Peechi for allowing me to carry out my analysis works in soil science lab. Also I thank sincerely to **Dr. V B Sreekumar,** Scientist Department of Botany, KFRI for providing me help and advice for my work

I am deeply indebted to **Mr. Abdulla Naseef S.A**, **Mr. Royal Tata, Mr. Yadhu Krishna, Mr. Sarath** Research fellows, Department of Forest Ecology, KFRI, Peechi, for their advice, help and support in completing the project.

I would also like to place on record my sincere thanks to all faculties and my colleagues in the Soil Science Dept. KFRI who helped me at different stages of my work, especially **Renuka Rajan**, Project Fellow and **Simi Peter**, Project Assistant.

I thank sincerely my teachers, **Dr. Betty Bastin,** in the Department of Soil Science College of horticulture Vellanikkara and Special officer **Dr.T.K Kunhamu** for their constant encouragement, help and involvement to fulfill my work. Forever thankful to my classmates.

I personally thank Prajith, Prasad, Yadhu, Sarath, Sandeep Das, Arya, Dhaneesh, Karthika, Rajkumar, Arundhathi, Sarath Chandran, Nikhil V G of Forest Ecology lab, KFRI, for their love and encouraging companionship throughout the period of work.

Finally, I must express my very profound gratitude to my parents and to my friends for providing me with unfailing support and continuous encouragement throughout the course of my study. Thank you.

NIRAJLAL K

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

Abbreviation	**Expansion**
CFC	Chlorofluorocarbon
CO_2	Carbon dioxide
GHG	Green House Gas
GtC	Giga tonnes of carbon
IPCC	Intergovernmental Panel on Climate Change
MPa	Mega Pascal
NO_X	Nitrous oxide
Pg C	Petagram of Carbon
ppm	parts per million
SOC	Soil organic carbon

INTRODUCTION

1. INTRODUCTION

The tropical forests play important role in the global carbon budget and are the greatest sources of net primary production in the world. Tropical forests contain up to 40 % of global terrestrial biomass carbon (Field *et al.*, 1998). Soil respiration is the single largest carbon loss component in the world which accounts for 40-70 % of total respiration (Kosugi *et al.*, 2007). Earth's soil releases 60 giga tonnes of carbon into the atmosphere each year and is far more than that of carbon release by burning fossil fuels which is 5.5 giga tonnes of carbon per year. Soil carbon release happens through a process called "carbon respiration" and this respiration is balanced by carbon releases to the atmosphere and carbon coming into the soil system from falling leaves and other plant matter as well as by the underground activities of plant roots. Globally, soil respiration releases approximately 80 Pg C into the atmosphere per year (Xiao *et al.*, 2014).

Carbon balance is controlled by biotic and abiotic factors of the earth such as soil temperature, soil moisture, microbial activity, soil surface litter and vegetation types. Change in any of the factor causes change in the process. Some of the studies on soil respiration showed that rising temperature increased the rate of soil respiration and the whole scientific communities worried that increasing temperature due to global warming would accelerate the decomposition of carbon in the soil resulting in global carbon imbalance. It is therefore important to quantify the variability in soil gas flux in the tropical forest and to evaluate the relationship between soil efflux and environmental variables that control flux, to enhance our understanding of the global carbon budget and how the balance might respond to global climate change.

Soil respiration, or CO_2 efflux from the soil surface, is produced by root respiration, microbial activity from consumption of soil organic matter and forest litter, and from chemical oxidation of carbon in the soil (Raich and Schlesinger, 1992). These factors are controlled by environmental conditions including soil temperature, air temperature, water content, and all of which vary spatially, seasonally, and diurnally. Many studies had shown that soil temperature and soil moisture are the most important factors controlling soil respiration. However the two variables often co-vary, making it difficult to separate the effects of each variable on soil respiration. While soil temperature plays a greater role than soil moisture in predicting soil respiration in temperate regions, soil moisture is a more effective index to estimate variation in soil respiration rate for tropical soils, because soil temperature remains relatively constant (Kosugi *et al.*, 2007). Soil respiration rates in the tropics are also difficult to quantify due to the high spatial variation. Soil respiration rate may vary spatially by up to 100 % at locations only 0.5-1m apart (Nakayama, 1990; Kosugi *et al.*, 2007). Seasonal changes in soil microclimate play an important role in defining seasonal differences in soil-CO_2 emissions within sites, and climatic differences.

Soil respiration also varied with vegetation. Respiration rates varied significantly among major biome types (Raich and Schlesinger, 1992), and side-by-side comparisons of different plant communities frequently demonstrated differences in soil respiration rates (Lundegårdh 1927; Lieth and Ouellette, 1962; Ellis, 1974). Such findings indicated that vegetation type is an important determinant of soil respiration rate, and therefore changes in vegetation have the potential to modify the responses of soils to environmental change which generate different soil respiration rates among distant sites (Raich and Potter, 1995).

In boreal forests, soil temperature is the main determinant of soil respiration and soil water has little effect (Morén and Lindroth, 2000). Soil respiration stops during the winter when freezing happens. In temperate forests, both soil temperature and soil water control soil respiration. Soil respiration changed seasonally with soil temperature and often decreases with decreasing soil water in the summer (Dong *et al.*, 2005; Londo *et al.*, 1999; Ohashi *et al.*, 1999). There are many studies on soil respiration in boreal and temperate forests. However, despite the large C efflux from soil in tropical forests (Malhi *et al.*, 1999), there are few reports on soil respiration in tropical forests compared to other climate regions (Medina *et al.*, 1980; Keller *et al.*, 1986; Mcgroddy and Silver, 2000).The difficulty of accessing to these regions that have tropical forests is perhaps one of the reasons for the shortage of studies of soil respiration in tropical forests. Most tropical forests exist in developing countries in low latitudes. Also, there are so many types of tropical forests; various structures, diversities of species and climate (Whitmore, 1990), compared with boreal and temperate forests. Thus, more studies of soil respiration in tropical forests are needed in the context of climate change.

Litter fall in terrestrial ecosystems represents the primary pathway for nutrient return to soil. Heterotrophic metabolism, done by small insects and leaching during precipitation events, result in the release of plant litter carbon as CO_2, into the atmosphere. The balance between litter inputs and heterotrophic litter decomposition influences the amount of carbon stored in the forest soil. Periodic measurements of litter fall and litter decomposition with standard techniques will provide much needed information on carbon and nutrient cycling in forests. Decomposition of leaf litter is a vital ecological process in C balance and nutrient cycling in terrestrial ecosystems (Scheffer *et al.*, 2001). The need to investigate changes that take place during litter decomposition and soil CO_2 fluxes has been amplified due to the projected global temperature increase of 0.6 °C to 1.1 ^{0}C over the period from 1880 to 2012 (IPCC, 2013) with rising levels of atmospheric CO_2 (IPCC,2001).Litter decomposition is influenced by climate, litter quality and decomposers (Austin and Vitousek 2000, Jacob *et al.* 2009).It is thus necessary to see whether the temperature sensitivity of soil respiration and litter decomposition are changing in a changing world. Mineralisation of litter contributes 50 % of the CO_2 flux from soil. Present regional tendencies of enhanced forest growth cause an increase in carbon absorption by plants. This also influences the potential size of the forest's carbon pool. Several bio-climatic models indicate that the ecosystem's absorption capacity is approaching its upper limit and should diminish in the future by forests becoming a net source of CO_2. Indeed, global warming could cause an increase in heterotrophic respiration and the decomposition of organic matter, and a simultaneous decrease of the sink effectiveness, thereby transforming the forestry ecosystems into a net source of CO_2 (Scholes *et al.,* 1999).

Since natural forests are both sink and source of global carbon cycle, understanding carbon dynamics of natural forest system is a primary process of concern.This is essential to formulate better conservation and restoration strategies in a climate change scenario. The study will also provide scientific data on the influence of change in weather parameters on litter dynamics and carbon efflux in the forest soil. Hence this research programme was taken up with the following objectives.

To understand the pattern and process of litter dynamics

To understand the role of weather on soil carbon efflux

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 Carbon dioxide and climate change

Carbon dioxide (CO_2) is a major greenhouse gas (GHG) because of its atmospheric concentration (about 398 ppm) and the strongest radiative forcing among all the known GHGs , despite having relatively lower warming potential (Forster *et al.*, 2007). They also reported that CO_2 along with atmospheric water vapours, contributes majorly to the greenhouse effect on the earth. Though other GHGs such as methane (CH_4), nitrous dioxide (NO_X) and chlorofluorocarbons (CFCs) are present at lower concentrations (about 2–6 orders of magnitude) than CO_2 in the atmosphere, their per molecule absorption of infrared (IR) radiation is many fold higher than CO_2 (Srivastava and Singh, 1989). According to the IPCC report 2014, the concentration of atmospheric CO_2 has increased from 280.0 to 398.6 ppm between 1750 and 2014 and is increasing currently at a rate of 2.11 ppm per year (IPCC 2014) which includes two major anthropogenic forcing fluxes: (i) CO_2 emissions from fossil-fuel combustion and industrial processes and (ii) the CO_2 flux from land-use change, mainly land clearing (Raupach *et al.*, 2007). A survey of trends in the atmospheric CO_2 budget (Raupach and Canadell, 2007) showed these two fluxes were, respectively, 7.9 gigatonnes of carbon (GtC) y^{-1} and 1.5 GtC y^{-1} in 2005 with the former growing rapidly over recent years, and the latter remaining nearly steady.Houghton (1996) raised concerns about potential global warming and positive feedback effects that warming could have on further release of CO_2 from terrestrial carbon pools, particularly soils. World soils contain an estimated 1550 Pg C in the surface meter alone (Eswaran *et al.*, 1993).According to Rustad *et al.* (2000), this is more than two times the amount of carbon in the atmosphere. Increased storage of carbon in world soils could help offset further anthropogenic emissions of CO_2, whereas a release could significantly exacerbate the atmospheric increases the tropospheric CO_2 concentrations are projected to increase from 355 ppm (v/v) to 710 ppm, by the year 2050 (Cure and Acock, 1986).

As per the National Academy of Science Report, the most sophisticated model suggests a mean warming of 2° to 3.5°C for doubling of the CO_2 concentration from 300 to 600 ppm. If atmospheric carbon dioxide concentrations increase from current levels near 385 ppm to a peak of 450–600 ppm over the coming century it will cause irreversible dry-season like rainfall reductions in several regions comparable to those of the "dust bowl" era and inexorable sea level rise. According to Solomon *et al.*, (2009) the thermal expansion of the warming ocean provides a conservative lower limit to irreversible global average sea level rise of at least 0.4–1.0 m if 21st century CO_2 concentrations exceed 600 ppm and 0.6–1.9 m for peak CO_2 concentrations exceeding $\approx$1,000ppm. The increasing trend in atmospheric CO_2 concentration has proved from lots of studies. Long term sustaining of this trend led to a change in global climate which has been identified as one of the most important scientific and political challenges of the twenty-first century (Abhilash *et al.*, 2016).

2.2Tropical forest as carbon source and sink

According to Hagen (1992), more holistic and ecology-focused approach to carbon and nutrient cycling in forests began with the emergence of ecosystem ecology as a distinct branch of ecology, with the ecosystem as a primary focus of attention. Tropical forests, including both regrowth and intact forests, play a critical role in the global carbon (C) cycle. They store an estimated 45 % of terrestrial C and account for over one third of terrestrial gross primary production (Bonan, 2008; Beer *et al.*, 2010).Soil organic matter and other organic compounds show a faster turnover in tropics compared to temperate soils (Gopika ,2015) Tropical forests also constitute the largest component of the terrestrial C sink. In early 2000's, forest regrowth on ~557 M ha (million hectare) of abandoned agricultural land in tropical regions has represented an estimated sink of 1.4-1.7 Pg C yr^{-1} (Pan *et al.*, 2011). In the present era of global climate change, tropical forests play a central role in determining the rate of increase in atmospheric CO_2. According to Pan *et al.*, (2011) tropical deforestation is of key significance; from 1990 to 2007, CO_2 emissions from tropical deforestation were ~3 Pg C yr $^{-1}$, equivalent to ~40 % of global fossil fuel emissions. At the same time, tropical forests are changing in response to climate change and other global change pressures, and this will alter their CO_2 exchange with the atmosphere (Anderson-Teixeira *et al.*, 2015). however, several terrestrial ecologists concluded that not only was it unlikely that terrestrial ecosystems would increase their carbon storage in response to increased atmospheric CO_2 but that the destruction of these ecosystems, primarily tropical forests, was releasing nearly as much CO_2 into the atmosphere as were industrial processes (Woodwell and Houghton, 1977). Myers (1980) reported that the tropical forests were exploited by people for a variety of purposes, including timber extraction, shifting cultivation, permanent agriculture, and pasture. Forest's capacity to sequester carbon varies with species, sites, spacing, and climate and age (Binsiya, 2016).These various land uses differed in their effects on vegetation and soil, and, therefore, differ in the quantity of CO_2 released when a unit area of forest was converted to each of these uses (Detwiler, 1986). According to Ewel *et al.*, (1981) the burning that followed most forest clearing in the tropics converted some of the felled vegetation immediately into CO_2.The decay of the remaining vegetation and the decline in soil organic matter adds additional CO_2 to the atmosphere for several years after an area was cleared of forest (Hall *et al.*, 1985). Some of the carbon contained in the vegetation may not enter the atmosphere, but may remain sequestered indefinitely in lumber, ash, and charcoal (Sanford *et al.*, 1985).According to Hall *et al.*, (1985) the natural recovery of forest vegetation sequesters some proportion of the carbon released as a result of clearing, thus, it is important to distinguish between temporary and permanent clearing in the tropics because the net release of CO_2 from the former is significantly less than that from the latter. Although currently functioning C sinks, intact tropical forests could become net C sources if, for example, drought and other disturbances substantially increase tree mortality (Lewis *et al.*, 2011; Brienen *et al.*, 2015). There is general agreement about the importance of tropical forests for the global carbon cycle and hence global climate. But researches proved that climate differed significantly for the

21

area affected by tropical deforestation, resulting increase in flux of carbon to the atmosphere and the feedbacks of this flux to the climate system (Achard *et al.*, 2002; DeFries *et al.*, 2002).Climate change is likely to increase the frequency and intensity of some natural disturbances like storms and droughts(IPCC, 2013; Trenberth *et al.*, 2014) and regional C balances will be strongly influenced by tropical forest regrowth dynamics, which are also likely to be altered by climate change (Anderson-Teixeira *et al.*, 2015). Altered disturbance-recovery dynamics have the potential to have a much stronger influence on regional C balances than metabolically-driven changes (Kurz *et al.*, 2008; Running, 2008; Anderson-Teixeira *et al.*, 2013). For some future climatechange scenarios, it has been shown that tropical forests could generate an unprecedented source of carbon, even in the absence of additional anthropogenic deforestation (Cox *et al.*, 2000; Cramer *et al.*, 2001).

