MODELLING SOIL CARBON DYNAMICS OF TWO MAJOR ECOSYSTEMS OF HUMID TROPICS

By

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2010-20-103

THESIS

Submitted in partial fulfillment of the

requirement for the degree of

BSc-MSc (Integrated) CLIMATE CHANGE ADAPTATION

Faculty of Agriculture

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2015

DECLARATION

I hereby declare that the thesis entitled "**Modelling soil carbon dynamics of two major ecosystems of humid tropics**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other university or society.

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ACKNOWLEDGEMENT

I would first like to thank my major advisor **Dr. Betty Bastin,** *Professor (Soil Science and Agrl. Chemistry), College of Horticulture, for her proper guidance, support, inspiration and the opportunities she has offered to me. She is incredibly organized and a great problem solver. Both of these qualities were immensely helpful in moving my work forward. Under her mentorship, I have learned the particulars of research work, which is an invaluable tool to have as my career moves forward and I shall be grateful to her forever.*

I express my sincere thanks to **Dr. E.K Kurien,** *Special Officer, ACCER, KAU, for his immense help towards my research work by providing necessary facilities. I could work in an enjoyable and meaningful manner throughout the period.*

My heartfelt thanks to **Dr. K.M Sunil,** *Assistant professor (Agrl.Meteorology), ACCER,KAU for timely suggestions, valuable help, proper guidance, expert advice and teaching during the research work.*

I express my gratitude to **Dr. S Sandeep,** *Scientist B, Soil Science Division, KFRI for his valuable suggestions, technical support and critical scrutiny of the manuscript. I sincerely thank him for sparing his valuable time for providing me proper guidance during the work.*

I would also like to thank **Dr. Manjunatha, M** *for his contribution to my work. Over the year, he had given me superb scientific insight and guidance, and*

demonstrated sincere interest in my work. Words are not enough to express my gratitude to him.

I would also like to acknowledge my sincere gratitude to ***Dr. Anitha, Dr.Moossa, P.P, Dr. Thulasi, Dr. Ilangovan Rangasamy, and Dr. S. Gopakumar*** *for their immense help.*

My special thanks to ***Mr. Kelvin Coleman,*** *Rothamsted Research, UK ,* ***Mr.Y.Shirato,*** *National Institute for Agro-Environmental services, Japan and the whole century model team for their timely help through specific suggestions and advice through email.*

I am thankful to my friends, especially ***Gayathri, Safia, Varsha, Harsha, Basil*** *and* ***Sandra*** *for their moral support, mental help and sincere co-operation for the study.*

Heartfelt thanks to ***my parents*** *for their continued prayers, support, inspiration and encouragement, especially* ***my Girijamma,*** *for always being with me.*

I am thankful to the ***Academy of Climate Change Education and Research*** *and* ***Kerala Agricultural University*** *for giving me a great opportunity to complete my studies and thesis work.*

Lastly, I bow my head in front of all Almighty ***GOD*** *who protected me by showering his blessings and giving ability to complete my work timely.*

Gopikarani

GOPIKA RANI K.S

Dedicated to fond memories of my
beloved Grandfather

(K.K Govindan)

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SYMBOLS AND ABBREVATIONS

CS	**Carbon sequestration**
DPM	**Decomposable plant material**
DSSAT	**Decision supporting system for agro technology transfer**
GHG	**Green house gas**
Gt C	**Gigatonnes of carbon**
IOM	**Inert organic matter**
IPCC	**Intergovernmental Panel on Climate Change**
ME	**Model efficiency**
NPP	**Net primary productivity**
Pg	**Pentagram**
RCP	**Representative concentration pathway**
RPM	**Resistant plant material**
SOC	**Soil organic carbon**
SOM	**Soil organic matter**
SSP	**Shared socio-economic pathway**
Std	**Standard deviation**
t C/ha	**Tonne carbon per hectare**
TOC	**Total organic carbon**

INTRODUCTION

CHAPTER 1

INTRODUCTION

At global level, 81 per cent of the carbon in the earth's biosphere is stored in soil. Carbon is a vital component of soil organic matter (SOM), created by cycling of organic compounds in plants, animals and microbes into the soil. The global pool of SOM is estimated to contain about 1500 Pg of carbon to 1 metre depth (Batjes, 1997). Soil carbon sequestration means the capture and long term storage of carbon in soil. So there is a reduction in carbon dioxide emission which has a substantial impact on long term opportunities to stabilize global warming and mitigate the impact of climate change. Due to the enhanced decomposition rate under high moisture and temperature, SOM and other organic compounds show a faster turnover in tropics compared to temperate soils.

Lal (2008) observed that the soil organic carbon concentration of India is severely depleted, and is below the critical limits for soil and ecosystem functions. The soils of India have lower soil organic carbon (SOC) pool and their capacity as determined by the climate and ecological factors; there is a large capacity for atmospheric carbon dioxide (CO_2). Generally, soils of Kerala show low organic carbon content in lower elevation and high in mid and higher elevations. Soils of highland south of Palaghat gap have varying features and are high in organic matter and low in cation exchange capacity (CEC) and base saturation (Krishnan *et al.*, 2005)

Rice (*Oryza sativa*) in Asia makes a major contribution to global rice supply. Globally, the area extent of wetland ecosystems ranges from 917 million hectares (Lehner and Doll, 2004) and has a major capacity to sequester carbon. The improved moisture and water holding capacity of wetlands can act as a long term sustainable system. Tropical forests, especially Teak (*Tectona grandis*) has an important role in global carbon cycle. About 187 million hectare forest plantations are there in world;

just half of them are in tropics. Teak is a major man made plantation in Kerala, both its soil and vegetation being large reservoirs to capture carbon. As it belongs to a long rotation species, it has long lasting storage period of carbon.

Measurements of SOM or soil organic carbon (SOC) in an ecosystem alone reveal little about how carbon has changed in the past or will change in the future. But to predict the effect of climate and land-use change need accurate dynamic models. Primary production (input) and decomposition (output) are two main primary processes which control soil carbon storage. Models were evaluated in terms of their ability to simulate observed soil carbon changes. Numerous studies and evaluation of simulation models have been reported. Among those models, Rothamsted Carbon model (Roth-C) and CENTURY are the two models most widely used and tested.

Roth-C model has been developed to predict organic carbon turnover in soils using monthly time steps and can model out to hundred thousand years. For paddy soils, Shirato and Yokozawa (2005) modified the model by tuning the decomposition rate constant of all pools separately for periods with and without submergence, on the basis of the slower decomposition rates of organic matter than in upland soils. CENTURY has been developed to simulate carbon and nutrient dynamics on monthly time steps for an annual cycle over time scales of centuries and millennia.

New research initiatives and action to deal with the concerns on soil quality for sustaining environmental integrity and soil quality as part of other natural resources and its role in human health have to be considered (Katyal, 2008). Climate change poses the single most important threat to the future of food production and security. The changes needing attention includes temperature, precipitation, sea level rise and atmospheric CO_2. So the future research should help in designing special programmes for adaptation to climate change (Swaminathan, 2008).

Scientifically prepared models with different parameters will be very much helpful in generating future climatic scenarios that are related to soil carbon dynamics of rice and teak ecosystems.

Hence, the present investigation was taken up with the following objectives.

To evaluate the suitability of Roth-C and CENTURY models for carbon turnover predictions in rice and teak ecosystems of tropics.

To analyse the soil organic carbon changes due to predicted climate change scenarios.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Carbon (C) circulates between three large reservoirs *viz.*, oceans, atmosphere and terrestrial ecosystems. The amount of carbon in soil of terrestrial ecosystems is greater than the amount in living vegetation. In global context, soil carbon content has importance, because of the potential of soil to act as a sink for atmospheric carbon dioxide. Therefore, it is important to understand the dynamics of soil carbon and its role in terrestrial ecosystems. Hence the present study tries to evaluate the prospects of soil organic carbon dynamics in rice and teak ecosystems of humid tropics of Kerala using two major soil carbon models such as Roth-C and CENTURY.

2.1 Carbon Sequestration

Climate change can significantly impact the soil carbon and nitrogen. The changes in temperature, precipitation and CO_2 concentration readily affect the carbon inputs to soil, carbon decomposition and nitrogen transformations (Mosier, 1998).

The Kyoto Protocol permits carbon emissions to be offset by demonstrable removal of carbon from the atmosphere; this removal includes improved management of agricultural soils as well as afforestation and reforestation. Carbon sequestration, and the extent to which it can be counted as a reduction in a nation's carbon emissions, have been the focus of substantial controversy in international negotiations subsequent to the Kyoto Protocol (IPCC, 2000).

The combustion of fossil fuels and the changes in land use contribute to the emission of greenhouse gas (GHG), especially carbon dioxide (CO_2). Consequently, the global surface air temperature has been rising steadily (IPCC, 2001). It is widely agreed that global warming would increase soil respiration, and release more CO_2 that further exacerbates the global warming (Emmett *et al.*, 2004).

Terrestrial C storage not only represents an important option for partially mitigating anthropogenic emissions, but also provides a number of other ecosystem services such as soil fertility, water quality, resistance to erosion, and climate mitigation through reduced feedbacks to climate change (Lal, 2004a).

Global climate has experienced drastic changes in the 20th century, and it has been suggested that even more drastic changes will take place in the 21st century if the GHG emission rate remains at or exceeds the current level (IPCC, 2007).

Carbon sequestration is defined as the removal of CO_2 from the atmosphere into various long lived chemically bound forms, either on land or in the ocean. Through the process of photosynthesis, CO_2 is sequestered from the atmosphere into plant tissues. Photosynthesis represents the largest transfer of CO_2 in the C cycle, and therefore, is of great importance in understanding how to manage the global C cycle. Carbon sequestration on land (or terrestrial C sequestration) occurs in standing biomass (e.g. trees), long-term harvested products (e.g. lumber), living biomass in soil (e.g., perennial roots and microorganisms), recalcitrant organic matter in surface soil (e.g., humus), and inorganic C in subsoil (e.g., carbonates) (Johnson *et al.*, 2007).

Smith *et al.* (2008) estimated that in the soil atmosphere net carbon flux is to be low, but there is a large potential to recover the carbon historically lost, and it has been estimated that 89 per cent of agriculture's greenhouse gas mitigation potential relies on carbon sequestration.

According to Reynaldo (2012) one of the major challenges of the 21^{st} century is to mitigate the effects of global environmental changes brought about by increasing emissions of greenhouse gases (GHGs), especially CO_2.

2.1.1 Carbon stocks in tropical forest

Forests contain large quantities of carbon, as approximately 77 per cent of the global vegetation carbon is in tree biomass and approximately 42 per cent of the global 1 m top soil carbon is in the forest soil (Bolin and Sukumar, 2000).

When forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2). Tropical deforestation is estimated to have released to the order of 1–2 billion tonnes of carbon per year during the period 1990, roughly 15–25 per cent of annual global greenhouse gas emissions (Fearnside and Laurance, 2003). The largest source of greenhouse gas emissions in most tropical countries is from deforestation and forest degradation.

The world's terrestrial ecosystems could mitigate from 1 to 2.3 Gt of carbon yearly, and the total global net forest sink was estimated to vary from 1.1 to 2.7 Gt of carbon every year between 1995 and 2050. In other words, forests sequester about 2.4 Gt C or 8.7 Gt CO_2 equivalents per year from the atmosphere (Nabuurs *et al.*, 2007). Moreover, clearing tropical forests also destroys globally important carbon sinks that are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilization (Stephens, 2007).

The sequestration potential of tropical forests may vary by 10 per cent from year to year depending on the length of the dry period and variation in solar radiation inputs and temperature, such as those caused by the eruption of Pinatubo or those that occur during strong El Nino years (Tian *et al.*, 2008).

According to Harris *et al.* (2012) tropical deforestation accounted for about 10 per cent of global emissions and 0.81 Gt C per year between 2000 and 2025. The tropical forest regrowth creates a carbon sink of 471 Gt C (55 per cent), and 56 per cent of this carbon is stored in biomass and 32 per cent in soil.

A study conducted by Bandyopadhya and Lal, (2015) found that the concentration of C and N in forest soil is higher than the cultivated soil.

2.2 Soil carbon sequestration

Worldwide, SOC stocks generally increase as mean annual temperature decreases (Post *et al.*, 1982). Jenkinson *et al.* (1991) proved that an approximate loss of 100 Pg of carbon from soils annually with such as 3 degree increase in temperature. According to them rise in temperature will accelerate the decomposition of SOM there by releasing carbon dioxide to the atmosphere and further enhancing the warming trend.

Various studies estimate that soil carbon sequestration may be increased to a rate of 0.44 to 0.88 Pg carbons per year and sustained over a 50 year time frame (Cole, 1997).

According to IPCC (2000), the historical loss from agricultural soils was 50 Pg C over the last half century, which represents one third of the total loss from soil and vegetation. Cool or cold, humid climate regions are characterized by their carbon rich soils (Hobbie *et al.*, 2000). Rosenberg and Izaurralde (2001) indicated that soil carbon sequestration may have an important strategic role due to its low cost and potential for early deployment within a portfolio of technologies to mitigate climate change.

Schuman *et al.*(2002) noticed that the total soil carbon pool is around 1400–1500 Pg C, which is approximately two times greater than the atmospheric pool of 750 Pg C. The soil carbon pools are divided into two classes namely, organic carbon (1500-2000 Pg) and inorganic carbon (700 -1000 Pg) (Lal, 2004b).

Sitch *et al.* (2004) proposed that in some instances, soil might be a comparatively stronger source of CO_2 in the future as temperature rises. Soil organic carbon has received increasing attention due to its potential capacity to play an important role in mitigating (human) GHG emissions (Wander and Nissen, 2004).

Soil carbon sequestration that will benefit global climate change scenarios will be a result of management strategies that increase organic matter inputs to soil (Janzen, 2006).

Blanco and Lal (2008) mentioned about soil that it is the fundamental and non-renewable natural resource which acts as the basic medium for plant growth and prone to rapid degradation over time due to human interventions. Stewart *et al.* (2008) pointed out the capacity for the soil to incorporate SOC into the soil carbon pools becomes maximum, known as the soil carbon saturation concept.

Any increase in soil organic carbon content due to changes in land management, with the implication by which it can increase soil carbon storage, mitigates climate change is known as carbon sequestration (Powlson *et al.*, 2011). Generally it is a process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately reemitted.

The future climate is full of uncertainty, although the general trends of atmospheric CO_2 concentrations and global mean temperatures are increasing (Jackson *et al.*, 2011).

2.3 Soil organic carbon

Soil organic carbon consists of different soil fractions, which differ in their physical and chemical stability, making projections into the future even more imprecise. Since the total soil organic matter contents in mineral soils equilibrate within decades to centuries to altered environmental conditions, the identification of more sensitive SOM fractions may help to elucidate changes and trajectories in the SOC pool at early stages of changes in land-use or management (Leifeld and Kogel-Knabner, 2005).

Liski *et al.* (2005) put forward the concept for separating several components of SOC with different stabilities, such as an active or labile C pool with a faster turnover rate than other passive or resistant C pools in order to estimate the potential loss of SOC during land management. To embody the conceptual C pools, the experimental techniques have also been developed based on measureable C pools by either chemical or physical fractionation approaches (Zimmermann *et al.*, 2007).

Soil organic matter imparts desirable physical environment to soils by favourably affecting soil texture expressed through soil porosity, aggregation, bulk density and soil water storage. It also exerts significant influence on chemical properties of soils and nutrient availability, CEC, retention and mobilization of metals. Soil organic matter can also be seen as a mixture biogenic component that includes invariable proportions and evolutionary stages, microorganisms and undecomposed plant materials (Suri, 2007). He also observed that the final products of organic matter decomposition in soil accumulate as humus and disappear as CO_2. As on today, more terrestrial organic matter has been lost in the form of CO_2 than it has been sequestrated in soils. This is evidenced by 28 per cent increase in CO_2 load of earth's atmosphere over the years.

In general, intensive cultivation leads to substantial reduction in soil organic carbon especially, in semi arid and arid tropical conditions as encountered in India (Yadav, 2007). Kumar *et al.* (2010) observed that significantly greater root mass in the 1m soil profile in tree grass areas than the pasture grass, clearly indicating the potential to deposit C deeper in the soil profile in silvopasture compared to pastures.

2.3.1 Influence of climate on soil organic carbon

Globally, soil CO_2 emissions are positively correlated to the mean annual air temperature and the mean annual precipitation (Raich and Schlesinger, 1992). The changes in temperature, precipitation and CO_2 concentration readily affect the carbon inputs to soil, the soil carbon decomposition and the soil nitrogen trans-formations (Cao and Woodward, 1998).

Precipitation affects soil CO_2 emission by controlling the soil water fluctuation in the surface layer where most biological activities and soil CO_2 emission take place. It is considered likely that global warming will increase soil respiration, release more CO_2 and further exacerbate global warming (Rustad and Fernandez, 1998)

The past century has seen a marked increase in atmospheric carbon dioxide concentrations and a concomitant 'greenhouse warming' that has drawn scientific attention to the link between global carbon stocks and climate change (Cox *et al.*, 2000). It is often understood, based on analyses of global scale soil data sets, that the SOC pool is inversely related to temperature and proportional to precipitation (Jobbagy and Jackson, 2000). Even in the most optimistic of scenarios, climate change can be detrimental to several production chains, with a strong impact on developing economics which depend largely on agriculture.

Holland *et al.* (2000) through their experimental studies indicated increased SOC decomposition at higher temperature. Sanderman *et al.* (2003) found out that the decomposition and turnover of SOM is recognised as an important determinant of carbon driven climate change. The climate change can significantly impact the soil carbon and nitrogen. The SOC content in most croplands is below the potential storage capacity, as determined by climatic, pedological and terrain characteristics (Lal, 2004a).

A study conducted in UK by Bellamy *et al.* (2005) mentioned that climate change is the primary cause of soil carbon decrease in England and Wales. There is a great deal of concern that climate change will increase the rates of organic matter decomposition. These increased decomposition rates could potentially cause a shift from soils as carbon sinks to soils as sources of atmospheric carbon dioxide, there by accelerating climate change through so called carbon cycle feedbacks. In particular, the regulatory effect of temperature on soil decomposition is crucial to the stability of terrestrial organic matter stocks. The response of this source of carbon dioxide will depend upon temperature sensitivity of decomposition of both young, labile, rapidly turned over and older, non-labile, longer standing soil carbon pools (Fang *et al.*, 2005).

However, both the impact of climate change on soil carbon dynamics and the feedbacks of soil carbon dynamics on climate are currently controversial. For example, Thomson *et al.* (2006) suggested that at higher temperature and precipitation, the soil carbon sequestration rate and the soil carbon content will increase.

2.4 Soil carbon dynamics

SOM consists of different types of organic components, but for modeling purpose they are mainly divided into three pools based on their rate of mineralization and turnover period (Parton *et al.*, 1987).

According to Dudal and Deckers (1993), SOC plays an important role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention and supporting soil biological activity. Dixon *et al.* (1993) indicated that tropical countries offer a large potential of carbon sequestration through reforestation and improvement of degraded agro ecosystems.

Regional and global C budget quantifications need to include an understanding of SOC dynamics and SOC distribution at a regional level (Paustian *et al.*, 1997).

Given the fact that most of the C gains are achieved in the first 25 years, annual increases for this time period range from 0.02 to 0.43 tonnes C/ha/year, which is higher than the estimates provided by (Lal *et al.*, 1999). They also mentioned that under poor management, in the case of an annual millet - sorghum rotation with no inputs and permanent browsing and pruning of tree resources, both soil and tree C continue to drop, reaching an absolute minimum level of 7.9 tonnes /ha and 0.6 tonnes / ha, respectively.

Post *et al.* (2007) observed that sequestration of atmospheric CO_2 into soil organic carbon dictates acquisitions of research data on equilibrium level of soil organic carbon pool under different land uses and associated soil management practises and the rate of change of soil organic carbon pool with change in land use and management. Important land uses and practises with the potential to sequester soil organic carbon include conversion of cropland to pastoral and forest lands, conventional tillage to conservation and no tillage, no manure use to regular addition of manure, and to soil specific fertilization rate.

Long-rotation plantations that allow for establishment of diverse understory plant communities and accumulation of vegetation and soil carbon is more beneficial than short-rotation plantations (Kuzyakov and Domanski, 2000).

There is a continuous turnover of organic carbon materials in soil, and SOC is not a uniform material but rather a complex mixture of organic compounds at different stages of decomposition. It is convenient to divide total SOC into different pools dependent on their ease of decomposition, namely labile (active) pool, slow pool (intermediate) and inert (passive) pool. The labile pool consists of easily decomposable organic materials which stay in the soil for fairly short periods, from a few days to months, the slow pool includes the well decomposed and stabilized organic materials, often referred to as humus and the inert pool represents biologically resistant organic materials which are thousands of years old in soils (Bending *et al.*, 2000).

Soil organic carbon is lost through erosion, runoff and leaching (Roose and Barthes, 2001). The dynamics of SOC and its relationship with soil structure is more often compartmentalised into four soil carbon pools; unprotected, physically protected chemically protected and biochemically protected (Six *et al.*, 2002). They are, microbial biomass pool, comprises of 5 -15 per cent of total SOM, easily mineralizable with a turnover period of months to years; slow pools comprises, 20-40 per cent of total SOM with turnover period of years to decades and stable or recalcitrant pools: comprises 60-70 per cent of total SOM with turnover period of hundreds to thousands of years (Rice, 2002).

Increases in SOC storage in cropland soils would benefit soil productivity and environmental health (Lal, 2004a). Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Vanlauwe, 2004).

Sparling *et al.* (2006) proposed that the management to improve SOC could have an environmental protection benefit of up to 40–70 times its benefit to productivity.The soil organic carbon is a dominant component of soil organic matter, denoted as Soil organic carbon pool moderates all physical, chemical and biological processes of soil. The soil organic matter maintains soil structure, rejuvenates root development, boosts water retention and nutrient availability, and enhances microbial processes.

The SOC reduces soil erosion by managing aggregates and reducing erodability, upgrading water infiltration rate and decreasing the amount and rate of overland flow (Blanco and Lal, 2008).

Henry (2008) noticed that the dynamics of organic carbon in soil showed that the level of organic carbon in soil is relatively sensitive to increasing temperatures in the temperate climatic zone. Luo *et al.* (2011) found out in their study that the effectiveness of any management practice on agricultural SOC balance is affected by the complex interaction between carbon production and decomposition processes as controlled by spatiotemporally changing environmental conditions, which hampers our ability to extrapolate the SOC dynamics over time and space.

Tan *et al.* (2012) observed in their study that the soil carbon dynamics, change rate caused by land surface disturbances and climate change are generally related to the magnitude of initial SOC. Provided that adequate organic matter is added to the soil, and intensive-farming systems should maintain soil C and there is also scope for carbon sequestration. These results are in agreement with findings in the field that provide no evidence for a decline in SOM in spite of increased cultivation pressure. However, the ability to realize future carbon sequestration will depend on a careful balance between cropping and livestock husbandry and the overall capacity of the system. Maintaining crop yields through the application of inorganic fertilizer alone will probably result in substantial losses of SOM.

In depth understanding of labile soil organic carbon pool is necessary to define the soil health and nutrient turnover, since it plays an important role in short term C, N cycles and climate change (Katyal, 2015).

2.4.1 Soil carbon dynamics in rice ecosystems

The lack of oxygen under submerged conditions, even a modest oxygen demand for microbial activity cannot be met if large pores are filled with water, resulting in a decreased rate of decomposition (Jenkinson, 1988). The rate of soil organic matter decomposition is lessened in submerged rice soils, apparently due to excessively reduced conditions (Wantanabe, 1994).

Several studies in China have also identified paddy soils as one of the most important SOC accumulators (Nue *et al.*, 1997). Bronson *et al.* (1998) indicated an increase in C stocks in soil due to the relatively slow rate of soil C mineralization under anaerobic conditions.

Total above and below ground biomass production, crop residue management (removal, burning or incorporation) and the quantities of organic amendments added to the soil, such as farmyard manure (FYM) and green manure (GM), determine total organic carbon inputs. Organic carbon additions through the crop include roots, (including fine roots that die and rapidly decompose, and root exudates), and crop residues. For a soil under cultivation, measures that increase above and below ground biomass production and or reduce removal from the field, will result in more favourable soil carbon balances (Buyanovsky and Wagner, 1998).

According to IPCC (2001), the management of rice agriculture for positive climate impact must consider the combined effects of carbon storage and soil greenhouse gas emissions. Long term experiments of treatments without fertilizer application in rice ecosystem generally shows a decline in SOC, compared to a constant or increasing SOC content under integrated nutrient management with combined application of inorganic fertilizers and organic amendments (Katyal *et al.*, 2001).

A decline in soil organic carbon content is a common phenomenon when land use changes from natural vegetation to cropping (Lal, 2002). The reasons for this decline include a reduction in total organic carbon inputs, increased rate of decomposition due to mechanical disturbance of the soil, higher soil temperatures due to exposure of the soil surface, more frequent wetting and drying cycles and increased loss of surface soil, rich in organic matter, through erosion. Therefore, there is incomplete decomposition of organic materials and decreased humification of organic matter under submerged conditions, resulting in net accumulation of organic matter in soils (Sharawat, 2004).

Conversion of upland croplands to rice paddies might be still an option to increase China's agricultural SOC sink as recommended by Lal (2004a).The dynamics of SOM in paddy soils differs considerably from that in upland soils because paddy soils are waterlogged, and therefore under anaerobic conditions, during the rice-growing period. Thereby soil organic matter decomposition becomes slowed down, resulting in higher soil organic carbon levels in paddy fields than in upland soil (Zhang and He, 2004).

The long term fertilizer experiments conducted over several years in different agro ecosystems of India reveal that the integrated nutrient management including

NPK along with farm yard improved SOC and enhanced crop productivity (Manna *et al.*, 2005).

Rice cultivation globally covers a total area of about 153 million ha and has been proposed to have a great potential in sequestrating atmospheric CO_2 (IPCC, 2007). According to Xie *et al.* (2007), paddy soils and upland soils are the two main types of agricultural soils in China, with area of 30 and 126 M ha and the paddy soils generally show higher SOC density and greater potential of C sequestration than upland soils.

Smith *et al.* (2008) estimated that 89 per cent of global potential for agricultural greenhouse gas mitigation would be through carbon sequestration. Thus, large quantities of carbon from the atmosphere would be removed, and agricultural activity can contribute substantially to cutting greenhouse gas emissions. The physical protection of carbon by soil aggregation was also proposed to explain the strong SOC sequestration in paddy fields (Zhou *et al.*, 2008). However, Kayranli *et al.* (2010) observed that due to the high productivity and slow decomposition rates, wetlands have the highest carbon density among all terrestrial ecosystems.

2.4.2 Soil carbon dynamics in teak ecosystems

Teak is a deciduous tree reaching its large dimensions in western and southern India (Champion and Seth, 1968).The teak soil is relatively fertile with high calcium, phosphorus, potassium, nitrogen and organic matter contents (Kaosa-ard, 1981).

Soil organic C in the topsoil layer (0–30 cm) varied across the southwest monsoon, inter monsoon and northeast monsoon periods. The total N content of the soil increased with increasing relative proportion of leucaena and available P levels were highest in teak-leucaena plots, while available K levels were highest in the teak-leucaena mixture and in pure leucaena plots. For teak it has been previously reported that wide seasonal variations occur in fine root biomass indicating a significant accumulation and disappearance pattern of fine root biomass. Soil organic C increases after the onset of the southwest monsoon and may continue until the dry summer when soil moisture availability limits fine root growth (Srivasthava and Singh, 1988)

About 40 per cent of global soil C inventory resides in forest ecosystems (Hudson *et al.*, 1994) and dynamics of forest soil organic C has significant implications to global C budget. The low SOC stocks in teak related to high temperatures and precipitation have a negative effect on organic matter accumulation (Jaramillo *et al.*, 1994).

It was reported by Singh (1994) that organic carbon content of the soil profile increased several fold under 20 years old tree plantations. Indian estimates of forest SOC are in the range 5.3-6.7 P g C (Dadhwal *et al.*, 1998), however most of these estimates are based on average global or regional soil C densities of various forest types. Carbon sequestered by the main stem wood results in longer sequestration while other components sequester and release carbon on shorter intervals due to natural pruning and decomposition (Montagmini and Porras, 1998).

Converting degraded soils under agriculture and other land uses into forests and perennial land use can enhance the SOC pool. The magnitude and rate of SOC sequestration with afforestation depends on climate, soil type, species and nutrient management (Lal, 2001).

Tree plantations can be an efficient tool for combating climate change as they help in carbon dioxide sequestration in the short term and mitigating atmosphere levels of carbon dioxide in the long term (House *et al.*, 2002). There are a number of factors that could diminish the effect of CO_2 fertilization on forest growth. Clearly, increasing temperature and drought can reduce growth, but perhaps more importantly, changing climatic parameters can affect the net ecosystem productivity (Knapp *et al.*, 2002).

The variation in the carbon sequestration in native plantations over time provides information on the possible associations between biodiversity and carbon stock (Kirby and Potvin, 2007). However, one of the most promising approaches to promote C sequestration in forests is a change in tree species composition.

Several researchers investigated the storage of SOC under different tree species and reported various effects (Vesterdal *et al.*, 2008). Most of these studies were restricted to the organic layer and uppermost mineral horizons and quantified only a certain proportion of total SOC stocks.

Kaul *et al.* (2010) observed that the net annual carbon sequestration rate was 2.0 t C /ha/ yr for moderate growing teak forests and 1.0 t C /ha/ yr for slow growing Sal forests. Miranda *et al.* (2011) predicted that the dynamics of biomass and carbon sequestration in planted forests is a difficult task because it requires destructive methods.

In order to increase C stocks in forests, several management practices were discussed such as thinning, drainage, extending of rotation period, fertilization, liming, site preparation, fire, storm and insect management, afforestation and reforestation, harvest management and input of harvest residues (Carroll *et al.*, 2012).

Thomas *et al.* (2013) reported that young plantations can sequester relatively larger quantities of carbon while a mature plantation can act as a reservoir. Long rotation species such as teak (*Tectona grandis*) has long carbon locking period compared to short duration species and has the added advantage that most of the teak wood is used indoors extending the locking period further. The soil in teak plantations continue to accumulate carbon and thus act as a sink always.

2.5 Soil carbon models

Mathematical modelling has been used to predict soil carbon evolution (Smith, 1979). Paustian *et al.* (1992) opined that the distribution and dynamics of soil

C at the regional level is also an important step for quantifying regional and global C balances and assessing the response and feedbacks of terrestrial ecosystems to climate change.

Soil organic matter models, which belong to biogeochemical models, have been used extensively during the last 20 years to improve our understanding of soil organic matter (SOM) dynamics (Parton and Rasmussen, 1995).

In soil carbon management, increasing the soil C pool has been substituted with the term of soil carbon sequestration (Paustian *et al.*, 2000). The use of soil organic matter models (simplified representations of a complex reality) is an important research tool to investigate soil organic matter evolution, and to examine the consequences of various intervention measures (Van Keulen, 2001). These models have the ability to simulate the complex processes in the humification and degradation of organic matter and describing the relationship between a numbers of soil properties controlling soil carbon evolution (Somarathne *et al.*, 2005).

Post *et al.* (2007) divided the models into four categories depending on their internal structure such as process oriented or (multi) compartment models, organism-oriented (food web) models, cohort models describing decomposition as a continuum and a combination of process oriented and organism oriented models. Reviews of process-oriented models have concluded that the assignment of model SOM compartments to measureable soil organic matter fractions is often difficult, due to a lack of correspondence of experimentally verifiable fractions with the incorporated C pools which in turn restricts the validation of these models with real world data.

Smith *et al.* (2008) reported that the performance of most processes-oriented models showed a high applicability for predicting long-term soil organic matter dynamics (decades) across a range of land uses, soil types and climatic regions. According to them only Soil organic matter models describes the meso and macro fauna and distinguishes different forms of organic matter based on the abundance of the soil fauna. The performance of most processes-oriented models showed a high applicability for predicting long-term soil organic matter dynamics (decades) across a range of land uses, soil types and climatic regions.

There is a substantial global effort in the area of soil C modelling involving a number of different models (Kirschbaum, 1995), including Century (Parton *et al.*, 1987) and Roth-C (Jenkinson *et al.*, 1991). Both of these models have similar structure, containing pools with a rapid turnover (month–year), moderate turnover (decadal), slow turnover (millennial or inert).

Del Grosso *et al.* (2001) simulated the interaction of carbon dynamics and nitrogen trace gas fluxes using the DAYCENT model. This model was used to compare the effects of land management on SOM, nitrous oxide emissions (NO_2), plant production, and NO_2 leaching for a Great Plain soil that has been used for wheat fallow rotations and for a Midwestern soil used for corn/winter and wheat or pasture rotations. Results of the study showed that some type of agriculture can dramatically reduce soil C levels from what they were in the native condition, and that the loss can be reversed by perennial cropping, N fertilizer, irrigation, organic matter additions, no-till cultivation, and reversion to the native condition. It was also suggested that the soils that are depleted in SOM can temporarily compensate for greenhouse gas emissions by changing land management, but observed however, that net carbon sequestration will not continue for more than 10 to 50 years, under such conditions.

McGuire *et al.* (2001) studied the IBIS model simulations which projected an increase in biomass, Net Primary Productivity (NPP) and soil organic carbon in all the teak grids. In the A2 scenario, the percentage increase in biomass averages around 130–150 per cent, while it is around 90–110 per cent in the B2 scenario. These large increases are primarily due to the CO_2 fertilization effect: previous studies have shown that IBIS simulates a higher fertilization effect compared to other models.

Food and Agriculture Organization (FAO) has developed a methodological framework for the assessment of carbon stocks and the prediction of carbon sequestration scenarios that links SOC turnover simulation models (particularly CENTURY) to geographical information systems and field measurement procedures (FAO, 2001).

Different model structures might be needed for forest and agricultural soils, but many models have been applied to both types of soil, although some with modified parameterization (Peng *et al.*, 2002). Post *et al.* (2007) opined that, there is no scientific evidence of soil biota abundance limiting soil organic matter processes such as degradation rates. In relation to this study, forest soils and agricultural soils differ in many respects, they experience different management or disturbance regime and there are differences in their vegetation and biota.

The higher sensitivity of IBIS to CO_2 fertilization is due to the following reason: Currently, IBIS simulates the effects of changes in the supply of sunlight, water and CO_2 to vegetation—limitations of important nutrients like nitrogen and phosphorus in the tropical soils are not considered. The addition of nitrogen and phosphorus cycles might diminish the magnitude of response to elevated CO_2 (Hungate *et al.*, 2003).

Gassman *et al.* (2003) used EPIC to estimate regional soil carbon and other environmental indicators in the entire 12-state North Central region of the U.S. They found that EPIC is a robust tool for regional analyses of soil carbon changes, nutrient and erosion losses, and other environmental indicators in response to variations in management practices, cropping systems, climate inputs, and soil types.

Ardo and Olsson (2003) used GIS and the CENTURY model to assess soil organic carbon in the Sudan, a semi-arid environment. They compiled a climate, land cover, and soil database and integrated it with the CENTURY ecosystem model. This enabled them to estimate historical, current and future pools of SOC as a function of land management and climate. They concluded that grassland and savannah SOC variations depend on grazing intensity and fire return interval, and that land management may affect future amounts of SOC in semi-arid areas thereby turning them from sources into sinks of carbon.

Roth-C and Century are being used increasingly in studies of SOC dynamics (Foereid and Hogh Jensen, 2004). Testing and validating these two widely used models in different conditions is essential in order to test their suitability for predicting changes in soil C stocks under a range of environmental and management conditions. However, few data are available to validate model performance in tropical conditions. Zimmermann *et al.* (2007) conducted a study on relating measureable SOM fractions to the conceptual C pools used in the Roth-C model. Results indicated that the proposed fractionation method can be used to initialize and evaluate Roth-C for a range of environmental conditions.

Lawrence *et al.* (2009) investigated whether the addition of microbial mechanisms of decomposition would improve models of SOM dynamics. The current preference is for process-oriented models over organism oriented models as predictive tools for policy makers and other stakeholders (Smith *et al.*, 1998). Within process-oriented models, CENTURY and Roth-C are the most frequently used to simulate SOM dynamics at a farm-scale (Viaud *et al.*, 2010).

2.5.1 Roth-C model

RothC-26.3 is a model for the turnover of organic carbon in non-waterlogged top soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (t ha $^{-1}$), microbial biomass carbon (t ha $^{-1}$) and $^{\Delta 14}$C (from which the equivalent radiocarbon age of the soil can be calculated) on a years to centuries timescale (Jenkinson and Coleman, 1994). Since Roth-C is solely concerned with soil processes it does not contain a submodel for plant production, thereby it differs from the Century model (Parton *et al.*, 1987).

The active compartments are the Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). It separates incoming plant residues into decomposable plant materials (DPM) and resistant plant materials (RPM), both of which undergo decomposition to produce microbial biomass (BIO) and humified organic matter (HUM) and to release CO_2 (Coleman and Jenkinson, 1996).

Shirato and Taniyama (2003) tested the model against data from long term experiments in Japan, and has successfully simulated changes in SOC over time for non-volcanic upland soils. However, the original model was not successful in simulating carbon turnover in Andosols and paddy soils. Then Shirato *et al.* (2004) modified the model for Andosols by changing the HUM decomposition rate.

For paddy soils, Shirato and Yokozawa (2005) modified the model by tuning the decomposition rate constant of all pools separately for periods with and without submergence, on the basis of the slower decomposition rates of organic matter in paddy soils than in upland soils.

2.5.2 CENTURY model

The CENTURY model, developed for the grassland (Parton *et al.*, 1987), simulates soil C, N, P and S dynamics, primary productivity and water balance. CENTURY model consists of several major sub models such as SOM/decomposition sub model, a water budget sub model, and a plant production sub model (Metherell *et al.*, 1993).

Subsequent model modifications have expanded its applicability to forest systems (Sanford *et al.*, 1991) and agricultural systems (Paustian *et al.*, 1996).

CENTURY has been successfully used in tropical agro ecosystem (Parton *et al.*, 1987) and temperate ecosystems (Kelly *et al.*, 1997).

Motavalli *et al.* (1994) studied that the forest soils reported a CENTURY overestimate of about 51 per cent carbon stock. Pennock and Frick (2001) described about this model that it can underestimate 25 per cent to 70 per cent carbon stocks from agricultural systems. The model can also be used to study the effects of erosion and deposition on carbon dynamics as shown by (Harden *et al.*, 1999). The model has been expanded to include more agricultural crops (Gijsman *et al.*, 2002) and temperate and tropical forest systems (Wang *et al.*, 2002).

Carvalho Leite *et al.* (2004) observed that the model, that uses a monthly time-step, requests two kind of soil parameters: a general or non-site specific parameters, which include the maximum specific decomposition rates for each compartment; the constant that splits the flows of decomposition products and the parameters that control the effects on soil texture, temperature and moisture on decomposition rates, site specific parameters and initial conditions, such as soil texture (sand, silt and clay content), bulk density, soil depth and total soil C and N content. The effect of climate change on the SOC is simulated by CENTURY based on the input climate data, including monthly minimum temperature, monthly maximum temperature, and monthly precipitation for each year.

The model was developed with the advanced version 5, to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agro-ecosystems .It could fully couple the carbon, nitrogen and water cycles in the plant-soil system (Levy *et al.*, 2004).

2.6 Model parameterization and evaluation

The model was parameterized to simulate soil organic matter dynamics in the top 20 cm of the soil. The model does not simulate organic matter in the deeper soil layers and increasing the soil depth parameter does not have much impact on the model. Deeper soil depths have lower decomposition rates because of lower temperature at deeper depths. Thus, it was assumed that the fraction of total SOM in the passive SOM would be greater. The major change for initializing the model for deep soil depths is adjusting the fraction of SOM in the different pools (more C in passive SOM). The initial soil C levels should reflect the observed soil C levels over that depth and the decomposition rates should be decreased for all of the SOM pools (Jenkinson *et al.*, 1991).

Ranatunga *et al.* (2005) defined model efficiency (ME) as it provides a comparison of the efficiency of the chosen model with the efficiency of describing the data as that as the mean of the measured data.

2.7 Predicted climate change scenarios

Projected increase in temperature and decrease in effective rainfall may decrease the NPP in many tropical regions, but increase it in the boreal forest regions (White *et al.*, 1999). So any changes in soil moisture and temperature regimes can affect species composition in the ecosystem. These may affect the SOC pool and soil physical properties because of the changes in biomass (detritus material, above ground and below ground biomass) returned to the soil. Hence, the effect of climate change may be different in tropical, temperate and boreal regions.

Projected climate change may affect soil moisture and temperature regimes. At the ecosystem level, the soil affects vegetation through its influence on water availability, elemental cycling and soil temperature regime (Cheddadi *et al.*, 2001).

Carbon sequestration rates, estimated for a number of individual crops and crop rotations in this study, can be used in spatial modelling analyses to more accurately predict regional, national, and global C sequestration potentials (Tristram and Wilfred, 2002).

According to the Bureau of Meteorology, the impacts of climate change on the environment and society will depend not only on the response of the earth system but also on how humankind responds through changes in technology, economy, lifestyle and policy. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway followed.

The Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community.

The radiative forcing estimates on which they are based do not include direct impacts of land use (albedo) or the forcing of mineral dust. The RCPs are not forecasts or boundaries for potential emissions, land use, or climate change. They are not policy prescriptive in that they do not represent specific futures with respect to climate policy action (or no action) or technological, economic, or political viability of specific future pathways or climates (IPCC, 2013).

There are four pathways: RCP 8.5, RCP 6.0, RCP 4.5 and RCP2.6. The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents. The four selected RCPs were considered to be representative of the literature, and included one mitigation scenario leading to a very low forcing level

(RCP 2.6), two medium stabilization scenarios (RCP 4.5 and RCP 6.0) and one very high baseline emission scenarios (RCP 8.5).

The RCP 8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi *et al.*, 2007).

The RCP 2.6 was developed by the IMAGE modelling team of the Planetary Boundary Layer (PBL) Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a peak and decline scenario; its radiative forcing level first reaches a value of around 3.1 W/m^2 by mid-century, and returns to 2.6 W/m^2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially, over time (Van Vuuren *et al.*, 2007).

The RCP 6.0 was developed by the AIM modelling team at the National Institute for Environmental Studies (NIES) in Japan. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions (Hijioka *et al.*, 2008).

The RCP 4.5 was developed by the GCAM modelling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long run radiative forcing target level (Wise *et al.*, 2009).

The Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5) also introduced "Shared Socio-Economic Pathways" (SSPs). It can be used in conjunction with the RCPs to develop scenarios for use by the research community. The SSPs will include qualitative narratives and quantitative elements. They are reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or climate policies (IPCC, 2013).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 Sources and details of the study

The study was based on secondary data sets collected from experiments done in paddy fields and teak plantations of Pattambi and Thrissur areas respectively which belong to humid areas.

Soils in natural forest were used as a baseline to compare the soil in rice fields and teak plantations of different age groups. As these ecosystems were established by clear felling of the natural forest, it can be assumed that the initial soil conditions were similar. Hence any variation in soil conditions in rice fields and teak plantations of different age classes can be considered as a result of various management operations and based on 1965 to 2050 year time sequence, it was reconstructed.

3.1.2 Weather parameters

Weather data of rainfall, evaporation, maximum and minimum temperature (2005-2014) were obtained from Department of Agricultural meteorology of College of Horticulture, Vellanikkara and Regional Agricultural Research Station (RARS), Pattambi. The other data sets related to rice and teak ecosystems were also collected from various resources of Kerala Agricultural University (KAU).

3.1.3 Other parameters

Geographic coordinate systems such as latitude and longitude of both ecosystems, soil parameters such as soil texture, bulk density, soil organic carbon, pH was collected from the above mentioned resources (Table 1).

Table 1. Site and control parameters

Site and soil variables		Rice	Teak
SITLAT	Site latitude (degrees) latitude of model site (degrees)	10.48	10.31
SITLNG	Longitude of model site (degrees)	78.16	76.13
SAND	Per cent fraction of sand in soil	0.58	0.70
SILT	Per cent fraction of silt in soil	0.09	0.18
CLAY	Per cent fraction of clay in soil	0.33	0.12
BULKD	Bulk density of soil (g/cm^3)	1.35	1.42
NLAYER	Total soil layers in column (No.)	1.00	3.0
AWILT	The wilting point of soil layer (Fraction)	0.16	0.08
AFIEL	The field capacity of soil layer (Fraction)	0.20	0.20
pH	Soil pH	6.00	7.0

Plate 1. Rice field in Pattambi

Plate 2. Teak plantation in Thrissur

3.2 Working of Roth-C model

Data requirement

1. Monthly rainfall (mm)
2. Monthly mean air temperature (°C)
3. Monthly open pan evaporation (mm)
4. Clay content of the soil (%)
5. Depth of soil layer
6. An estimate of the decomposability of the incoming plant material – the ratio between Decomposable Plant Material and Resistant Plant Material (DPM/RPM ratio).
7. Soil cover – whether the soil surface is bare or vegetated.
8. Monthly input of plant residues or monthly input of farmyard manure.

Structure of the model

In this model, soil organic carbon is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM).Incoming plant carbon is split between DPM and RPM, depending on the DPM/RPM ratio of the particular incoming plant material.

A DPM/RPM ratio of 1.44, a value typical for most agricultural crops and grass land and for deciduous or tropical woodland a DPM/RPM ratio of 0.25 were used (Coleman and Jenkinson 1996). Monthly average temperature, monthly precipitation and open pan evaporation (average of 10 years from 2005 to 2014) were obtained from the RARS, Pattambi and COH, Vellanikkara. The IOM was set using the equation below (Falloon *et al*, 1998).

$$IOM=0.049\ TOC^{1.139}$$

Where TOC is Total organic carbon, t C/ ha

IOM is inert organic matter, t C/ h

Running of the model

Initially the files for weather management and land management were created. The scenario was created by entering an output file name, site name and land management file name. Then the year of start, the number of years the model is to be run, number of years to get the monthly output and the initial soil organic carbon were recorded. After incorporating all those parameters, the model was kept ready to run.

3.2.1 Rice ecosystem

As per the specification, the weather management file was created for the model (Table 2). Soils were assumed to be covered with crops from January to March. In the first cropping season (April to August) and the second cropping season (September to December) input of plant residues at 5 t C/ha has to be added for each as per recommendation of Package of Practices (KAU, 2011). The input of plant residues are split into 2.0 t C/ha, 1.50 t C/ha, 1.00 t C/ha and 0.50 t C/ha, because the annual distribution of inputs makes little difference in the calculated SOC, even if carbon is added in a single pulse (Coleman and Jenkinson, 1996). The DPM/RPM ratio was considered as 1.44. The IOM was calculated as 2.84 t C/ha.

3.2.1 Teak ecosystem

The weather management file for teak was created as per specification for the model (Table 3). It was assumed that during the first three months and the remaining last five months in year, no input was added. The monthly input of plant residues such as 1.01t C/ha, 0.98 t C/ha, 0.78 t C/ha and 0.63 t C/ha was added respectively for the months from April to July (Manjunatha, 2015). The DPM/RPM ratio was considered as 0.25. The IOM was calculated as 4.86 t C/ha.

Table 2. Weather parameters used in Roth- C model for rice ecosystem

Months	Temperature(°c)	Precipitation(mm)	Evaporation(mm)
January	27.03	21.00	2587.00
February	27.91	117.00	2445.00
March	29.98	314.00	2279.00
April	29.92	871.00	2270.00
May	29.33	1536.00	2157.00
June	27.14	5985.00	1082.00
July	26.38	6533.00	858.00
August	26.64	3436.00	1346.00
September	26.95	3264.00	1352.00
October	27.43	2684.00	1590.00
November	27.71	830.00	1809.00
December	26.87	175.00	2242.00

Table 3.Weather parameters used in Roth-C model for teak ecosystem

Months	Temperature(°c)	Precipitation(mm)	Evaporation(mm)
January	27.53	8.00	1757.00
February	28.54	192.00	1653.00
March	29.76	371.00	1716.00
April	29.74	875.00	1366.00
May	28.92	2079.00	1244.00
June	26.76	6901.00	855.00
July	26.06	6997.00	812.00
August	26.35	4650.00	896.00
September	26.59	3807.00	871.00
October	27.18	3034.00	957.00
November	27.34	1055.00	1019.00
December	27.24	114.00	1481.00

3.3 Working of CENTURY model

Data requirement

This model requires weather parameters such as monthly maximum and minimum temperature and monthly rainfall. In addition to that, it requires twelve data files (Table 4). Each file contains a certain subset of variables. Within each file, there may be multiple options in which the variables are defined for multiple variations of the event. For example, within the *cult.100* file, there may be several cultivation options defined such as ploughing or sweep tillage, thinning operations etc. For each option, the variables are defined to simulate that particular option. Each data input file is named with a ".100" extension to designate it as a CENTURY file. These files can be updated and new options created through the FILE.100 program.

Structure of the model

This SOM model includes three soil organic matter pools (active, slow and passive) with different potential decomposition rates, above and below ground litter pools and a surface microbial pool which is associated with decomposing surface litter. The active pool (SOM1C(2)) represents soil microbes and microbial products (total active pool is 2 to 3 times the live microbial biomass level) and has a turnover time of months to a few years depending on the environment and sand content. The soil texture influences the turnover rate of the active soil SOM (higher rates for sandy soils) and the efficiency of stabilizing active SOM into slow SOM (higher stabilization rates for clay soils). The surface microbial pool (SOM1C(1)) turnover rate is independent of soil texture, and it transfers material directly into the slow SOM pool (SOM2C). The slow pool includes resistant plant material derived from the structural pool and soil-stabilized microbial products derived from the active and surface microbial pools. It has a turnover time of 20 to 50 years. The passive pool (SOM3C) is very resistant to decomposition and includes physically and chemically

Table 4. Files used in CENTURY model

1	*fix.100*	File with fixed parameters primarily relating to organic matter decomposition and not normally adjusted between runs
2	*site.100*	Site-specific parameters such as precipitation, soil texture, and the initial conditions for soil organic matter; the name of this file is provided by the user
3	*crop.100*	Crop options file
4	*cult.100*	Cultivation options file
5	*fert.100*	Fertilization options file
6	*fire.100*	Fire options file
7	*graz.100*	Grazing options file
8	*harv.100*	Harvest options file
9	*irri.100*	Irrigation options file
10	*omad.100*	Organic matter addition options file
11	*tree.100*	Tree options file
12	*trem.100*	Tree removal options file

stabilized SOM and has a turnover time of 400 to 2000 years. The proportions of the decomposition products which enter the passive pool from the slow and active pools increase with increasing soil clay content.

Running of the model

The site data (location) and site specific parameters were collected and create *site.100* file. Then the site specific event options such as crop, cultivation, fertilizer, fire, etc. were created in the Event.100 file. Along with that, the schedule file which determines the order and types of events was created. After that the simulation was kept ready to run.

3.3.1 Rice ecosystem

The weather file was created for the model as given in Table 5. The parameters were prepared to be compatible with the models using *.100* file. The site specific parameters which include latitude and longitude of site, soil texture, bulk density, field capacity, wilting point, pH etc were created (Table 1). Site specific event options such as *site.100*, *crop.100*, *fert.100*, *cult.100*, *irri.100*, *harv.100* and *fire.100* were used. The next step was the creation of schedule files which determined the order and types of events that were included in the simulation and, the model was run.

3.3.2 Teak ecosystem

The weather file was created for the model and is presented in Table 6. The parameters were prepared to be compatible with the models using *site. 100* file. The site specific parameters which include latitude and longitude of site, soil texture, bulk density, field capacity, wilting point, pH etc were created (Table 1). Site specific event options such as *site.100*, *tree.100* and *fire.100* were used. The next step was the creation of schedule files which determined the order and types of events that were included in the simulation and, the model was run.

Table 5. Weather parameters used in CENTURY model for rice ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	20.72	33.35	0.21	0.66
February	20.93	34.9	1.16	2.03
March	24.25	35.72	3.14	5.34
April	24.78	35.07	8.71	7.29
May	24.86	33.81	15.35	9.7
June	23.91	30.37	59.85	16.98
July	23.46	29.31	65.33	30.78
August	23.55	29.74	34.36	11.47
September	23.54	30.36	32.64	14.87
October	23.79	31.08	26.84	10.38
November	22.59	32.83	8.29	4.35
December	21.31	32.44	1.75	3.7

Table 6.Weather parameters used in CENTURY model for teak ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	22.23	32.83	0.08	0.24
February	22.58	34.52	1.92	3.39
March	24.21	35.31	3.70	6.57
April	25.0	34.49	8.74	6.36
May	24.87	32.98	20.79	18.65
June	23.63	29.9	69.01	16.36
July	23.06	29.06	69.97	25.39
August	23.1	29.6	46.5	16.24
September	23.07	30.12	38.07	16.84
October	23.1	31.28	30.41	15.9
November	23.05	31.65	10.55	9.58
December	22.74	31.75	1.14	1.38

3.3.3 Data files used in the model

Site.100

Site.100 file gives information related to environment and site characteristics. The parameters included are *precip* (1-12) and *precstd* (1-12) which indicates the precipitation from January to December and standard deviation respectively expressed in terms of centimeters per month. The parameters *tmn2m* (1-12) and *tmx2m* (1-12) indicate the minimum and maximum temperature.

The estimates of the *site.100* file is based on the C, N and S pools in biomass by components (leaf, fine roots, branches, large woods, coarse root, dead large wood and standing dead trees) from *tree.100* data present in CENTURY model.

Crop.100

It contains the parameters that govern the effect produced by crop cultivation (Appendix II). The default values present in the model for rice crop was used for the model simulation.

The parameter *prdx(1)* narrates potential aboveground monthly production for crops (g C/m^2) where as *pltmrf* specifies planting month reduction factor to limit seedling growth. *Fulcan* depicts value of *aglivc,* the full canopy cover, above which potential production is not reduced.

Frtc(1) and *frtc(2)* narrates the initial and final fraction of C allocated to roots which is set to 0. *Frtc(3)* depicts about the time after planting at which the final value is reached.

The parameter biomax specifies biomass level (gram biomass per square meter) above which the minimum and maximum C/E ratios of new shoot increments equal *pramn* and *pramx* respectively. The parameters for computing minimum and maximum C to N ratio for belowground matter as a linear function of annual precipitation are narrated by *prbmn* and *prbmx* respectively.

The Parameter *fling* represents intercept for equation to predict lignin content fraction based on annual rainfall for aboveground material, while *fligni* represents intercept for equation to predict lignin content fraction based on annual rainfall for belowground material. *Himax* details harvest index maximum (fraction of aboveground live C in grain). *Hiwsf* and *himon* depicts harvest index water stress factor and the number of months prior to harvest in which to begin accumulating water stress effect on harvest index.

The parameter, *efrgrn* narrates fraction of the aboveground which goes to grain and *vlossp* specifies fraction of aboveground plant N which is volatilized (occurs only at harvest). *Fsdeth* depicts the level of aboveground C above which shading occurs and shoot senescence increases.

Parameter *fallrt* specifies fall rate (fraction of standing dead which falls each month) and *rdr* gives maximum root death rate at very dry soil conditions (fraction/month). *Rtdtmp* indicates the physiological shutdown temperature for root death and change in shoot to root ratio.

fert.100

For rice cultivation, the average NPK was added as 90kg/ha, 45kg/ha and 45kg/ha respectively (KAU, 2011).

Manjunatha (2015) mentioned the values of NPK additions in the first year of teak planting, as 30 g $m^{-2} yr^{-1}$ and from 4th year, it becomes 50 g $m^{-2} yr^{-1}$.

For each rate of fertilizer application, the *feramt* parameter was set to the appropriate value. All other parameter values were set to zero (*aufert* is 0).

cult.100

The *cult.100* file was modified based on the crop cultivation. For rice cultivation, KAU (2011) recommended that ploughing and harrowing the fields two or three times until the soil is thoroughly puddled and levelled. So two ploughing options are there, first one includes the ploughing option adjusted to increase its effect on decomposition (Metherell *et al.*, 1993 and Six *et al.*, 2002). The second change was added to increase the length of time which effects decomposition by ploughing. Since CENTURY runs on a monthly time-step, each action only affects the carbon dynamics for that particular month. Studies have shown that ploughing affects decomposition for several months. This option was created by setting the *clteff* (cultivation's effect on decomposition) values to 4.0, as they are with ploughing. since only decomposition rates were to be effected, all parameters other than those for *clteff* were set to zero.

irri.100

The *irri.100* file specifies a parameter called *auirri,* which controls the automatic irrigation depending on the irrigation type, whose values can be fixed at 0, 1, 2 and 3, which were included in the Century manual to provide various types of irrigation methods.

For rice crop, maintenance of the water level was done at 1.5 cm during transplanting. Thereafter, it has to be increased gradually to about 5 cm. until maximum tillering stage. Drainage of water has to be done 13 days before harvest (KAU, 2011).

The other parameters namely *fawhc,* indicates the fraction of available water holding capacity beyond which automatic irrigation will be used (when *auirri* is1 or 2), *irraut* specifies amount of water to automatically applied (in centimeters), and *irramt* indicates amount of water to be applied regardless of soil water status estimates (in centimeters).

harv.100

The harv.*100* file contains different parameters of harvest. For rice crop, *flghrv*=1 indicates that the grain was to be harvested, otherwise the value was 0.

tree.100

The *tree.100* file parameter gives information on vegetation and physiological characteristics of a tree. The default values present in the model for teak was used for the model simulation (Appendex III).

The parameters *prdx* are plant production variables. It provides values of maximum gross primary production (GPP), expressed in terms of biomass gram per unit area per month and is concerned with regulation of maximum net primary production (NPP) expressed in biomass added every month.

In Century, total plant primary production is assumed to be distributed to all the parts of the plant and net primary production is allocated into five different plant components of the tree (leaves, fine roots, branches, stems, and coarse roots). The parameters that govern this allocation are *cerfor*, *fcfrac*, *wooddr*, *leafdr* and *wdling* which indicate the lignin fraction of tree components.

The parameter *cerfor* generally gives the maximum, minimum and initial C to N, P and S ratios that is contained in five different components of the tree. In this study, *cerfor* was used only for studying the C to N ratio. The *fcfrac* parameter indicates the value of carbon allocated from net primary production to different tree parts based on the characteristics of the tree. The *wooddr* specifies the fraction of biomass turnover rates of five different tree components, *wdlig* depicts the fraction of lignin, which determines the rate of decomposition of litter in the tree components; *leafdr* gives the death rate of leaf for each month. The values of parameters discussed above are included in the appendices.

fire.100

The *fire.100* file parameters were modified to medium fire. Default values were used in two parameters; first one being *fderem1* which indicates the fraction of standing dead plant material removed by a fire event as 0.7 and second one being *fderem2*, that specifies the fraction of surface litter removed by a fire event as 0.3. The studies conducted by Balagopalan (1987) and Suzuki *et al.* (2007) reported that the fraction of aboveground materials of N, P and S removed by a fire event were used to estimate *fret* parameters. So the effects of fire on increase in maximum C to N ratio of shoots are 10 and 30 respectively (Harris *et al.*, 2012). This file was used in the model to convert the forest into the relevant ecosystems.

3.4 Model evaluation and validation

The model outputs were examined for accuracy with net primary productivity (NPP). The NPP prediction by the model was taken as an accuracy index for other model outputs represented at that site. Thus, the simulated carbon values were compared with the carbon baseline data obtained from rice and teak plantation ecosystems.

From RARS Pattambi,- the soil organic carbon values of rice fields were collected for eight years. In 2004, the recorded value was 1.32% and during 2005 to 2007 it was 1.33%. Again in 2008, it had reached the same value as that of 2004. Then it became 1.31% in 2009 followed by 1.30 % in 2010 and 2011 (Singh *et al.*, 2009).

Manjunatha (2015) estimated the soil organic carbon values of teak plantations from different places in Thrissur district (Table 7). The soil organic carbon showed a decreasing trend with an increasing age class. Based on his study, the teak plantations were divided into 5 age classes. The age classes were 0-5, 6-10, 11-20, 21-30 and above 30 years. The reason for selecting these five age groups was that the first and second mechanical as well as the silvicultural thinning would be over during the period of 5-25 years after the establishment, while third and fourth silvicultural thinning would be over during the period of 25-45 years, after which there will not be further operations in the plantation.

Table 7. Observed soil organic carbon of teak plantations

Thrissur	**Age**	**Soil organic carbon (%)**
Machad	0-5 year	2.36
Pattikkad	6-10 year	1.68
Vadakanchery	11-20 year	1.52
Vazhachal	21-30 year	1.38
Athirapally	>30 year	1.20

Models were evaluated in terms of their ability to simulate observed soil carbon changes. Visual examination of graphic output allows qualitative evaluation. The measured (observed) and modeled datasets were compared qualitatively through graphs and quantitavely by statistical tests which were used to evaluate the model performances.

The Model Efficiency (ME) was calculated based on the equation as

$$ME = 1 - \sum (\text{observed} - \text{simulated})^2 / \sum (\text{observed-mean})^2$$

To find out mean

$$\sum \text{Error}^2 = \sum (\text{observed-simulated})^2$$

$$\text{Mean} = \sum \text{Error}^2 / \text{Number of observations}$$

If the ME is less than 0 the performance of the model is not satisfactory. If it is between 0 to 0.5, then it is satisfactory and greater than 0.5 very good to use.

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{t=1}^{n}(\text{Pi} - \text{Oi})^2}{n}}$$

Where, Pi and Oi refer to the predicted (simulated) and observed values for the studied variables respectively and n, the mean of the observed variables.

3.5 Soil organic carbon changes due to predicted climate change scenarios

Scenarios help to understand what future conditions might be. They give information about what might happen under different assumptions. Scenarios generally blend both model output and other information, such as observed trends. They are not predictions or forecasts, and no probabilities are associated with them. Instead, they provide a range of future conditions to bound uncertainty.

The climate change projections in the form of Representative Concentration Pathways RCP (2.6, 4.5, 6.0, and 8.5) were downloaded from runs of the DSSAT weather generator model archived by the IPCC Data Distribution Center, developed in Fifth Assessment Report. The weather parameters such as maximum temperature, minimum temperature and rainfall (predicted) were obtained for both Pattambi and Vellanikkara over a period from 2015 to 2050 and were given as inputs to the model. The model was run without changing other parameters that had already been mentioned in the model. Then a comparison was made with each RCP along with the dynamics of total soil organic carbon in both ecosystems.

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The results and discussion of the study "Modelling soil carbon dynamics of two major ecosystems of humid tropics" are furnished in this chapter. The study was conducted to evaluate the suitability of Roth-C and CENTURY models in rice and teak ecosystems and also to analyse the soil organic carbon changes due to predicted climate change scenarios in these ecosystems.