2.3 Carbon respiration from soil

The efflux of CO_2 from the soil surface (soil respiration) is one of the major components of the ecosystem; C balance contributes 50–95 % of total ecosystem respiration (Yuste *et al.*, 2005).Soil respiration is the sum of multiple processes, such as root respiration and microbial decomposition (Hanson *et al.*, 2000; Kuzyakov, 2006). It varies significantly in time and space according to small- and large-scale changes in the biological, physical, and chemical properties of the soil (Hibbard *et al.*, 2005). Previous studies of Stoyan *et al.*, (2000) and La Scala *et al.*, (2000) conducted in various types of forest ecosystems reported considerable and variable patterns of spatial variation in soil respiration with changes in moisture (Stoyan *et al.*, 2000), C content (La Scala *et al.*, 2000), litter biomass (Fang *et al.*, 2001), microbial biomass (Scott-Denton *et al.*, 2003), and root biomass (Hanson *et al.*, 1993). Previously reported data suggested that the magnitude of spatial variation in soil respiration is larger in tropical forests than in other forest ecosystems because soil respiration is normally higher in tropical areas (Davidson *et al.*, 2000). Thus the determination of factors affecting the spatial variation in soil respiration are crucial not only for understanding CO_2 dynamics but also for accurately estimating the total amount of soil respiration (Katayama *et al.*, 2009).Roots contribute to total soil respiration through root respiration and root litter C decomposition due to fine root turnover and root exudates (Davidson *et al.*, 2002). Since root respiration and root litter C decomposition depend on belowground C allocation by trees, they can be closely linked to the forest structure in some ecosystems (Stoyan *et al.*, 2000). Therefore, knowledge of the spatial arrangement of trees and canopy structure (i.e., forest structure) can be a practical tool to explain spatial variations in soil respiration in tropical forests, which enable us to extrapolate measurements based on spatially limited sampling to stand-scale estimates. In addition, the use of forest structural factors has advantages over the use of other factors that require special devices and techniques for measurement (Katayama *et al.*, 2009). Also there is little information on the effects of forest structure on spatial variations in soil respiration in tropical rainforests (Sotta *et al.*, 2004). Studies by Singh and Gupta (1977) reported that soil respiration is governed directly or indirectly by two major environmental factors, viz. temperature and moisture. It was also affected by nutrient status of the soil and soil depth. They also stated that the soil atmosphere showed changes in oxygen and CO_2 concentrations which may also influence the rate of soil respiration and it varied with season and small range of time.

Reiners (1968) plotted soil CO_2 output rates against soil temperatures and showed a curvilinear, virtually exponential relationship while the semi log plots of CO_2 rates against soil temperatures produced a linear curve. The studies by Medina and Zelwer(1972) stated that the soil respiration rates from tropical communities were also logarithmically correlated with soil temperature. In a tall grass prairie, the highest rates of soil respiration occurred during the warmest months of July and August while in the later part of January for a period of approximately 22 days, no CO_2 output could be detected (Kucera and Kirkham, 1971). In a warm temperate, evergreen broad leaf forest, Kirita (1971) found that soil respiration rates showed a marked annual cycle closely following the seasonal changes in the temperature of soil surface. A logarithmic increase in soil CO_2 production with rising soil temperature was also noted for chestnut and beech forests with Q10 of 3.2 in the temperature range of 5 to 150 °c (Anderson, 1973). Anderson's study further indicated that temperature became a limiting factor for soil respiration during winter months when abundant precipitation occurred. Lundegardh (1921) recorded a rapid rise in the rate of soil respiration up to 600°C; and in a later study he found that soil respiration followed a Q10 of 2 between 10° and 200 °C (Lundegardh, 1927). The soil respiration rates are minimum when ambient temperature 0 ° C (Feher, 1927). Koepf (1953) reported that the rate of CO_2 production in the soil followed a Q_{10} of about 2 between 10 and 400 °C, decreasing rapidly with further increase in temperatures perhaps because of a detrimental effect on soil biota. The daily fluctuations in soil respiration were attributed mainly to the temperature changes in the soil (Meyer and Koepf, 1960).

The addition of water to a more or less dry soil caused increased CO_2 production from soil which can be attributed to increased microbiological activity (McKinley, 1931). However, Lundegardh (1924) did not find a good correlation between rainfall and soil activity. Nevertheless, he observed an increase in CO_2 of the soil atmosphere with increasing water content. The effect of rainfall on metabolism depended upon soil type and the level of humus accumulation. In shallow soil, soil moisture may enhance the rate of soil respiration by affecting microbiological activity and the decomposition of organic matter (Van Schreven, 1967). Wiant (1967) had shown a curvilinear increase in CO_2 production with increasing moisture content under laboratory conditions. In the forest patches of Calabozo, Medina and Zelwer (1972) measured daily fluctuations of soil respiration rates in the beginning of a dry period and reported that for similar soil temperatures, CO_2 production rate was positively affected by soil water content. Rainfall also affects measured rates due to CO_2 displacement in the soil air by rain water. Kucera and Kirkham (1971) found that under saturated or water-logged condition the rates of CO_2 evolution were depressed, and when the surface soil reached a permanent wilting percentage, the CO_2 evolution was again reduced.

Diurnal fluctuations in the rate of soil respiration have been reported by Koepf (1954). Harris and Van Bavel (1957) found maximum rates of root respiration in tobacco, corn, and cotton plants at 4 p.m. and the minimum between 2 a.m. and 10 a.m. which can be attributed to changes in temperature. During the transition from rainy to dry period in October-November 1968, Medina and Zelwer (1972) measured soil respiration rate in the forest patches of Calabozo for 3 weeks. They observed that the night values were always higher than the day values and attributed these higher rates to the presence of higher relative humidity during night which perhaps favours the activity of microbiota, and to high soil temperatures at the beginning of night. During the night, the soil air was warmer than the air above it facilitating evolution of CO_2 from the soil air. De Jong and Schappert (1972) estimated total diurnal variation in CO_2 evolution to be 25 % over a period of 32 hr. In chestnut and beech forests, Anderson (1973) found a depression in CO_2 output rates during midday. Edwards and Sollins (1973) also investigated the daily patterns of CO_2 evolution on the basis of 24-hr and 48-hr runs. In the litter layer the diurnal fluctuations in CO_2 evolution were marked with a night time increase during the dry periods.

In earlier work by Romell (1922) it was reported that the CO_2 concentration increased with depth in the soil profile. Lundegardh (1924) found greater CO_2 (0.271 g CO_2 m^{-2} hr^{-1}) production in the surface layer which decreased rapidly with soil depth (0.009 g CO_2 m^{-2} hr^{-1} at 30-40 cm depth). The higher rates of CO_2 production in the surface layers were due to the concentration of soil activity in the surface layer. High CO_2 production from the surface layers of the soil and a decrease with depth was also reported by Smith and Brown (1932). In a grass-woods peat and a thick sedge-hypnum peat, Makarov (1960) reported that the intensity of soil respiration at 0-10 cm depth of the soil was 6.77 and 7.93 kg CO_2 ha^{-1} hr^{-1} and the value decreased with increase in depth reaching a minimum (2.65 and 2.33 kg CO_2 ha $^{-1}$ hr $^{-1}$) at 60 cm soil depth. The higher values of soil respiration at 0-10 cm depth could be explained on the basis that this layer contained the bulk of all plant roots and a higher bacterial density.

It was observed that the response of soil carbon to future temperature change would influence atmospheric composition and climate (Davidson and Janssens, 2006; Conant *et al.*, 2011), but the direction and magnitude of the resulting climate feedback remained unclear (IPCC 2013; Wieder *et al.*, 2013). This is especially so for tropical forests, which constitute a disproportionately large component of the global carbon cycle, exchanging more CO_2 with the atmosphere than any other ecosystem and accounting for over two-thirds of terrestrial plant biomass (Pan *et al.*, 2011) and a third of global soil carbon (Jobbagy and Jackson, 2000). But the future carbon cycle of tropical forests, for which in situ temperature manipulation experiments had not been conducted (Cavaleri *et al.*, 2015), remained an important source of uncertainty in climate model projections (Cox *et al.*, 2013).

2.4 Litter fall and decomposition in tropical forests

Tree litterfall is one of the major pathways in C and nutrient cycles that connect above- and below-ground processes (Vitousek and Sanford, 1986). As an important and regular source of nutrients and organic matter, litter fall had been well studied over the past few decades (Carnol and Bazgir, 2013). Nonetheless, litter fall varied considerably between ecosystems, depending on climate, tree species composition, stand structure and soil fertility (Vitousek and Sanford, 1986). According to Ensslin *et al.* (2015) elevation is strongly affecting these parameters in montane ecosystems and is of particular importance regarding potential ecosystem shifts through climate change (Beniston, 2003). The mechanisms determining litter fall seasonality remained poorly understood (Restrepo-Coupe *et al.*, 2013). Moreover, understanding of the seasonality of litter inputs in forested ecosystems is a limiting factor in ecosystem models, especially for tropical forests (De Weirdt *et al.*, 2012), which represent a large portion of global litter inputs and NPP (Clark *et al.*, 2001). Coupled with this, the chemical quality and decomposability of the material that falls at certain times of the year is an important regulator of biogeochemical cycles (Cornwell *et al.*, 2008). Understanding of how litter quality varied within years and between environments is thus essential in comprehending plant phenology, responses to the environment, and the effects on ecosystems and global cycles. According to De Weirdt (2012) the litter fall comparisons over multiple locations were required to make inferences about patterns in litter seasonality. Recent reviews of tropical forests had shown that increased rainfall seasonality generally caused more seasonal litter inputs (Zhang *et al.*, 2014). These meta-analyses provided important insights to general trends; however there is potential there in to conceal finer scale drivers of variability. This is especially true in understanding phenology and litter patterns in tropical forests, due to high species richness and diversity in plant phenological characteristics (Townsend *et al.*, 2008). For instance, deciduous species in seasonally wet tropical forests can shed litter as a response to new growth (e.g. in wetter or warmer months), or as a response to dry seasons and cooler/low growth periods (Hyland *et al.*, 2002).

The litter decomposition is a fundamental ecosystem process, and a rich history of research showed that climate and litter chemistry strongly controlled rates of litter decay (Meentemeyer, 1978; Swift *et al.*, 1979; Melillo *et al.*, 1982; Hobbie, 1996; Adair *et al.*, 2008). Across multiple ecosystem types, temperature, indices of water availability, and measures of litter quality, such as nitrogen (N) availability, lignin content, or lignin:N ratios, are useful for predicting rates of mass loss (Vitousek *et al.*, 1994). Litter synthesis even suggested a remarkable global consistency in the predominant controls over decomposition, leading to the sense that litter decomposition is one key ecosystem process that is well understood (Parton *et al.*, 2007).

According to Coley and Barone (1996) in the forest ecosystems, most leaves fall uneaten to the forest floor. There they are decomposed by fungi and bacteria, which in turn feed the rest of the brown food web (Swift *et al.*, 1979). The study of Sterner and Elser (2002) reported that the trees and microbes that help drive the carbon cycle needed perhaps 25 chemical elements to grow and reproduce. Decomposer microbes are strong candidates for multiple nutrient limitation. Leaf-litter decomposition required the sequential breakdown of a variety of substrates (e.g. waxes, phenolics, lignins, celluloses) requiring a variety of enzymes produced by different microbes (Da Silva and Williams, 2001).A few experimental studies in boreal and temperate forests had shown that nitrogen rich leaves decomposed faster than nitrogen poor leaves (Berg and Laskowski, 2005). In contrast, most lowland tropical forests lie on highly weathered soils that are relatively nitrogen rich but have been depleted with time of a variety of rock-derived chemical elements (Wardle *et al.*, 2004). Much circumstantial and some experimental evidence suggested that phosphorus played a key role in controlling leaf litter decomposition in lowland tropical forests (Cleveland et *al.*, 2011).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Study area