4.1 Weather parameters

4.1.1 Temperature

The temperature data analysis showed that March was the hottest month at both the locations, Pattambi and Vellanikkara with an average monthly temperature of 29.98°C and 29.76°C respectively, followed by April and May (Fig.1). From June onwards, the temperature gradually came down due to the arrival of South West monsoon. July was the month which recorded the lowest average monthly temperature with values of 26.38°C and 26.06°C for Pattambi and Vellanikkara, respectively. It was noticed that Pattambi experienced the highest temperature than Vellanikkara during this period.

4.1.2 Rainfall

It was observed that July was the month with highest rainfall over Pattambi and Vellanikkara with an average monthly rainfall of 65.35 and 69.97 cm, respectively followed by June and August. There was very little rainfall in the month of January for both these places and there was a declining trend from September onwards (Fig.2).The highest variation in rainfall between these two places was found to be in the month of June.

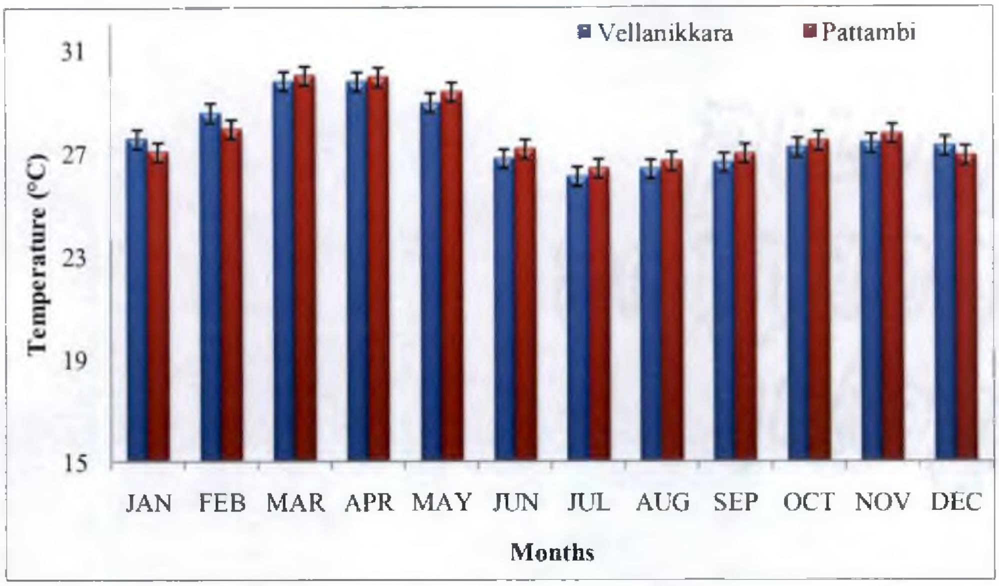

Fig.1 Monthly average temperature of Vellanikkara and Pattambi (2005-2014)

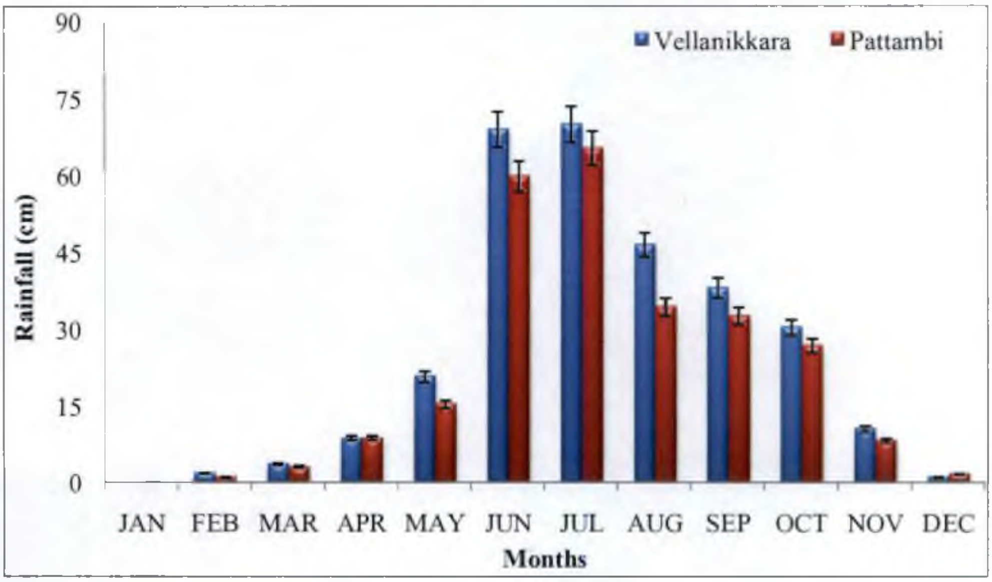

Fig.2 Monthly average rainfall of Vellanikkara and Pattambi (2005-2014)

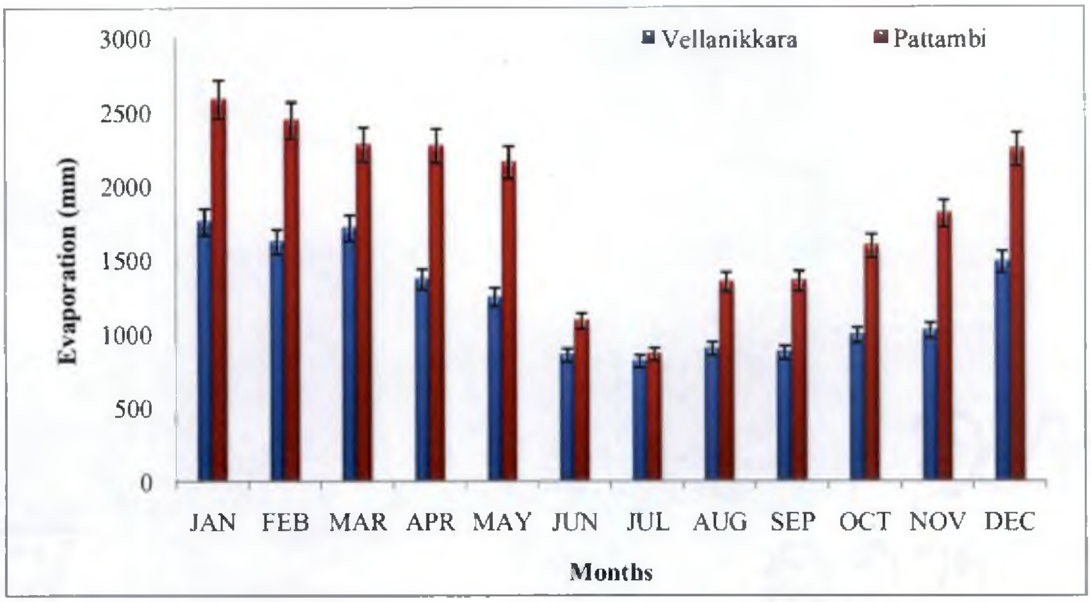

Fig.3 Monthly average evaporation of Vellanikkara and Pattambi (2005-2014)

4.1.3 Evaporation

Pattambi and Vellanikkara recorded highest average monthly evaporation with values of 2587 and 1757 mm, respectively in the month of January followed by February, March, April and May (Fig.3). By the month of June and July, there was a gradual decline, and then from August onwards it followed an increasing trend. In all months, evaporation rate of Pattambi was always higher than Vellanikkara, except in the month of July with only a slight difference between the two places.

4.2 Dynamics of soil organic carbon in rice ecosystem

4.2.1 Simulation by Roth-C and CENTURY model

The simulated data of Roth-C model showed that the total soil organic carbon (Table 8 and Fig.4) was 4339.23 g C m^{-2} in the starting year (1965) and it declined slowly and reached a value of 3492.55 g C m^{-2} in the year 2015. Later on, it decreased at a very slow rate throughout the year.

In case of CENTURY model, the total soil organic carbon (Table 8 and Fig.5) declined to about 50 per cent of the initial value from 4744.28 g C m^{-2} to 2719.81 g C m^{-2} in 20 years. Thereafter, soil organic carbon increased at a slower rate till 2005 and started to decrease over the remaining years up to 2050.

Land use change in the form of conversion from forest to agriculture is usually associated with loss of soil organic carbon. Houghton *et al.* (1983) indicated that transforming forest into cropland reduces soil organic carbon densities substantially as similar to the above study.

Regular tillage, planting, and harvesting lead to enhanced oxidation of organic matter in the soils, which is emitted into the atmosphere as carbon dioxide (Carroll *et al.*, 2012). Hence the soil organic carbon in cultivated soils is continuing to decline in many areas of the world. However, the use of fertilizers, high-yielding plant varieties,

Table 8. Decennial changes in total soil organic carbon (g C m^{-2}) in rice ecosystem simulated by Roth-C and CENTURY model (1965-2050)

Year	Roth-C model	CENTURY model
1965	4339.23	4744.28
1975	4060.41	3323.84
1985	3854.96	2719.81
1995	3699.14	3027.34
2005	3581.44	3592.50
2015	3492.55	3485.22
2025	3425.40	3490.45
2035	3374.69	3324.89
2045	3336.39	3193.01

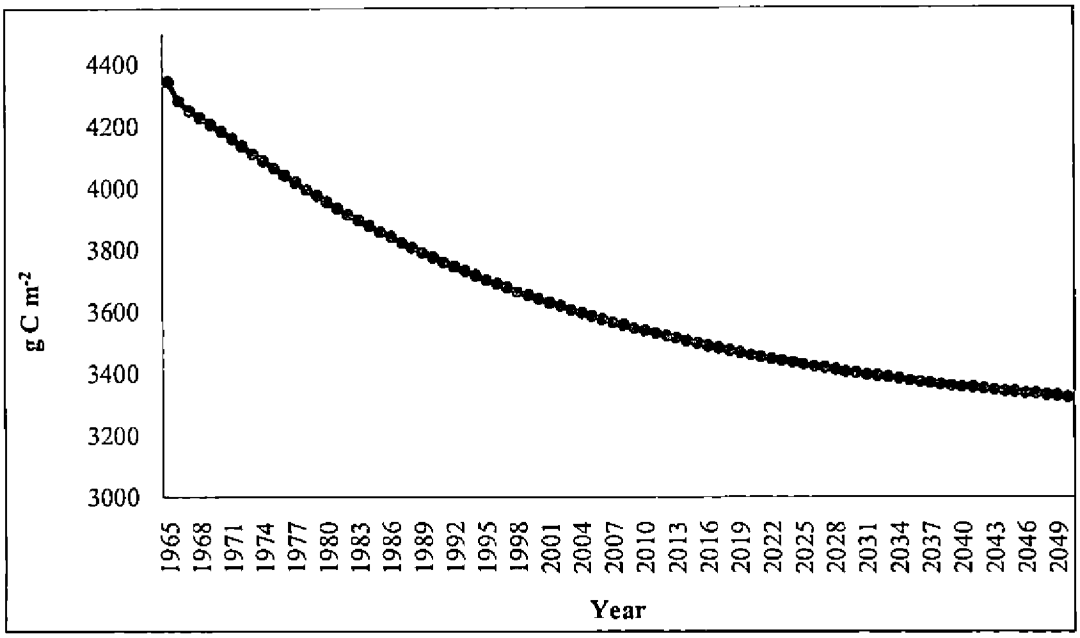

Fig. 4 Roth-C model simulated total soil organic carbon in rice ecosystem

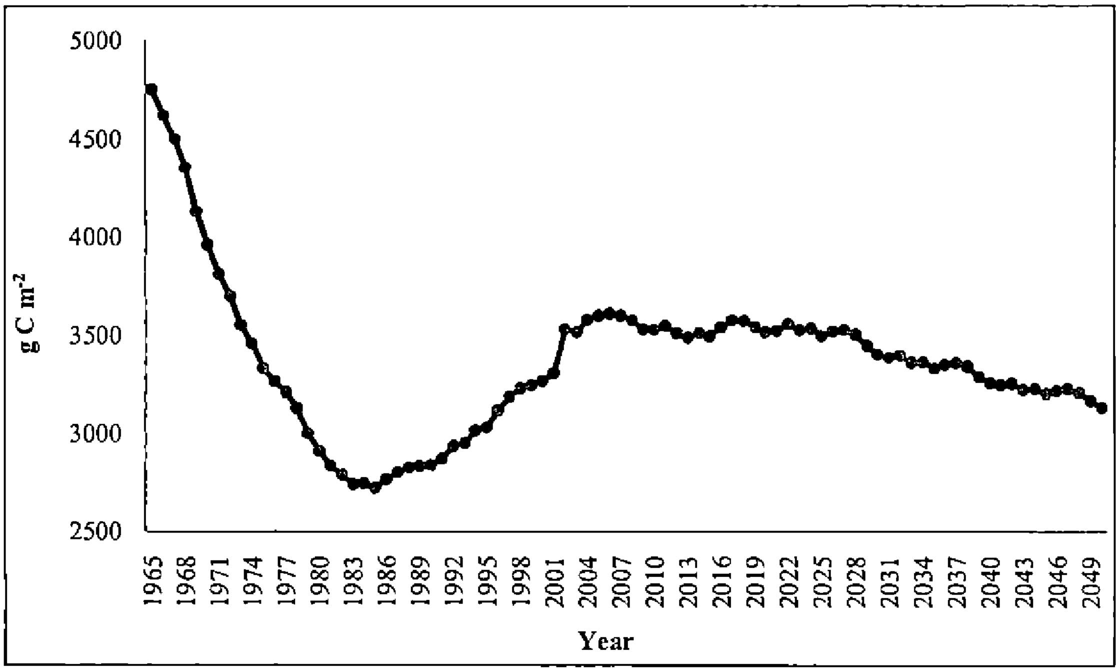

Fig. 5 CENTURY model simulated total soil organic carbon in rice ecosystem

residue management and reduced tillage for erosion control have found to contribute the stabilization or increase in soil organic carbon (Cole *et al.*, 1993).

4.2.2 Dynamics of different carbon pools

The dynamics of the different carbon pools in rice ecosystem during the period 1965 to 2050 was also studied. The simulation of active carbon (Table 9 and Fig. 6) indicated that in 1965, the value for this fraction was 5.18 g C m^{-2} it reached 1.11 g C m^{-2} by 1975 and there was a rapid increase to15.54 g C m^{-2} during 1989. The active carbon reached its maximum (21.85 g C m^{-2}) by 1999 after which the values varied irregularly up to 2050.

The labile (active) SOC in paddy fields would have mainly accumulated during the rice cultivation period. Topsoil SOC stock significantly increased shortly after paddy was introduced. The concurrent bursts of microbial biomass suggested improved substrate availability, and the increased topsoil SOC was probably caused by the anaerobic decomposition products of straws from the last growing season. In agreement with this, Suetsugu *et al.* (2005) observed strong increases in dissolved and particulate organic matter during the rice-growing season of paddy fields. An experiment by Iqbal *et al.* (2009), also found that SOC sequestered in paddy soils seemed to be more labile than in afforested soils, despite the greater SOC sequestration of paddy fields.

The simulated value of slow carbon in the starting year of 1965 was 3482.73 g C m^{-2} and it declined throughout the years and reached a value of 1251.33 g C m^{-2} in 1990. Thereafter, it showed an increasing trend to 1695.24 g C m^{-2} by 2004 and again it started declining (Table 9 and Fig. 6).

According to the finding of Stevenson (1982) soil aggregation is considered to be the important processes of stabilizing soil organic matter pools. Soil manipulations that disrupt soil aggregates (e.g. tillage) can influence the turnover of slow carbon pool, by exposing previously protected organic material to microbial decomposition.

Table 9. Dynamics of soil organic carbon pools in rice ecosystem

Year	Active carbon (g C m^{-2})	Slow carbon (g C m^{-2})	Passive carbon (g C m-^{2})
1965	5.18	3482.73	1164.21
1970	0.72	2661.76	1222.90
1975	1.11	1993.35	1263.77
1980	1.32	1551.18	1293.89
1985	4.25	1269.28	1315.99
1990	7.59	1251.33	1340.13
1995	10.23	1346.63	1367.29
2000	12.32	1507.60	1399.89
2005	12.29	1714.17	1443.42
2010	11.27	1741.91	1482.10
2015	11.80	1728.04	1517.38
2020	11.64	1727.11	1553.67
2025	10.96	1697.76	1587.97
2030	9.71	1620.77	1620.97
2035	9.61	1525.75	1649.28
2040	8.78	1444.60	1676.52
2045	8.75	1361.56	1699.94
2050	8.02	1291.66	1722.66

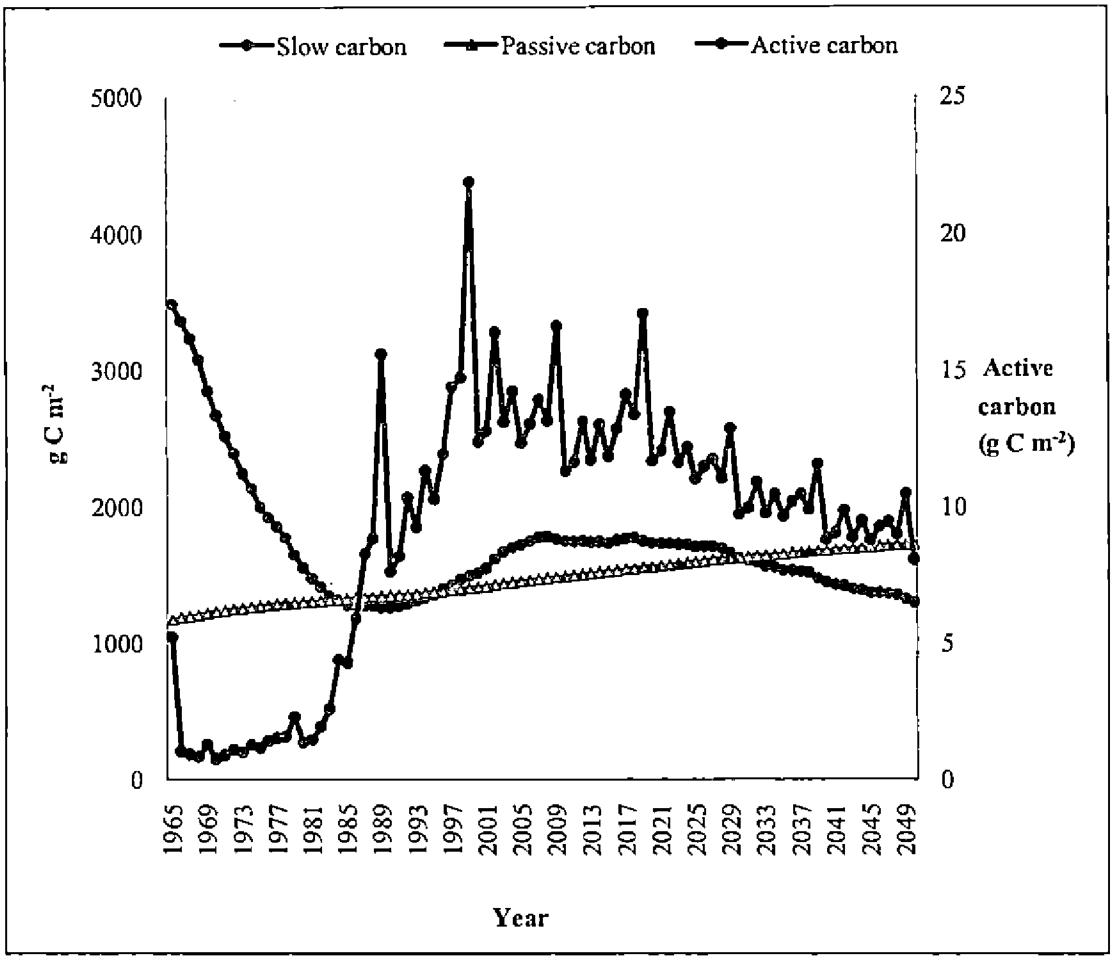

Fig. 6 Dynamics of soil organic carbon pools in rice ecosystem

The passive carbon simulated (Table 9 and Fig.6) by the model kept on increasing from an initial value of 1164.21 g C m^{-2} in 1965 to a value of 1722.66 g C m^{-2} to the end year 2050.

Carvalho Leite *et al.* (2004) in his study also observed similar result. An increase in the passive carbon fraction occurred in cultivated soil compared to soil under no-till. Another experiment done by Feba *et al.* (2014) also obtained the same result that, the paddy soil had the greatest qualities of labile and recalcitrant carbon counter parts and it also showed the result of disturbances, even though it contained high levels of soil organic carbon.

4.3 Dynamics of soil organic carbon in teak ecosystem

4.3.1 Simulation by Roth-C and CENTURY models

In teak ecosystem, the results showed .that the total soil organic carbon declined from 4893.53 g C m^{-2} to 4027.76 g C m^{-2} within 10 years of establishment in simulating Roth-C model. A declining trend was noticed throughout the period and it reached a value of 1912.96 g C m^{-2} by 80 years of plantation establishment (Table 10 and Fig.7).

The simulated total soil organic carbon by CENTURY model declined to 3346.82 g C m^{-2} which was about 50 per cent of the initial value of 6656.87 g C m^{-2} within 30 years of establishment (Table 10 and Fig.8) and got stabilized during the following 26 years. During the 56th year, it showed a gradual decline of 3142.79 g C m^{-2} .Further it decreased to 2683.73 g C m^{-2} by the next five years after which it became stabilized.

The loss of SOC can be attributed to many reasons. Teak, being an early fast grower, canopy generally closes in about four years after planting. Subsequently, thinning is done in order to prevent crowding. Hence the disturbance to the soil

Table 10. Decennial changes in total soil organic carbon (g C m^{-2}) in teak ecosystem simulated by Roth-C and CENTURY model (1965-2050)

Age	Year	Roth-C model	CENTURY model
1	1965	4897.53	6656.87
10	1975	3939.91	4144.46
20	1985	3231.00	3491.22
30	1995	2758.07	3346.82
40	2005	2442.63	3351.43
50	2015	2232.24	3396.81
60	2025	2091.91	2683.73
70	2035	1998.31	2752.25
80	2045	1935.88	2854.31

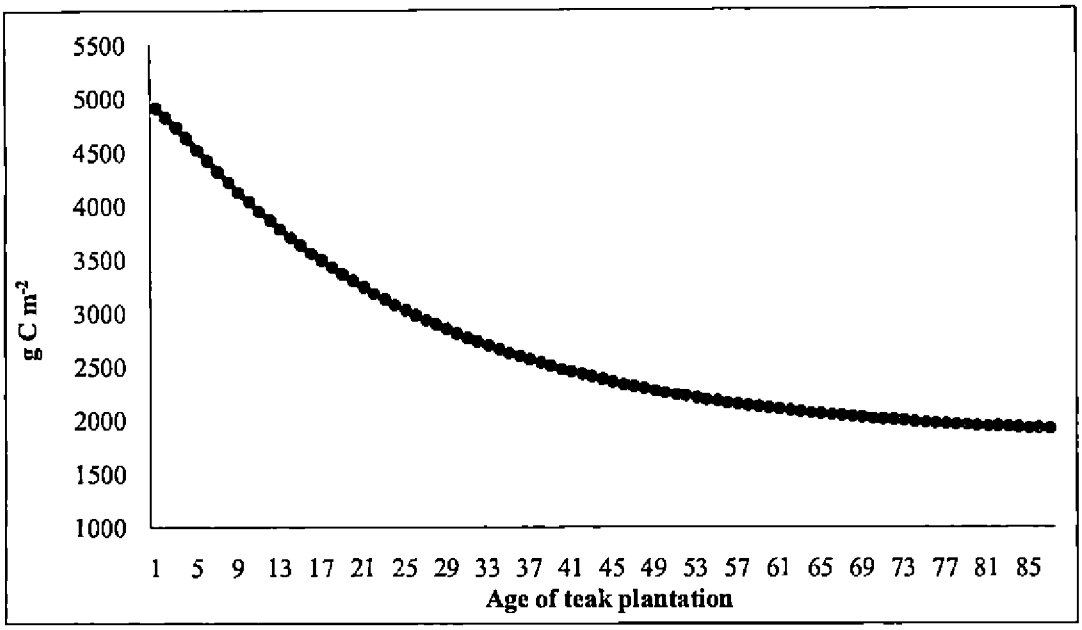

Fig.7 Roth-C model simulated total soil organic carbon in teak ecosystem

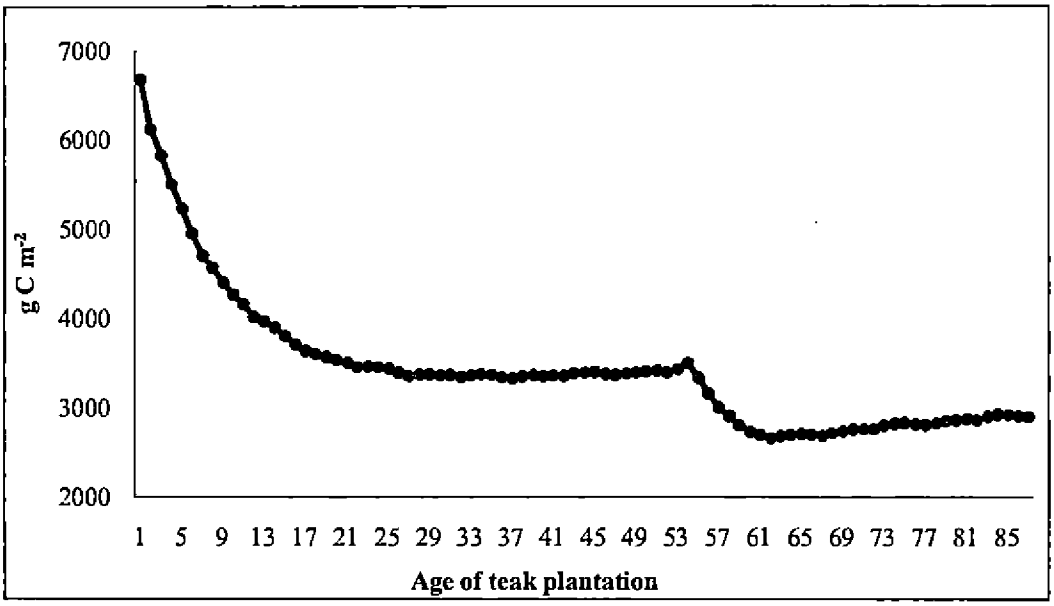

Fig. 8 CENTURY model simulated total soil organic carbon in teak ecosystem

carbon. Litter production at this stage appears to be inadequate to balance for the loss of organic carbon. The net result is progressive loss of soil organic carbon. The mechanical and silvicultural thinning ends by 25 years. Thereafter the soil starts to recuperate. It is probable that at this stage, the rate of nutrient return to the soil through the fall and break down of litter is greater than its loss from soil. Thus an increase in soil organic carbon occurs (Kadambi, 1992).

Mapa (2005) reported that teak plantations showed an increase in soil hydraulic conductivity and macro porosity compared to grazed lands. So they generally showed a high erosion rate, in which most of the top soil is lost and the subsurface layer is exposed, leading to the loss of soil organic carbon during the initial years when the soil disturbance is high..

4.3.2 Dynamics of different carbon pools

The simulation of active carbon in teak ecosystem indicated that the value of 15.34g C m^{-2} during the beginning year showed a steep decline to 2.99 g C m^{-2} by the subsequent years. From the 3rd year onwards, it showed an increasing trend which reached a maximum value of 15.831g C m^{-2} by 14th year and again it declined to 13.043 g C m^{-2} in the 15th year. A sudden increase was noticed in the following years *viz.*, 20th, 23rd, 28th, 33rd and 43rd as 17.32 g C m^{-2}, 19.32 g C m^{-2}, 18.19 g C m^{-2}, 21.41 g C m^{-2} and 23.35 g C m^{-2}, respectively. Compared to all other years it was found that the active carbon recorded a maximum value of 24.72g C m^{-2} by the age of 53 year of plantation establishment. Then it showed a steep decline and a gradual increase with a fluctuating trend (Table 11 and Fig. 9).

Labile soil organic carbon plays a key role in the maintenance of soil fertility as a source of plant nutrients due to its chemical composition and rapid turnover rate. The disturbance of soil during the plantation establishment processes and decrease of soil cover leads to loss of soil organic carbon. Litter addition at this stage appears to be inadequate to balance for the loss of organic carbon. The net result is progressive

Table 11. Dynamics of soil organic carbon pools in teak ecosystem

Year	Active carbon ($g\ C\ m^{-2}$)	Slow carbon ($g\ C\ m^{-2}$)	Passive carbon ($g\ C\ m^{-2}$)
1	15.34	4842.05	1667.80
5	6.47	3309.30	1664.11
9	11.01	2451.29	1656.55
13	15.54	2002.97	1647.74
17	12.77	1719.95	1637.12
21	17.32	1583.67	1626.72
25	16.36	1518.54	1615.87
29	18.19	1473.20	1604.39
33	21.41	1467.91	1593.84
37	17.67	1472.66	1582.64
41	21.66	1497.08	1572.43
45	20.26	1532.62	1562.21
49	21.68	1548.22	1551.67
53	24.72	1575.54	1542.15
57	3.70	1399.53	1531.06
61	5.77	1074.77	1518.79
65	8.24	980.22	1506.40
69	11.41	994.47	1493.94
73	15.11	1042.88	1482.73
77	12.32	1090.80	1471.01
81	16.34	1144.02	1460.43
85	15.40	1202.08	1449.92

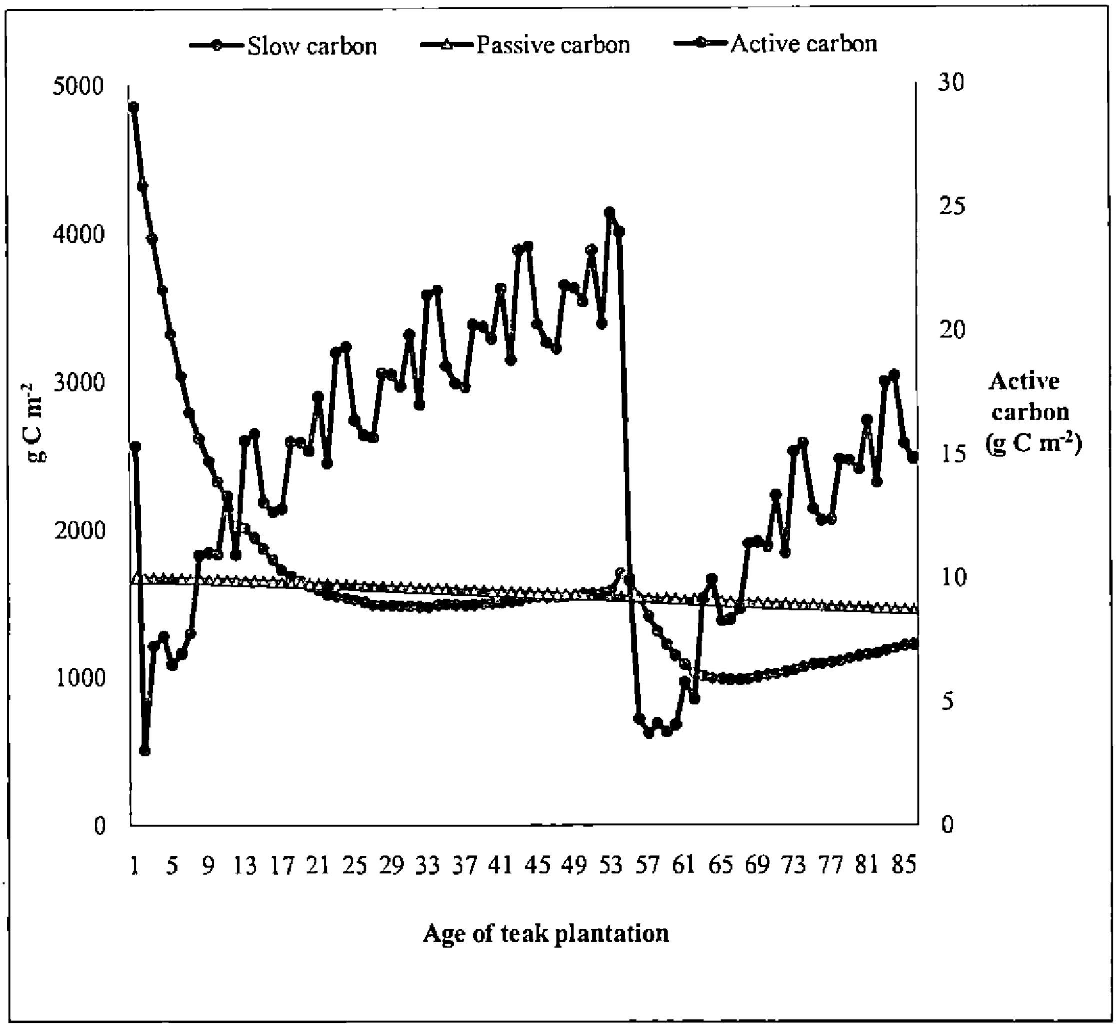

Fig. 9 Dynamics of soil organic carbon pools in teak ecosystem

loss of active or labile soil organic carbon. The macroclimate, principally soil temperature and moisture, regulates the rates of decomposition of labile soil organic carbon (Jenkinson and Ayanaba, 1977). Soil carbon stock usually increases over time after planting trees (Sakai *et al.,* 2010), due to carbon input from litter fall and the turnover of dead roots (Richter *et al.,* 1999). At the end of simulation period, the active carbon got stabilized as the actual teak plantation. Thus, active soil organic carbon is a sensitive indicator for the changes in soil organic carbon following land use changes (Cheng and Wang, 2012).