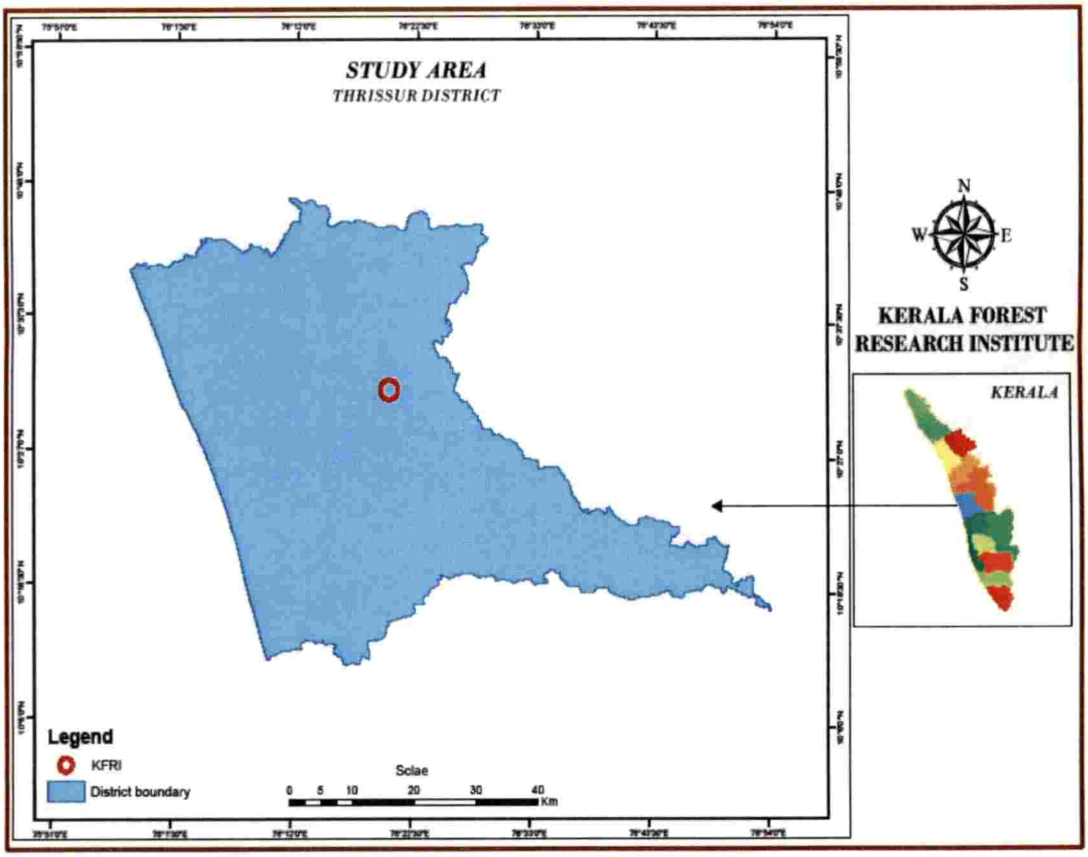

Fig 1. Large scale schematic map of study area

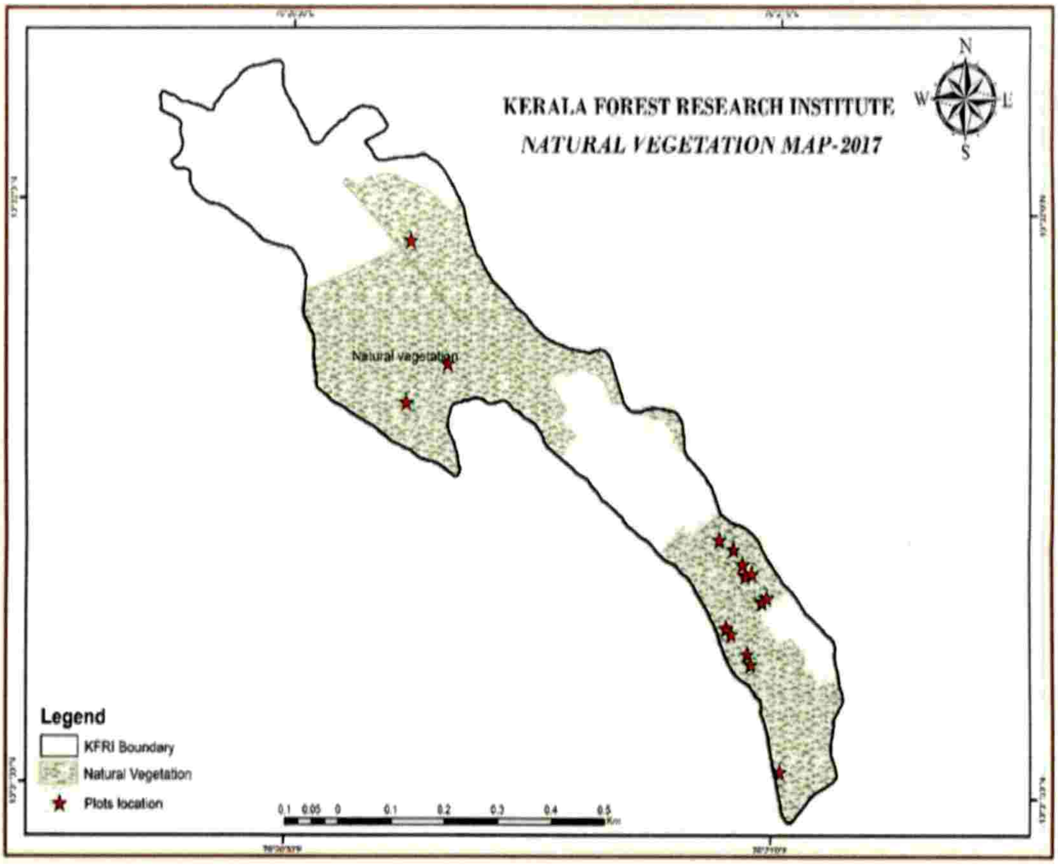

Fig 2. Map of study area showing sample plots

The study area Kerala Forest Research Institute (KFRI) campus is located in Thrissur taluk of Thrissur district. The study area lies between 10° 31’ 25” N and 10° 32’ 10” N latitude and between 76° 20’ 20” E and 76° 21’ 10” E longitude. The study area falls in the Survey of India Top sheets 58B/06 in 1:50,000 scale. It covers an area of 28.17 ha of which 24.51 ha is covered by dense vegetation and 3.66 ha by buildings. The campus is divided lengthwise by the Thrissur -Peechi road and the left bank irrigation canal of the Peechi dam reservoir cuts across it almost through the middle. The campus is of undulating terrain and the maximum altitude of the area is about 100 m above the mean sea level.

Fig 3. Vegetation of sample plot (a)

Fig 4. Vegetation of sample plot (b)

3.2 Climate

The climate is humid tropical influenced by both South-West and North-East monsoons. On an average, the area receives around 3018 mm rainfall annually. Temperature fluctuates between 18°C to 37°C and the humidity varies from 60 to 98 per cent

3.3 Vegetation and sample plot selection

Natural forest of KFRI campus is moist deciduous type of forest. Common tree species found are *Tectona grandis*, *Xylia xylocarpa, Terminalia paniculata, Macaranga peltata and Caryota urens*. Fifteen 10 m x10 m sample plots were established for this study

3.4 Meteorological data

Daily data of temperature, rainfall and relative humidity were collected from automatic weather station of KFRI.

3.5 Litter fall, decomposition and biomass loss

3.5.1 Litter fall

Litter fall was quantified using litter traps. Four circular litter traps with 0.25 m^2 area and 75 cm height were placed in the four corners of each plot. The fallen litter were taken from the traps. Samples were collected on monthly basis and categorized based on the four species that are *Tectona grandis*, *Xylia xylocarpa*, *Terminalia paniculata* and *Macaranga peltata* .The litter were air dried and quantified for a period of six months.

Fig 5. A Litter trap fixed in the field

3.5.2 Litter decomposition and biomass loss

Freshly fallen litter samples were collected from litter traps. Fresh green leaves were omitted .Samples were air dried at room temperature, cleaned of debris, and were categorized into four dominant species that are *Tectona grandis, Xylia xylocarpa, Terminalia paniculata, Macaranga peltata* to determine species wise decomposition .The remaining litter was mixed thoroughly so as to accurately determine site-specific decomposition rates under natural conditions which were heterogeneous (Borders *et al.* 2006).A total of 10 g of leaves and 10 g of twigs less than 2 cm diameter were weighed and put into a polyethylene net measuring 15 cm × 15 cm with 1 mm mesh size and which was modified into a bag. The bags were sewn using nylon thread and tagged. Species wise bags were also made .Subsamples were reserved prior to litterbag preparation for initial analysis

A total of 171 litterbags were made in which 135 litter bags represented field heterogeneous litter and 36 represented four selected species litter .In each of the 15 plots, 9 fields representing litterbags were placed and 36 species representing litterbags were placed in 4 plots randomly. The bags were placed horizontally on the forest floor and lightly covered with natural litter layer in April 2017 and tagged.

Three litterbags of representing field and three litterbags representing species was retrieved every two months for a period of six months (3 replications x 3 collection) from 15 plots from April 2017 to September 2017. At the laboratory, litterbags were air dried, carefully brushed off contaminants and oven dried at 65 °C until constant weight. The weights of samples were recorded. The difference in weight was taken as biomass loss and decomposition rate constant was calculated from the exponential equation of plotted biomass loss curve.

Fig 6. Prepared litterbags used to quantify litter decomposition

3.5.3 Litter carbon analysis

Muffle furnace experiment was carried out to determine carbon content of litter. Litter samples of weight, 0.5 g were weighed and placed inside the muffle furnace for 8 hours at 600°c.The weight difference before and after ignition of muffle furnace were estimated All the litter samples became ash and the change in the weight in % is taken as its biomass content. Half of the value of biomass content is taken as carbon content.

3.6 Soil measurements

3.6.1 Sampling

Soil samples were collected from the centre part of sample plot within an area of 10 cm x 10 cm at a depth of 20 cm.Soil collection was carried out at an interval of three weeks in a month for six months.

3.6.2 pH

Soil pH was calculated using an aqueous suspension of soil and water (1:2.5) using Elico pH meter (Model Li 613).

3.6.3 Moisture

Soil moisture was calculated using gravimetric method. Weight of the water present in the soil sample is the weight difference between wet and oven dry soil sample (Reynolds, 1970).

3.6.4 Temperature

Initial soil temperature was measured using portable soil thermometer probe and recorded in degree Celsius. Later based on the air temperature and soil moisture status, soil temperature was found out for specific period using a regression equation. The regression equation used is given below

Soil temperature = $-13.5 + 0.076\text{SM}(\%) + 1.63\text{AT}\ (^{0}\text{C})$

3.6.5 Organic carbon

Each sample was air dried for 24 hours and passed through 2mm sieve prior to the analysis. Soil organic carbon was analyzed using wet digestion method (Walkley and Black, 1934).

3.6.6 Carbon dioxide efflux

The soil carbon efflux was measured using portable closed chamber system named EGM-4 developed by PP systems. The EGM-4 CO_2 is a non-dispersive, infrared gas analyzer that has an "Auto-Zero" facility. Using infra-red gas analysis techniques, it can readily determine CO_2 concentrations to within a few ppm and instantaneous measurements are possible. Gases with di-atomic molecules such as CO_2 strongly absorbs photons in the infra-red range. When carbon dioxide is passed down the sample cell, it absorbs some of the infra-red and the sensor reading decreases. The "Auto-Zero" feature, which occurs at regular intervals, allows for fast warm-up, adaptation to changing ambient conditions and excellent stability of the CO_2 signal. A ready measurement carbon dioxide flux is taken in the unit of $g\ m^{-2}\ h^{-1}$

Soil carbon efflux was determined adjacent to those places where soil samples were collected.

Fig 7. Soil CO$_2$ efflux analyzer (EGM-4) to quantify CO$_2$ flux from soil

3.7 Statistical analysis

Correlation analysis between soil carbon efflux and weather and soil parameters were done.

RESULTS

4. RESULTS

4.1 Meteorological data

4.1.1 Temperature

The range of monthly mean temperature of the study area from April to September was 31.60 ^{0}C and 25.59 ^{0}C, generally showing a decreasing trend. A marginal decrease was seen from April to May. Later after June the temperature decreased gradually in July and remained almost the same temperature range till September. A high of temperature was seen in the month of April with a value of 31.60 ° c and the lowest temperature in the month of July with a value of 25.25 ^{0}C (Table.1).

4.1.2 Rainfall

During April to September monthly total rainfall ranged from 34.8 mm to 577.6 mm. Rainfall during April showed the lowest amount of 34.8 mm and afterwards from May to September a marginal increase was observed with the highest rainfall in the month of June with 577.6 mm.Slight decrease in rainfall occurred in July with a value of 411.6 mm.Again rainfall increased in August and reached a value of 545.2 mm. This was followed by a decrease during the month of September (Table 1).

4.1.3 Relative humidity

The monthly mean relative humidity range of the study area from April to September was between 64.0 % and 97.5 %. The month of April showed the least amount of relative humidity of 64.0 % and the highest amount of 97.50 % was in August .An increasing trend was noticed from April to August and very slight decrease was observed in the month of September (Table 1).

Table 1. Monthly mean weather parameters during the period from April to September

Months	Temperature(^{0}C)	Total Rainfall(mm)	Relative humidity (%)
April	31.60(±0.02)	34.8	64.00(±0.07)
May	29.92(±0.04)	272	70(±0.13)
June	26.49(±0.06)	577.6	85.80(±0.31)
July	25.25(±0.06)	411.4	97.30(±0.16)
August	25.38(±0.06)	545.2	97.50(±0.17)
September	25.59(±0.05)	304.8	96.60(±0.13)

4.2 Soil studies

Soil samples were analyzed for pH, moisture, temperature, Organic Carbon and CO_2 efflux

4.2.1 pH

Monthly average Soil pH levels are not significantly different for different months. It is almost same from May to September and high pH level of 6.08 can see in the month of April only (Table 2)

4.2.2 Moisture

The monthly mean soil moisture content of the study period was between 9.03 % and 29.29 % generally increase in soil moisture content was observed from April to September with lowest moisture content of 9.03% in April and the highest moisture content of 29.29 % in September. A sudden increase in moisture level occurred in the month of May there after the moisture level was found to be uniform in the months June, July and August (Table 2).

4.2.3 Temperature

Soil temperature levels were high in the month of April with a value of 39.8 ^{0}C. Decrease in temperature levels was seen from April to July and slight increase in trend was seen in the months August and September. The lowest recorded soil temperature was 28.8 ^{0}C ° c in July (Table2).

4.2.4 Organic carbon

The monthly mean soil organic carbon content during the study period did not vary significantly. The organic content ranged from 2.61 % to 4.04 % in which the month of August showed the lowest amount of soil organic carbon and the month of May showed a higher value. Almost same amount of organic carbon content was noticed during on June and July and also for the months August and September (Table 2).

4.2.5 Carbon dioxide efflux

A decreasing trend of soil carbon dioxide efflux was found during April to June and an increase in flux occurred in July. A decreasing trend was noticed in August and September. The highest level of flux is occurred in the month of July resulting in a value of 226.58 mg m^{-2} h^{-1} and lowest CO_2 flux occurred in the month of June with a value of 186.75 mg m^{-2} h^{-1} (Table 2).

Table 2. Monthly mean Soil parameters during the period from April to September

Parameter	April	May	June	July	Aug	Sept
pH	6.08 (±0.08)	5.63 (±0.09)	5.65 (±0.09)	5.24 (±0.09)	5.63 (±0.09)	5.36 (±0.05)
Moisture (%)	9.03 (±0.64)	17.86 (±0.74)	24.45 (±0.48)	24.71 (±0.70)	25.59 (±0.83)	29.29 (±1.48)
Temperature (^{o}c)	39.8	35.3	31.1	28.8	30.1	31.9
Organic carbon (%)	3.56 (±0.20)	4.04 (±0.27)	3.61 (±0.26)	3.67 (±0.19)	2.61 (±0.20)	2.77 (±0.22)
Carbon dioxide efflux (mg m^{-2} h^{-1}.)	207.82 (±9.8)	215.62 (±8.11)	186.75 (±7.86)	226.58 (±7.87)	216.28 (±8.00)	205.76 (±9.95)

4.3 Litter studies

4.3.1 Litter fall pattern

Table 3. Litter fall of the study area during April to September

Month	Weight (t ha^{-1})
April	10.52
May	8.34
June	12.71
July	12.88
August	12.79
September	9.72

Table 3 indicates monthly litter fall from sample plots in tonnes per hectare. The highest litter fall occurred in July followed by August, June and April. The lowest litter fall was observed in the months of May and September.

4.3.2 Decomposition of litter

Table 4. Cumulative biomass loss and decomposition rate of field representing litter

Months	Days	Cumulative biomass loss (g)
April-May	60	1.90(±0.21)
April-July	120	3.86(±0.28)
April-September	180	5.57(±0.25)
Decomposition rate constant k = 0.009 day^{-1}		

From the initial 10 g of litter mass of 1.9 g is lost in first 60 days. The loss of 3.86 g and 4.98 g occurred in 120 and 180 days respectively (Table 4). Biomass loss showed an increasing trend with increasing number of days .A positive relation existed between biomass loss and number of days. The decomposition rate constant k was found to be 0.008 day^{-1}.This was obtained from the exponential equation of the biomass loss and days for decomposition. The highest biomass loss of 1.90 g and 1.96 g occurred in the initial 2 months period from April to May and June to August. The decrease in biomass loss which occurred during the last two months of August and September was about 0.5 g.

4.3.3 Litter Carbon content and Carbon loss

Table 5. Carbon content and loss of carbon content of field representing litter

Months	**Period (Day)**	**Carbon content (%)**	**Cumulative litter carbon loss (%)**
Initial	0	47.49 (±0.19)	0
April-May	60	46.33 (±0.41)	1.16
April-July	120	45.29 (±0.56)	2.2
April-September	180	44.24 (±0.34)	3.25

Table 5 indicated that the initial litter carbon content before decomposition was about 47.49 % and decrease in carbon content occurred in subsequent days. Only slight change in carbon content occurred during the decomposition period and decomposed litter had greater than 40% of carbon even after decomposition for 180 days. The lowest changes in carbon occurred in the period of 60 to 120 days and highest loss in first 60 days period.

4.4 Species wise litter studies

4.4.1 Leaf Litter fall pattern of *Tectona grandis*

Table 6. Leaf Litter fall of *Tectona grandis*

Month	***Tectona grandis* (t ha^{-1})**
April	0.94
May	0.62
June	1.19
July	1.35
August	1.15
September	0.75

In all the tables and figures under species wise litter studies 60 days indicates April and May, 120 days indicates April to July and 180 days indicates April to September.

While referring Table 6 it was found that the highest leaf litter fall occurred in the month of July with a value of 1.35 t ha^{-1} and lowest in the month of May with a value of 0.62 t ha^{-1}. There was high and low trend of litter fall was noticed in the period from April to June but a decreasing trend occurred during the period of July to August.

4.4.2 Decomposition of *Tectona grandis*

Table 7. Cumulative biomass loss and decomposition rate of *Tectona grandis*

Months	**Period (Day)**	**Cumulative biomass loss (g)**
April-May	60	4.03(±0.29)
April-July	120	6.89(±0.79)
April-September	180	8.35(±0.1.45)
Decomposition rate constant k =0.0087 day^{-1}		

The highest biomass loss occurred during the initial 60 days period of decomposition i.e. from April to May. The lowest biomass loss occurred during the 120-180 days i.e. for the period from August to September. The value of decomposition constant, k was 0.008 (Table 7).

4.4.3 Carbon content and carbon loss of *Tectona grandis*

Table 8. Carbon content and loss of carbon content of *Tectona grandis*

Months	**Period (Day)**	**Carbon content (%)**	**Carbon loss (%)**
April	0	47.73(±0.35)	0
April-May	60	47.25(±0.48)	0.47
April-July	120	46.13(±0.60)	1.60
April-September	180	45.74(±0.94)	1.98

Results (Table 8) indicated that initially the carbon content was 47.73% for *Tectona grandis* and change in carbon content occurred during decomposition. The highest carbon loss occurred during the second 60 days of period and the lowest carbon loss was in the last 60 days.

4.4.4 Leaf Litter fall pattern of *Xylia xylocarpa*

Table 9. Leaf Litter fall of *Xylia xylocarpa*

Month	*Xylia xylocarpa* (t ha^{-1})
April	0.69
May	0.50
June	1.19
July	1.15
August	1.06
September	0.68

Table 9 indicated leaf litter fall of *Xylia xylocarpa*. It was the highest in the month of June and lowest in the month of May. A sudden increase in leaf litter occurred in the month of June and a decreasing trend of leaf litter fall was noticed from June to September.

4.4.5 Decomposition of *Xylia xylocarpa*

Table 10. Cumulative biomass loss and decomposition rate of *Xylia xylocarpa*

Months	Period (Day)	Cumulative biomass loss (g)
April-May	60	0.95(±0.78)
April-July	120	2.11(±0.82)
April-September	180	2.95(±0.70)
Decomposition rate constant=0.0094 day^{-1}		

The biomass loss was the highest between 60 to 120 days, during the period from June to July and decrease was noticed between 120 to 180 days from August to September. The difference between biomass losses during the first 60 days and the last 60 days was about 0.1g (Table 10). A decomposition rate constant k value of about 0.009 day^{-1} was obtained from exponential equation of litter biomass loss and period of decomposition.

4.4.6 Carbon content and carbon loss of *Xylia xylocarpa*

Table 11. Carbon content and loss of carbon content of *Xylia xylocarpa*

Months	Period (Day)	Carbon content %	Cumulative carbon loss %
April	0	47.18 (±0.33)	0
April-May	60	46.67 (±1.51)	0.51
April-July	120	46.06 (±0.75)	1.12
April-September	180	44.34 (±2.46)	2.84

An initial carbon content of 47.18% was found for the litter of *Xylia xylocarpa*. The highest carbon loss was found in the period between 120 to 180 days of decomposition and the lowest during the first 2 months period (Table 11).

4.4.7 Leaf Litter fall pattern of *Terminalia paniculata*

Table 12. Leaf Litter fall of *Terminalia paniculata*

Month	*Terminalia paniculata* (t ha^{-1})
April	1.08
May	0.86
June	1.23
July	1.11
August	1.31
September	0.87

The highest litter fall occurred in the month of August for *Terminalia paniculata* and the lowest leaf litter fall occurred in the month of May. Alternative increasing and decreasing trend was found in leaf litter fall throughout the study period. Also no sudden change in litter fall occurred over this period (Table 12).

4.4.8 Decomposition of *Terminalia paniculata*

Table 13. Cumulative biomass loss and decomposition rate of *Terminalia paniculata*

Months	Period (Day)	Cumulative biomass loss (g)
April-May	60	3.74 (±1.65)
April-July	120	4.92 (±2.68)
April-September	180	5.85 (±2.05)
Decomposition rate constant= 0.0037 day^{-1}		

The biomass loss was greater for the period of first 60 days. Decrease in biomass loss was observed between 120 days to 180 days. A significant change in biomass loss had occurred during first 60 days compared to the other two periods. Decomposition rate constant of 0.0037 day^{-1} was calculated from exponential equation of litter biomass loss and decomposition period (Table 13).

4.4.9 Carbon content and carbon loss of *Terminalia paniculata*

Table 14. Carbon content and loss of carbon content of *Terminalia paniculata*

Months	Period (Day)	Carbon content (%)	Cumulative carbon loss (%)
April	0	47.05 (±0.79)	0
April-May	60	46.67 (±0.76)	0.38
April-July	120	46.06 (±1.71)	0.99
April-September	180	44.34 (±1.78)	2.71

Initial carbon content of *Terminalia paniculata* was 47.05%.The highest carbon loss occurred in last 60 days of decomposition and lowest carbon loss in first 60 days period (Table 14).

4.4.10 Leaf Litter fall pattern of *Macaranga peltata*

Table 15. Leaf Litter fall of *Macaranga peltata*

Month	*Macaranga peltata* (t ha^{-1})
April	0.22
May	0.12
June	0.38
July	0.28
August	0.26
September	0.18

Table 15 indicated leaf litter fall of *Macaranga peltata* which was higher in June with a value of 0.38 t ha^{-1} and lower in May and September with value of 0.12 t ha^{-1} and 0.18 t ha^{-1}

4.4.11 Decomposition of *Macaranga peltata*

Table 16. Cumulative biomass loss and decomposition rate of *Macaranga peltata*

Months	Period (Day)	Cumulative biomass loss %
April-May	60	1.88 (± 0.47)
April-July	120	4.41 (± 0.10)
April-September	180	6.32 (± 2.18)
Decomposition rate constant = 0.01 day^{-1}		

The decomposition constant of 0.01 day^{-1} is calculated from exponential equation of the biomass loss graph of *Macaranga peltata*. The lowest biomass loss was found in the first 60 days of decomposition and highest in the second 60 days of decomposition. The biomass loss of first 60 days and last 60 days was not significantly different (Table 16).

4.4.12 Carbon content and carbon loss of *Macaranga peltata*

Table 17. Carbon content and loss of carbon content of *Macaranga peltata*

Months	Period (Day)	Carbon content %	Cumulative carbon loss %
April	0	46.71 (±1.55)	0
April-May	60	44.08 (±0.85)	2.62
April-July	120	43.18 (±0.64)	3.52
April-September	180	41.18 (± 1.85)	5.52

Table.17 and Fig.16 depict carbon loss of *Macaranga peltata*. Initial carbon content of *Macaranga peltata* was about 46.71%.The highest loss of carbon content was found in the first 60 days of decomposition period and lowest carbon loss in the second 60 days period.

In species wise litter studies, the litter fall pattern of all the four species was almost similar. There was a decrease in litter fall in all species during April and May followed an increase in the months of June, July and August. In the month of September, there was a reduction in litter fall in all the species which was near similar to the litter fall of April in some species. Generally a significant increase in litter fall was seen from May to June. Also the lowest litter fall was found in the month of May in all the species. *Terminalia paniculata* contributed the highest leaf litter fall of 6.49 t ha^{-1} followed by *Tectonia grandis* (6.02 t ha^{-1}), *Xylia xylocarpa* (5.29 t ha^{-1}) and *Macaranga peltata* (1.47 t ha^{-1})

For all the species, biomass loss occurred with increase in number of days. The biomass loss of *Tectona grandis* was high in first 60 days(April and May) and low in last 60 days(August and September).For *Xylia xylocarpa*, higher biomass loss occurred on second 60 days of decomposition(June and July) and lower in last 60 days (August and September). In the case of *Terminalia paniculata*, high biomass loss occurred in the first 60 days (April and May) and lower biomass loss occurred in the last 60 days (August and September). *Macaranga peltata* exhibited the highest and lowest biomass loss in second 60 days (June and July) and first 60 days (April and May) respectively. The decomposition rate constant was the highest for *Macaranga peltata* followed by *Xylia xylocarpa, Tectona grandis* and *Terminalia paniculata*. The decomposition rate constant for all Terminalia, Tectona, and Xylia was almost same and Macaranga showed much difference in value.

For all the species, carbon loss occurred with increase in number of days. The carbon loss in two months interval for all species was different. For *Tectona grandis,* the highest carbon loss was during second 60 days (June and July) and the lowest during the last 60days (August and September). In the case of *Xylia xylocarpa*, the highest carbon loss was observed during the last 60 days (August and September) and lowest carbon loss during first 60 days (April and May) of decomposition. The highest carbon loss occurred in last 60 days (August and September) and lowest during first 60 days (April and May) for *Terminalia Paniculata*. For *Macaranga peltata,* the highest carbon loss occurred during first 60 days (April and May) and the lowest carbon loss occurred on second 60 days (June and July).

DISCUSSION

5. DISCUSSION

The study was conducted to analyze the changes in soil carbon dioxide flux in moist deciduous forest for six months and also to understand the pattern and process of litter dynamics across this period. In this section changes or variation in carbon dioxide flux as related to soil parameters and weather conditions is discussed. Also litter fall pattern and litter decomposition was analyzed

5.1 Meteorological parameters

5.1.1 Temperature

Atmospheric temperature was found to be decreasing with months (Fig 8) .From middle of May onwards-southwest monsoon sets over western coast of India including Kerala and this monsoon period will last till September. So the initiation of rain and subsequent cloudy atmosphere formed causes decrease in temperature. Kerala and the Arabian Sea island stations continue to experience rains from the south-west monsoon till the end of September which decreases summer hotness of land area (Ananthakrishnan and Rajan 1986).

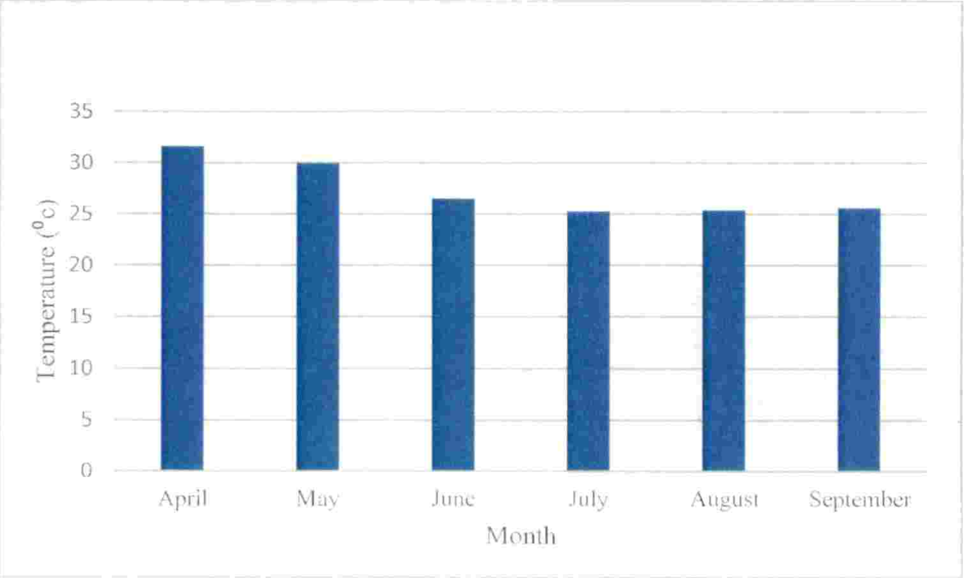

Fig 8. Monthly average temperature in the study area from April to September

5.1.2 Rainfall

Increase in rainfall was noticed from May to June (Fig 9). This may be due to the introduction of monsoon after May. The monsoon event which starts in May usually extends upto September over Kerala and the months of June and July usually get the highest rainfall. Monsoon represented significant changes in the large-scale atmospheric and oceanic circulations in the Indo-Pacific regions (Pai and Nair 2009). So changes in global oceanic circulation would also affect the monsoon events.

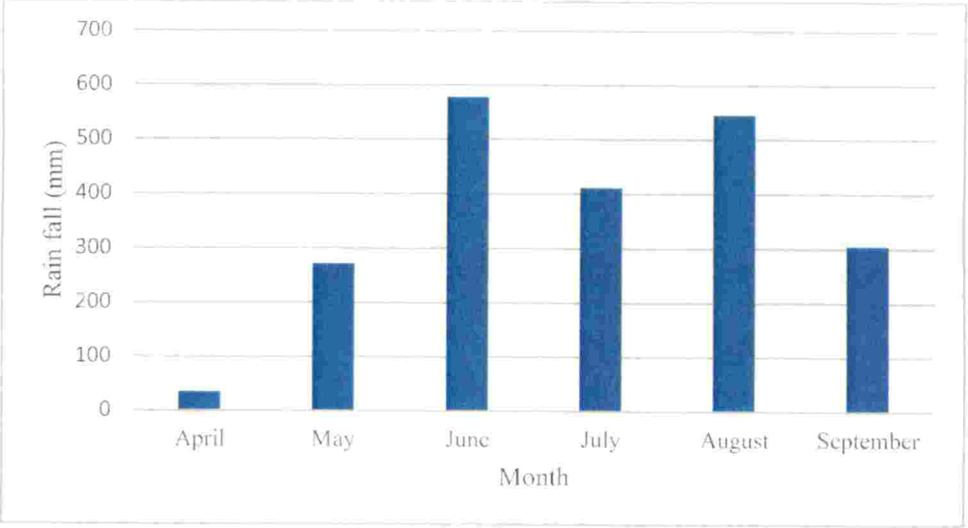

Fig 9. Monthly total rainfall in the study area from April to September

7.1.3 Relative humidity

The increase in relative humidity can be attributed to increase in rainfall. Increased rainfall creates an increase in evaporation and transpiration from plants. High vegetation in the study area created more humid conditions rapidly. Relative humidity level reached almost saturation point in the month of July due to frequent rainfall during June-July months (Fig 10). Locally, rainfall generally increases the relative humidity as a result of evaporation because the air into which rain falls is not completely saturated with water vapour. This evaporation cooled the air and increased the absolute moisture content of air locally.

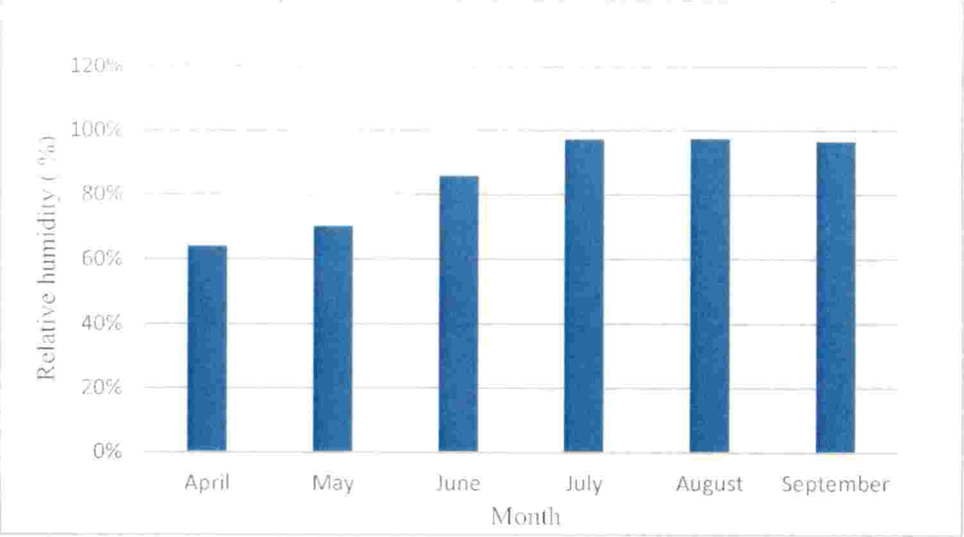

Fig 10. Monthly average relative humidity in the study area from April to September

5.2 Soil parameters

5.2.1 Moisture

An increase was recorded in the amount of soil moisture during April-September. The impact of rainfall was observed from the increase of soil moisture after April (Fig 11). The moisture level of soil had not reduced with the reduction in rainfall. This indicated that the water evaporation from soil was less during the study period. This low evaporation rate could be due to low disturbance and dense vegetation of the study site. Dense vegetation lead to higher litter cover and this in combination with low disturbance condition significantly reduced the soil moisture loss. In an earlier study (Findell and Eltahir 1997), analyzed direct observations on soil moisture and rainfall from Illinois and found a significant but small lag correlation between soil moisture and rainfall. In the studies of Li *et al*., (2014) the results revealed that the litter reduced runoff and delayed the beginning of runoff, and significantly reduced soil loss. This indicated that litter cover reduced loss of soil moisture and soil disturbance to a significant level.