During the initial period, the value of slow carbon was 4842.04 g C m $^{-2}$ and it kept on decreasing up to 1498.58 g C m $^{-2}$ by the 34th year. Then it became stabilized by the following years and reached a value of 1692.96 g C m $^{-2}$ by 54th year of establishment. After that it had shown a gradual decline (Table 11 and Fig. 9) and an increase in a stabilized manner.

The simulation indicated substantial loss of slow carbon pool from the system. The most recalcitrant components of soil organic matter are highly polymerized humic substances, resulting from decomposition of plant debris (lignin-like substances) or condensation of soluble organic compounds released through the decomposition of sugars, amino-acids, polyphenols and lignin (Stevenson, 1982).

The passive carbon (Table 11 and Fig. 9) content was 1667.80 g C m $^{-2}$ in the initial year and it kept on declining in a very slow manner throughout the following years and reached a value of 1449.92 g C m^{-2} by the end of simulation.

Hendrickson and Robinson (1984) reported that the initial rapid decline in soil carbon over a few weeks represents the rapid decomposition of the active fraction and fine roots. Then the rate decreases, reflecting carbon losses from the slow fraction, and becomes asymptotic to the residual carbon in passive SOM. Manjunatha (2015) in a study on teak ecosystem found that the passive carbons in this ecosystem.

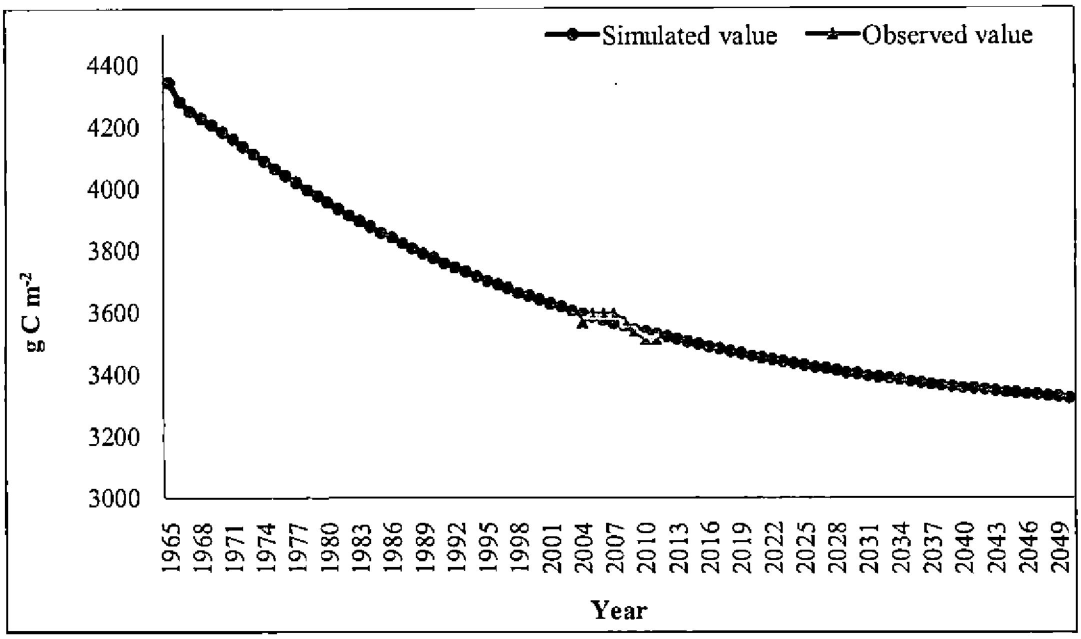

Fig. 10 Observed and Roth-C model simulated total soil organic carbon in rice ecosystem

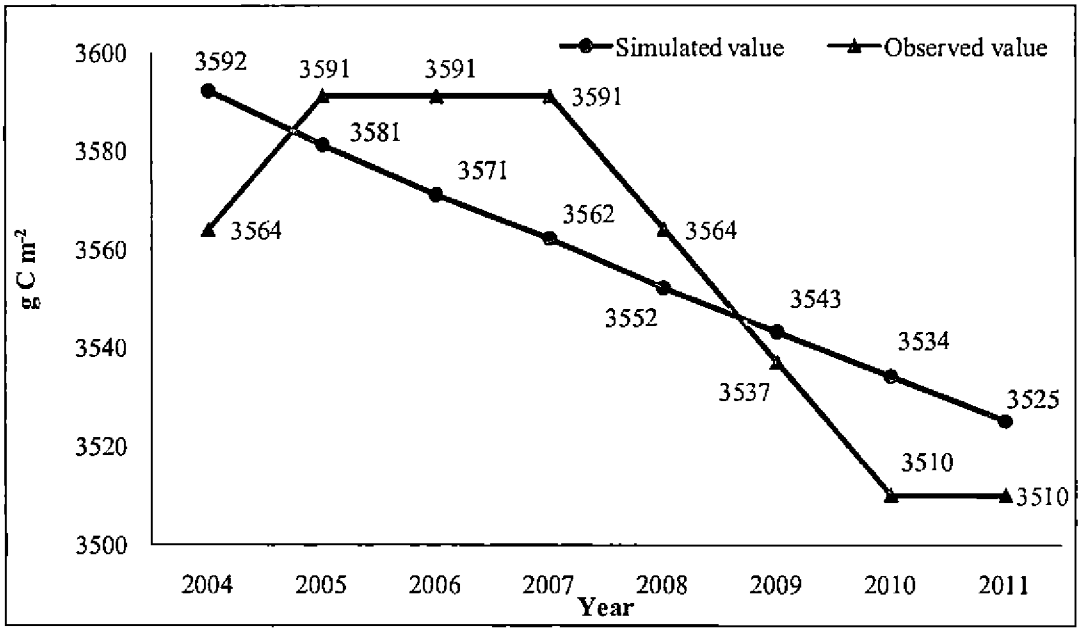

Fig.11 Relationship between observed and Roth-C simulated total soil organic carbon in rice ecosystem

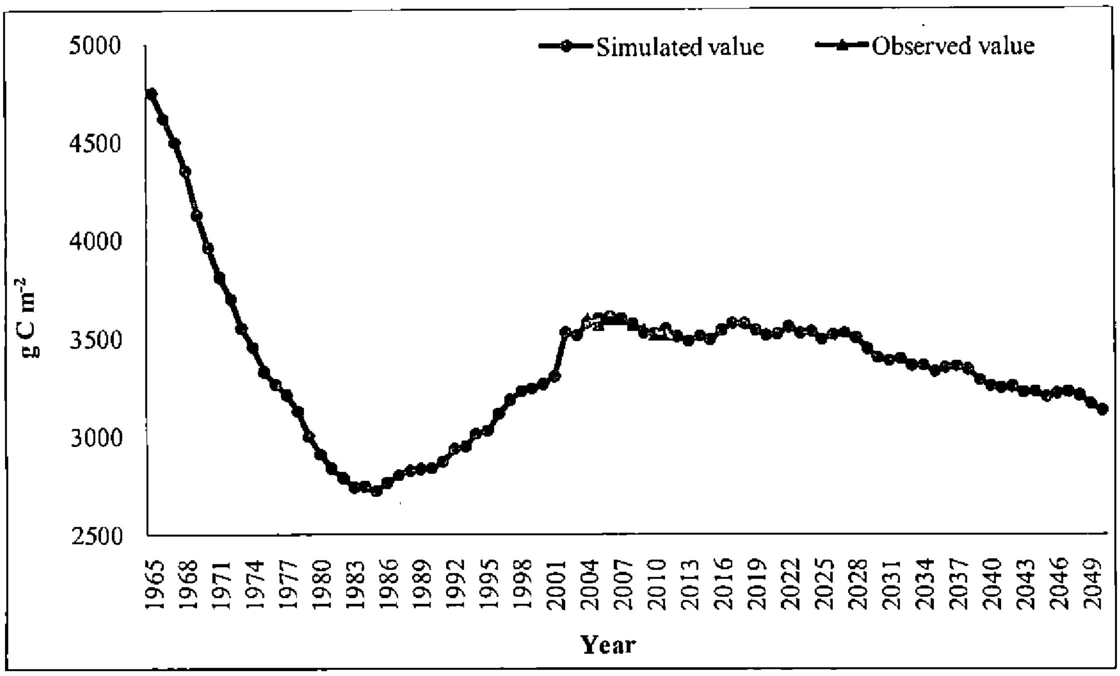

Fig. 12 Observed and CENTURY model simulated total soil organic carbon in rice ecosystem

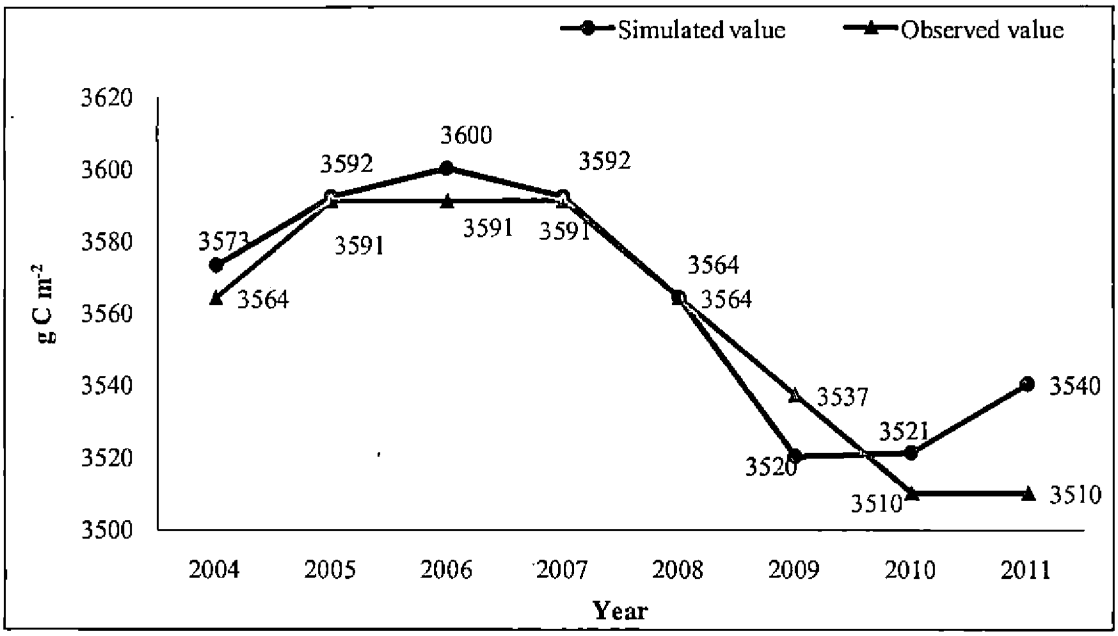

Fig. 13 Relationship between observed and CENTURY simulated total soil organic carbon in rice ecosystem

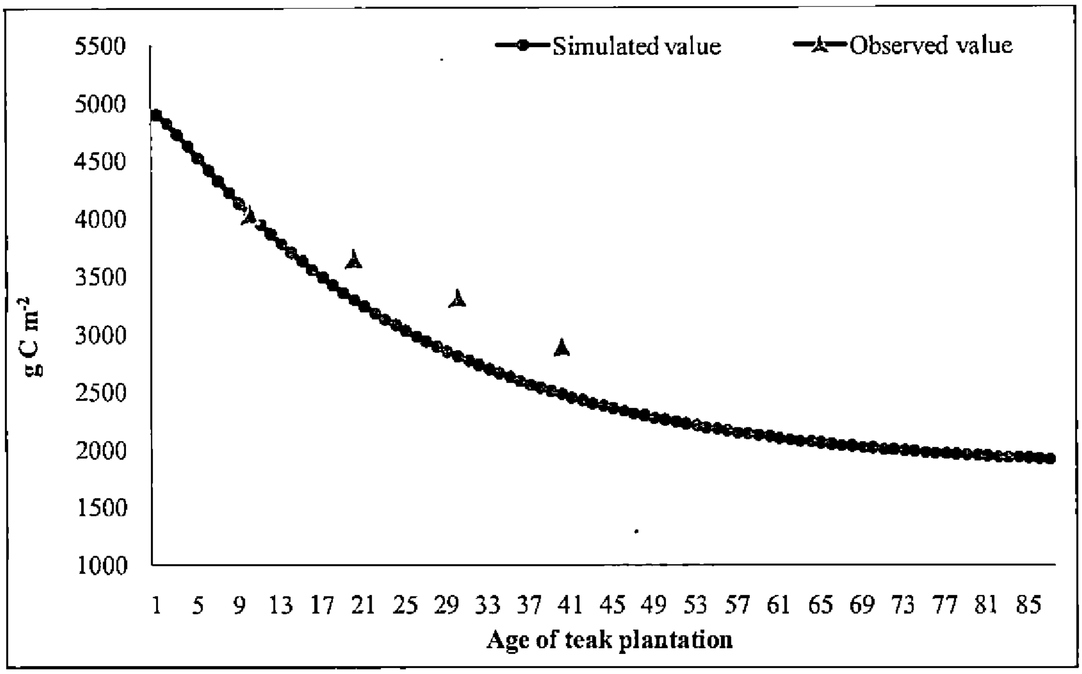

Fig.14 Observed and Roth-C model simulated total soil organic carbon in teak ecosystem

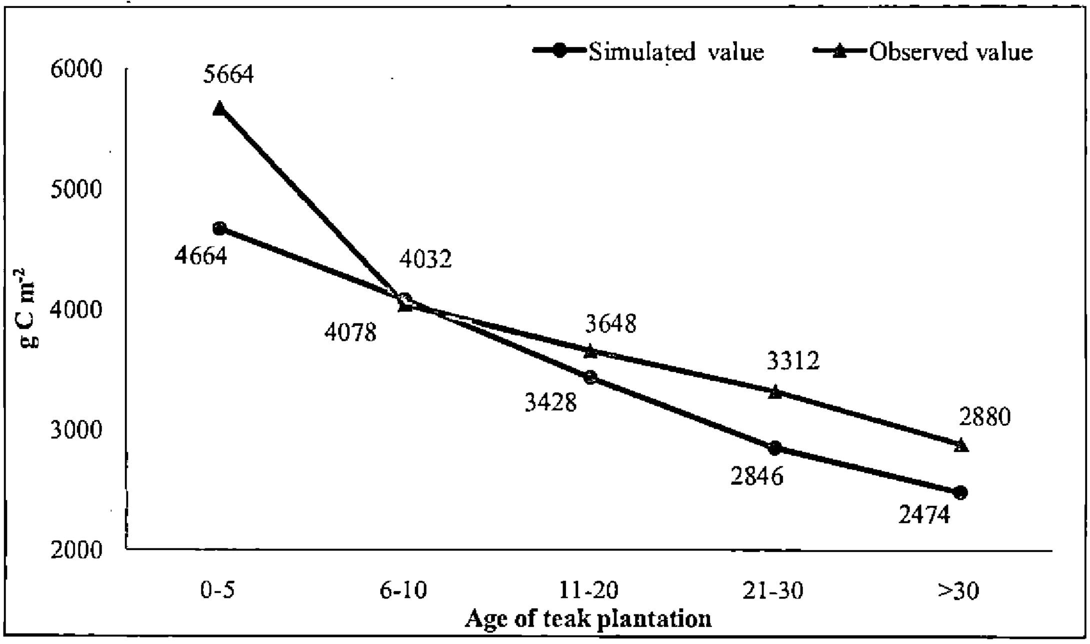

Fig.15 Relationship between observed and Roth-C simulated total soil organic carbon in teak ecosystem

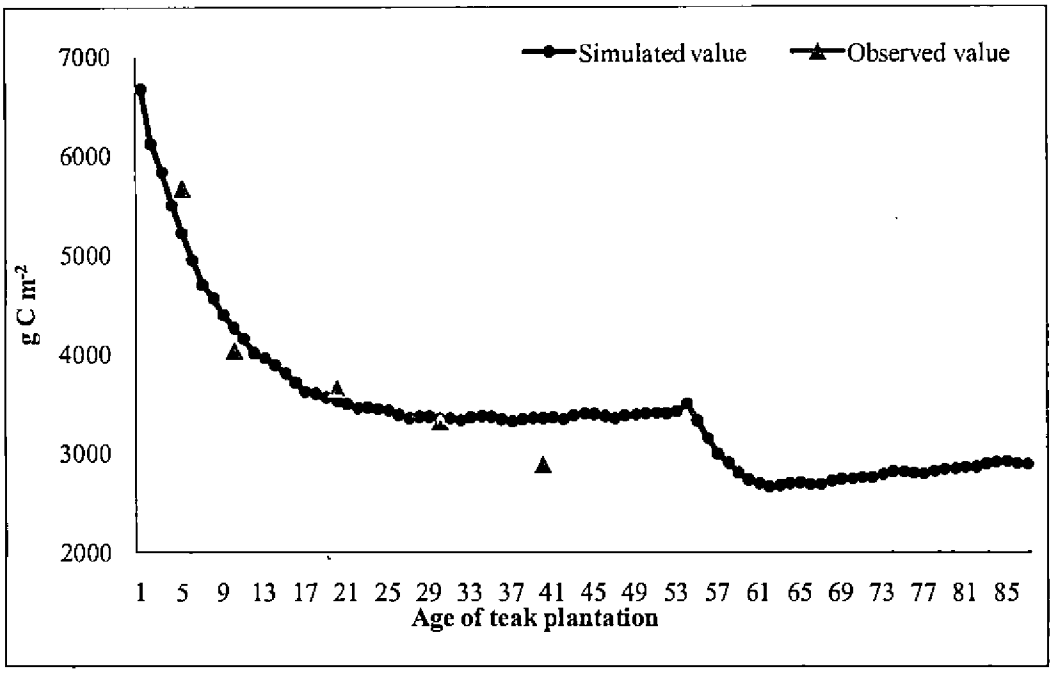

Fig. 16 Observed and CENTURY model simulated total soil organic carbon in teak ecosystem

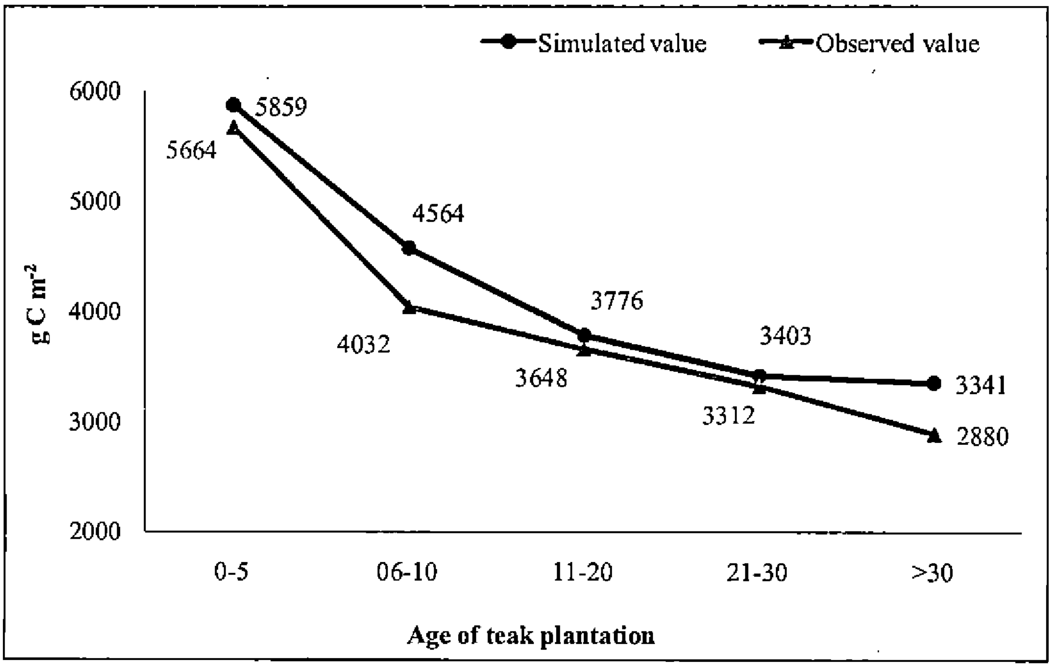

Fig. 17 Relationship between observed and CENTURY simulated total soil organic carbon in teak ecosystem

remained more or less stable. The teak plantation has the lowest qualities of labile and recalcitrant carbon counterparts compared to rice ecosystem.

4.4 Performance of Roth-C and CENTURY models in rice ecosystem

The observed SOC of rice fields for the eight years from 2004 to 2011 were 3564 , 3591 , 3591, 3591 , 3564 , 3537, 3510 and 3510 g C m^{-2} (Table 13).

Then t test was conducted and it was proved that both models were reliable in this ecosystem (Fig.10 to 13). RMSE and R^2 for Roth-C model were found to be 0.93 and 0.59, respectively and for CENTURY model it is 0.64 and 0.83 (Table 12). It was found that the efficiency of Roth-C and CENTURY models for rice ecosystem was 0.63 and 0.82, respectively (Table 13).

4.5 Performance of Roth-C and CENTURY models in teak ecosystem

The total SOC was measured in different aged classes of teak plantations. The age classes of 1-5, 6 -10, 11- 20, 21-30 and more than 30 years showed average SOC values of 5664 g C m^{-2}, 4032 g C m^{-2}, 3648 g C m^{-2}, 3312 g C m^{-2} and 2880 g C m^{-2}, respectively (Table 15).

A linear relationship existed between observed and simulated total soil organic carbon values for teak ecosystem by Roth-C and CENTURY models (Fig 14 to 17). It was found that the Roth-C model recorded the values of RMSE and R^2 as 32.73 and 0.84, respectively whereas, 22.53 and 0.95 by CENTURY model (Table 14). The efficiency of Roth-C and CENTURY models was found to be (Table 15) 0.69 and 0.88, respectively for teak ecosystems.

Based on the above observations, it was concluded that CENTURY model was more suited to simulate soil carbon dynamics in both ecosystems than Roth-C model.

Table 12. Evaluation of model performance in rice ecosystem

Model	RMSE	R^2
Roth-C	0.93	0.59
CENTURY	0.64	0.83

Table 13. Comparison of the model efficiency of Roth-C and CENTURY models in rice ecosystem

Year	**Observed values**	**Roth-C model simulated values**	**CENTURY model simulated values**
2004	3564	3592	3573
2005	3591	3581	3592
2006	3591	3571	3600
2007	3591	3562	3592
2008	3564	3552	3564
2009	3537	3543	3520
2010	3510	3534	3521
2011	3510	3525	3540
Model efficiency		**0.63**	**0.82**

Table 14. Evaluation of model performance in teak ecosystem

Model	RMSE	R^2
Roth-C	32.73	0.84
CENTURY	22.53	0.95

Table 15. Comparison of the model efficiency of Roth-C and CENTURY models in teak ecosystem

Year	Observed values	Roth-C model simulated values	CENTURY model simulated values
0-5	5664	4664	5860
6-10	4032	4078	4564
11-20	3648	3428	3776
21-30	3312	2846	3403
>30	2880	2474	3341
Model efficiency		**0.69**	**0.88**

Similar observations were also made by Smith *et al.* (1997) in his experimental study in which he assessed the performance of nine different carbon models using datasets from seven long term experiments and found that CENTURY, Roth-C and DAISY models met the criteria of the good model performance across all the simulations, most of the times. Moreover, CENTURY model performance was found to be better for grass, forest and crop system among all the models.

Manjunatha (2015) using CENTURY and STELLA model also got the similar results that the efficiency of the CENTURY model was much better than the other.

4.7 Predicted climate change scenarios

From the model evaluation studies, it was observed that the simulation of CENTURY model was much better than Roth-C. Hence it was used to predict the dynamics of total soil organic carbon in both ecosystems using different scenarios of IPCC such as RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The monthly values for maximum temperature, minimum temperature and precipitation over Pattambi (Tables 16 to 19) and Vellanikkara (Table 20 to 23) were obtained from the IPCC database for the period, 2015–2050.

4.8. Predicted weather parameters over Pattambi and Vellanikkara region

4.8.1. Maximum temperature

The predicted scenarios over both Pattambi and Vellanikkara regions, showed that the temperature (Fig.18 and 21) was more or less same from the starting year 2015 to 2026. During the period from 2027 to 2050, except RCP 8.5, all other scenarios followed a similar trend. At the beginning year of 2015, RCP 8.5 recorded the lowest value of 31.92°C followed by RCP 2.6, RCP 6.0, RCP 4.5 as 31.96, 31.97 and 32.03°C, respectively in Pattambi whereas in Vellanikkara 32°C followed by 31.96, 32.03 and 32.09°C. When it reached 2050, in Pattambi the highest value recorded by RCP 8.5 was 33.15°C followed by RCP 4.5, RCP 6.0, RCP 2.6 as 32.71, 32.58

Table 16. Predicted weather parameters by RCP 2.6 scenario in CENTURY model for rice ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.09	33	0.004	0.01
February	24.09	34.17	0.98	0.06
March	25.75	35.38	1.93	0.03
April	26.81	35.1	9.53	0.04
May	26.16	33.56	24.2	0.08
June	24.49	30.18	60.83	0.04
July	23.82	29.18	71.61	0.12
August	24.27	29.56	37.45	0.44
September	24.39	30.59	23.36	0.52
October	24.58	31.16	28.47	0.28
November	24.28	31.98	14.7	0.36
December	23.18	32.43	2.27	0.31

Table 17.Predicted weather parameters by RCP 4.5 scenario used in CENTURY model for rice ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.17	33.13	0.09	0.01
February	24.19	34.35	1.01	0.05
March	25.88	35.57	1.90	0.03
April	26.9	35.28	9.49	0.16
May	26.28	33.64	24.45	0.49
June	24.6	30.35	60.47	0.22
July	23.92	29.3	71.68	0.08
August	24.35	29.65	37.42	0.39
September	24.49	30.66	23.33	0.57
October	24.68	31.25	28.59	0.78
November	24.37	32.09	14.65	0.86
December	23.27	32.51	2.02	0.19

Table 18. Predicted weather parameters by RCP 6.0 scenario in CENTURY model for rice ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.33	33.2	0.001	0.003
February	24.28	34.41	0.94	0.02
March	25.95	35.59	1.96	0.04
April	27.05	35.42	9.39	0.05
May	26.41	33.79	24.64	0.2
June	24.72	30.45	61.33	0.2
July	24.05	29.47	70.84	0.28
August	24.49	29.8	37.12	0.55
September	24.63	30.84	23.40	0.46
October	24.84	31.36	29.47	0.28
November	24.54	32.17	15.46	1.01
December	23.46	32.63	2.42	0.1

Table 19. Predicted weather parameters by RCP 8.5 scenario in CENTURY model for rice ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.09	33.02	0.01	0.01
February	24.09	34.22	1.01	0.05
March	25.76	35.4	1.90	0.03
April	26.8	34.17	9.49	0.16
May	26.2	33.57	24.45	0.49
June	24.5	30.27	60.47	0.22
July	23.85	29.26	71.68	0.08
August	24.28	29.59	37.42	0.39
September	24.4	30.65	23.33	0.57
October	24.61	31.21	28.59	0.78
November	24.3	31.98	14.65	0.87
December	23.24	32.43	2.02	0.19

Table 20. Predicted weather parameters by RCP 2.6 scenario in CENTURY model for teak ecosystem

Month	Temperature(°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.16	33.07	0.01	0.01
February	24.22	34.32	1.07	0.06
March	25.77	35.46	2.08	0.03
April	26.77	35.12	9.11	0.04
May	26.19	33.66	25.28	0.10
June	24.49	30.12	65.6	0.04
July	23.87	29.33	74.32	0.14
August	24.4	29.58	43.25	0.44
September	24.38	30.55	25.85	0.49
October	24.67	31.24	29.11	0.35
November	24.35	31.9	14.35	0.37
December	23.31	32.53	2.42	0.33

Table 21. Predicted weather parameters by RCP 4.5 scenario in CENTURY model for teak ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.24	33.2	0.01	0.01
February	24.32	34.5	1.10	0.10
March	25.90	35.64	2.04	0.03
April	26.87	35.29	9.09	0.15
May	26.30	33.73	25.56	0.52
June	24.59	30.29	65.2	0.21
July	23.96	29.44	74.32	0.14
August	24.48	29.67	43.26	0.34
September	24.48	30.63	25.84	0.61
October	24.75	31.32	29.11	0.75
November	24.44	32.00	14.22	0.87
December	23.40	32.60	2.14	0.20

Table 22. Predicted weather parameters by RCP 6.0 scenario in CENTURY model for teak ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.17	33.09	0.013	0.012
February	24.23	34.37	1.12	0.04
March	25.79	35.49	2.10	0.06
April	26.78	35.18	9.11	0.09
May	26.23	33.66	25.60	0.04
June	24.50	30.21	65.20	0.45
July	23.90	29.41	74.33	0.41
August	24.41	29.61	43.26	0.11
September	24.40	30.61	25.73	0.23
October	24.70	31.28	29.43	0.48
November	24.38	31.9	14.71	0.75
December	23.36	32.52	2.63	0.24

Table 23. Predicted weather parameters by RCP 8.5 scenario in CENTURY model for teak ecosystem

Month	Temperature (°C)		Precipitation (cm)	
	Min	Max	Mean	Std
January	23.4	33.27	0.03	0.01
February	24.42	34.55	1.04	0.01
March	25.97	35.66	2.14	0.03
April	27.01	35.43	8.96	0.07
May	26.44	33.88	25.79	0.21
June	26.44	30.40	63.16	12.96
July	24.72	29.63	73.52	0.25
August	24.10	29.82	42.92	0.55
September	24.63	30.81	15.06	0.49
October	24.93	31.44	2.60	0.31
November	24.62	32.10	15.08	1.02
December	23.60	32.72	2.60	0.12

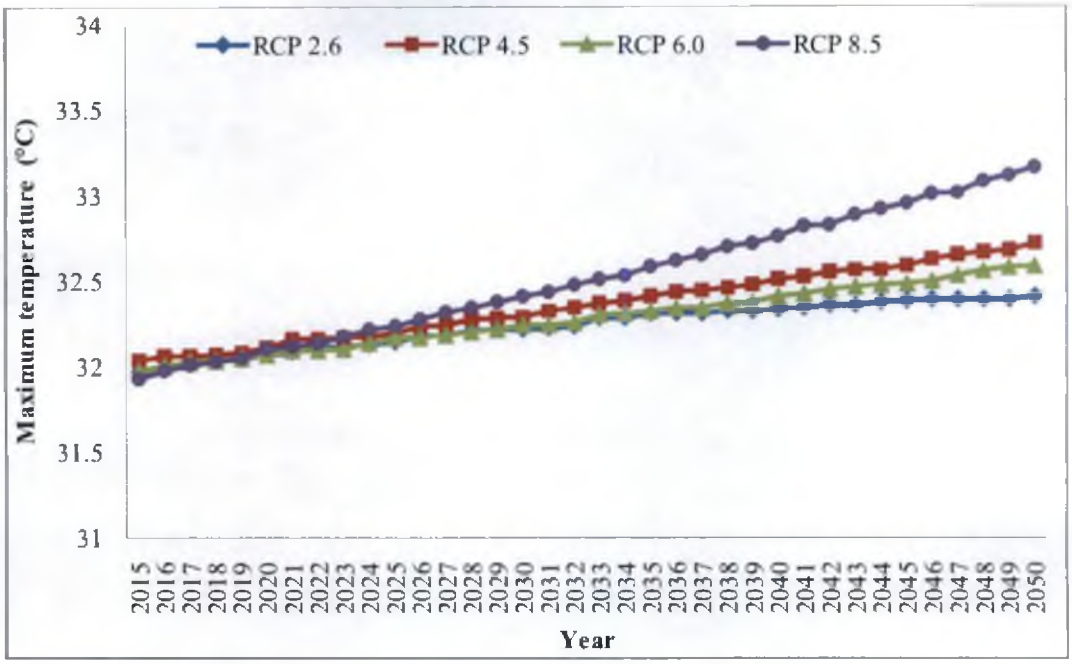

Fig. 18 Predicted maximum temperature at Pattambi (2015-2050)

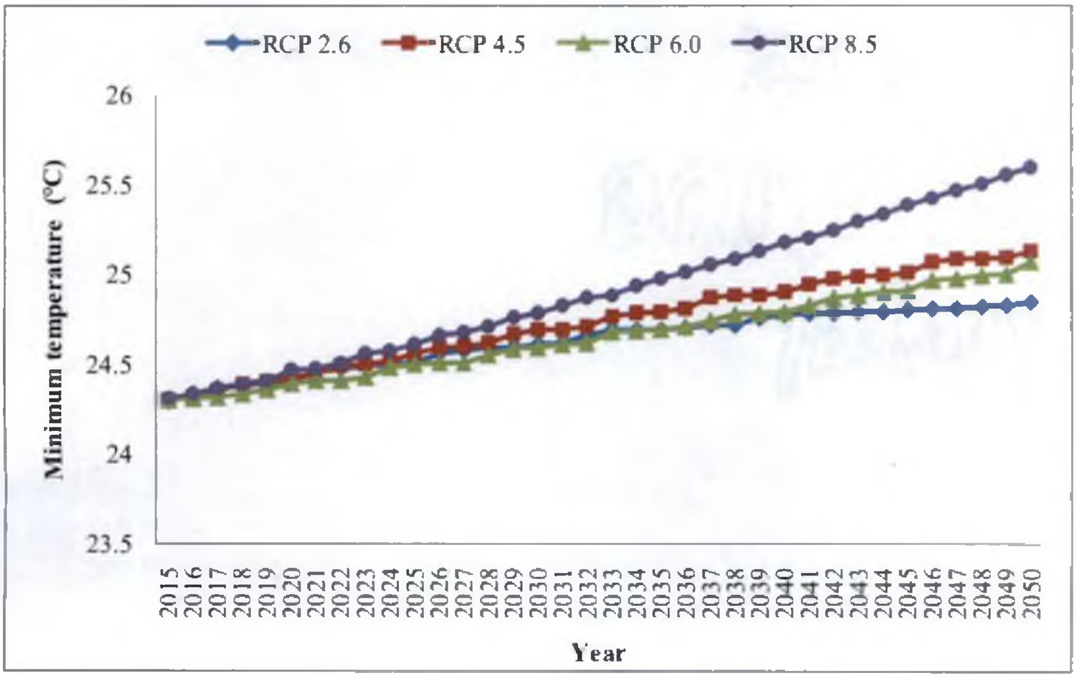

Fig. 19 Predicted minimum temperature at Pattambi (2015-2050)

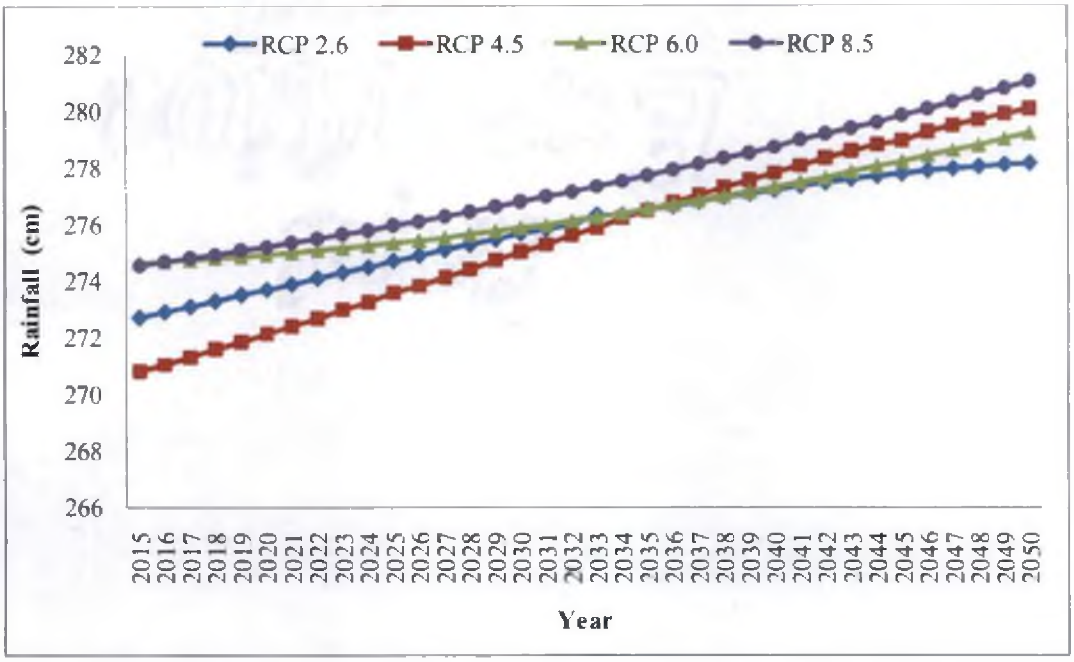

Fig. 20 Predicted rainfall at Pattambi (2015-2050)

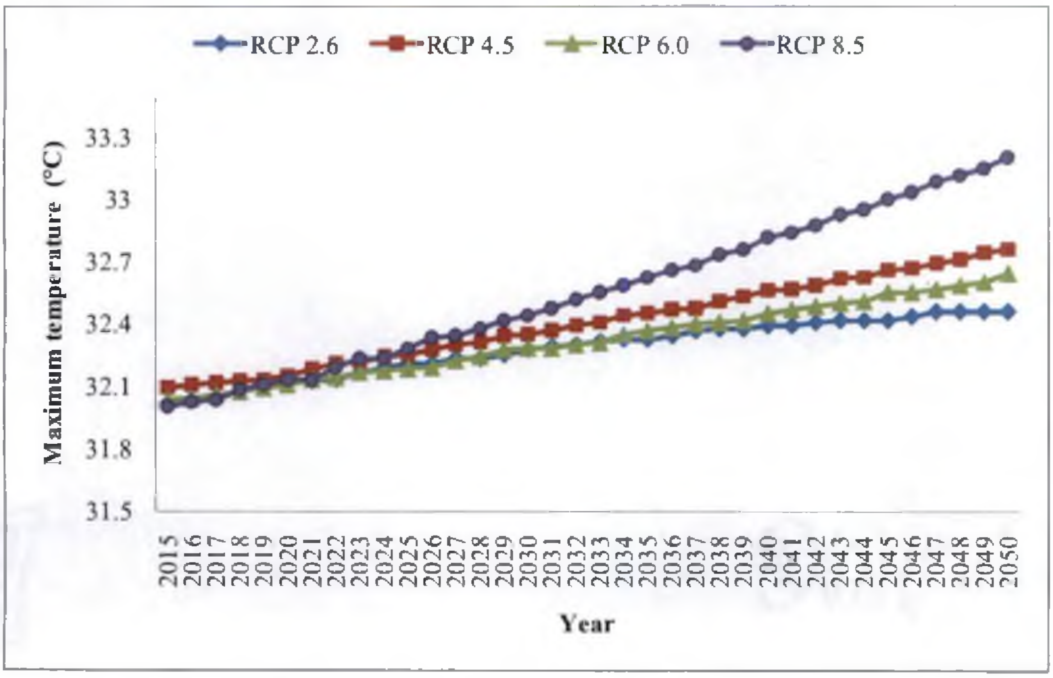

Fig.21 Predicted maximum temperature at Vellanikkara (2015-2050)

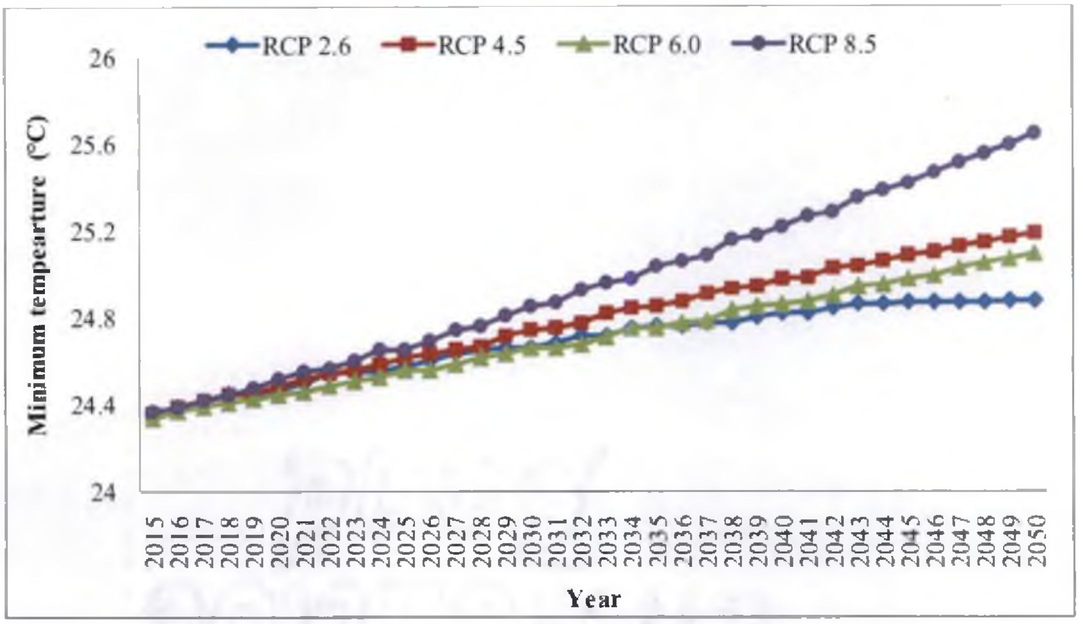

Fig. 22 Predicted minimum temperature at Vellanikkara (2015-2050)

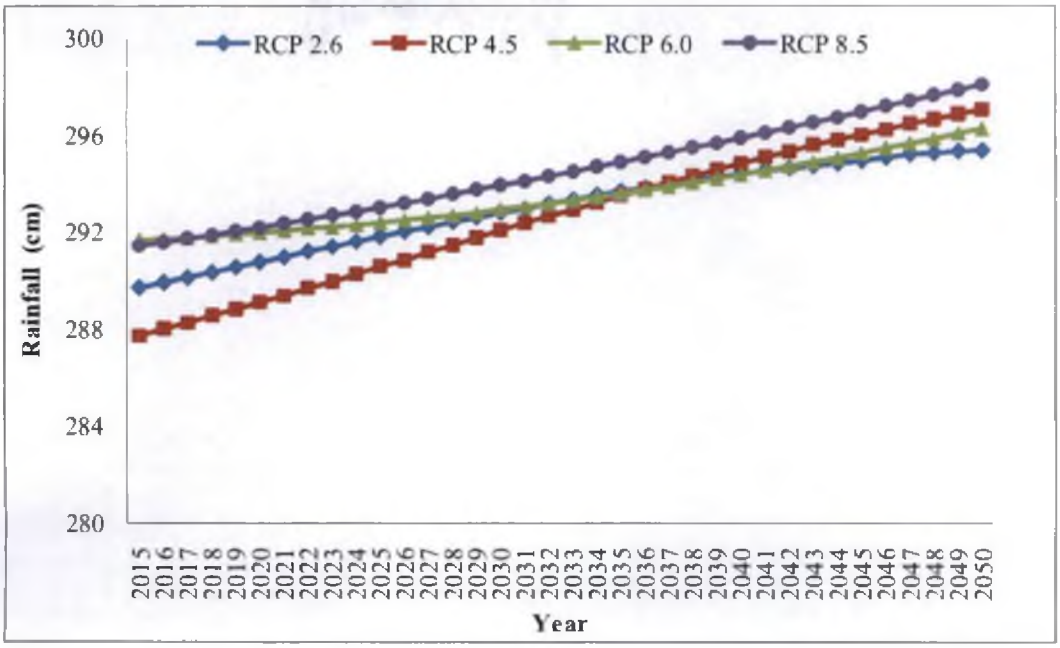

Fig. 23 Predicted rainfall at Vellanikkara (2015-2050)

and 32.40°C, respectively, whereas in Vellanikkara 33.2°C followed by 32.75°C, 32.64°C and 32.46°C.

4.8.2 Minimum temperature

The temperature (Fig.19 and 22) was more or less same during the period from 2015 to 2026. Afterwards, except RCP 8.5, all other scenarios followed a similar trend. In Pattambi, the RCP 2.6 recorded the lowest value of 24.29 °C followed by RCP 4.5, RCP 6.0, RCP 8.5 as 24.3, 24.3 and 24.30 °C, respectively in 2015 whereas, in Vellanikkara RCP 6.0 had recorded the lowest value of 24.33°C followed by RCP 4.5, RCP 2.6, RCP 8.5 as 24.35, 24.35 and 24.36°C . The highest minimum temperature was predicted in 2050 by RCP 8.5 in Pattambi followed by RCP 4.5, RCP 6.0 and RCP 2.6 as 25.60, 25.13, 25.01 and 24.84°C, respectively whereas, in Vellanikkara it was 25.64°C followed by, 25.18, 25.09 and 24.87°C.

4.8.3 Rainfall

It was observed that in 2015, the lowest average annual rainfall recorded by RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 were 270.8 , 272.7 , 274.62 and 274.53 cm, respectively over Pattambi whereas RCP 4.5, RCP 2.6, RCP 8.5 and RCP 6.0 as 287.72, 289.70, 291.44 and 291.66 cm over Vellanikkara (Fig. 20 and 23). During the period from 2033 to 2038, except RCP 8.5 all others followed a similar trend. Thereafter RCP 8.5 predicted high rainfall of 286.99 cm during 2050 in Pattambi followed by RCP 4.5, RCP 6.0 and RCP 2.6 with values of 280.04 , 279.18 and 278.11 cm, respectively whereas 298.07 cm followed by 297.02 , 296.23 and 295.34 cm in Vellanikkara.

Table 24. Total soil organic carbon (g C m^{-2}) under predicted climate change scenarios for rice ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	3459.64	3455.15	3458.86	3432.16
2016	3466.92	3462.63	3466.30	3439.75
2017	3474.65	3470.68	3474.28	3447.92
2018	3470.04	3465.90	3469.74	3443.08
2019	3478.47	3474.56	3478.15	3451.59
2020	3487.30	3482.53	3486.75	3460.27
2021	3488.23	3483.20	3488.74	3461.23
2022	3490.32	3486.90	3490.06	3463.76
2023	3476.76	3474.01	3476.66	3450.22
2024	3459.66	3457.27	3459.48	3433.20
2025	3441.52	3439.30	3440.83	3414.91
2026	3423.21	3420.98	3422.29	3396.61
2027	3405.19	3403.07	3404.16	3378.43
2028	3387.52	3385.86	3386.61	3360.93
2029	3370.52	3369.30	3369.76	3344.20
2030	3354.33	3353.37	3353.42	3327.91
2031	3338.81	3337.92	3337.63	3312.31
2032	3323.84	3323.01	3322.56	3297.17
2033	3309.42	3308.74	3307.97	3282.55
2034	3295.39	3294.94	3293.77	3268.47
2035	3281.60	3281.54	3280.08	3254.65
2036	3268.24	3268.26	3266.59	3241.15
2037	3255.18	3255.31	3253.50	3228.06
2038	3242.41	3242.74	3240.65	3215.01
2039	3229.88	3230.38	3227.98	3202.31
2040	3217.60	3218.19	3215.62	3189.94
2041	3205.43	3206.17	3203.34	3177.48
2042	3193.51	3194.33	3191.42	3165.37
2043	3181.79	3182.76	3179.72	3153.30
2044	3170.24	3171.35	3168.04	3141.52
2045	3158.94	3159.94	3156.68	3129.92
2046	3147.20	3147.00	3145.91	3118.75
2047	3137.52	3135.79	3135.76	3107.71
2048	3127.66	3125.23	3125.72	3097.31
2049	3117.71	3115.01	3115.73	3087.28
2050	3107.64	3104.95	3105.57	3077.17

Table 25. Simulated active carbon (g C m^{-2}) under predicted climate change scenarios for rice ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	10.85	10.90	10.88	10.74
2016	10.76	10.86	10.85	10.68
2017	10.75	10.87	10.84	10.72
2018	10.93	10.98	10.86	10.73
2019	10.97	11.02	10.91	10.77
2020	11.02	11.06	10.95	10.81
2021	10.65	10.87	10.75	10.56
2022	10.41	10.48	10.34	10.20
2023	9.86	9.92	9.79	9.65
2024	9.47	9.52	9.40	9.25
2025	9.21	9.24	9.13	8.98
2026	9.02	9.03	8.95	8.79
2027	8.87	8.88	8.80	8.64
2028	8.74	8.75	8.67	8.51
2029	8.63	8.63	8.56	8.39
2030	8.52	8.51	8.45	8.29
2031	8.43	8.41	8.35	8.19
2032	8.33	8.30	8.26	8.09
2033	8.24	8.21	8.16	8.00
2034	8.14	8.11	8.07	7.91
2035	8.06	8.01	7.99	7.82
2036	7.97	7.92	7.90	7.73
2037	7.89	7.83	7.81	7.65
2038	7.80	7.75	7.73	7.56
2039	7.72	7.66	7.65	7.49
2040	7.64	7.57	7.57	7.41
2041	7.56	7.49	7.49	7.33
2042	7.49	7.41	7.42	7.25
2043	7.41	7.34	7.34	7.18
2044	7.34	7.26	7.26	7.11
2045	7.27	7.18	7.20	7.04
2046	7.18	7.08	7.08	6.92
2047	7.18	7.14	7.08	6.93
2048	7.13	7.13	7.03	6.90
2049	7.06	7.09	6.97	6.85
2050	6.99	7.03	6.90	6.79

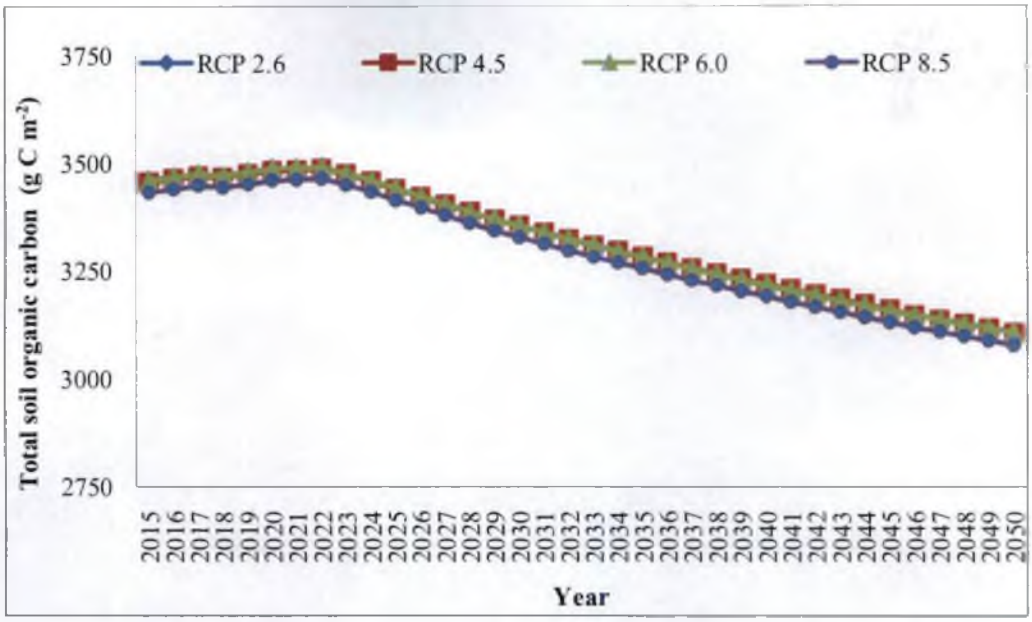

Fig. 24 Simulated total soil organic carbon under predicted climate change scenarios for rice ecosystem

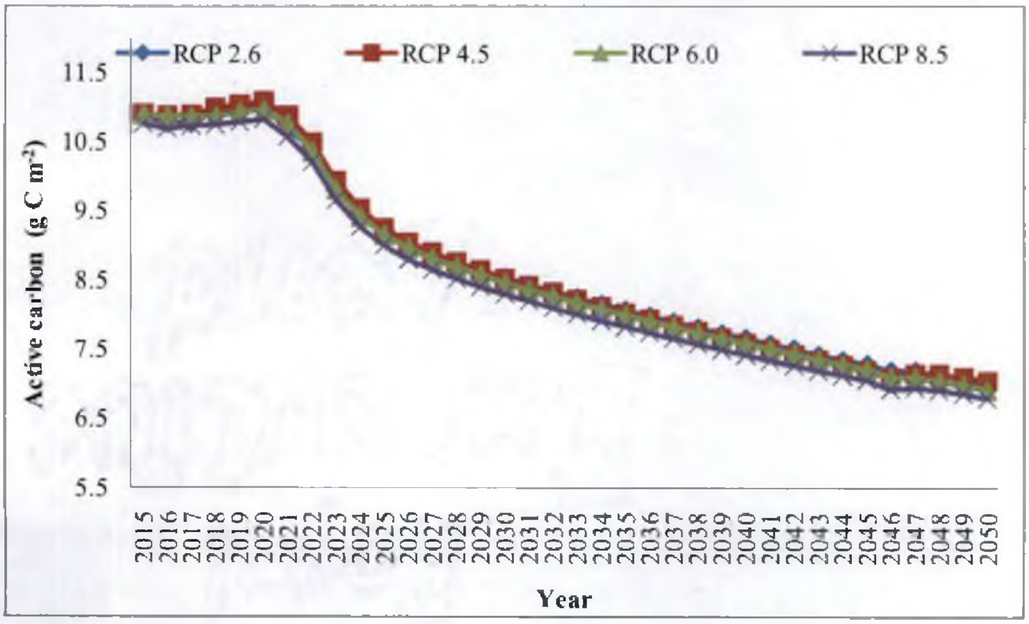

Fig. 25 Simulated active carbon under predicted climate change scenarios for rice ecosystem

Table 26. Simulated slow carbon (g C m^{-2}) under predicted climate change scenarios for rice ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	1621.51	1619.24	1618.06	1594.16
2016	1621.21	1618.99	1617.81	1594.19
2017	1621.16	1619.17	1617.89	1594.51
2018	1623.07	1621.06	1619.81	1596.29
2019	1623.47	1621.71	1620.19	1596.90
2020	1624.17	1622.10	1620.78	1597.72
2021	1616.42	1614.11	1613.05	1590.20
2022	1621.70	1620.48	1618.37	1595.70
2023	1613.69	1613.10	1610.43	1587.84
2024	1602.25	1602.19	1598.94	1576.55
2025	1588.45	1588.83	1584.82	1562.79
2026	1572.95	1573.64	1569.06	1547.39
2027	1556.29	1557.23	1552.18	1530.67
2028	1538.70	1540.11	1534.52	1513.20
2029	1520.60	1522.53	1516.44	1495.33
2030	1502.33	1504.70	1498.03	1477.09
2031	1484.04	1486.70	1479.48	1458.77
2032	1465.82	1468.66	1461.05	1440.46
2033	1447.77	1450.83	1442.77	1422.24
2034	1429.92	1433.21	1424.64	1404.28
2035	1412.21	1415.85	1406.82	1386.48
2036	1394.78	1398.60	1389.20	1368.90
2037	1377.64	1381.58	1371.90	1351.68
2038	1360.79	1364.88	1354.88	1334.58
2039	1344.23	1348.45	1338.08	1317.79
2040	1327.95	1332.26	1321.61	1301.35
2041	1311.90	1316.29	1305.35	1285.01
2042	1296.14	1300.53	1289.44	1269.01
2043	1280.64	1285.08	1273.83	1253.17
2044	1265.40	1269.88	1258.38	1237.61
2045	1250.45	1254.81	1243.25	1222.31
2046	1235.38	1238.76	1228.78	1207.55
2047	1221.37	1223.19	1214.61	1192.61
2048	1207.73	1208.40	1200.87	1178.33
2049	1194.36	1194.23	1187.44	1164.58
2050	1181.13	1180.49	1174.09	1151.05

Table 27. Simulated passive carbon pool (g C m^{-2}) under climate change scenarios of rice ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	1593.31	1590.73	1596.69	1596.36
2016	1601.28	1598.59	1604.65	1604.24
2017	1609.25	1606.46	1612.62	1612.17
2018	1611.76	1608.98	1615.12	1614.65
2019	1619.72	1616.84	1623.12	1622.60
2020	1627.70	1624.71	1631.15	1630.56
2021	1632.52	1630.65	1635.20	1635.79
2022	1643.71	1640.46	1647.30	1646.60
2023	1651.58	1648.32	1655.28	1654.51
2024	1659.29	1656.03	1663.90	1662.29
2025	1666.82	1663.56	1670.73	1669.87
2026	1674.18	1670.94	1678.20	1677.30
2027	1681.35	1678.15	1685.50	1684.55
2028	1688.37	1685.22	1692.66	1691.64
2029	1695.23	1692.14	1699.66	1698.59
2030	1701.95	1698.91	1706.52	1705.41
2031	1708.53	1705.57	1713.24	1712.09
2032	1714.98	1712.12	1719.85	1718.66
2033	1721.32	1718.54	1726.34	1725.09
2034	1727.54	1724.86	1732.71	1731.42
2035	1733.65	1731.08	1738.97	1737.65
2036	1739.65	1737.18	1745.14	1743.75
2037	1745.56	1743.18	1751.20	1749.74
2038	1751.35	1749.08	1757.14	1755.65
2039	1757.05	1754.89	1762.97	1761.42
2040	1762.65	1760.59	1768.70	1767.10
2041	1768.13	1766.20	1774.34	1772.66
2042	1773.51	1771.70	1779.88	1778.12
2043	1778.79	1777.10	1785.33	1783.49
2044	1783.98	1782.41	1790.65	1788.74
2045	1789.08	1787.64	1795.88	1793.89
2046	1794.11	1792.75	1800.94	1798.89
2047	1798.93	1797.35	1805.61	1803.40
2048	1803.68	1801.85	1810.21	1807.83
2049	1808.34	1806.29	1814.73	1812.20
2050	1812.91	1810.66	1819.20	1816.52

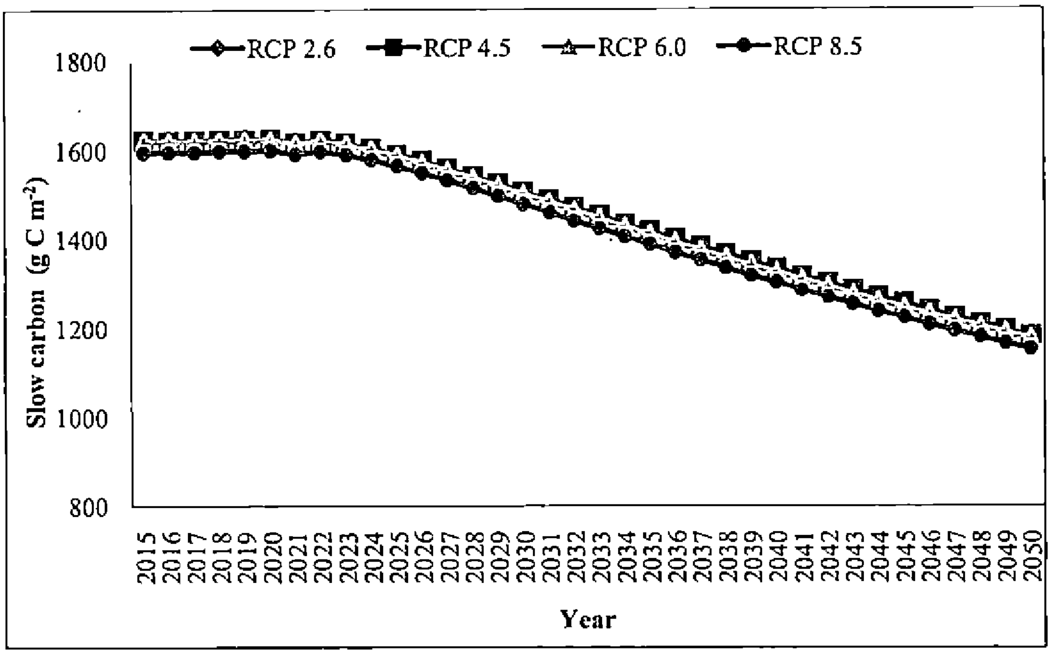

Fig.26 Simulated slow carbon under predicted climate change scenarios for rice ecosystem

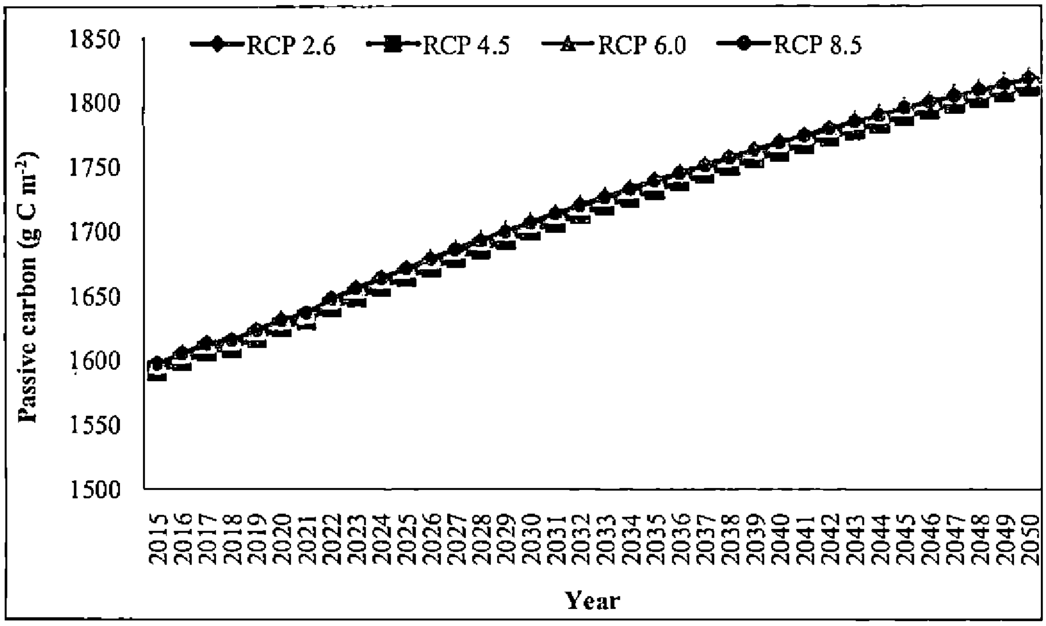

Fig. 27 Simulated passive carbon under predicted climate change scenarios for rice ecosystem

4.9 Soil organic carbon changes due to predicted climate change scenarios in rice ecosystem

The predicted total soil organic carbon using different scenarios (Table 24 and Fig.24) revealed that during the initial year of 2015 the total soil organic carbon recorded higher values such as 3459.64 g C m^{-2} by RCP 2.6 followed by RCP 6.0, RCP 4.5 and RCP 8.5 as 3458.86, 3455.15 and 3432.16 g C m^{-2}, respectively. The SOC values showed a slight increase up to the year 2020 and thereafter declined gradually. At the end of the simulation period (2050), the highest value of total soil organic carbon of 3107.64 g C m^{-2} was recorded by RCP 2.6 followed by RCP 6.0, RCP 4.5, and RCP 8.5 as 3105.57 g C m^{-2}, 3104.95 g C m^{-2} and 3077.17 g C m^{-2}, respectively. All these scenarios followed a uniform trend throughout the years.