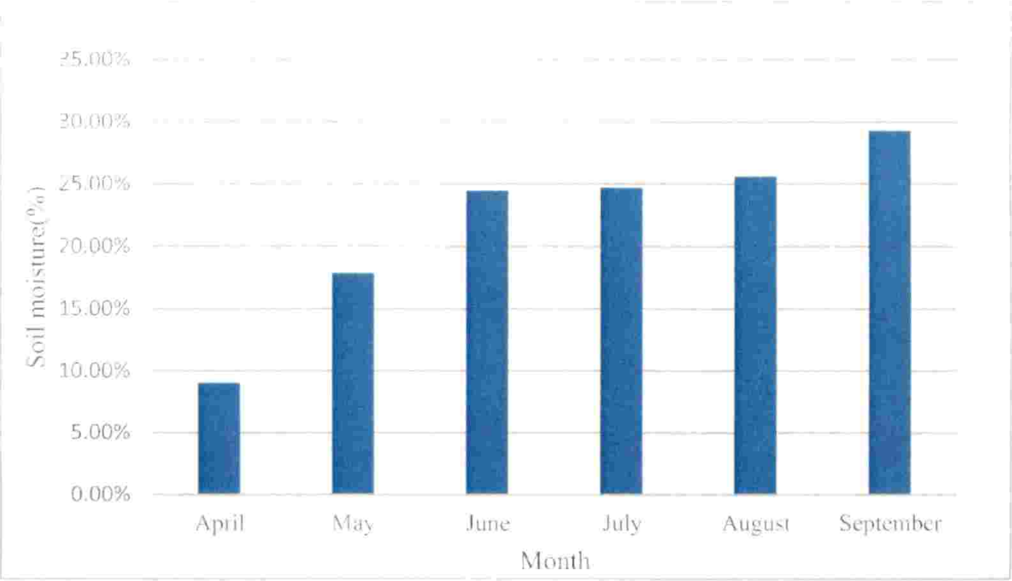

Fig 11. Monthly average soil moisture content in the study area from April to September

5.2.2 Organic carbon

The soil organic carbon (SOC) content of a site is determined by both inherent properties and the extrinsic factors to which the soil is exposed. However determining what factors make changes in the soil organic content is not relevant for this study. In top soil effect of climate and other external factors influence organic carbon content, while with depth the plant functional types such as root structure and its intrusion significantly affects the SOC content. In this study soil observations were taken in 20 cm depth i.e. in the top layer so that climate and other physical factors will have great influence on SOC than plant functional types. Figure 12 shows decrease in SOC content in monsoon season which shows a negative relation between top SOC and rainfall (Table 18). Leaching and runoff of top soil caused by rainfall reduces organic carbon content and other nutrients there by a negative relation existing between them and this may also alter the relation between temperature and top SOC. Studies by Chen,

61

X *et al.*, (2015) indicates precipitation treatment in all mixed forest, pine forest and broad leaf forest in subtropical China results in a decrease in SOC content

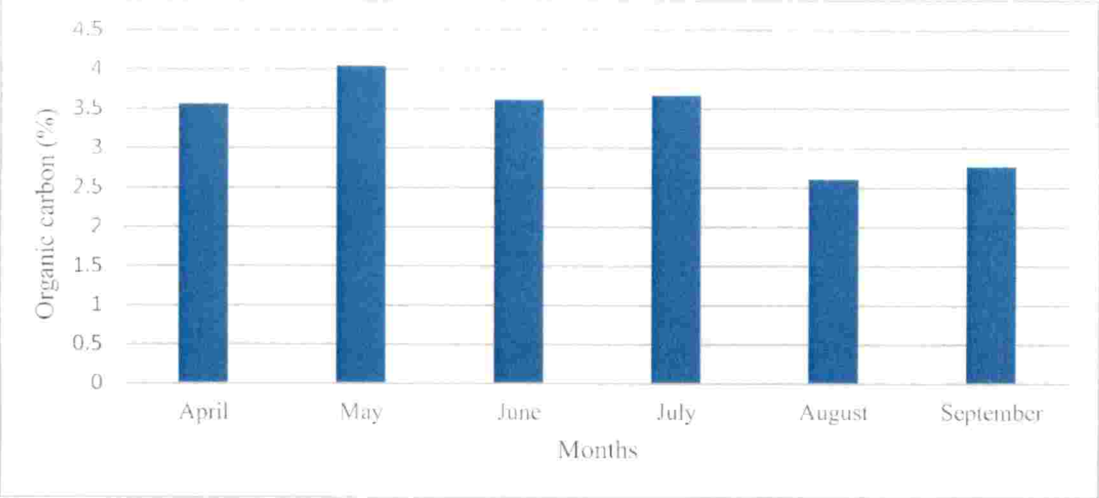

Fig 12. Monthly average Soil organic carbon in the study area from April to September

Table 18. Correlation between soil organic carbon and rainfall

	Soil organic carbon	**Rainfall**
Soil organic carbon	1	
Rainfall	-0.43	1

5.2.3 pH

Soil pH level ranging from 5.24 to 6.08 indicated the acidic nature of soil. Variation in pH level is within the acidic range. More variation in soil pH was exhibited during May whereas April recorded a higher pH value (Fig 13). Rainfall and soil mineralization could be the major factors affecting the soil pH level. Usually acidic soils are found in high rainfall regions, so rainfall should have significant influence on soil pH. Temperature and rainfall control leaching intensity and soil mineral weathering. In warm, humid environments, soil pH decreases over time called soil acidification, due to leaching from high amounts of rainfall (McLean, 1982).

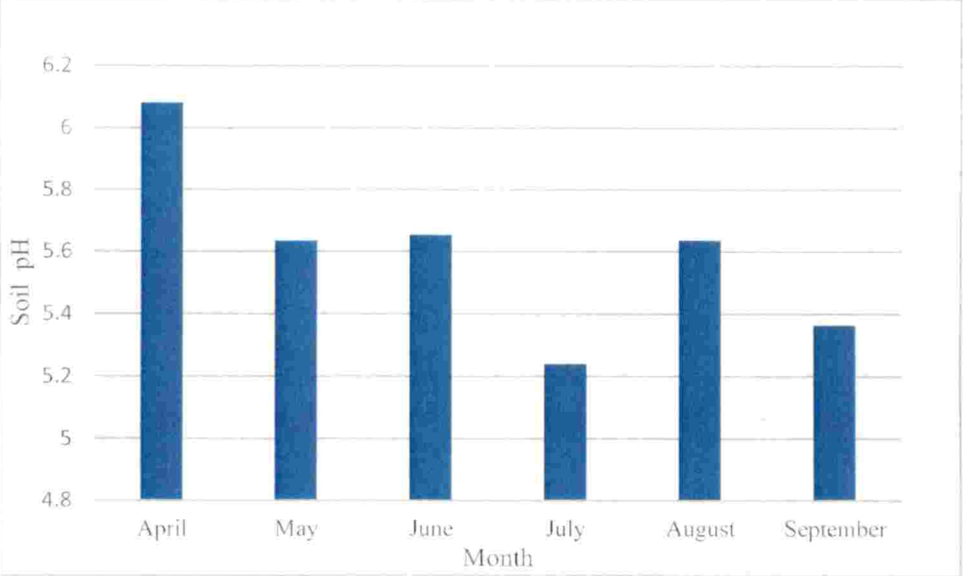

Fig.13. Monthly average soil pH in the study area from April to September

5.2.4 Soil temperature

Soil temperature had great influence on amount of rainfall in tropical regions. Decrease in soil temperature was see in the figure 14. This result may be due to increased rainfall in that period other soil characteristics like porosity, soil texture also have influence on it. Studies indicated that thermal conductivity increased with increase in particle size of the soil. Considering the primary focus of most of the relevant work on the thermal properties, the impacts of the physical properties of the soil on soil temperature can be advantageously summarized within the context of thermal conductivity, heat capacity and thermal diffusivity, the physical features that inherently affect soil temperature (Lehnert 2014).The thermal conductivity of soil is mainly influenced by the volume fraction of solid, liquid and gaseous substances (Lu *et al.*, 2007).

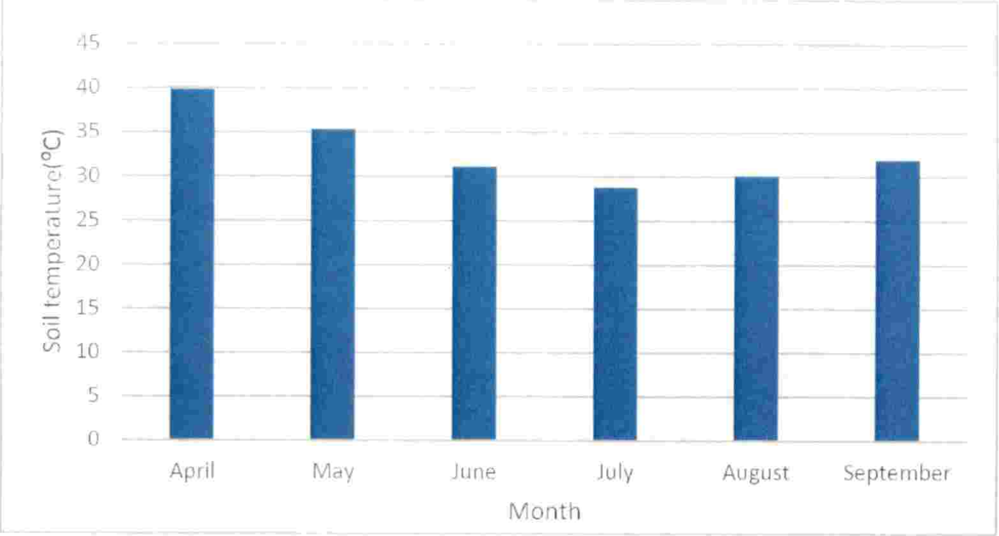

Fig. 14 Monthly average Soil temperature in the study area from April to September

5.2.5 Carbon dioxide efflux

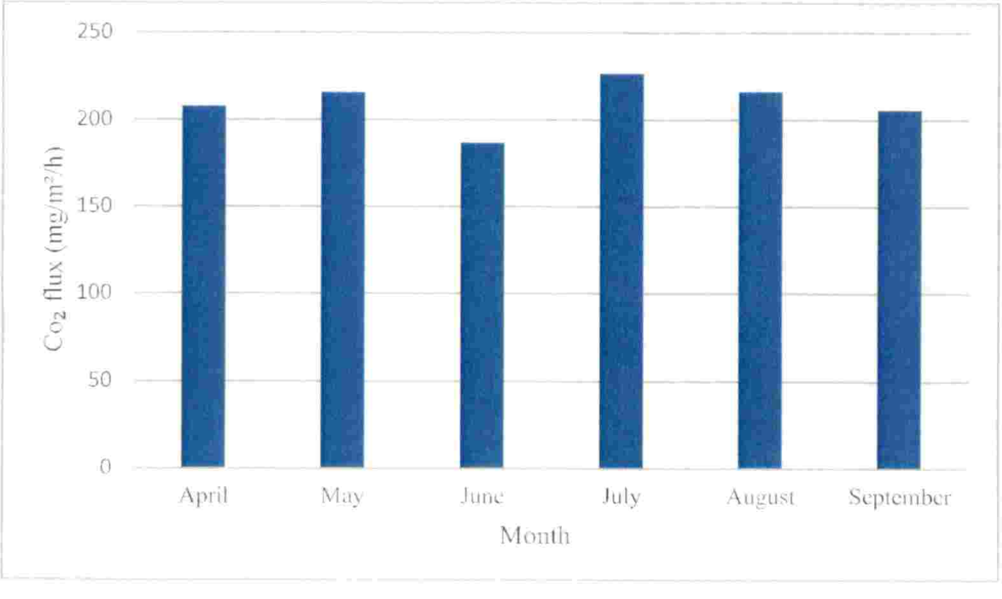

Fig. 15 Monthly average CO_2 efflux in the study area from April to September

5.2.5(a) Effect of weather on soil carbon dioxide flux

Table 19.Correlation between CO_2 efflux and weather

	CO_2efflux	**Temperature**	**Relative humidity**	**Rainfall**
CO_2 efflux	1			
Temperature	-0.36	1		
Relative humidity	0.27	-0.96	1	
Rainfall	0.31	-0.79	0.71	1

In the present study, all the correlation coefficients relating to soil CO_2 efflux and weather parameters indicated weak relationship among themselves. A weak correlation is indicated when the values of correlation coefficient lies between 0 to 0.3.In this study temperature and rainfall exhibited higher correlation of the order -0.36 and 0.31 respectively, while relative humidity exhibited a lower correlation value of 0.27 which is the least among the three parameters considered in the study (Table 19).Temperature indicated a weak negative correlation while rainfall and relative humidity indicated a weak positive correlation. The study revealed that soil respiration is directly proportional to rainfall and relative humidity and inversely proportional to temperature.

Earlier studies point outs that increasing temperature accelerates soil respiration but it may change regionally across world. In this study temperature exhibited a decreasing trend due to monsoon rainfall, but soil respiration showed an increasing trend (Table 19). The temperature range in this study was between 25 ^{0}C to 32 ^{0}C (Fig.6) and soil respiration was active at temperatures below 30 ^{0}C than at 32 ^{0}C

(Fig.16). The Studies by Carey *et al.*, (2016) describes that climatic warming is hypothesized to increase rates of soil respiration, potentially fueling further increases in global temperatures. However, despite considerable scientific attention in recent decades, the overall response of soil respiration to anticipated climatic warming remains unclear across all non-desert biomes, soil respiration increases with decreasing soil temperature up to a threshold of ~25 °C, above which respiration rates decrease with further increase in temperature. In this study the threshold level seems to be at 30 ^{0}C, since at 32 ^{0}C the respiration rate decreased. These results may not be parallel with the aforementioned work by Carey et al., (2016) since the study was conducted during monsoon period. For drawing more meaningful results, soil respiration measurements in summer dry periods is also needed.

In the case of relative humidity, it seemed to be directly correlated with soil respiration (Table 19). Studies by Melling *et al.* (2005) indicated that the closed canopy of the forest ecosystem enhanced the relative humidity and cooled the surrounding air. He also mentioned that relative humidity measurements between 72% and 85% in the forest ecosystem contributed to the largest mean CO_2 flux of 405 mg C m^{-2} h^{-1} implying high soil respiration in high humidity range. Humidity had a larger effect on total soil respiration than on root respiration and root-wrenched soil respiration (Liu *et al.*, 2005) which indicates high microbial activity is the cause of increased soil respiration in high humidity range.

Rainfall seemed to be directly correlated with soil respiration (Table 19). Changes in soil moisture under different precipitation treatments could influence the response of soil respiration to precipitation and there is no doubt that precipitation is usually the driving factor of the dynamics in soil moisture (Deng *et al.*, 2012). Harper *et al.*, (2005) reported that Soil CO_2 flux was related to both soil temperature and soil water content in regression analyses; which explained as much as 64% of the variability in CO_2 flux across dates under ambient rainfall timing. Soil respiration was suppressed by decreased precipitation and was enhanced by increased precipitation (Miao *et al.*,

66

2017). Study by Unger *et al.*, (2010) resulted in sudden pulse-like events of rapidly increasing CO_2-efflux occur in soil under seasonally dry climates in response to rewetting after drought. All the above studies showed that rainfall have some sort of positive impact to soil respiration.

5.2.5 (b) Effect of soil parameters on soil carbon dioxide flux

Table 20. Correlation between soil CO_2 efflux and soil parameters

	CO_2 efflux	Soil moisture	Soil organic carbon
CO_2efflux	1		
Soil moisture	0.16	1	
Soil organic carbon	0.08	0.07	1

In this part soil pH and soil temperature were not taken into correlation since pH is very insensitive for such a short period and lack of replication of soil temperature variables rendered chances of correlation very low. Remaining parameters such as soil moisture and soil organic carbon content showed very weak correlation of 0.16 and 0.08. Despite weak correlation values, the negative and positive signs can be used to predict whether relation is directly proportional or inversely proportional. Here both soil moisture and organic carbon is directly correlated with soil CO_2 efflux, where soil moisture was more correlated than soil organic carbon.

Study by Pingintha *et al.*, 2010 suggests that the effect of moisture content on soil CO_2 flux is complex and difficult to elucidate as it affects the respiratory activity of roots, microbes and also gaseous transport via soil. The study by Orchard and Cook, (1983) supports the findings. Even at −0.01 MPa (Mega Pascal), a decrease in water potential from −0.01 to −0.02 MPa caused a 10% decrease in microbial activity. Rewetting the soil caused a large and rapid increase in the soil respiration rate which also showed that soil respiration had a positive relation to soil moisture. Soil moisture was an important stimuli in initiating elevated soil CO_2 fluxes (Doff Sotta *et al.,* 2004).

Soil organic carbon content also exhibited positive correlation with soil CO_2 respiration. SOC content is another important factor affecting soil respiration since it supplies substrates to microbial heterotrophs. The study conducted by Ramana *et al.*, (2017) in Guvvalacheruvu reserve forest observed a positive correlation between soil organic carbon and soil respiration. The variation in soil respiration among different vegetation types could be well explained by soil organic carbon. Higher soil respiration in woodland can be attributed to higher soil organic carbon residues and its storage in the upper 20 cm of soil (Wang *et al.,* 2013).Lai *et al.,* (2012) explained in their study that the lower correlation between soil respiration and SOC content might indicate that the SOC content is not the determinant factor of variations in soil respiration among natural ecosystems. Also the weak relation indicated that factors other than microbial activity played important role in soil respiration. So it was evident that under certain conditions, root respiration played a greater role than microbial respiration. But it could not be concluded whether the major contribution was due to root respiration or by microbial respiration unless more information was obtained on root respiration and different types of soil organic carbon pools.

5.3 Litter dynamics

5.3.1 Litter fall pattern

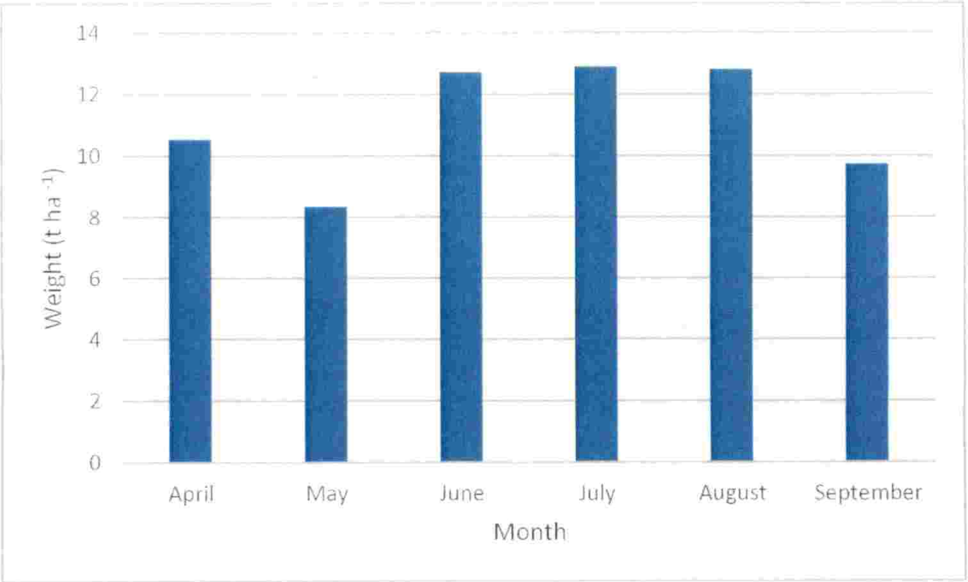

Fig 16. Litter fall of the study area during the period from April to September

Changes in litter fall were found to be different in different months. Litter fall mainly depended on seasonal and plant physiological events. Study by Kumar and Deepu (1992) showed that in Western Ghat forests annual litter fall ranged from 12.18 to 14.43 t ha^{-1} which is quite too similar to litterfall in this study. Litter fall usually started from winter months of December and ended in April or May because of temperature and water stress during that period. Followed by a high litter fall in winter and summer periods there will be decrease in amount of litter in April and May. Summer showers of April caused sprouting of new leaves and hence during this period new leaves will emerge. The aging and fall of the newly emerged leaves takes place in June to September so that an increased litter fall was observed during those months. Litter deposition followed a diphasic pattern with a major peak in February 2012 and two minor peaks in May and December 2011 the major peak of February might be associated with natural senescence of leaves induced by temperature and/or moisture stress (Kumar and Deepu, 1992). The studies by Parsons *et al*., (2014) in tropical forest denotes that litterfall mostly in summer (wet warm) months in the region, but other peaks occurred throughout the year which also supports this study

5.3.2 Decomposition of litter

The decomposition constant k value of field representing litters was found to be 0.009 day^{-1} were biomass loss was different for different intervals (Table 4). He *et al.* (2009) investigated litter decomposition in Jiang Fengliang montane forest, China above 800 m above mean sea level and concluded that the litter decay constant was 0.08–0.1 month^{-1} at 20 °C at higher altitudes. Prescott (2005) observed values for high elevations were between -0.0026 and -0.0042 day^{-1}. In temperate forests low value of 0.05 month^{-1} observed. By comparing results of these studies it was found that a decomposition constant was higher for these moist deciduous plots than montane and temperate types of forests. The decomposition rate constant of 0.008 day^{-1} to 0.009 day^{-1} was found in a study conducted in Nilambur forest of Western Ghats by Kuruvilla *et al.* (2016).Similar results were obtained in the present study for decomposition rate constant as that obtained for moist deciduous type of forests in the Western Ghats.

5.3.3 Carbon loss

Investigating the loss of carbon in relation to environmental conditions will not be a valid study when there is lack of data about important carbon constituents in plants. Carbon is an important constituent in litter and is usually related to lignin degradation and lignin represents 30% of the carbon sequestered in plant materials annually (Austin and Ballare, 2010). Increased lignin in Sungai Kial forest during early stages was due to decomposition of easily degradable compounds that left lignin levels intact to enrich the decomposing litter layer (Berg and McClaugherty, 2008).So lignin quantification is important for comparing carbon loss with environmental conditions. However, degradation of lignin or other carbon constituents were not determined in the present study.

5.4 Species wise litter dynamics

Result on litter study indicated that *Terminalia paniculata* followed *by Tectona grandis, Xylia xylocarpa* and *Macaranga peltata* contributed the highest leaf litter. The dominance level of species distribution was in the order of *Tectona grandis, Xylia xylocarpa, Terminalia paniculata* and *Macaranga peltata*. Litter fall pattern was purely determined by the physiology or structural parameters of the individual plant and its environmental factors. So there may be change in prediction that dominant species sheds more litter because each species physiological function and structural parameters are different from other species. Relating litter production to structural parameters revealed a positive correlation within dominant species (Capellesso *et al.*, 2016). In deciduous forests of Western Ghats, *Terminalia paniculata* contributed significantly greater amount of leaf litter to annual litter production (Sundarapandian and Swamy, 1999).Higher litter fall was recorded during the period from June to August and the lowest in May for all plant species. The litter fall pattern of the study site Moist Deciduous Forest (MDF) followed the same pattern of litter fall for individual species.

5.4.1 Species wise carbon content and decomposition rate

Table 21. Species wise carbon content

Species	Carbon content (%)
Tectona grandis	47.73
Xylia xylocarpa	47.18
Terminalia paniculata	47.05
Macaranga peltata	46.71

The carbon content among these species was the highest for *Tectona grandis*. It was followed by *Xylia xylocarpa*, then *Terminalia paniculata* and finally *Macaranga peltata* (Table 28); differences existed in biomass loss amount and pattern is because of structural qualities of litter. Study by Jeyanny *et al.*, 2015 indicated Carbon constitutes more than 40% of the leaf nutrients.

Table 22. Species wise decomposition rate

Species	**Decomposition rate constant k (day^{-1})**
Tectona grandis	0.0087
Xylia xylocarpa	0.0094
Terminalia paniculata	0.0037
Macaranga peltata	0.0101

Decomposition rate constant 'k' value was found to be the highest for *Macaranga peltata* followed by *Xylia xylocarpa, Tectona grandis* and *Terminalia paniculata* (Table 19). For all species wise decomposition and biomass loss the environmental parameters had strong influence. The variability in decomposition rate is due to change in nutrient constituents among them. The lignin content and the lignin: nitrogen ratio are also important, which controls the amount of metabolic fraction present in plant residues (Bernhard-Reversat and Schwartz, 1997). Values for C: N and lignin: N were unique depending on their respective inert qualities of leaf litter (Parsons and Congdon 2008, He *et al.*, 2009) which indicated that it varies within the species.

SUMMARY AND CONCLUSION

6. SUMMARY AND CONCLUSION

Soil carbon dioxide efflux is one of the major contributors of atmospheric carbon dioxide which is the main concern of global warming and climate change. Study about pattern and different conditions of soil carbon dynamics is important to predict the contribution of soil ecosystem to global atmospheric carbon. Litter dynamics is of great interest in carbon dynamic studies due to their roles in recycling carbon and nutrients. The forest ecosystem has remarkable contribution in global carbon cycle. Mostly tropical ecosystem possesses high vegetation than other forest types. So it is important to determine the role of tropical forests in carbon cycle. In this context, present study entitled "Soil carbon efflux and litter decomposition of natural forest of KFRI Peechi campus" was carried out as part of MSc dissertation at the Academy of Climate Change Education and Research, Kerala Agricultural University, Vellanikkara, Thrissur during 2016-2017.

The study was carried out in the natural vegetation of KFRI campus which is a moist deciduous type of forest. The data collection was from fifteen sample plots were carried out for six months. Soil carbon dioxide efflux and soil parameters such as moisture, organic carbon, temperature and pH were determined three weeks in a month .Monthly data of temperature, rainfall, and relative humidity was collected from automatic weather station of KFRI. Litter fall was determined on monthly basis and litter biomass loss was determined once in two months from every sample plots and decomposition rate was calculated. Litter fall, biomass loss and decomposition rate of four major species (*Tectona grandis, Xylia xylocarpa, Terminalia paniculata, Macaranga peltata*) were also determined. The study generalized the following conclusion:

Significant changes in temperature and relative humidity were associated with rainfall events. The onset of monsoon significantly decreased temperature and increased the relative humidity of the study region. Rainfall was high in the months of June and August and the lowest in April and May.

The soil parameters were closely related to weather conditions. A weak negative correlation existed between top soil organic carbon and rainfall.

Among weather parameters, soil carbon dioxide efflux had weak positive correlation with rainfall and relative humidity and had weak negative correlation with temperature. Soil carbon dioxide efflux also showed a very weak positive correlation with soil organic carbon and soil moisture.

Litter fall was the highest in monsoon onset periods and decreased with monsoon withdrawal because water availability increased due to rainfall which would have increased plant's physiological events.

Decomposition rate constant for moist deciduous forest was 0.009 day^{-1} which was found to be greater than decomposition rate constant of temperate and montane type of forests.

Carbon content of litter was 47.49% and most of the carbon was lost during decomposition.

The species, *Terminalia paniculata* possessed higher and *Macaranga peltata* possessed least deciduous properties.

The highest carbon content among the four species studied was for *Tectona grandis* and the lowest carbon content was for M*acaranga peltata.*

Decomposition rate was the highest for *Macaranga peltata* and lowest for *Terminalia paniculata.*

This study concluded that increasing conditions of rainfall and relative humidity had a positive correlation and cause accelerated soil carbon dioxide efflux. Increased temperature cause decreased soil carbon dioxide flux and temperature below certain threshold level was found to increase soil respiration. The prevailing positive conditions for soil carbon dioxide efflux increases atmospheric carbon dioxide and prevailing positive conditions for biomass decomposition and litter fall increases carbon sequestration in these soils.

REFERENCES

REFERENCES

Abhilash, P.C., Tripathi, V., Edrisi, S.A., Dubey, R.K., Bakshi, M., Dubey, P.K., Singh, H.B., and Ebbs, S.D. 2016. Sustainability of crop production from polluted lands. *Energy, Ecology and Environment.* 1(1): 54-65.

Achard, F., Eva, H. D., Stibig, H. J., Mayaux, P., Gallego, J., Richards, T., and Malingreau, J. P. 2002. Determination of deforestation rates of the world's humid tropical forests. *Sci.* 297: 999–1002.

Adair, E.C., Parton, W.J., Del Grosso, S.J., Silver, W.L., Harmon, M.E., Hall, S.A., Burke, I.C., and Hart, S.C. 2008. Simple three pool model accurately describes patterns of long term litter decomposition in diverse climates. *Global Change Biology.* 14(11): 2636-2660.

Ananthakrishnan, R. and Kajan, C. K. 1987. Some features of the south-west monsoon rainfall of Cochin and Minicoy. *Int. J. Climatol.* 7(4): 355-372.

Anderson, J. M. 1973. Carbon dioxide evolution from two temperate, deciduous woodland soils. *J. Appl. Ecol.* 10(2): 361-378.

Anderson-Teixeira, K. J., Davies, S. J., Bennett, A. C., Gonzalez-Akre, E. B., Muller-Landau, H. C., Joseph Wright, S., Abu Salim, K., Almeyda Zambrano, A. M., Alonso, A., Baltzer, J. L., and Basset, Y. 2015. CTFS-ForestGEO: a worldwide network monitoring forests in an era of global change. *Glob. Change Biol.* 21(2): 528-549.

Austin, A.T. and Ballaré, C. L. 2010. Dual role of lignin in plant litter decomposition in terrestrial ecosystems. *Proc. Natl. Acad. Sci.* 107(10): 4618-4622.