Starting from the initial year of 2015, the active carbon had recorded higher values such as 10.90 g C m^{-2} by RCP 4.5 followed by RCP 2.6, RCP 6.0, RCP 8.5 as 10.85, 10.88 and 10.74 g C m^{-2}, respectively. There was a slight increase up to 2020 followed by a gradual decline. Then by 2050 highest value of active carbon of 7.032 g C m^{-2} was recorded by RCP 4.5, followed by RCP 2.6, RCP 6.0, RCP 8.5 as 6.99, 6.90 and 6.79 g C m^{-2}, respectively. Uniform trend similar to the above, was observed here also (Table 25 and Fig.25)

The slow carbon (Table 26 and Fig.26) recorded higher values such as 1621.51 g C m^{-2} by RCP 2.6 followed by RCP 4.5, RCP 6.0, RCP 8.5 as 1619.21 g C m^{-2}, 1618.06 g C m^{-2} and 1594.16 g C m^{-2}, respectively. Thereafter a gradual decline occurred and by 2050, the highest value of 1181.13 g C m^{-2} was recorded by RCP 2.6 followed by RCP 4.5, RCP 6.0, RCP 8.5 as 1180.49 g C m^{-2}, 1174.09 g C m^{-2} and 1151.05 g C m^{-2}, respectively. All these scenarios followed a uniform trend throughout the years.

Simulation of passive carbon using different scenarios showed that during the initial year of 2015, the passive carbon recorded a higher value of 1596.69 g C m^{-2} by

RCP 6.0 followed by RCP 8.5, RCP 2.6, and RCP 4.5 as 1596.36, 1593.31 and 1590.73 g C m^{-2}, respectively. It was noticed that all these scenarios followed a uniform trend throughout the years. In the year 2050 highest value of 1819.20 g C m^{-2} was recorded by RCP 6.0 followed by RCP 8.5, RCP 2.6, and RCP 4.5 with the values of 1816.52, 1813.91 and 1810.66 g C m^{-2}, respectively (Table 27 and Fig.27).

Studies have also shown that cropland soils may serve as a large sink for atmospheric CO_2 by enhancing SOC (Ogle *et al.*, 2005 and Follett *et al.*, 2005). On the other hand, rice soils are known to retain higher amounts of resilient carbon among all terrestrial ecosystems (Liu *et al.*, 2006, Stern *et al.*, 2007 and Xie *et al.*, 2007).

It is important to note that organic matter preferentially accumulates in continuous rice systems as a result of submerged conditions. Slower decomposition of organic matter and higher net productivity of submerged paddy soils lead to net carbon accumulation (Sharawat, 2004). Hence paddy soils had significantly larger active and slow SOC pools but a smaller resistant SOC pool than woodland soils. Therefore, SOC sequestered in paddy soils seemed to be more labile than in afforested soils, despite the greater SOC sequestration of paddy fields (Iqbal *et al.*, 2008). He also observed that climate significantly influenced large-scale patterns of soil carbon sequestration. Irrespective of land management practices, higher sequestration rates were observed in the wettest locations with annual precipitation above 1,500 mm.

Accumulation of the slow pool C in the paddy soils (Zhou *et al.*, 2006) does not seem to contribute proportionally to the mineralization and the warming effect. This C pool is generally considered as physically protected in macro-aggregates (Six *et al.*, 2002), and is shown as not readily accessible to microbial mineralization even under warming (Garten *et al.*, 1999). Many studies have demonstrated that the C sequestration in paddy soils is characterized by the increase of SOC in physically

Table 28. Simulated total soil organic carbon (g C m^{-2}) under predicted climate change scenarios for teak ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	3268.14	3272.51	3259.71	3270.20
2016	3272.57	3277.04	3264.03	3274.20
2017	3276.88	3281.43	3268.35	3278.29
2018	3348.21	3352.92	3340.07	3350.27
2019	3182.15	3187.39	3173.96	3183.78
2020	3024.40	3030.51	3015.96	3025.48
2021	2896.11	2903.56	2888.13	2897.23
2022	2792.57	2799.97	2784.50	2793.16
2023	2699.30	2706.59	2691.28	2699.21
2024	2622.82	2629.74	2615.03	2621.59
2025	2570.40	2576.54	2563.03	2567.20
2026	2541.14	2546.39	2533.99	2535.98
2027	2528.52	2532.99	2521.49	2521.66
2028	2526.36	2530.37	2519.42	2518.17
2029	2530.44	2534.12	2523.46	2521.13
2030	2537.68	2541.10	2530.70	2527.57
2031	2546.60	2549.86	2539.65	2535.72
2032	2556.17	2559.34	2549.22	2544.69
2033	2565.96	2568.94	2558.90	2553.93
2034	2575.66	2578.46	2568.45	2563.02
2035	2585.31	2587.84	2577.98	2572.15
2036	2594.90	2597.19	2587.52	2581.25
2037	2604.56	2606.62	2597.07	2590.21
2038	2614.19	2616.08	2606.70	2599.27
2039	2623.78	2625.49	2616.24	2608.33
2040	2633.34	2634.82	2625.78	2617.47
2041	2642.83	2644.08	2635.24	2626.61
2042	2652.15	2653.35	2644.55	2635.63
2043	2661.38	2662.47	2653.68	2644.73
2044	2670.47	2671.44	2662.77	2653.61
2045	2679.51	2680.26	2671.83	2662.46
2046	2688.45	2688.99	2681.06	2671.23
2047	2699.21	2700.21	2691.73	2685.03
2048	2711.61	2712.53	2703.64	2699.48
2049	2722.76	2723.78	2714.56	2711.12
2050	2733.27	2734.35	2724.82	2721.82

Table 29. Simulated active carbon (g C m^{-2}) under predicted climate change scenarios for teak ecosystem

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	19.46	19.52	19.32	19.40
2016	19.58	19.64	19.43	19.51
2017	19.68	19.75	19.54	19.63
2018	22.60	22.59	22.57	22.69
2019	9.72	9.74	9.69	9.75
2020	4.17	4.19	4.16	4.19
2021	3.64	3.66	3.62	3.65
2022	3.61	3.63	3.59	3.61
2023	3.44	3.46	3.42	3.44
2024	3.51	3.52	3.49	3.48
2025	3.92	3.93	3.90	3.86
2026	4.62	4.61	4.59	4.52
2027	5.41	5.40	5.37	5.29
2028	6.17	6.17	6.12	6.04
2029	6.86	6.87	6.80	6.72
2030	7.45	7.47	7.40	7.31
2031	7.97	7.99	7.92	7.84
2032	8.43	8.47	8.39	8.30
2033	8.86	8.89	8.80	8.72
2034	9.24	9.28	9.18	9.10
2035	9.60	9.63	9.53	9.45
2036	9.93	9.96	9.87	9.78
2037	10.24	10.28	10.18	10.09
2038	10.55	10.59	10.49	10.39
2039	10.84	10.88	10.78	10.67
2040	11.12	11.15	11.06	10.94
2041	11.39	11.42	11.33	11.21
2042	11.66	11.68	11.59	11.46
2043	11.90	11.93	11.83	11.71
2044	12.13	12.16	12.07	11.95
2045	12.37	12.38	12.30	12.17
2046	12.59	12.60	12.53	12.39
2047	13.05	13.02	12.94	12.82
2048	13.35	13.34	13.23	13.18
2049	13.59	13.58	13.48	13.41
2050	13.81	13.80	13.69	13.63

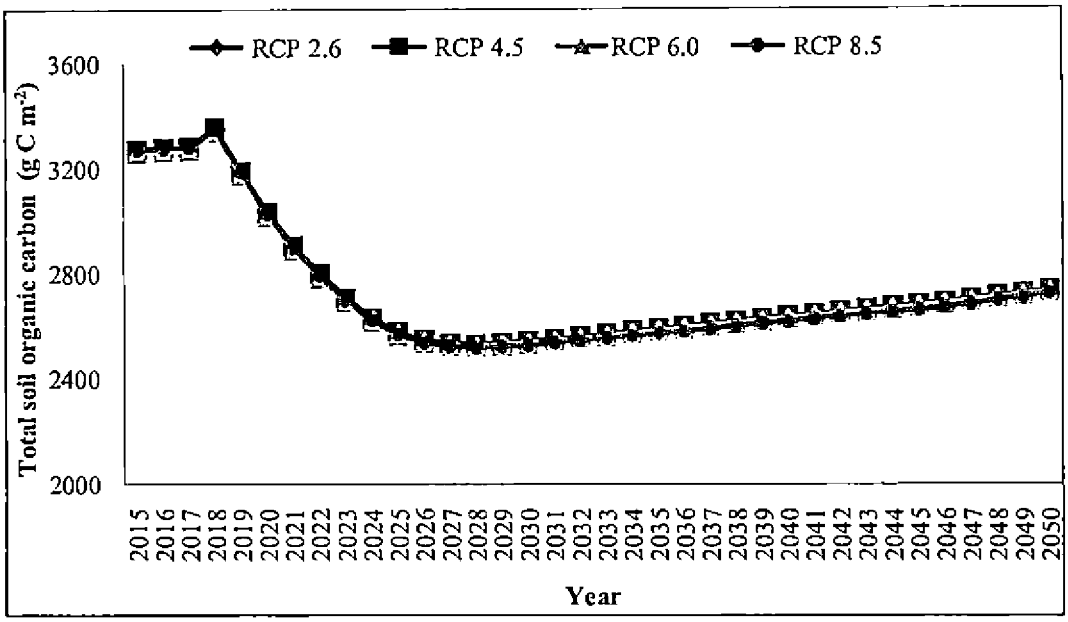

Fig.28 Simulated total soil organic carbon under predicted climate change scenarios for teak ecosystem

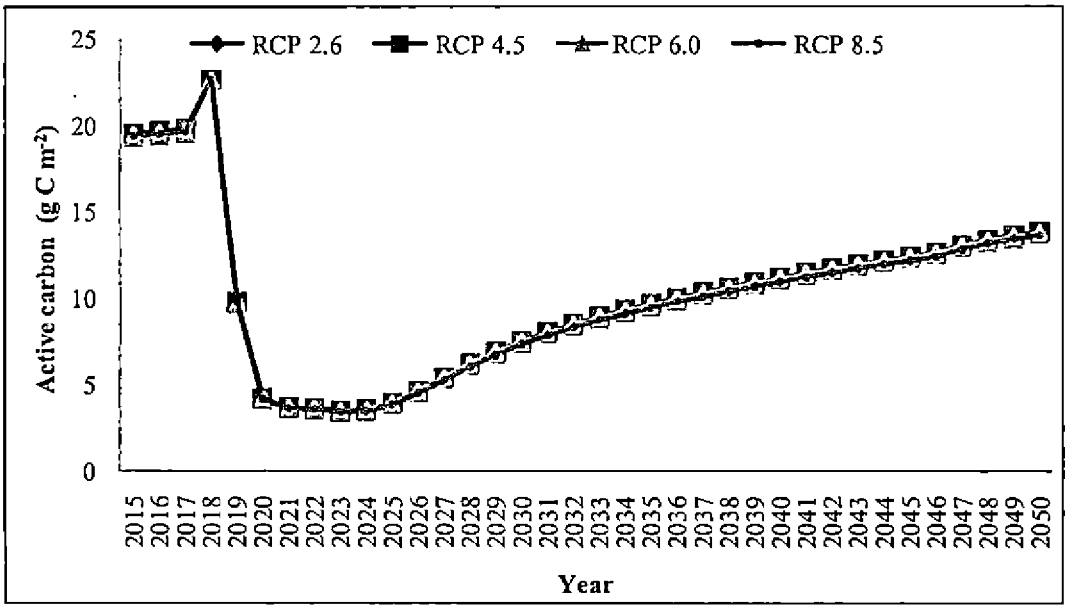

Fig.29 Simulated active carbon under predicted climate change scenarios for teak ecosystem

Table 30. Simulated slow carbon (g C m^{-2}) under predicted climate change scenarios for teak ecosystem

Year	RCP2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	1469.15	1472.15	1462.40	1470.66
2016	1475.85	1478.95	1469.02	1477.10
2017	1482.42	1485.64	1475.55	1483.48
2018	1572.35	1575.03	1566.68	1574.52
2019	1526.46	1529.48	1520.55	1528.49
2020	1426.36	1430.48	1419.91	1427.92
2021	1317.40	1323.48	1310.52	1318.47
2022	1221.73	1228.11	1214.73	1222.50
2023	1132.15	1138.62	1125.15	1132.52
2024	1052.72	1059.12	1045.85	1052.48
2025	987.98	994.01	981.47	986.75
2026	939.44	944.85	933.22	937.01
2027	905.65	910.38	899.73	902.02
2028	884.25	888.36	878.60	879.53
2029	872.64	876.22	867.19	866.92
2030	868.37	871.50	863.13	861.82
2031	869.47	872.22	864.40	862.20
2032	874.39	876.80	869.40	866.46
2033	881.90	884.01	876.93	873.38
2034	891.10	892.97	886.15	882.06
2035	901.43	903.05	896.44	891.91
2036	912.46	913.85	907.46	902.51
2037	923.97	925.13	918.92	913.54
2038	935.78	936.74	930.70	924.88
2039	947.75	948.51	942.64	936.39
2040	959.80	960.34	954.65	948.01
2041	971.86	972.20	966.69	959.67
2042	983.81	984.04	978.65	971.31
2043	995.74	995.82	990.52	982.94
2044	1007.53	1007.48	1002.29	994.48
2045	1019.15	1018.99	1013.96	1005.93
2046	1030.66	1030.37	1025.54	1017.27
2047	1042.70	1042.35	1037.47	1030.65
2048	1055.71	1055.29	1050.27	1045.15
2049	1068.71	1068.27	1063.07	1058.27
2050	1081.51	1081.08	1075.67	1071.20

Table 31. **Simulated passive carbon (g C m^{-2}) under predicted climate change scenarios for teak ecosystem**

Year	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2015	1534.74	1535.60	1533.73	1534.29
2016	1532.06	1532.93	1531.03	1531.59
2017	1529.40	1530.28	1528.34	1528.92
2018	1527.42	1528.32	1526.34	1526.94
2019	1524.52	1525.46	1523.41	1524.03
2020	1521.40	1522.37	1520.26	1520.90
2021	1518.08	1519.13	1516.91	1517.58
2022	1514.84	1515.92	1513.65	1514.33
2023	1511.50	1512.60	1510.27	1510.98
2024	1508.08	1509.20	1506.83	1507.56
2025	1504.63	1505.79	1503.36	1504.10
2026	1501.20	1502.37	1499.91	1500.65
2027	1497.78	1498.97	1496.47	1497.22
2028	1494.38	1495.60	1493.05	1493.80
2029	1491.02	1492.25	1489.66	1490.41
2030	1487.67	1488.94	1486.30	1487.05
2031	1484.36	1485.64	1482.97	1483.72
2032	1481.06	1482.37	1479.67	1480.41
2033	1477.79	1479.13	1476.38	1477.12
2034	1474.55	1475.91	1473.12	1473.86
2035	1471.32	1472.70	1469.89	1470.62
2036	1468.12	1469.52	1466.67	1467.40
2037	1464.94	1466.36	1463.48	1464.20
2038	1461.78	1463.23	1460.31	1461.03
2039	1458.63	1460.11	1457.17	1457.87
2040	1455.51	1457.01	1454.04	1454.74
2041	1452.41	1453.93	1450.93	1451.63
2042	1449.34	1450.87	1447.85	1448.53
2043	1446.27	1447.83	1444.78	1445.46
2044	1443.24	1444.81	1441.74	1442.41
2045	1440.22	1441.81	1438.72	1439.38
2046	1437.23	1438.82	1435.72	1436.37
2047	1434.34	1435.92	1432.81	1433.44
2048	1431.47	1433.05	1429.91	1430.53
2049	1428.62	1430.20	1427.04	1427.65
2050	1425.79	1427.37	1424.19	1424.79

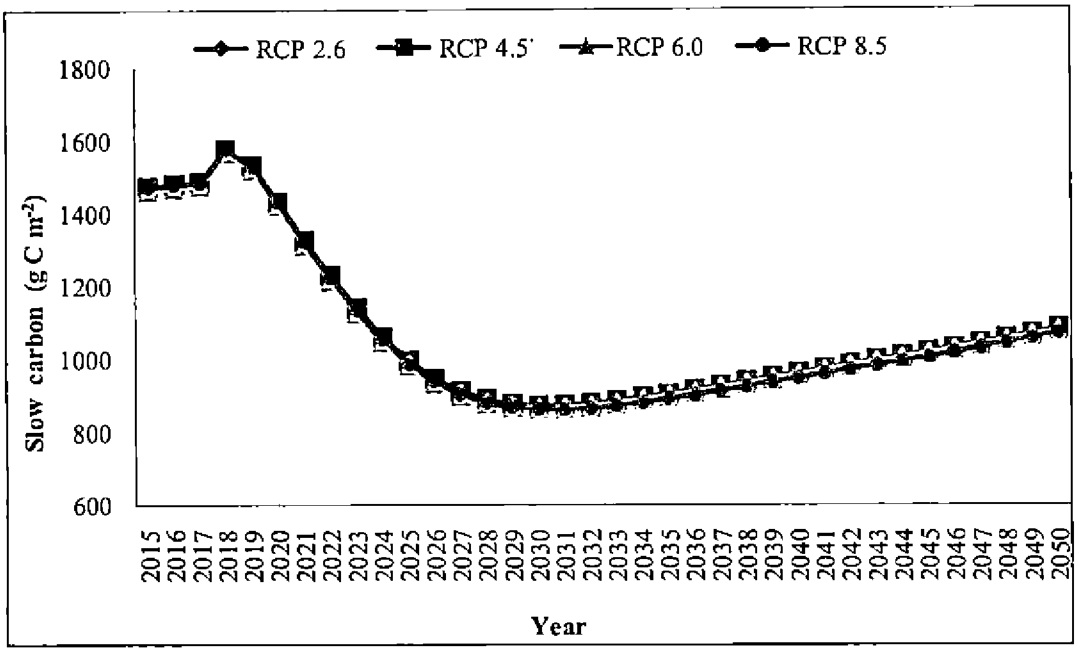

Fig. 30 Simulated slow carbon under predicted climate change scenarios for teak ecosystem

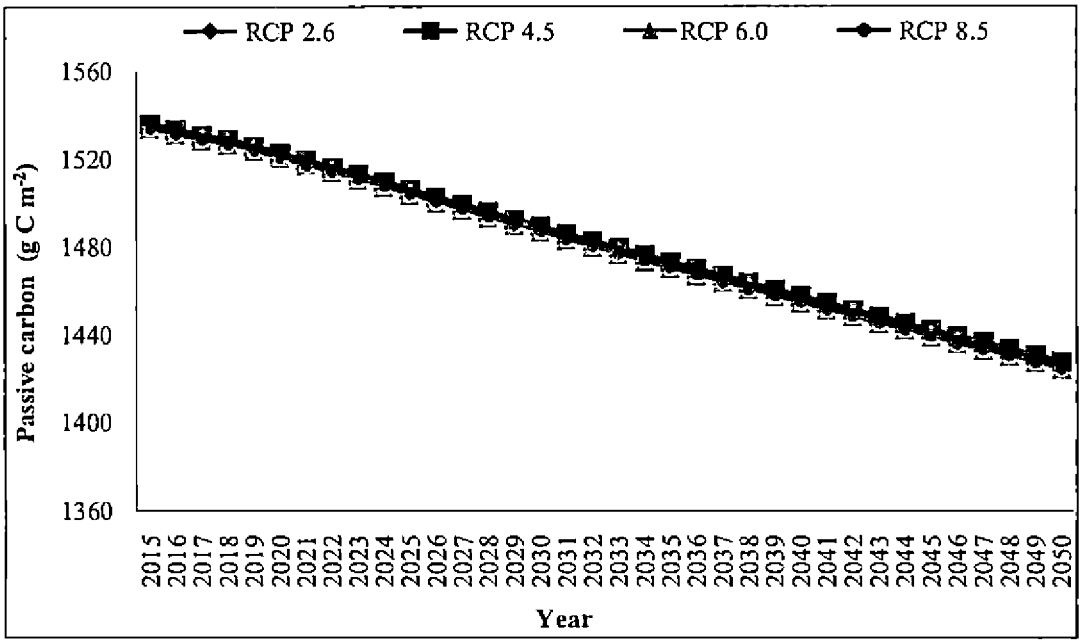

Fig.31 Simulated passive carbon under predicted climate change scenarios for teak ecosystem

protected coarse aggregates in the size of sand particles (Li *et al.*, 2007 and Yuan *et al.*, 2004).The results of the study by Guojian *et al.* (2004) noticed that the soils with higher clay content sequestered carbon at higher rates. Supplemental irrigation and water harvesting were needed to minimize production risks in dry land agriculture.

4.10 Soil organic carbon changes due to climate change scenarios in teak ecosystems

The predicted total soil organic carbon using different scenarios showed that during the beginning year of 2015 the total soil organic carbon recorded higher values such as 3272.51g C m^{-2} by RCP 4.5 followed by RCP 8.5, RCP 2.6 and RCP 6.0 as 3270.20 g C m^{-2}, 3268.14 g C m^{-2} and 3259.71 g C m^{-2}, respectively. Then there was a slight increase up to three years and it declined up to 2025. From there onwards, it remained more or less stable with a slight increase and by 2050, the highest value of total soil organic carbon of 2734.35 g C m^{-2} was recorded by RCP 4.5 followed by RCP 2.6, RCP 6.0, RCP 8.5 as 2733.27 , 2724.82 and 2721.82 g C m^{-2}, respectively (Table 28 and Fig.28).

During the initial year of 2015 (Table 29 and Fig.29), the active carbon values were higher such as 19.52 g C m^{-2} by RCP 4.5 followed by others such as RCP 2.6, RCP 6.0, RCP 8.5 as 19.46, 19.40 and 19.32 g C m^{-2}, respectively and a gradual decline of active carbon, by 2026. By 2050, the highest value of active carbon of 13.86 g C m^{-2} was recorded by RCP 4.5 followed by RCP 2.6, RCP 6.0, and RCP 8.5 as 13.81, 13.69 and 13.63 g C m^{-2}, respectively.

The slow carbon recorded higher values such as 1472.15 g C m^{-2} by RCP 4.5 followed by RCP 8.5, RCP 2.6, RCP 6.0 as 1470.66 , 1469.15 and 1462.40 g C m^{-2}, respectively in 2015 (Table 30 and Fig.30). Then there was a gradual decline, up to 2025 and thereafter, a slight increase was noticed. The highest value of slow carbon of 1081.51 g C m^{-2} was recorded by RCP 2.6 followed by RCP 4.5, RCP 6.0, and RCP 8.5 as 1081.08, 1075.67 and 1071.20 g C m^{-2}, respectively by 2050.

Simulation on passive carbon using different scenarios it was found that in the starting year of 2015, the passive carbon recorded higher values such as 1535.60 g C m^{-2} by RCP 4.5 followed by RCP 2.6, RCP 8.5, RCP 6.0 as 1534.74 , 1533.73 and 1534.29 g C m^{-2}, respectively (Table 31 and Fig.31). Then there was a gradual decline was noticed and by 2050, the highest value of 1457.37 g C m^{-2} was recorded by RCP 4.5 followed by RCP 2.6, RCP 8.5, and RCP 6.0 as 1425.79, 1424.79 and 1424.19 g C m^{-2}, respectively.

The teak plantations are thought to induce high erosion rates, which is usually attributed to reduction in understory vegetation due to excessive light reduction and allelopathy, low organic matter accumulation due to low litter production and increase in raindrop erosivity because the large leaves of the teak induce an increase in raindrop size (Carle *et al.*, 2009).

Global warming just by 2°C is predicted to increase additional C release from soil by more than 10 Pg C (pentagram or 10^{15} gm of C) per year, resulting into more GHE. Under such circumstances characterizing the temperature response for forest soils is particularly important, because these soils contain more than 70 per cent of the world's pool of C in the soil. The size of soil organic matter pools in natural ecosystems decreases exponentially with temperature (Lal, 2008). However, the scenarios that predict the highest carbon sequestration rates are often associated with the introduction of trees to the system. This was because, the inputs of C from trees are more resistant to decomposition than those from herbaceous crops. Consequently, it could cause marked increases in the level of soil C (Falloon and Smith, 2002).

SUMMARY AND CONCLUSIONS

CHAPTER 5
SUMMARY AND CONCLUSIONS

The summary and conclusions of the study "Modelling soil carbon dynamics of two major ecosystems of humid tropics" are furnished in this chapter.

Soils in natural forest were used as a baseline to compare the soil in rice fields and teak plantations of different age groups. Paddy and teak ecosystems were assumed to be established by clear felling of natural forest bringing similar initial soil conditions. Any variation in soil conditions in rice fields and teak plantations can be considered as a result of various management operations. Based on the period 1965 to 2050 year time sequence, it was reconstructed and the results of the present study are based on this.

The temperature and evaporation rate in Pattambi were found to be higher than that at Vellanikkara over the period of observation (2005 to 2014) where as the rainfall was lower in Pattambi when compared to Vellanikkara. The simulated total soil organic carbon by Roth-C and CENTURY models was found to be declining in rice ecosystem. But a rapid decline was noticed in Roth-C than CENTURY. The active carbon of rice ecosystem indicated a decreasing trend during the first eighteen years of simulation (1965 to 1983) and thereafter an increasing trend. In case of slow carbon, a gradual declining trend was noticed during the first twenty five years (1965-1990). There after it increased during the next eleven years followed by a decrease. It was noticed that the passive carbon in rice ecosystem kept on increasing throughout the simulation period. The model efficiencies of Roth-C and CENTURY in rice ecosystems were found to be 0.63 and 0.82, respectively.

In teak ecosystem, both Roth-C and CENTURY models predicted a declining trend of total soil organic carbon. But the CENTURY model was not showing a uniform trend as that of Roth-C model. The active carbon of teak ecosystem decreased by the end of third year of simulation and slowly increased by ninth year.

By the end of fifty five year it showed a sharp decline and then onwards an increase was noted. Slow carbon declined during the first thirty years and a steady increase was noticed during the next thirty years. Then it showed a rapid decline followed by an increase towards the end of the simulation. In case of passive carbon, it exhibited a gradual decrease during the study period. The model efficiencies of Roth-C and CENTURY in teak ecosystems were found to be 0.69 and 0.88, respectively.

Hence it was concluded that the CENTURY model was more suited to simulate soil carbon dynamics in both ecosystems than Roth-C model.

It was observed from the study based on different RCP scenarios, RCP 8.5 had predicted higher temperatures and precipitation values compared to others (RCP 6.0, RCP 4.5 and RCP 8.5) over both Pattambi and Vellanikkara from 2015 to 2050.

In rice ecosystem, it was noticed that in 2015 and 2050, RCP 2.6 recorded the highest values of total soil organic carbon while the lowest values by RCP 8.5. In the case active carbon, RCP 4.5 recorded the highest values and RCP 8.5 recorded the lowest values. The highest value of slow carbon was recorded by RCP 2.6 and the lowest by RCP 8.5. The predicted values of passive carbon showed highest values by RCP 6.0 and recorded the lowest by RCP 4.5.

In the study based on predicted climate change scenarios in teak ecosystem, RCP 4.5 recorded highest values of total soil organic carbon in 2015 and 2050 where as the lowest value was found by RCP 6.0 in 2015 and RCP 8.5 in 2050. The highest value of active carbon was found in 2015 by RCP 4.5 and in 2050 by RCP 2.6. The lowest values of active carbon were recorded by RCP 6.0 and RCP 8.5 in 2015 and 2050, respectively. In 2015 the highest value of slow carbon was recorded by RCP 4.5 and in 2050 by RCP 2.6. The least value of slow carbon was recorded in 2015 by RCP 6.0 and in 2050 by RCP 8.5. The passive carbon simulated by different RCPs, it was observed that RCP 4.5 predicted the highest values in 2015 and 2050. Then the lowest values were recorded by RCP 6.0.

Hence the present investigation indicated that the soil carbon modelling is suitable for studying soil carbon dynamics. CENTURY model performed better compared to Roth-C model in rice and teak ecosystems. A range of future conditions of soil organic carbon pools can be predicted using RCP scenarios in both these ecosystems.

REFERENCES

REFERENCES

Ardo, J. and Olsson, L. 2003. Assessment of soil organic carbon in semi arid Sudan using GIS and the CENTURY model. *J. Arid Environ.* 5(4):633-651.

Balagopalan, M.1987. *Properties of soils in natural forests and plantations of Trivandrum forest Division.* Division of soil science, Kerala Forest Research Institute, Peechi. 99p.

Bandyopadhyay, K.K. and Lal, R. 2015. Effect of long term land use management practises on distribution of C and N pools in water stable aggregates in Alfisols. *J. Indian Soc. Soil Sci.* 63(1):55-63.

Batjes, N.H. 1997. Total carbon and nitrogen in soils of world. *European J. Soil Sci.* 4(7): 151-163.

Bellamy, P.H., Loveland P. J., Gradley, R.L., Lark R, M., and Kirk. G.J. 2005. Carbon losses from all soils across England and Wales. *Nature.* 437(56):246-248.