Austin, A.T. and Vitousek, P.M. 2000. Precipitation, decomposition and litter decomposability of Metrosiderospolymorpha in native forests on Hawai'i. *Journal of Ecology.* 88(1): 129-138.

Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., Rödenbeck, C., Arain, M.A., Baldocchi, D., Bonan, G.B., and Bondeau, A. 2010.

78

Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. *Science*. 329(5993): 834-838.

Beniston, M., 2003. Climatic change in mountain regions: a review of possible impacts. *Clim. Change*. 59(1): 5-31.

Berg, B. and Laskowski, R. 2005. Litter decomposition: A guide to carbon and nutrient turnover. *Advances in ecological research*. 38: 448p.

Berg, B. and McClaugherty, C. 2008. *Plant litter: Decomposition, humus formation, carbon sequestration* (2nd Ed.) Springer, Berlin, Germany, 315p.

Bernhard-Reversat, F. and Schwartz, D. 1997. Change in lignin content during litter decomposition in tropical forest soils (Congo): comparison of exotic plantations and native stands. *C. r.'Acad. sci., Saer. II Sci. terreplanaetes*. 325(6): 427-432.

Binsiya, T.K. 2016. Carbon dynamics in Teak planted laterite soils of kerala. M.Sc. thesis,Kerala Agricultural University, Thrissur, 73p.

Bonan, G.B. 2008. Forests and climate change: forcings, feedbacks, and the climatebenefits of forests. *Science*. 320(5882): 1444-1449.

Borders, B. D., Pushnik, J. C., and Wood, D. M. 2006. Comparison of leaf litter decomposition rates in restored and mature riparian forests on the Sacramento River, California. *Restor. Ecol.* 14: 308–315.

Brienen, R.J., Phillips, O.L., Feldpausch, T.R., Gloor, E., Baker, T.R., Lloyd, J., Lopez-Gonzalez, G., Monteagudo-Mendoza, A., Malhi, Y., Lewis, S.L., and Martinez, R.V. 2015. Long-term decline of the Amazon carbon sink. *Nature*. 519(7543): 344-348.

Capellesso, E. S., Scrovonski, K. L., Zanin, E. M., Hepp, L. U., Bayer, C. and Sausen, T. L. 2016. Effects of forest structure on litter production, soil chemical composition and litter-soil interactions. *Acta Botanica Brasilica*. 30(3): 329-335.

Carey, J.C., Tang, J., Templer, P.H., Kroeger, K.D., Crowther, T.W., Burton, A.J., Dukes, J.S., Emmett, B., Frey, S.D., Heskel, M.A., and Jiang, L. 2016.

Temperature response of soil respiration largely unaltered with experimental warming In: *Proceedings of the National Academy of Sciences*, 29 November 2016, USA [On-line]. Available: https://experts.umn.edu/en/publications/temperature-response-of-soil-respiration-largely-unaltered-with-e.

Carnol, M. and Bazgir, M. 2013. Nutrient return to the forest floor through litter and throughfall under 7 forest species after conversion from Norway spruce. *Forest Ecol. Manag.* 309: 66-75.

Cavaleri, M. A., Reed, S. C., Smith, W. K., and Wood, T. E. 2015. Urgent need for warming experiments in tropical forests. *Global Change Biol.* 21(6): 2111-2121.

Chen, X., Zhang, D., Liang, G., Qiu, Q., Liu, J., Zhou, G., Liu, S., Chu, G., and Yan, J. 2015. Effects of precipitation on soil organic carbon fractions in three subtropical forests in southern China. *Journal of Plant Ecology*. 9(1): 10-19.

Clark, D. A., Brown, S., Kicklighter, D. W., Chambers, J. Q., Thomlinson, J. R., and Ni, J. 2001. Measuring net primary production in forests: concepts and field methods. *Ecol. Appl.* 11(2): 356-370.

Cleveland, C.C., Townsend, A.R., Taylor, P., Alvarez Clare, S., Bustamante, M., Chuyong, G., Dobrowski, S.Z., Grierson, P., Harms, K.E., Houlton, B.Z., and Marklein, A. 2011. Relationships among net primary productivity, nutrients and climate in tropical rain forest: a pan-tropical analysis. *Ecology letters*. 14(9): 939-947.'

Coley, P.D. and Barone, J.A. 1996. Herbivory and plant defenses in tropical forests. *Annual review of ecology and systematics*. 27(1): 305-335.

Conant, R.T., Ryan, M.G., Ågren, G.I., Birge, H.E., Davidson, E.A., Eliasson, P.E., Evans, S.E., Frey, S.D., Giardina, C.P., Hopkins, F.M., and Hyvönen, R., 2011. Temperature and soil organic matter decomposition rates–synthesis of current knowledge and a way forward. *Global Change Biol.* 17(11): 3392-3404.

Cornwell, W. K., Cornelissen, J. H., Amatangelo, K., Dorrepaal, E., Eviner, V. T., Godoy, O., Hobbie, S. E., Hoorens, B., Kurokawa, H., Pérez-Harguindeguy, N., and Quested, H. M. 2008. Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecol. Lett.* 11(10): 1065-1071.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., and Totterdell, I. J. 2000 Acceleration of global warming due to carbon cycle feedbacks in a coupled climate model. *Nature.* 408: 184-187.

Cox, P. M., Pearson, D., Booth, B. B., Friedlingstein, P., Huntingford, C., Jones, C. D., and Luke, C. M. 2013. Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability. *Nature.* 494(7437): 341-344.

Cramer, W., Bondeau, A., Woodward, F. I., Prentice, I. C., Betts, R. A., Brovkin, V., Cox, P. M., Fisher, V., Foley, J. A., Friend, A. D., and Kucharik, C. 2001. Global response of terrestrial ecosystem structure and function to CO_2 and climate change: results from six dynamic global vegetation models. *Global Change Biol.* 7(4): 357-373.

Cure, J. D. and Acock, B. 1986. Crop responses to carbon dioxide doubling: a literature survey. *Agric. For. Meteorol.* 38(1): 127-145.

Davidson, E. A. and Janssens, I. A. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature.* 440(7081): 165-173.

Davidson, E. A., Savage, K. V. L. V., Verchot, L. V., and Navarro, R. 2002. Minimizing artifacts and biases in chamber-based measurements of soil respiration. *Agric. For. Meteorol.* 113(1): 21-37.

Davidson, E. A., Verchot, L. V., Cattanio, J. H., Ackerman, I. L., and Carvalho, J. E. M. 2000. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. *Biogeochem.* 48(1): 53-69.

De Jong, E. and Schappert, H. J. V. 1972. Calculation of soil respiration and activity from CO_2 profiles in the soil. *Soil Sci.* 113(5): 328-333.

De Weirdt, M., Verbeeck, H., Maignan, F., Peylin, P., Poulter, B., Bonal, D., Ciais, P., and Steppe, K. 2012. Seasonal leaf dynamics for tropical evergreen forests in a process-based global ecosystem model. *Geosci. Model Dev.* 5(5): 1091-1108.

DeFries, R. S., Houghton, R. A., Hansen, M. C., Field, C. B., Skole, D., and Townshend, J. 2002. Carbon emissions fromtropical deforestation and regrowth based on satellite observationsfor the 1980s and 1990s. *Proc. Natl Acad. Sci.* 99(22): 14256-14261.

Deng, Q., Hui, D., Zhang, D., Zhou, G., Liu, J., Liu, S., Chu, G., and Li, J. 2012. Effects of precipitation increase on soil respiration: a three-year field experiment in subtropical forests in China. *PLoS One*. 7(7): 1057-1076.

Detwiler, R. P. 1986. Land use change and the global carbon cycle: the role of tropical soils. *Biogeochem. 2*(1): 67-93.

Doff Sotta, D., Meir, P., Malhi, Y., Nobre, A. D., Hodnett, M., and Grace, J. 2004. Soil CO_2 efflux in a tropical forest in the central Amazon. *Global Change Biol.* 10: 601–617.

Dong, Y., Qi, Y., Liu, J., Geng, Y., Manfred, D., Yang, X., and Liu, L. 2005. Variation characteristics of soil respiration fluxes in four types of grassland communities under different precipitation intensity. *Chinese Science Bulletin*. 50(6): 583-591.

Edwards, N. T. and Sollins, P. 1973. Continuous measurement of carbon dioxide evolution from partitioned forest floor components. *Ecol.* 54(2): 406-412.

Ensslin, A., Rutten, G., Pommer, U., Zimmermann, R., Hemp, A., and Fischer, M. 2015. Effects of elevation and land use on the biomass of trees, shrubs and herbs at Mount Kilimanjaro. *Ecosphere*. 6(3): 1-15.

Eswaran, H., Van Den Berg, E., and Reich, P. 1993. Organic carbon in soils of the world. *Soil Sci. Soc. Am. J.* 57(1): 192-194.

Ewel, J., Berish, C., Brown, B., Price, N., and Raich, J. 1981. Slash and burn impacts on a Costa Rican wet forest site. *Ecol.* 62(3): 816-829.

Fang, J., Chen, A., Peng, C., Zhao, S., and Ci, L. 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. *Sci.* 292(5525): 2320-2322.

Feher, D. 1927. Untersucheniiber die Kohlenstoffernahrung des Waldes. *Flora.* 21:316-333.

Field, C. B., Behrenfeld, M. J., Randerson, J. T., and Falkowski, P. 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. *Sci.* 281(5374): 237-240.

Findell, K. L. and Eltahir, E. A. 1997. An analysis of the soil moisture-rainfall feedback, based on direct observations from Illinois. *Water Resour. Res.* 33(4): 725-735.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., and Nganga, J. 2007. Changes in atmospheric constituents and in radiative forcing. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, KB., Tignor, M., and Miller, HL. (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom, pp.129-234.

Gopika Rani, K.S. 2015. Modelling soil carbon dynamics of two major ecosystems of humid tropics. M.Sc. thesis, Kerala Agricultural University, Thrissur, 117p.

Hagen, J. B. 1992. *An entangled bank: the origins of ecosystem ecology*. Rutgers University Press, New Jersey, 245p.

Hall, C. A., Detwiler, R. P., Bogdonoff, P., and Underhill, S. 1985. Land use change and carbon exchange in the tropics: I. Detailed estimates for Costa Rica, Panama, Peru, and Bolivia. *Environ. Manage.* 9(4): 313-333.

Hanson, P. J., Edwards, N. T., Garten, C. T., and Andrews, J. A. 2000. Separating root and soil microbial contributions to soil respiration: a review of methods and observations. *Biogeochem.* 48(1): 115-146.

Hanson, P. J., Wullschleger, S. D., Bohlman, S. A., and Todd, D. E. 1993. Seasonal and topographic patterns of forest floor CO2 efflux from an upland oak forest. *Tree physiol.* 13(1): 1-15.

Harper, C.W., Blair, J.M., Fay, P.A., Knapp, A.K., and Carlisle, J.D. 2005. Increased rainfall variability and reduced rainfall amount decreases soil CO_2 flux in a grassland ecosystem. *Global Change Biology*. 11(2): 322-334.

Harris, D. G. and Van Bavel, C. H. M. 1957. Root respiration of tobacco, corn, and cotton plants. *Agron. J.* 49(4): 182-184.

He, Y., Wang, J., Wang, L., Chen, Z. J., Yan, C., Yang, H., Tang, H., Zhu, C., Gong, Q., Zang, Y., and Evans, A. C. 2009. Uncovering intrinsic modular organization of spontaneous brain activity in humans. *PloS one*. 4(4): 265-290.

Hibbard, K. A., Law, B. E., Reichstein, M., and Sulzman, J. 2005. An analysis of soil respiration across northern hemisphere temperate ecosystems. *Biogeochem.* 73(1): 29-70.

Hobbie, S.E. 1996. Temperature and plant species control over litter decomposition in Alaskan tundra. *Ecological Monographs*. 66(4): 503-522.

Houghton, J. T. (ed.). 1996. *Climate change 1995: The science of climate change: on Climate Change* (Vol. 2). Cambridge University Press, pp. 99-118.

Hyland, B. P. M., Whiffen, T., Christophel, D. C., Gray, B., and Elick, R. W. 2002. *Australian Tropical Rainforest Plants – Trees,Shrubs and Vines*, CSIRO, Melbourne, 58p.

IPCC (International Panel on Climate Change) 2001. *Third Assessment Report 1995-2001.*International Panel on Climate Change, Geneva, Switzerland, 1144p.

IPCC (International Panel on Climate Change) 2014. *Fifth Assessment Report 2007-2014.* International Panel on Climate Change, Geneva, Switzerland, 151p.

Jobbágy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* 10(2): 423-436.

Katayama, A., Kume, T., Komatsu, H., Ohashi, M., Nakagawa, M., Yamashita, M., Otsuki, K., Suzuki, M., and Kumagai, T. O. 2009. Effect of forest structure on the spatial variation in soil respiration in a Bornean tropical rainforest. *Agric. For. Meteorol.* 149(10): 1666-1673.

Keller, M., Kaplan, W.A. and Wofsy, S.C., 1986. Emissions of N_2O, CH_4 and CO_2 from tropical forest soils. *J. Geophys. Res. Atmospheres*. 91(D11):11791-11802.

Kirita, H.1971. Re-examination of the absorption method of measuring soil respiration under field conditions. IV. An improved absorption method using a disc of plastic sponge as absorbent holder. *Jpn. J. Ecol.* 21: 119–127.

Koepf, H. 1953. Die Temperatur/Zeit–Abhängigkeit der Bodenatmung. ExperimentelleUntersuchungunterVerwendung des Ultrarotabsotionsschreibers (URAS). *J. Plant Nutr. Soil Sc.* 61(1): 29-48.

Koepf, H. V. 1954. Die biologischeAktivität des Bodens und ihreexperimentelleKennzeichnung. *J.Plant Nutr. Soil Sci.* 64(2): 138-146.

Kosugi, Y., Mitani, T., Itoh, M., Noguchi, S., Tani, M., Matsuo, N., Takanashi, S., Ohkubo, S., and Nik, A. R. 2007. Spatial and temporal variation in soil

85

respiration in a Southeast Asian tropical rainforest. *Agric. Forest Meteor.* 147(1): 35-47.

Kucera, C. and Kirkham, D. R. 1971. Soil respiration studies in tallgrass prairie in Missouri. *Ecol.52*(5): 912-915.

Kumar, B. M. and Deepu, J. K. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular India. *Forest Ecol. Manag.* 50(3-4): 181-201.

Kuruvilla, T., Jijeesh, C. M., and Seethalakshmi, K. K. 2016. Litter production and decomposition dynamics of a rare and endemic bamboo species Munrochloaritcheyi of Western Ghats, India. *Trop. Ecol.* 57(3): 601-606.

Kurz, W.A., Dymond, C.C., Stinson, G., Rampley, G.J., Neilson, E.T., Carroll, A.L., Ebata, T., and Safranyik, L. 2008. Mountain pine beetle and forest carbon feedback to climate change. *Nature*. 452(7190): 987-990.

Kuzyakov, Y. 2006. Sources of CO_2 efflux from soil and review of partitioning methods. *Soil Biol. Biochem.* 38(3): 425-448.

La Scala, N., Marques, J., Pereira, G. T., and Cora, J. E. 2000. Carbon dioxide emission related to chemical properties of a tropical bare soil. *Soil Biol. Biochem.* 32(10): 1469-1473.

Lai, L., Zhao, X., Jiang, L., Wang, Y., Luo, L., Zheng, Y., Chen, X., and Rimmington, G.M. 2012. Soil respiration in different agricultural and natural ecosystems in an arid region. *PloS one*. 7(10): 1-9.

Lehnert, M. 2014. Factors affecting soil temperature as limits of spatial interpretation and simulation of soil temperature. *ActaUniversitatisPalackianaeOlomucensis – Geographica. 45*(1): 5-21.

Lewis, S.L., Brando, P.M., Phillips, O.L., van der Heijden, G.M., and Nepstad, D. 2011. The 2010 amazon drought. *Science*. 331(6017): 554-554.

Li, X., Niu, J. and Xie, B. 2014. The effect of leaf litter cover on surface runoff and soil erosion in Northern China. *PloS one*. 9(9): 1273-1287.

86

Liu, Y., Han, S., Hu, Y., and Dai, G. 2005. Effects of soil temperature and humidity on soil respiration rate under Pinus sylvestriformis forest. *Chinese Journal of Applied Ecology*. 16(9): 1581-1585.

Londo, A. J., Messina, M. G., and Schoenholtz, S. H. 1999. Forest harvesting effects on soil temperature, moisture, and respiration in a bottomland hardwood forest. *Soil Sci. Soc. Am. J.* 63(3): 637-644.

Lu, S., Ren, T., Gong, Y., and Horton, R. 2007. An improved model for predicting soil thermal conductivity from water content at room temperature. *Soil Sci. Soc. Am. J.* 71(1): 8-14.

Lundegårdh, H. 1924. *Carbonic Acid Cycle in Nature*. Verlag Von Gustav Fischer, Jena, 90p.

Lundegardh, H. 1921. Ecological studies in the assimilation of certain forest plants and shore plants. *SvenskBotaniskaTidskrift*. 15: 46-94.

Lundegardh, H. 1927. Carbon dioxide evolution of soil and crop growth. *Soil Sci.* 23(6): 417-453.

Makarov, B. 1960. Soil respiration and the composition of the soil air in drained peat-bog soils. *Pochvovedenie*. 2: 56-62.

Malhi, Y. A., Baldocchi, D. D., and Jarvis, P. G. 1999. The carbon balance of tropical, temperate and boreal forests. *Plant Cell Environ.* 22(6): 715-740.

McGroddy, M. and Silver, W. L. 2000. Variations in belowground carbon storage and soil CO2 flux rates along a wet tropical climate gradient. *Biotropica*. 32(4): 614-624.

McKinley, A. D. 1931. Effect of sorghum plants on biological activities in the soil. *Soil Sci.* 32: 469-480.

McLean, E. O. 1982. *Soil pH and lime requirement*. Soil Science Society of America, pp. 199-224.

Medina, E. and Zelwer, M. 1972. Soil respiration in tropical plant communities. In: Golley, P. M. and Golley, F. B. (eds), *Tropical ecology with an emphasis on organic production*. University of Georgia, Athens, pp. 245-269.

87

Medina, E., Klinge, H., Jordan, C., and Herrera, R. 1980. Soil respiration in Amazonian rain forests in the Rio Negro Basin. *Flora*. 170(3): 240-250.

Meentemeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. *Ecology*. 59(3): 465-472.

Melillo, J.M., Aber, J.D., and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology*. 63(3): 621-626.

Melling, L., Hatano, R., and Goh, K.J., 2005. Soil CO_2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus B*. 57(1): 1-11.

Meyer, L. and Koepf, H. 1960. The carbon dioxide and the carbon dioxide in the soil. In: *Encyclopedia of plant physiology* (Vol. 5). Springer Berlin Heidelberg, pp. 24-46.

Miao, Y., Han, H., Du, Y., Zhang, Q., Jiang, L., Hui, D., and Wan, S. 2017. Nonlinear responses of soil respiration to precipitation changes in a semiarid temperate steppe. *Scientific Reports*. 7: 1-8.

Morén, A. S. and Lindroth, A. 2000. CO_2 exchange at the floor of a boreal forest. *Agric. Forest Meteor.* 101(1): 1-14.

Myers, N. 1980. *Conversion of tropical moist forests*. The National Academies Press, 206p.

Nakayama, F.S., 1990. Soil respiration. *Remote Sensing Reviews*. *5*(1): 311-321.

Ohashi, M., Gyokusen, K., and Saito, A. 1999. Measurement of carbon dioxide evolution from a Japanese cedar (Cryptomeria japonica D. Don) forest floor using an open-flow chamber method. *Forest Ecol. Manage.* 123(2): 105-114.

Orchard, V.A. and Cook, F.J. 1983. Relationship between soil respiration and soil moisture. *Soil Biology and Biochemistry*. 15(4): 447-453.

Pai, D. S. and Nair, R. M. 2009. Summer monsoon onset over Kerala: new definition and prediction. *J. Earth System Sci.* 118(2): 123-135.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., and Ciais, P. 2011. A

88

large and persistent carbon sink in the world's forests. *Science*. 333: 988-993.

Parsons, S.A., Valdez-Ramirez, V., Congdon, R.A., and Williams, S.E. 2014. Contrasting patterns of litterfall seasonality and seasonal changes in litter decomposability in a tropical rainforest region. *Biogeosciences*. 11: 5047-5056.

Parton, W., Silver, W.L., Burke, I.C., Grassens, L., Harmon, M.E., Currie, W.S., King, J.Y., Adair, E.C., Brandt, L.A., Hart, S.C., and Fasth, B. 2007. Global-scale similarities in nitrogen release patterns during long-term decomposition. *Science.* 315(5810): 361-364.

Pingintha, N., Leclerc, M.Y., Beasley Jr, J., Zhang, G., and Senthong, C. 2010. Assessment of the soil CO_2 gradient method for soil CO_2 efflux measurements: comparison of six models in the calculation of the relative gas diffusion coefficient. *Tellus B*. 62(1): 47-58.

Prescott, C. E. 2005. Do rates of litter decomposition tell us anything we really need to know? *Forest Ecol. Manage.* 220(1): 66-74.

Raich, J. W. and Potter, C. S. 1995. Global patterns of carbon dioxide emissions from soils. *Global Biogeochem. Cycles*. 9(1): 23-36.

Raich, J. W. and Schlesinger, W. H. 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B*. 44(2): 81-99.

Ramana, C.V., Raju, K.N., Basha, P.O., and Reddy, M.S. 2017. Estimation of soil organic carbon and soil respiration in a dry forest-Guvvalacheruvu Reserve Forest of Kadapa hill ranges. In: Zhang, W. (ed.), *Proceedings of the International Academy of Ecology and Environmental Sciences*, 1 December 2017, pp.90-96.

Raupach, M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.G., Klepper, G., and Field, C.B., 2007. Global and regional drivers of accelerating CO_2 emissions. *Proceedings of National Academy of Sciences,* 12 June 2007, USA [On-line]. Available: http://www.pnas.org/content/pnas/104/24/10288.full.pdf.

Reiners, W. A. 1968. Carbon dioxide evolution from the floor of three Minnesota forests. *Ecol.* 49(3): 471-483.

Restrepo-Coupe, N. Christoffersen, B., da Rocha, H. R., da Araujo, A. C., Borma, L. S., Cabral, O. M. R., de Camargo, P. B., Cardoso, F. L., da Costa, A. C. L., Fitzjarrald, D. R., and Goulden, M. L. 2013. Gross ecosystem productivity seasonality in the tropics: issues posed by the absence of CO_2 profile measurements at eddy flux systems. *Agric. For. Meteorol.* 182: 128-144.

Reynolds, S.G., 1970. The gravimetric method of soil moisture determination Part IA study of equipment, and methodological problems. *J Hydrol.* 11(3): 258-273.

Romell, L. G. 1922. The floor ventilation as Soil Factor. *Meddel. Stat. Skogsf6rs6ksanst.* 19: 281-359.

Running, S.W. 2008. Ecosystem disturbance, carbon, and climate. *Science*. 321(5889): 652-653.

.Rustad, L. E., Huntington, T. G., and Boone, R. D. 2000. Controls on soil respiration: implications for climate change. *Biogeochem.* 48(1): 1-6.

Scheffer, R.A., Van Logtestijn, R.S., and Verhoeven, J.T.A. 2001. Decomposition of Carex and Sphagnum litter in two mesotrophic fens differing in dominant plant species. *Oikos*. 92(1): 44-54.

Scholes, R.J., Schulze, E.D., Pitelka, L.F., and Hall, D.O. 1999. Biogeochemistry of terrestrial ecosystems. In: Walker, B., Steffen, W., Canadell, J., and Ingram, J. (eds), *The terrestrial biosphere and global change; implicatons for natural and managed ecosystems*. Cambridge University Press, Cambridge, United Kingdom, pp. 271-303.

Scott-Denton, L. E., Sparks, K. L., and Monson, R. K. 2003. Spatial and temporal controls of soil respiration rate in a high-elevation, subalpine forest. *Soil Biol. Biochem.* 35(4): 525-534.

Singh, J. S. and Gupta, S. R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Rev.* 43(4): 449-528.

Smith, F. B. and Brown, P. E. 1932. Methods for determining carbon dioxide production in soils. *Electr. J. Res. Bull. Iowa Agric. Exp. Sta.* [e-journal] 12(147). Available: http://lib.dr.iastate.edu/researchbulletin/vol12/iss147/1. ISSN: 0021-0692 [May 2017].

Solomon, S., Plattner, G.K., Knutti, R., and Friedlingstein, P. 2009. Irreversible climate change due to carbon dioxide emissions. In: Raikhel, V.N. (ed.), *Proceedings of the national academy of sciences*, 10 February 2009, USA, pp.1704-1709.

Sotta,D.E., Meir, P., Malhi, Y., Donatonobre, A., Hodnett, M., and Grace, J. 2004. Soil CO_2 efflux in a tropical forest in the central Amazon. *Global Change Biology*. 10(5): 601-617.

Srivastava, S.C. and Singh, J.S., 1989. Effect of cultivation on microbial carbon and nitrogen in dry tropical forest soil. *Biology and Fertility of Soils*. 8(4): 343-348.

Sterner, R.W. and Elser, J.J. 2002. *Ecological stoichiometry: the biology of elements from molecules to the biosphere*. Princeton University Press, 439p.

Stoyan, H., De-Polli, H., Böhm, S., Robertson, G.P., and Paul, E.A. 2000. Spatial heterogeneity of soil respiration and related properties at the plant scale. *Plant and soil*. 222(1-2): 203-214.

Sundarapandian, S.M. and Swamy, P.S. 1999. Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. *Forest Ecology and Management*. 123(2-3): 231-244.

Swift, M.J., Heal, O.W., and Anderson, J.M. 1979. *Decomposition in Terrestrial Ecosystems* (Vol. 5). University of California Press, 372p.

91

Townsend, A. R., Asner, G. P., and Cleveland, C. C. 2008. The biogeochemical heterogeneity of tropical forests. Trend. *Ecol. Evolut.* 23: 424–31.

Unger, S., Máguas, C., Pereira, J.S., David, T.S., and Werner, C. 2010. The influence of precipitation pulses on soil respiration–Assessing the "Birch effect" by stable carbon isotopes. *Soil Biology and Biochemistry*. 42(10): 1800-1810.

Van Schreven, D. A. 1967. The effect of intermittent drying and wetting of a calcareous soil on carbon and nitrogen mineralization. *Plant and Soil*. 26(1): 14-32.

Vitousek, P. M. and Sanford Jr, R. L. 1986. Nutrient cycling in moist tropical forest. *Annu. Rev. Ecol. Systematics.* 17(1): 137-167.

Vitousek, P.M., Turner, D.R., Parton, W.J., and Sanford, R.L. 1994. Litter decomposition on the Mauna Loa environmental matrix, Hawai'i: patterns, mechanisms, and models. *Ecology*. 75(2): 418-429.

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 37(1): 29-38.

Wang, W., Zeng, W., Chen, W., Zeng, H., and Fang, J. 2013. Soil respiration and organic carbon dynamics with grassland conversions to woodlands in temperate China. *PLoS One.* 8(8): 1-10.

Wardle, D.A., Walker, L.R., and Bardgett, R.D. 2004. Ecosystem properties and forest decline in contrasting long-term chronosequences. *Science*. 305(5683): 509-513.

Whitmore, T. C. 1990. *An introduction to tropical rain forests*. Clarendon Press, University of Minnesota, Minneapolis, 226p.

Wiant, H. V. 1967. Influence of Moisture Content on. *J. Forestry.* 65(12): 902-903.

Wieder, W. R., Bonan, G. B., and Allison, S. D. 2013. Global soil carbon projections are improved by modelling microbial processes. *Nat. Clim. Change.* 3(10): 909-912.

Woodwell, G. M. and Houghton, R. A. 1977. Biotic influences on the world carbon budget. In: W. Stumm. (ed.), *Global chemical cycles and their alterations by man*. Dahlem konferenzen, Berlin, pp. 61-72.

Xiao, W., Ge, X., Zeng, L., Huang, Z., Lei, J., Zhou, B., and Li, M. 2014. Rates of litter decomposition and soil respiration in relation to soil temperature and water in different-aged Pinusmassoniana forests in the three gorges reservoir area, China. *PloS one*, 9(7): 1720-1729.

Yuste, J. C., Konôpka, B., Janssens, I. A., Coenen, K., Xiao, C. W., and Ceulemans, R. 2005. Contrasting net primary productivity and carbon distribution between neighboring stands of Quercusrobur and Pinussylvestris. *Tree Physiol.* 25(6): 701-712.

Zhang, H., Yuan, W., Dong, W., and Liu, S. 2014. Seasonal patterns of litter fall in forest ecosystem worldwide. *Ecol. Comple*

SOIL CARBON EFFLUX AND LITTER DECOMPOSITION IN NATURAL FORESTS OF KFRI PEECHI CAMPUS

By

NIRAJLAL K.

(2012 - 20 - 121)

ABSTRACT OF THE THESIS
Submitted in partial fulfilment of the
Requirements for the degree of

B.Sc. – M.Sc. (Integrated) CLIMATE CHANGE ADAPTATION
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA
2017

ABSTRACT

Litter dynamics and soil respiration are of great interest in climate change studies due to their roles in recycling carbon and nutrients. Present study was conducted with the objectives of understanding patterns and the process of litter dynamics and the role of weather on soil carbon efflux. Litterbag technique was used to determine the decomposition of litter for 180 days. Soil CO_2 fluxes were measured for a period of three weeks in a month for up to 180 days. Mass loss, total carbon of decayed litter and litter fall were quantified. Major tree species' litter dynamics were also determined. Relationship between soil CO_2 efflux with soil and weather parameters were determined using correlation technique. Decomposition constant with a value of 0.009 day^{-1} was found in moist deciduous forest. Among weather parameters, soil carbon dioxide efflux had weak positive correlation with rainfall and relative humidity and had weak negative correlation with temperature. Among soil parameters, soil carbon dioxide efflux had very weak positive correlation with soil organic carbon and soil moisture. The weak correlation coefficient value came due to lesser variables which indicates duration of this study is not enough. Among species wise study, *Terminalia paniculata* possess higher deciduous properties that directly contributing more to soil carbon sequestration and it was also found that *Tectona grandis* had high carbon content per unit volume compared to other species. But the species *Macaranga peltata* might sequestered more amount of carbon in a short time due to its high decomposition rate. The study highlights the different responses of soil CO_2 efflux to weather and soil parameters but suggests a long duration study for in-depth analysis which is very relevant in carbon dynamics and climate change studies.