Bending, G.D., Putland, C., and Rayns F. 2000. Changes in microbial community metabolism and labile organic matter fractions as early indicators of the impact of management on soil biological quality. *Biol. Fert. Soils.* 31(15): 78–84.

Blanco, H. and Lal, R. 2008. *Principles of Soil Conservation and Management*, Springer, Science Business Media, pp. 513-534.

Bolin, B. and Sukumar, R. 2000. *Global perspective: Land use, land-use change, and forestry.* In: Watson, R.T. (ed.). A Special Report of the IPCC. Cambridge University Press, pp. 23–51.

Bronson, K.F., Cassman, K.G., Wassmann, R., Olk, D.C., van Noord-wijk, M., and Garrity, D.P.1998. *Soil carbon dynamics in different cropping systems in principal eco regions of Asia.* In: Lal, R. (ed.). Management of carbon sequestration in soil. pp.35 – 57.

Buyanovsky, G.A. and Wagner, G.H. 1998. Changing role of cultivated land in the global carbon cycle. *Biol. Fert. Soils.* 2(7): 242–245.

Cao, M.K. and Woodward, F.I. 1998. Dynamic responses of terrestrial ecosystem carbon cycling to global climate change. *Nature.* 39(3):249–252.

arle, J.B., Ball, J.B., and Del Lungo, A. 2009. *The global thematic study of planted forests.* In: Evans, J. (ed.). Planted Forests: Uses, Impacts and Sustainability. CAB International, FAO, Rome, pp. 33–46.

Carroll, M., Milakovsky, B., Finkral, A., Evans, A., and Ashton, M.S., 2012. *Managing carbon sequestration and storage in temperate and boreal forests.* In: Ashton, M.S., Tyrrell, M.L., Spalding, D and Gentry, B. (eds). Managing Forest Carbon in a Changing Climate. Springer, New York, pp. 205–226

arvalho Leite L.F., Sa mendonça E., Ameida machado P.L.O., Fernandes Filho E.I., and Lima Neves J.C. 2004. Simulating trends in soil organic carbon of an Acrisol under no-tillage and disc-plow systems using the CENTURY model. *Geoderma.* 21(2):283-295.

Champion, H.G. and Seth, S.K. 1968. *A Revised Survey of the Forest Types of India,* Government of India Publications, Delhi, pp. 49-51

Cheddadi, R., Guiot, J., and Jolly, D. 2001. The Mediterranean vegetation: what if the atmospheric CO_2 increased? *Landscape Ecol.* 16(2):667–675.

Cheng, G. and Wang, G.2012. Eco-environment changes and changes and causal analysis of headwater region in Qinghai-Xizang plateau. *J. Adv. Earth Sci.* 13(6):24-31.

Cole, C.V. 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutri Cycl. Agroecosyst.* 4(9): 221–228.

Cole, C.V., Flach, K., Lee, J., Sauerbeck., D., and Stewart, B. 1993. Agricultural sources and sinks of carbon. *Water Air Soil Pollut.* 70(2): 111-122.

Coleman. K. and Jenkinson. D, S. 1996. *RothC-26.3 – A model for the turnover of carbon in soil.* In: Powlson, D. S Smith,P and Smith, J.U. (eds). Evaluation of Soil Organic Matter Models. Springer Verlag, Berlin, pp. 237–246.

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.* 40(8): 184–187.

Dadhwal, V.K., Pandya, N., and Vora, A.B.1998. *Carbon cycle for Indian forest ecosystem: A preliminary estimate.* In: Subbaraya, B.H., Rao, D.P., Desai, P.S., Manikyam. and Rajaratnam, P. (eds). Global Change Studies: Scientific Results from ISRO-GBP. ISRO, Bangalore, pp. 411-430.

Del Grosso, S.J., Parton, W.J., Mosier, A.R., Hartman, M.D., Brenner, J., Ojima, D.S., and Schimel, D.S. 2001. *Simulated interaction of carbon dynamics and nitrogen trace gas fluxes using the DAYCENT model.* In: Schaffer (eds). Modeling carbon and nitrogen dynamics for soil management. CRC Press, Boca Raton, Florida, USA, pp. 303-332.

Dixon, R.K., Andrasko, K.J., Sussman, F.G., Lavinson, M.A., Trexler, M.C., and Vinson, T.S. 1993. Forest sector carbon offset projects: near term opportunities to mitigate greenhouse gas emissions. *Water Air Soil Pollut.* 70(2): 561–577.

Dudal, R. and Deckers, J. 1993. *Soil organic matter in relation to soil productivity.* In: Mulongoy, K., and Merckx, R. (eds). Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. John Wiley and Son, West Sussex, United Kingdom, pp. 28-35.

Emmett, B.A., Beier, C., Estiarte, M., Tietema, A., Kristensen, H.L., Williams, D., Penuelas, J., Schmidt, I., and Snowerby, A. 2004. The response of soil processes to climate change: Results from manipulation studies of shrub lands across an environmental gradient. *Ecosyst.* 7(9): 625–637.

Falloon, P., Smith, P., Coleman, K., and Marshall, S. 1998. Estimating the size of the inert organic matter pool for use in the Rothamsted carbon model. *Soil Bio. Biochem.* 30(5): 1207-1211

Falloon, P. and Smith P. 2002. Simulating SOC changes in long-term experiments with RothC and CENTURY: model evaluation for a regional scale application. *Soil Use. Manage.* 18(6): 101-111.

FAO [Food and Agriculture Organization]. 2001. Soil Fertility Management in Support of Food Security in Sub-Saharan Africa. FAO, Rome. 35p.

Fang, C.M., Smith, P., Moncrieff, J.B., and Smith, J.U. 2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature.* 43(3): 57–59.

Fearnside, P. M. and Laurance, W. F. 2003 .Comment on Determination of deforestation rates of the world's humid tropical forests. *Sci.* 29(7): 10-15.

Feba Merin,C., Sreekath, N.P., Shanthi Prabha, V., Babu, P., and Thomas, A.P. 2014. Soil carbon dynamics and global warming potential of selected soil series and landuse categories. *J. Env. Res.* 2(1): 10-21.

Foereid, B. and Hogh Jensen, H. 2004.Carbon sequestration potential of organic agriculture in northern Europe a modelling approach. *Nutr Cycl. Agroescosys*. 13(5): 13–24.

Follett, R. F., Shafer, S. R., Jawson, M. D., and Franzluebbers, A. J. 2005. Research and implementation needs to mitigate greenhouse gas emissions from agriculture in the USA. *Till Res*. 8(3): 159-166.

Garten, C. T., Post,W., and Hanson, P. J .1999. Forest soil carbon invertories and dynamics along an elevation gradient in the southern appellation mountains. *J. Biogeochem*. 45(8): 115–145.

Gassman, P.W., Campbell,T., Izaurralde,C., Thomson, A.M., and Atwood. J. D. 2003. *Regional Estimation of Soil Carbon and Other Environmental Indicators Using EPIC and i_EPIC*. CARD Technical Report 30 TR 46. Center for Agricultural and Rural Development Lowa state University, pp. 50-60.

Gijsman, A.J. Hoogenboom, G. Parton, W.J., and Kerridge. P.C. 2002. Modifying DSSAT for low-input agricultural systems, using a SOM module from CENTURY. *J. Agron*. 9(4): 462–474.

Guo Jian Fen, Xie Jin Sheng, Lu HaoLiang, Dong Xia, Yang Yu Sheng., and Chen Guang Shui. 2004. Carbon return and dynamics of litterfall in natural forest and monoculture plantations in subtropical China, Studies in China, pp. 33-36.

Harden, J. W., Sharpe, J. M., Parton, W. J., Ojima, D. S., Fries, T. L., Huntington, T. G., and Dabney, S. M. 1999. Dynamic replacement and loss of soil carbon on eroding cropland. *Global Biogeochem. Cycles*. 13(4): 885–901.

Harris, N.L., Brown,S., Hagen, S.C., Saatchi, S.S., Petroval, S., Salas, W., Hansen, M.C., Potapov, P.V., and Lotsch, A. 2012. Baseline map of carbon emissions from deforsetstion in tropical regions. *Sci*. 33(6): 1573-1576.

Hendrickson, O.Q. and Robinson, J.B. 1984. Effects of tools and litter on mineralization processes in forest soil. *Plant Soil*. 80(1): 391-405.

Henry, H.L. 2008. Climate change and soil freezing dynamics: historical trends and projected changes. *Clim. Chan*. 82(1): 421–434.

Hijioka Y, Matsuoka Y, Nishimoto H, Masui, T., and Kainuma,-M. 2008. Global GHG emission scenarios under GHG concentration stabilization targets. *J. Glob Environ. Eng*. 13(4): 97–108.

Hobbie, S.E., Schimel, J.P., Trumbore, S.E., and Randerson, J.R. 2000. Controls over carbon storage and turnover in high latitude soils. *Glob Change Biol.* 6(1):196–210.

Holland, E.A., Neff, J.C., Townsend, A.R., and Mckeown, B. 2000. Uncertainties in the temperature sensitivity of decomposition in tropical and subtropical ecosystems: implications for models. *Glob Biogeochem. Cycles.* 1(4): 1137–1151.

Houghton, R. A., Hobbie, J. E., Melillo, J. M., Moore, B., Peterson, B. J., Shaver, G. R., and Woodwell, G. M. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO2 to the atmosphere. *Ecol.* 5(3): 235–262.

Hudson, J.M., Gherini, S.A., and Goldstein, R.A. 1994. Modeling the global carbon cycle: nitrogen fertilization of the terrestrial biosphere and the missing CO_2 sink. *Global Biogeochem. Cycles.* 8(1): 307-333.

House, J.I., Colin Prentice, I., and Le Quere, C. 2002. Maximum impacts of future reforestation or deforestation on atmospheric carbon dioxide. *Global change Biol.* 8(11):1047-1052.

Hungate, B.A., Dukes, J.S., Shaw, R., and Luo Field, C. B. 2003. Nitrogen and climate change. *Sci.* 30(2):1512-1513.

IPCC [Intergovernmental Panel on Climate Change]. 2000. *Land use, Land Use Change and forestry* In: Watson, R. T., Noble, I. R., Bolin, B., Verardo, D. J., and Dokken, D. J (eds). Cambridge University Press, Cambridge. 377p.

IPCC [Intergovernmental Panel on Climate Change]. 2001. *Climate change 2001: the scientific basis. Contribution of working group1 to the third assessment report of the intergovernmental panel on climate change.* In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A. (eds). Cambridge University Press, Cambridge. 985p.

IPCC [Intergovernmental Panel on Climate Change]. 2007. Climatic Change 2007: The physical science basis-summary for policymakers.1202p.

IPCC [Intergovernmental Panel on Climate Change]. 2013.Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and

P.M. Midgley (eds). Cambridge University Press, Cambridge, United Kingdom and New York, USA. 1535p.

Iqbal, J., Hu, R., and Du, L. 2008. Differences in soil CO_2 flux between different land use types in mid-subtropical China. *Soil Biol Biochem.* 40(2): 2324–33.

Jackson, C. R., Meister, R., and Prudhomme, C. 2011. Modelling the effects of climate change and its uncertainty on UK Chalk groundwater resources from an ensemble of global climate model projections. *J. Hydrol.* 39(9): 12–28.

Janzen, H.H. 2006. The soil carbon dilemma: Shall we hoard it or use it? *Soil Bio & Biochem.* 38(4): 419–424.

Jaramillo, D.F., Parra, L.N., and Gonzalez, L.H. 1994. El recursosuelo en Colombia: distribución y evaluación. Instituto de Ciencias Naturales y Ecología (ICNE), Universidad Nacional de Colombia, Medellín, pp. 26-40.

Jenkinson, D.S.1988. *Soil organic matter and its decomposition.* In: Wild A. (Ed.). Russel's Soil Conditions and Plant Growth, Longman, London, pp. 464-506.

Jenkinson, D.S., Adams, D.E., and Wild, A. 1991. Model estimates of CO_2 emissions from soil in response to global warming. *Nature.* 35(1): 304-306

Jenkinson, D.S. and Ayanaba, A.1977. Decomposition of C-14 labeled plant material under tropical conditions. *Soil Sci. Soc. Am.J.,* 4(1): 912-915.

Jenkinson, D. S. and Coleman, K.1994. Calculating the annual input of organic matter to soil from measurements of total organic carbon and radiocarbon. *Europ J. Soil Sci.* 4(5):167-174.

Jobbagy, E. G. and Jackson, R. B. 2000. The vertical distribu-tion of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* 10(1): 423–436.

Johnson, J.M.F., Franzluebbers, A.J., Lachnicht, W. S., and Reicosky, D.C. 2007. Agricultural opportunities to mitigate greenhouse gas emissions. *Environ Pollut.* 15(4): 107-124.

Kadambi, K.1992. *Silviculture and management of Teak.* Austin state University, Bulletin 24, Wacogdoches, Texas. 137p.

Kaosa-ard, A. 1981. Teak its natural distribution and related factors. *Nat.His. Bull. Siam. Soc.* 2(9): 55-74.

Katyal, J.C., Rao, N.H., and Reddy, M.N. 2001. Critical aspects of organic matter management in the tropics: the example of India. *Nut. Cycl. Agroecosyst.* 6(1): 77–88.

Katyal, J. C. 2008. Presidential Address deliverd on 27 November in the inaugural function of the 73rd Annual Convention of the Indian Society of Soil Science at University of Agricultural Sciences. *J. Indian Soc. Soil Sci.* 56(4): 322-324.

Katyal, J.C. 2015. Withering soil science education- Revival and resurgence boosters. *J .Indian Soci. Soil Sci.* 63(1): 1-13.

Kaul, M., Mohren, G.M.J and Dadhwal, V. K. 2010. Carbon storage and sequestration potential of selected tree species in India. *Mitig. Adapt. Strat. Glob. Change.* 15(1): 489–510.

KAU. 2011. *Package of Practices Recommendations: Crops.* (14th Ed.). Directorate of Extension, Kerala Agricultural University, Thrissur. 360p.

Kayranli, B., Scholz, M., Mustafa, A., and Hedmark, A. 2010. Carbon storage and fluxes within freshwater wetlands: a critical review. *Wetlands.* 30(3): 111–124

Kelly, R. H., Parton, W. J., Crocker, G. J., Grace, P. R., Klir, J., Korschens, M., Poulton, P.R., and Richter, D.D. 1997.Simulating trends in soil organic carbon in long-term experiments using the Century model. *Geoderma.* 8(1):75-90.

Kirby, R. K. and Potvin, C. 2007. Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. *Forest Ecol. Manag.* 24(6): 208–221.

Kirschbaum, M.U.F.1995. The temperature dependence of soil organic matter decomposition and the effect of global warming on soil organic carbon storage. *Soil Biol.Biochem.* 2(7): 753-760.

Knapp, A. K., Fay, P. A., Blair, J. M., Collins, S. L., Smith, D., Carlisle, J. D., Harper, C. W., Danner, B. T., Lett, M. S., and McCarron, J. K. 2002. Rainfall variability, carbon cycling and plant, Species diversity in mesic grassland. *Sci.* 29(8): 2202- 2205

Krishnan ,P., Reddy, R.S., Natarajan,A., Srinivas, S., and Vadivelu, S. 2005. *Soil Resources of South India.* Proc. Natl.Workshop on soil resources management. Soil survey organisation, Govt of Kerala, pp. 12-13.

Kumar, S., Udawatta, R. P., and Anderson, S. H. 2010. Root length density and carbon content of agroforestry and grass buffers under grazed pasture systems in a Hapludalf. *Agrofor. Syst.* 80(3): 85-96.

Kuzyakov, Y. and Domanski, G .2000. Carbon input by plants into the soil. Review. *J. Plant Nutr Soil Sci.* 163(4): 421-431.

Lal, R. 2001. *Soil Carbon Sequestration and the Greenhouse Effect.* Soil Science Society American special publication, Madison, WI, 236p.

Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. *Environ. Pollut.* 11(6): 353–362

Lal, R. 2004a. Offsetting China's CO_2 emissions by soil carbon sequestration. *Clim Chan.* 6(5): 263–275.

Lal, R. 2004b. Soil carbon sequestration impacts on global climate change and food security. *Sci.* 30(4): 1623–1627.

Lal, R. 2008. Soils and India's food security. *J. Indian Soc. Soil Sci* .25(6):129-138.

Lal, R.,, Hassan, H. M., and Dumanski, J. 1999. *Desertification control to sequester carbon and mitigate the greenhouse effect.* In: Rosenberg, N., Izaurralde, R.C., and Columbus Ohio, E.L (Eds.). Carbon sequestration in soils: Science monitoring and beyond .Malone Battelle Press.

Lawrence, C. R., Neff, J. C., and Schimel, J. P. 2009. Does adding microbial mechanisms of decomposition improve soil organic matter models? A comparison of four models using data from a pulsed rewetting experiment. *Soil Biol. Biochem.* 4(1): 1923-1934.

Lehner, B. and Doll, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *J. Hydrol.* 29(6): 1–22.

Leifeld, J. and Kogel-Knabner, I. 2005. Soil organic matter fractions as early indicators for carbon stock changes under different land-use? *Geoderma.* 12(4): 143–155.

Levy P.E., Wendler R., Van Oijen M., Cannel M.G.R., and Millard P. 2004. *Water Air Soil Pollut.* 467p.

Li, Z., Pan, G., and Zhang, X. 2007. Changes in pool distribution and ^{13}C natural abundance of organic carbon of a paddy soil after corn cultivation for 3 years. *J. Acta Pedologica Sinica*).

Liski, J., Palosuo, T., Peltoniemi, M., and Sievänen, R. 2005. Carbon and decomposition model Yasso for forest soils. *Ecol. Modell.* 18(9): 168–182.

Liu, Q. H., Shi, X. Z., Weindorf, D. C., Yu, D. S., Zhao, Y. C., Sun,W. X., and Wang, H. J. 2006. Soil organic carbon storage of paddy soils in China using the 1:1,000,000 soil database and their implications for C sequestration. *Global Biogeochem Cycles.* 20(4): 3024-3028.

Luo, Z. K., Wang, E. L., Sun, O. J., Smith, C. J., and Probert, M. E. 2011. Modeling long-term soil carbon dynamics and sequestration potential in semi-arid agro-ecosystems. *Agr. Forest Meteorol.* 15(1): 1529–1544.

Manjunatha, M. 2015. Modeling carbon dynamics in teak plantations of Kerala, Phd (Forestry) thesis, Kerala Agricultural University.137p.

Mapa, R.B.1995. Effect of reforestation using *Tectona grandis* on in filtration and soil water retention. *Forest. ecol. manag.* 7(7): 119-125.

Manna, M.C., Swarup, A., Wanjari, R.H., Misra, B., Saha, M.N., Singh, Y.V., Sahi, D.K., and Sarap, P.A. 2005. Long term effect of fertilizer and manure application on soil carbon storage quality and yield sustainability under sub humid and semi arid tropical India. *Field crops research.* 9(3): 264:280.

McGuire A.D., Sitch, S., Clein, J.S., Dargaville, R., and Esser, G. 2001. Carbon balance of the terrestrial biosphere in the twentieth century: analyses of CO_2, climate and land-use effects with four process- based ecosystem models. *Glob Biogeochem Cycles* 15(1): 183-206.

Metherell A.K., Harding L.A., Cole C.V., and Parton W.J. 1993. CENTURY soil organic matter model environment: technical documentation, Agroecosystem Version 4.0. Great Plains Systems Research Unit Technical Report No 4. USDA, Fort Collins, pp. 45-52.

Miranda,D.L.C., Melo, A.C.G., and Sanquetta, C.R.2011.Equaçõesalométricasparaestimativa de biomassa e carbonoemárvores de reflorestamentos de restauração. *Rev. Árvore.* 3(5): 679–689.

Montagmini, F. and Porras C.1998.Evaluating the role of plantations as carbon sinks: An example of an integrative approach from the humid tropics, *Environ. And Manage.*2(2):459-470.

Mosier, A.R. 1998. Soil processes and global change. *Biol. Fert of Soils.* 2(7):221–229.

Motavalli P.P., Palm P.C.A., Parton W.J., Elliot E.T., and Freys S.D. 1994.Soil organic carbon in soils of tropics. *Biol.Biochem.* 2(6): 935-965.

Nabuurus, G.J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford- Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W.A., Matsumoto, M., Oyhantcabal, W., Ravindaranath, N.H., Sanchez, M.J.Sanz., and Zhang, X. 2007.*Climate change 2007: Mitigation of Climate Change. Forestry. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* In: Metz,B., Davidson,O.R., Bosch, P.R., Dave, R., and Meyer, L.A. (eds).Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 24-29.

Neue, H.U., Gaunt, J.L., Wand, Z. P., Becker-Heidmann. P., and Quijano.1997. Carbon in tropical wetlands. *Geoderma.* 14(2): 163-185.

Ogle, S. M., Breidt, F. J., and Paustian, K. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochem.*7(2): 87-121

Parton, W. J. and Rasmussen, P.E. 1994. Long term effects of crop management in M'heat fallow:Century Model simulation. *Soil Sci. Soc. Am. J.* 58(5): 530-536.

Parton, W. J., Schimel, D. S., Cole, C.V., and Ojima, D.S. 1987.Analysis of factors controlling soil organic matter levels in Great plains grasslands. *Soil Sci. Soc.Am.J.* 51(3): 1173-1179.

Paustian, K., Elliot E.T., Peterson ,G.A., and Killion, K. 1996. Modeling climate, CO_2 and management impacts on soil carbon in semi arid agroecosystem. *Plant and soil* 18(7): 351-365.

Paustian, K., Levine, E., Post, W.M., and Ryzhova, I.M. 1997. The use of models to integrate information and understanding of soil C at the regional scale. *Geoderma* .7(9): 227–260.

Paustian, K., Parton W.J., and Persson J. 1992. Different land management practises in sub tropics. *Soil Sci. Soc. Am.J.* 5(6): 476-480.

Paustian, K., Six, J., Elliott, E. T., and Hunt, H.W. 2000. Management options for reducing CO_2 emissions from agricultural soils. *Biogeochem.* 4(8):147-163

Peng, C. Jiang, H., Apps, M.J., and Zhang, Y. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: a process model simulation. *Ecological Modelling.* 15(5): 177–189.

Pennock, D.J. and Frick A.H. 2001. The role of field studies in landscape scale applications of process models: An example of soil redistribution and soil organic carbon modelling using century. *Soil till. Res.* 58(2):183-191.

Post, W.M., Emanuel, W.R., Zinke, P.J., and Stangenberger, A.G. 1982. Soil carbon pools and world life zones. *Nature.* 29(8): 156–159.

Post, J., Krysanova, V., Suckow, F., Mirschel, W., Rogasik, J., and Merbach, I. 2007. Integrated eco-hydrological modelling of soil organic matter dynamics for the assessment of environmental change impacts in meso- to macro-scale river basins. *Ecological Modelling.* 20(6): 93-109.

Powlson, D.S., Whitmore, A.P., and Goulding, K.W.T. 2011. Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *Europ. J. Soil Sci* .62(4): 42-55.

Raich, J.W. and Schlesinger, W.H. 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus 44B, pp. 81–99.

Ranatunga, K., Hill, M .J., Probert, M.E., and Dalal., R.C. 2005. Comparative application of apsim, rothc and century to predict soil carbon dynamics. *Sci.* pp. 733-739.

Reynaldo, V. 2012. *The benefits of soil carbon.* In UNEP Year Book, pp.19–33

Riahi, K., Grubler. A., and Nakicenovic, N.2007. Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technol. Forecast .Soc Chang* .7(4): 887–935.

Rice, C. W.2002. *Organic matter and nutrient dynamics.* In: Lal. R. (ed.).The encyclopedia of soil science. New York. Dekker. 92p

Richter, D.D., Markewitz, D., Trumbore, S. E., and Wells, C.G.1999. Rapid accumulation and turnover of soil carbon in a re-establishing forest. *Nature.* 40(1): 56-58.

Roose, E. and Barthes, B. 2001. Organic matter management for soil conservation and productivity restoration in Africa: a contribution from francophone research. *Nutr Cyc. Agroecosyst.* 6(1): 159–170.

Rosenberg, N.J. and Izaurralde, R.C. 2001. Storing carbon in agricultural soils to help head-off global warming and to combat desertification. *Clim. Chang.* 5(1): 1–10.

Rustad, L.E. and Fernandez, I.J .1998. Experimental soil warming effects on CO_2 and CH_4 flux from a low elevation spruce-fir forest soil in Maine, U.S.A. *Global Change Biol.* 4(1): 597– 605.

Sanderman, J., Amundson, R., and Baldocchi, D.D., 2003. Application of eddy covariance measurements to the temperature dependence of soil organic matter mean residence time. *Global Biogeochem Cycl.* 17(5):1061–1075.

Sanford, R.L. Jr., W.J. Parton, D.S. Ojima ., and D.J. Lodge. 1991. Hurricane effects on soil organic matter dynamics and forest production in the Luquillo Experimental Forest, Puerto Rico: results of simulation modeling. *Biotropica.* 2(3): 364-372.

Sakai, H., Inagaki, M., Noguchi, K., Sakata, T., Yatskov, M.A., Tanouchi, H., and Takahashi, M. 2010. Changes in soil organic carbon and nitrogen in an area of Andisol following afforestation with Japanese cedar and Hinoki cypress. *Soil Sci. Plant nutri.* 5(6): 332-343.

Schuman G.E., Janzen H.H., and Herrick, J.E. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. *Environ pollut.* 11(6): 391–396.

Sharawat, K.L. 2004. Organic matter accumulation in submerged soils. *Adv. Agron.* 8(1): 169–201.

Shirato, Y., Hakamata, T., and Taniyama, I. 2004. Modified Rothamsted carbon model for Andosols and its validation: changing humus decomposition rate constant with pyrophosphate extractable. *Soil Sci. Plant Nutr.* 50 (3):149–158.

Shirato,Y. and Taniyama, I. 2003. Testing the suitability of the Rothamsted carbon model for long-term experiments on Japanese non volcanic upland soils. *Soil Sci. Plant Nutr.* 49(2): 921–925.

Shirato,Y. and Yokozawa, M. 2005. Applying the Rothamsted Carbon Model for long-term experiments on Japanese paddy soils and modifying it by simple tuning of the decomposition rate. *Soil Sci. Plant Nutr.* 5(1): 405–415.

Singh, G. 1994. *Affoerstation and agroforesstry for salt affected soils.* In: Rao, D.L.N., Singh, N.T., Gupta, G.K., and Tyagi, N.K (eds). Salinity management for sustainability. Central soil salinity research institute, Karnal. 260-281.

Singh, Muneshwar., and Wanjari, R.H. 2013. *Annual Report, 2012-2013.* All India Coordinated Research Project on Long Term Fertilizer Experiments to study changes in soil quality, crop productivity and sustainability. AICRP-LTFE. Indian Institute of Soil Science (ICAR). Nabibagh. Bhopal. 142p.

Sitch, S., Huntingford, C., Gedney, N., Levy, P.E., Lomas, M., Piao, S.L., Betts, R., Ciais, P.,Cox, P., Friedlingstein, P., Jones, C.D., Prentice, I.C. and Woodward, Wander, M.and Nissen, T. 2004. Value of soil organic carbon in agricultural lands. *Mitigat. Adaptat. Strateg. Global Change.* 9(2): 417–431.

Six, J., Conant, R.T., Paul, E.A., and Paustian, K. 2002. Stabilization mechanisms of soil organic matter: implications for C-sequestration of soils. *Plant. Soil.* 24(1): 155–176.

Smith, O.L.1979. Analytical model of the decomposition of soil organic-matter. *Soil Biol. Biochem.* 1(1): 585–606.

Smith, P., Andren, O., Brussaard, L., Dangerfield, M., Ekschmitt, K., Lavelle, P., and Tate, K. 1998. Soil biota and global change at the ecosystem level: Describing soil biota in mathematical models. *Global Change Biol.* 4(1): 773–784.

Smith, P., Martino, D.,. Cai, Z., Gwary, D., Janzen, H., Kumar, P., Mc Carl B., Ogle, S., O'Mara F, Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., and Smith, J. 2008. Greenhouse gas mitigation in agriculture, Philosophical Transaction of The Royal Soceity. *Bio Sci.* 36(3):789-813.

Smith, P., Smith J.U., Pawlson, D.S., McGill, W.B., Arah, J.R.M.,Chertov, O.G., Coleman, K., Frnko, U., Frolking, S., Jekinsan, L.S., Kelly, R.H., Klein-Gunneweik, H., Komam., A.S.,Li, C., Molina, J.A.E., Mueller, T., Parton, W.J., Thornley, J.H.M., and Whitmore, A.P.1997. A comparison of the performance of nine soil organic matter models using datasets from seven long term experiments. *Geoderma.* 14(5): 113-222.

Somarathne, S., Seneviratne, G., and Coomaraswamy, U. 2005. Importance of soil organic matter in terms of soil health. *Soil Sci. Soc. Am. J.* 6(9): 1580-1589.

Sparling, G.P., Wheeler, D., Vesely, E.T., and Schipper, L.A. 2006. What is soil organic matter worth? *J. Environ. Quality.* 3(5): 548–557.

Srivastava, S.S., and Singh, A.K. 1998. *Simlipal bioshere reserve.* In: Maikhuri, R.K., Rao, K.S., and Rai, R.K. (eds). Biosphere Reserves and Management in India. Himavikas

Occassional Publication No. 12, G.B. Pant Institute of Himalayan Environment and Development, India, pp. 65–70.

Stephens, B .S. 2007.Weak Northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2. *Sci.* 3(16):1732–1735.

Stern, J., Wang, Y., Gu, B., and Newman, J. 2007.Distribution and turnover of carbon in natural and constructed wetlands in the Florida Everglades. *Appl. Geochem.* 2(2): 1936-1948.

Stevenson, F. J. 1982. *Humus chemistry: genesis, composition reactions*. John Wiley and Sons. Netherlands. 443p.

Stewart, C.E., Plante, A.F., Paustian, K., Conant, R.T., and Six, J. 2008. Soil carbon saturation:linking concept and measurable carbon pools. *Soil Sci Soc.Am.J.* 7(2): 379–392.

Suetsugu, A., Sato, T., and Kaneta,Y. 2005. Effects of organic-mineral complexes on flocculation, settlement and vertical distribution of bio elements in soil suspensions. *Soil Sci Plant Nutr.*5 (1): 323–3.

Suri, V.K. 2007. Perspectives in soil health management- a looking glass. *J. Indian Soci.Soil Sci.* 55(4): 436:443.

Suzuki, R., Takeda, S., and Hla Maung Thein. 2007. Chronosequence changes in soil properties of teak (*Tectona grandis*) plantations in the Bago Mountains, Myanmar. *J. Trop. For. Sci.* 1(9): 207-217.

Swaminathan, M.S. 2008. Growth in Agriculture. *Yojana,* pp. 40-48.

Tan, Z., Liu, S., Bliss, N., and Tieszen, L.L. 2012. Current and potential sustainable corn stover feedstock for biofuel production in the United States. *Biom. Bioener.*4(7):372–386.

Thomson, A.M., Izaurralde, R.C., Rosenberg, N.J., and He, X. 2006. Climate change impacts on agriculture and soil carbon sequestration potential in the Huang-Hai.456p

Thomas, P. T., Rugmini,P., and Balagopalan, M. 2013.Carbon storage potential of different age teak plantations of Kerala. KFRI, pp. 20-28.

Tian, B., Waliser, D.E., Kahn, R.A., Li, Q., Yung, Y.L., Tyranowski, T.,Geogdzhayev, I.V., Mishchenko, M.I., Torres, O., and Smirnov, A. 2008. Does the Madden – Julian Oscillation influence aerosol variability? *J.Geophys Res.* 12(2):113-215.

Tristram, O. W. and Wilfred M, P. 2002. Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Sci. Soc. Am. J.* 6(6): 1930–1946.

Van Keulen, H. 2001. Dynamics of the vegetation and microbe population on some forest fire areas. *Nutr.Cycl.Agroecosyst.* 6(1): 33-42.

Vanlauwe, B. 2004. *Integrated soil fertility management research at TSBF: the framework, the principles, and their application.* In: Bationo, A. (ed.). Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Academy Science Publishers, Nairobi, Kenya, pp. 50-58.

Van Vuuren, D., M. den Elzen, P. Lucas, B. Eickhout, B. Strengers, B. van Ruijven, S. Wonink, R., and van Houdt. 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Clim Chang.* 21(2): 101-105.

Vesterdal, L., Schmidt, I.K., Callesen, I., Nilsson, L.O., and Gundersen, P. 2008. Carbon and nitrogen in forest floor and mineral soil under six common European tree species. *For. Ecol. Manage.* 25(5): 35-48.

Viaud, V., Angers, D. A., and Walter, C.2010. Towards landscape-scale modeling of soil organic matter dynamics in agroecosystems. *Soil Sci Soci of Am J.* 7(4): 1-14.

Wander, M. and Nissen, T. 2004. Value of soil organic carbon in agricultural lands. mitigation and adaptation strategies for global change. *Soil Sci Soc. Am. J.* 9 (5):417-431.

Wang, H., Conell, J., and Hall, D.P. 2002. Marley Spatial and seasonal dynamics of surface soil carbon in the Luquillo experiment. *For Ecol. Model.* 14 (7):105–122.

Watanabe, I.1984. Anaerobic decomposition of organic matter in rice. International Rice Research Institute, Manila, Philippines, pp. 237 – 258.

White, A., Cannell, M.G.R ., and Friend, A.D.1999. Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment. *Glob Environ Chan.* 9(2): 21–30.

Wise, M., Calvin, K., Thomson, A., Clarke, L., Bond-Lamberty, B., Sands, R., Smith, S.J., Janetos, A., and Edmonds, J. 2009. Implications of limiting CO_2 concentrations for land use and energy. *Sci.* 32(4):1183–1186.

Xie, Z., Zhou, J., Liu, G., Cadisch, G., Hasegawa, T., Chen, C., Sun, H., Tang, H., and Zeng, Q. 2007. Soil organic carbon stocks in China and changes from 1980s to 2000s. *Glob. Chang Biol.* 13(2):1989–2007.

Yadav J.S.P .2007. Soil productivity enhancement: prospects and problems. *J Indian Soc. Soil Sci.* 55 (4): 455- 463.

Yuan, Y., Li, H., and Huang, Q. 2004. Effects of different fertilization on soil organic carbon distribution and storage in micro–aggregates of red paddy topsoil. *J. Acta Ecologica Sinica.* 24(3): 2961–2966.

Zhang, M. and He, Z. 2004. Long-term changes in organic carbon and nutrients of an Ultisol under rice cropping in southeast China. *Geoderma.* 11(8): 167-179.

Zhou, P., Song, G., Pan, G., Li, L., Zhang, X ., and Wu, L. 2008. SOC accumulation in three major types of paddy soils under long-term agro-ecosystem experiments from south China I. Physical protection in soil micro aggregates. *Acta Pedol.Sin.* 45(2): 1063–1071.

Zhou, P., Zhang, X., and Pan G. 2006. Effect of long-term different fertilization on total and particulate organic carbon of a paddy soil an example of Huangnitu from the Tai Lake region, China. *J. Plant Nutri. Fertiliz Sci.* 12(4): 765–771.

Zimmermann, M., Leifeld, J., Schmidt, M.W.I., Smith, P., and Fuhrer, J. 2007. Measured soil organic matter fractions can be related to pools in the Roth C model. *Eur. J. Soil Sci.* 58(3): 658–667.

APPENDICES

APPENDIX 1

Site 100- Site parameters

Name	Description	Values	References
External N input			
EPNFA(1)	Average annual dry N deposition (g $N/m^2/yr$)	0.21	Default value
EPNFA(2)	Slope for determining the effect of annual precipitation on atmospheric N deposition	0.0028	Default value
Initial soil carbon pools			Manjunatha, 2015
SOM1CI(1,1)	Initial value for C in forest system leaf component (g C/m^2)	53.75	
SOM1CI(2,1)	Initial value for N in a forest system leaf component (g N/m^2)	278.4	
SOM2CI(1)	Initial value for C in forest system fine branch component (g C/m^2)	4837.20	
SOM3CI(1)	Initial value for C in SOM with slow turnover (g C/m^2)	1535.84	
CLITTR(1,1)	Initial value for C in plant residue (g C/m^2)	45.09	

Organic matter initial values			
RCES1(1,1)	Initial C:N ratio in surface organic matter with fast turnover (active SOM)	20.29	Manjunatha, 2015
RCES1(1,2)	Initial C:P ratio in surface organic matter with fast turnover (active SOM)	74.29	Kumar *et al.*, 1989
RCES1(1,3)	Initial C:S ratio in surface organic matter with fast turnover (active SOM)	810.76	Manjunatha, 2015
RCES1(2,1)	Initial C:N ratio in SOM with fast turnover (active SOM)	4.76	
RCES1(2,2)	Initial C:P ratio in SOM with fast turnover (active SOM)	77.95	
RCES1(2,3)	Initial C:S ratio in SOM with fast turnover (active SOM)	357.29	
RCES2(1)	Initial C:N ratio in SOM with intermediate turnover (slow SOM)	63.97	
RCES2(2)	Initial C:P ratio in SOM with intermediate turnover (slow SOM)	350.93	
RCES2(3)	Initial C:S ratio in SOM with intermediate turnover (slow SOM)	2878.12	
RCES3(1)	Initial C:N ratio in SOM with slow turnover (passive SOM)	33.17	
RCES3(2)	Initial C:P ratio in SOM with slow turnover (passive SOM)	181.96	
RCES3(3)	Initial C:S ratio in SOM with slow turnover (passive SOM)	1492.36	
RCELIT(1,1)	Initial C:N ratio for surface litter	121.75	Manjunatha, 2015
RCELIT(1,2)	Initial C:P ratio for surface litter	445.76	
RCELIT(1,3)	Initial C:S ratio for surface litter	4864.57	
RCELIT(2,1)	Initial C:N ratio for soil litter	121.75	
RCELIT(2,2)	Initial C:P ratio for soil litter	445.76	
RCELIT(2,3)	Initial C:S ratio for soil litter	4864.76	
AGLIVE(1)	Aboveground N initial value (gN/m^2)	16.54	Takahashi *et al.*, 2009
AGLIVE(2)	Aboveground P initial value (gP/m^2)	2.094	Kumar *et al.*, 1989
AGLIVE(3)	Aboveground S initial value (gS/m^2)	0.406	Kumar *et al.*, 1989
BGLCIS(1)	Initial value for belowground live C (gC/m^2)	252.23	Sreejesh *et al.*, 2013
BGLIVE(1)	Initial value for belowground live N (gN/m^2)	21.03	

APPENDIX II

Crop 100- Crop parameters (Rice ecosystem)

BIOFLG	Value indicating whether production should be reduced by physical obstruction: BIOFLG is a continuous measure ranging from 0 to 1, where the extremes are 0 = production should not be reduced at all and 1 = production should be reduced completely	0
BIOK5	Level of aboveground standing dead + 10% STRUCC(1) C in grams of carbon per square meter (g C /m^2) at which production is reduced to half maximum due to physical obstruction by the dead material. Used only when BIOFLG = 1	1800
BIOMAX	Biomass level above which the minimum and maximum C / E ratios of the new shoot increments	700
CO2ICE(1,1,1)	In a grassland/crop system, the effect on minimum C / N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.20
CO2ICE(1,1,2)	- In a grassland/crop system, the effect on minimum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,1,3)	In a grassland/crop system, the effect on minimum C / S ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,2,1)	In a grassland/crop system, the effect on maximum C / N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm	1.20
CO2ICE(1,2,2)	In a grassland/crop system, the effect on maximum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,2,3)	In a grassland/crop system, the effect on maximum C / S ratio of doubling the A reduction will have a negative effect atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2IPR(1)	In a grassland/crop system, the effect on plant production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.20
CO2IRS(1)	In a grassland/crop system, the effect on root-shoot ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ITR(1)	In a grassland/crop system, the effect on transpiration rate of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	0.80
CRPRTF(1)	Fraction of N transferred to a vegetation storage pool from grass/crop leaves at death	0.0
CRPRTF(2)	Fraction of P transferred to a vegetation storage pool from grass/crop leaves at death	0.0
CRPRTF(3)	Fraction of S transferred to a vegetation storage pool from grass/crop	0.0

BGLIVE(2)	Initial value for belowground live P (gP/m^2)	6.09	
BGLIVE(3)	Initial value for belowground live S (gS/m^2)	0.681	Sreejesh *et al.*, 2013
STDCIS(1)	Initial value for standing dead C (gC/m^2)	168.2	
STDEDE(1)	Initial value for N in standing dead (gN /m^2)	. 12.36	Chandrashekara, 1996
STDEDE(2)	Initial value for P in standing dead (gP/m^2)	1.58	
STDEDE(3)	Initial value for S in standing dead (gS/m^2)	0.148	
Forest organic matter initial parameters			
RLVCIS(1)	Initial value for C in forest system leaf component (g C/m^2)	164.5	Swarnalatha and Reddy, 2011
RLEAVE(1)	Initial value for N in a forest system leaf component (g N/m^2)	4.32	
FBRCIS(1)	Initial value for C in forest system fine branch component (g C/m^2)	17.0	Thamos *et al.*, 2013
FBRCHE(1)	Initial value for N in a forest system fine branch component (g N/m^2)	0.657	Kumar *et al.*, 2009
RLWCIS(1)	Initial value for C in forest system large wood component (g C/m^2)	6311	Thamos *et al.*, 2013
RLWODE(1)	Initial value for N in a forest system large wood component (g N/m^2)	50.73	Kumar *et al.*, 1989
FRTCIS(1)	Initial value for C in forest system fine root component (g C/m^2)	312.0	Thomas *et al.*, 2013
FROOTE(1)	Initial value for N in a forest system fine root component (g N/m^2)	5.804	Manjunatha, 2015
CRTCIS(1)	Initial value for C in forest system coarse root component (g C/m^2)	1102.5	
CROOTE(1)	Initial value for N in a forest system coarse root component (g N/m^2)	18.36	
WD1CIS(1)	Initial C values for forest system dead fine branch material (g/m^2)	111.5	
WD2CIS(1)	Initial C values for forest system dead large wood material (g/m^2)	1265	
WD3CIS(1)	Initial C values for forest system dead coarse root material (g/m^2)	272	
CLITTR(2)	Initial C values for forest system dead fine root material (g/m^2)	38.9	

APPENDIX II

Crop 100- Crop parameters (Rice ecosystem)

BIOFLG	Value indicating whether production should be reduced by physical obstruction: BIOFLG is a continuous measure ranging from 0 to 1, where the extremes are 0 = production should not be reduced at all and 1 = production should be reduced completely	0
BIOK5	Level of aboveground standing dead + 10% STRUCC(1) C in grams of carbon per square meter (g C /m^2) at which production is reduced to half maximum due to physical obstruction by the dead material. Used only when BIOFLG = 1	1800
BIOMAX	Biomass level above which the minimum and maximum C / E ratios of the new shoot increments	700
CO2ICE(1,1,1)	In a grassland/crop system, the effect on minimum C / N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.20
CO2ICE(1,1,2)	- In a grassland/crop system, the effect on minimum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,1,3)	In a grassland/crop system, the effect on minimum C / S ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,2,1)	In a grassland/crop system, the effect on maximum C / N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm	1.20
CO2ICE(1,2,2)	In a grassland/crop system, the effect on maximum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ICE(1,2,3)	In a grassland/crop system, the effect on maximum C / S ratio of doubling the A reduction will have a negative effect atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2IPR(1)	In a grassland/crop system, the effect on plant production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.20
CO2IRS(1)	In a grassland/crop system, the effect on root-shoot ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	1.0
CO2ITR(1)	In a grassland/crop system, the effect on transpiration rate of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.	0.80
CRPRTF(1)	Fraction of N transferred to a vegetation storage pool from grass/crop leaves at death	0.0
CRPRTF(2)	Fraction of P transferred to a vegetation storage pool from grass/crop leaves at death	0.0
CRPRTF(3)	Fraction of S transferred to a vegetation storage pool from grass/crop	0.0

	leaves at death	
DEL13C	Delta ^{13}C value for stable isotope labeling	-15.0
EFRGRN(1)	Fraction of the aboveground N which goes to grain	0.50
EFRGRN(2)	Fraction of the aboveground P which goes to grain	0.50
EFRGRN(3)	Fraction of the aboveground S which goes to grain	0.50
FALLRT	Fall rate (fraction of standing dead which falls each month)	
FLIGNI(1,1)	Intercept for equation to predict lignin content fraction based on annual rainfall for aboveground material	0.15
FLIGNI(2,1)	Slope for equation to predict lignin content fraction based on annual rainfall for aboveground material For crops, set to 0	0.0
FLIGNI(1,2)	Intercept for equation to predict lignin content fraction based on annual rainfall for belowground material	0.06
FLIGNI(2,2)	Slope for equation to predict lignin content fraction based on annual rainfall for belowground material For crops, set to 0	0.0
FRTC(1)	Initial fraction of C allocated to roots; for Great Plains equation based on precipitation, set to 0	.45
FRTC(2)	Final fraction of C allocated to roots	0.10
FRTC(3)	Time after planting (months with soil temperature greater than RTDTMP) at which the final value is reached; must not equal 0	3.0
FSDETH(1)	Maximum shoot death rate at very dry soil conditions (fraction/month); for getting the monthly shoot death rate, this fraction is multiplied times a reduction factor depending on the soil water status	0.20
FSDETH(2)	Fraction of shoots which die during senescence month; must be greater than or equal to 0	0.40
FSDETH(3)	Additional fraction of shoots which die when aboveground live C is greater than FSDETH(4).	0.0
FSDETH(4)	The level of aboveground C above which shading occurs and shoot senescence increases	500.0
FULCAN	Value of AGLIVC at full canopy cover, above which potential production is not reduced	150
HIMAX	Harvest index maximum (fraction of aboveground live C in grain). If a harvest event can be scheduled for this plant, the value should be >0)	0.40
HIMON(1)	Number of months prior to harvest in which to begin accumulating water stress effect on harvest index	1.0
HIMON(2)	Number of months prior to harvest in which to stop accumulating water stress effect on harvest index	0.0
HIWSF	Harvest index water stress factor: 0 = no effect of water stress upon grain yield 1 = no grain yield with maximum water stress	0.50

PLTMRF	Planting month reduction factor to limit seedling growth; should be 1, 0 for grass	
PPDF(1)	Optimum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth	30
PPDF(2)	Maximum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth	45
PPDF(3)	Left curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth	1.0
PPDF(4)	Right curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth	2.50
PRAMN(1,1)	Minimum C / N ratio with zero biomass	20.0
PRAMN(2,1)	Minimum C / P ratio with zero biomass	100
PRAMN(3,1)	Minimum C / S ratio with zero biomass	100
PRAMN(1,2)	Minimum C / N ratio with biomass equal BIOMAX.	60
PRAMN(2,2)	Minimum C / P ratio with biomass equal BIOMAX.	160
PRAMN(3,2)	Minimum C / S ratio with biomass greater than or equal to BIOMAX.	200
PRAMX(1,1)	Maximum C / N ratio with zero biomass	40
PRAMX(2,1)	Maximum C / P ratio with zero biomass	200
PRAMX(3,1)	Maximum C / S ratio with zero biomass	230
PRAMX(1,2)	Maximum C / N ratio with biomass equal BIOMAX.	120
PRAMX(2,2)	Maximum C / P ratio with biomass equal BIOMAX.	260
PRAMX(3,2)	Maximum C / S ratio with biomass greater than or equal to BIOMAX.	270
PRBMN(1,1)	Intercept parameter for computing minimum C / N ratio for belowground matter as a linear function of annual precipitation	45
PRBMN(2,1)	Intercept parameter for computing minimum C / P ratio for belowground matter as a linear function of annual precipitation	390
PRBMN(3,1)	Intercept parameter for computing minimum C / S ratio for belowground matter as a linear function of annual precipitation	340
PRBMN(1,2)	Slope parameter for computing minimum C / N ratio for belowground matter as a linear function of annual precipitation	0
PRBMN(2,2)	Slope parameter for computing minimum C / P ratio for belowground matter as a linear function of annual precipitation	0
PRBMN(3,2)	Slope parameter for computing minimum C / S ratio for belowground matter as a linear function of annual precipitation	0
PRBMX(1,1)	Intercept parameter for computing maximum C / N ratios for belowground matter as a linear function of annual precipitation	60
PRBMX(2,1)	Intercept parameter for computing maximum C / P ratios for belowground matter as a linear function of annual precipitation	240
PRBMX(3,1)	Intercept parameter for computing maximum C / S ratios for belowground matter as a linear function of annual precipitation	240

PRBMX(1,2)	Slope parameter for computing maximum C / N ratios for belowground matter as a linear function of annual precipitation	0
PRBMX(2,2)	Slope parameter for computing maximum C / P ratios for belowground matter as a linear function of annual precipitation0	0
PRBMX(3,2)	Slope parameter for computing maximum C / S ratios for belowground matter as a linear function of annual precipitation	0
PRDX(1)	Potential aboveground monthly production for crops (g biomass/m^2/month)	500
RDR	Maximum root death rate at very dry soil conditions (fraction/month); for getting the monthly root death rate, this fraction is multiplied times a reduction factor depending on the soil water status	0.05
RTDTMP	Physiological shutdown temperature for root death and change in shoot/root ratio	2.0
SNFXMX(1)	Symbiotic N fixation maximum for grassland/crop (g N fixed/g C new growth)	0.00300
VLOSSP	Fraction of aboveground plant N which is volatilized This is applied at harvest for grain crops and at senescence for grasses	0.04

APPENDIX III

Tree 100 – Tree parameters (Teak ecosystem)

BASFC2	A basal factor used to calculate the N reaction; if not running savanna, set to 1.0.	1.00
BASFCT	A constant used to calculate the tree basal area. If not running savanna, set to 1.0.	400
CERFOR(1,1,1)	Minimum C / N ratio for leaves.	20
CERFOR(1,1,2)	Minimum C / P ratio for leaves	700
CERFOR(1,1,3)	Minimum C / S ratio for leaves.	100
CERFOR(1,2,1)	Minimum C / N ratio for fine roots.	35
CERFOR(1,2,2)	Minimum C / P ratio for fine roots	765
CERFOR(1,2,3)	Minimum C / S ratio for fine roots.	129
CERFOR(1,3,1)	Minimum C / N ratio for fine branches.	120
CERFOR(1,3,2)	Minimum C / P ratio for fine branches.	1366
CERFOR(1,3,3)	Minimum C/S ratio for fine branches	92
CERFOR(1,4,1)	Minimum C / N ratio for large wood.	150
CERFOR(1,4,2)	Minimum C / P ratio for large wood.	2260
CERFOR(1,4,3)	Minimum C / S ratio for large wood.	183
CERFOR(1,5,1)	Minimum C / N ratio for coarse roots.	150
CERFOR(1,5,2)	Minimum C / P ratio for coarse roots.	2478
CERFOR(1,5,3)	Minimum C / S ratio for coarse roots	175
CERFOR(2,1,1)	Maximum C / N ratio for leaves	40
CERFOR(2,1,2)	Maximum C / P ratio for leaves.	700
CERFOR(2,1,3)	Maximum C / S ratio for leaves.	100
CERFOR(2,2,1)	Maximum C / N ratio for fine roots.	60
CERFOR(2,2,2)	Maximum C / P ratio for fine roots.	765
CERFOR(2,2,3)	Maximum C / S ratio for fine roots.	129
CERFOR(2,3,1)	Maximum C / N ratio for fine branches.	180
CERFOR(2,3,2)	Maximum C / P ratio for fine branches.	1366
CERFOR(2,3,3)	Maximum C / S ratio for fine branches.	92
CERFOR(2,4,1)	Maximum C / N ratio for large wood.	300
CERFOR(2,4,2)	Maximum C / P ratio for large wood.	2260

CERFOR(2,4,3)	Maximum C / S ratio for large wood.	183
CERFOR(2,5,1)	Maximum C / N ratio for coarse roots.	300
CERFOR(2,5,2)	Maximum C / P ratio for coarse roots	2478
CERFOR(2,5,3)	Maximum C / S ratio for coarse roots	175
CERFOR(3,1,1)	Initial C / N ratio for leaves	40
CERFOR(3,1,2)	Initial C / P ratio for leaves	700
CERFOR(3,1,3)	Initial C / S ratio for leaves.	100
CERFOR(3,2,1)	Initial C / N ratio for fine roots	76
CERFOR(3,2,2)	Initial C / P ratio for fine roots.	765
CERFOR(3,2,3)	Initial C / S ratio for fine roots	129
CERFOR(3,3,1)	Initial C / N ratio for fine branches.	84
CERFOR(3,3,2)	Initial C / P ratio for fine branches.	1366
CERFOR(3,3,3)	Initial C / S ratio for fine branches	92
CERFOR(3,4,1)	Initial C / N ratio for large wood.	155
CERFOR(3,4,2)	Initial C / P ratio for large wood.	2260
CERFOR(3,4,3)	Initial C / S ratio for large wood.	183
CERFOR(3,5,1)	Initial C / N ratio for coarse roots.	155
CERFOR(3,5,2)	Initial C / P ratio for coarse roots.	2478
CERFOR(3,5,3)	Initial C / S ratio for coarse roots.	175
CO2ICE(2,1,1)	In a forest system, the effect on minimum C:N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid range 0.5 to 1.5	1.25
CO2ICE(2,1,2)	In a forest system, the effect on minimum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.25
CO2ICE(2,1,3) -	In a forest system, the effect on minimum C / S ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.25

CO2ICE(2,2,1)	In a forest system, the effect on maximum C / N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.00
CO2ICE(2,2,2)	In a forest system, the effect on maximum C / P ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.00
CO2ICE(2,2,3)	In a forest system, the effect on maximum C / S ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.250
CO2IPR(2)	In a forest system, the effect on plant production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.00
CO2IRS(2)	In a forest system, the effect on root-shoot ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.00
CO2ITR(2)	In a forest system, the effect on transpiration rate of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm. A value of 1 will have no effect. A reduction will have a negative effect. And an increase will have a positive effect. Valid Range: 0.5 to 1.5	1.00
DECID -	Flag for type of forest: 0= forest is continuous evergreen 1= forest is temperate deciduous 2= forest is tropical deciduous	2

DECW1	Decomposition rate for WOOD1 (dead fine branch) per year (/y).	1.50
DECW2	Decomposition rate for WOOD2 (dead large wood) per year (/y).	0.50
DECW3	Decomposition rate for WOOD3 (dead coarse root) per year (/y).	0.60
DEL13C	Delta 13C value for stable isotope labeling	0.00
FCFRAC(1,1)	C allocation fraction of new leaves for juvenile forest.	0.25
FCFRAC(2,1)	C allocation fraction of new fine roots for juvenile forest.	0.25
FCFRAC(3,1)	C allocation fraction of new fine branches for juvenile forest.	0.10
FCFRAC(4,1)	C allocation fraction of new large wood for juvenile forest.	0.30
FCFRAC(5,1)	C allocation fraction of new coarse roots for juvenile forest.	0.10
FCFRAC(1,2)	C allocation fraction of old leaves for mature forest.	0.34
FCFRAC(2,2)	C allocation fraction of old fine roots for mature forest.	0.25
FCFRAC(3,2)	C allocation fraction of old fine branches for mature forest.	0.11
FCFRAC(4,2)	C allocation fraction of old large wood for mature forest.	0.22
FCFRAC(5,2)	C allocation fraction of old coarse roots for mature forest.	0.08
FORRTF(1)	Fraction of N retranslocated from green forest leaves at death.	0.20
FORRTF(2)	Fraction of P retranslocated from green forest leaves at death.	0.00
FORRTF(3)	Fraction of S retranslocated from green forest leaves at death.	0.00
KLAI	Large wood mass in grams per square meter (g C /m2) at which half of the theoretical maximum leaf area (MAXLAI) is achieved	1000
LAITOP	Parameter determining relationship between LAI and forest production.	-0.47
LEAFDR(1)	Monthly death rate fraction for leaves for month 1.	0.070
LEAFDR(2)	Monthly death rate fraction for leaves for month 2.	0.070
LEAFDR(3)	Monthly death rate fraction for leaves for month 3.	0.070
LEAFDR(4)	Monthly death rate fraction for leaves for month 4.	0.070
LEAFDR(5)	Monthly death rate fraction for leaves for month 5.	0.070
LEAFDR(6)	Monthly death rate fraction for leaves for month 6.	0.070
LEAFDR(7)	Monthly death rate fraction for leaves for month 7.	0.070
LEAFDR(8)	Monthly death rate fraction for leaves for month 8.	0.070
LEAFDR(9)	Monthly death rate fraction for leaves for month 9.	0.070
LEAFDR(10)	Monthly death rate fraction for leaves for month 10.	0.070
LEAFDR(11)	Monthly death rate fraction for leaves for month 11.	0.070
LEAFDR(12)	Monthly death rate fraction for leaves for month 12.	0.070

MAXLAI .	Theoretical maximum leaf area index achieved in mature forest	8.00
MAXLDR	Multiplier for effect of N availability on leaf death rates (continuously growing forest systems only); a ratio between death rate at unlimited vs. severely limited N status.	1.00
PPDF(1)	Optimum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth.	9999.0
PPDF(2)	Maximum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth.	200
PPDF(3) .	- Left curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth	30.0
PPDF(4)	Right curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth.	45.0
PRDX(2)	Gross forest production.	1.00
PRDX(3)	Maximum forest production excluding respiration.	2.50
SAPK	Controls the ratio of sapwood to total stem wood, expressed as gC m-2; it is equal to both the large wood mass (RLWODC) at which half of large wood is sapwood, and the theoretical maximum sapwood mass achieved in mature forest.	1500
SITPOT	(Savanna only) Site potential; the N fraction. A measure of the aboveground herbaceous layer production in kilograms per hectare per year in the absence of trees. (SITPOT = 2400 * monthly N availability in grams of N per square meter per year.)	2400
SNFRMX(2)	Symbiotic N fixation maximum for forest in grams of nitrogen fixed per gram of carbon of new growth (g N fixed/g C new growth)	0.00
SWOLD	Year at which to switch from juvenile to mature forest carbon allocation fractions for tree production. Valid Range: simulation year range	0.00

WDLIG(1)	Lignin fraction for forest system leaf production	0.15
WDLIG(2)	Lignin fraction for forest system fine root production.	0.28
WDLIG(3)	Lignin fraction for forest system fine branch production.	0.35
WDLIG(4)	Lignin fraction for forest system large wood production.	0.35
WDLIG(5)	Lignin fraction for forest system coarse root production.	0.35
WOODDR(1)	Controls the proportion of leaves that drop during senescence month or at the end of the growing season when DECID = 1 or 2. This is especially useful for drought-deciduous systems where only a portion of the leaves drop. Also useful when you are attempting to simulate a deciduous/coniferous mixed system of forest.	1.00
WOODDR(2)	Monthly death rate fraction for fine root component.	0.030
WOODDR(3)	Monthly death rate fraction for fine branch component.	0.010
WOODDR(4) -	Monthly death rate fraction for large wood component.	0.002
WOODDR(5)	Monthly death rate fraction for coarse root component.	0.004

MODELLING SOIL CARBON DYNAMICS OF TWO MAJOR ECOSYSTEMS OF HUMID TROPICS

By

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ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the
requirement for the degree of

BSc-MSc (Integrated) CLIMATE CHANGE ADAPTATION

Faculty of Agriculture

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

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KERALA, INDIA

2015

ABSTRACT

A study on "Modelling soil carbon dynamics of two major ecosystems of humid tropics" was carried out in the Academy of Climate Change Education and Research (ACCER) during 2014-2015. The study was done using two soil carbon models such as Roth-C and CENTURY. The objectives of the study included the evaluation of suitability of these two models in rice and teak ecosystems and also to analyse the soil organic carbon changes due to predicted climate change scenarios.

The study was based on secondary data sets collected from experiments done in paddy fields and teak plantations of Pattambi and Thrissur areas respectively belonging to humid areas.

The simulated total soil organic carbon (1965 to 2050) by Roth-C and CENTURY models was found to be declining in rice ecosystem. The active carbon in rice ecosystem showed decreasing trend and thereafter it was showing an increasing trend. In case of slow carbon it showed a gradual declining trend during the period from 1965 to 1990. There after it started to increase in a rapid manner during the next eleven years and afterwards it started decreasing. The passive carbon in rice ecosystem kept on increasing throughout the simulation period.

In teak ecosystem, both the models Roth-C and CENTURY predicted a declining trend of total soil organic carbon. The active carbon of teak ecosystem decreased by the end of third year and slowly increased by ninth year. By the end of fifty five year it showed a rapid decline and slowly increased by the following years. Slow carbon pool showed a declining trend up to thirty years and kept on increasing to the next thirty years. Then it showed a rapid decline and thereafter it started to increase. The passive carbon kept on decreasing throughout the period.

The model efficiency of Roth-C and CENTURY models for rice ecosystem were 0.63 and 0.82, respectively whereas for teak ecosystem the values were 0.69 and 0.88. Hence it was concluded that for simulation of soil organic carbon, both the models are suitable, but CENTURY model was more efficient than Roth- C model.

From the study based on different RCP scenarios, RCP 8.5 had predicted higher temperature and precipitation values compared to others (RCP 6.0, RCP 4.5 and RCP 2.6) over both Pattambi and Vellanikkara. In rice ecosystem, it was noticed that in 2015 and 2050, RCP 2.6 recorded the highest values of total soil organic carbon and the lowest values were by RCP 8.5, respectively. In the case active carbon, RCP 4.5 recorded the highest values and RCP 8.5 recorded the lowest values. The highest value of slow carbon was recorded by RCP 2.6 and the lowest by RCP 8.5. The predicted values of passive carbon showed highest values by RCP 6.0 and recorded the lowest by RCP 4.5.

In the study based on predicted climate change scenarios in teak ecosystem, RCP 4.5 recorded highest values of total soil organic carbon in 2015 and 2050 where as the lowest value was found by RCP 6.0 in 2015 and RCP 8.5 in 2050. The highest value of active carbon was found in 2015 by RCP 4.5 and in 2050 by RCP 2.6. The lowest values of active carbon were recorded by RCP 6.0 and RCP 8.5 in 2015 and 2050 respectively. In 2015 the highest value of slow carbon was recorded by RCP 4.5 and in 2050 by RCP 2.6. The least value of slow carbon was recorded in 2015 by RCP 6.0 and in 2050 by RCP 8.5. The passive carbon simulated by different RCPs, it was observed that RCP 4.5 predicted the highest value in 2015 and 2050. Then the lowest values recorded by RCP 6.0, respectively

The present study indicated that modelling is suitable for studying carbon dynamics in soils under rice and teak ecosystems. It highlights the potential of CENTURY model over Roth-C model in terms of simulation of soil carbon. Using different scenarios it is possible to know that, what might be the future conditions of soil carbon and its different pools.