CARBON SEQUESTRATION POTENTIAL OF TROPICAL HOMEGARDENS AND RELATED LAND-USE SYSTEMS IN KERALA, INDIA

By

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To my wife, parents, and sister

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Storing carbon (C) in biosphere is one of the strategies accepted by the United Nations for mitigating high atmospheric concentrations of carbon dioxide and other greenhouse gases that cause global warming. Agroforestry and other tree-based land-use systems are believed to have high potential for storing C in soils compared to treeless agricultural systems. This hypothesis was tested for homegardens (HG), a popular and sustainable agroforestry system in the tropics, in Thrissur district, Kerala, India (10º 0' – 10º 47' N; 75º 55' – 76º 54' E). The major objective was to estimate soil C storage in HGs, in comparison with common land-use systems of the region: forest, coconut (*Cocos nucifera*), rice (*Oryza sativa*)-paddy, and rubber (*Hevea brasiliensis*) plantation in relation to soil-size fractions, tree density, species richness, and size and age of HGs. Soil samples collected from four depths (0 – 20, 20 – 50, 50 – 80, 80 – 100 cm) were fractionated (wet sieving) to three fraction-size classes (250 – 2000µm, 53 – 250µm, <53µm) and their total C content determined. Using a questionnaire survey, farmers' perceptions to adoption of management practices such as tillage and fertilizer application that are known to influence soil C storage were assessed in relation to their cultural beliefs and educational- and income levels. Within 1 m soil profile, total C stock was highest in forests

(176.6 Mg ha^{-1}), followed by small HG (<0.4 ha) (119.3), rubber plantation (119.2), large HG (> 0.4 ha) (108.2), coconut plantation (91.7), and rice-paddy field (55.6 Mg ha^{-1}). In terms of C stock in three soil fraction-size classes, differences among land-use systems were most pronounced for macro-size (250 – 2000 µm), followed by micro-size (53 – 250µm) and silt + clay (< 53 µm) fractions. Soil C stock was directly related to tree density, species richness, and age of HGs. The results also indicated that socioeconomic factors such as traditional beliefs, education, connection to peers, and economic importance of HG strongly influenced farmers' decisions on HG management practices. Results of this pioneering study that indicate the environmental benefits of integrated land-use systems could have applications in broader ecological contexts.

CHAPTER 1
INTRODUCTION

Background

The increasing concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere is now widely recognized as the leading cause of global warming (Intergovernmental Panel on Climate change (IPCC), 2007). In order to reduce the GHGs in the atmosphere, two key activities are relevant: reduce the anthropogenic emissions of CO_2 and create or promote carbon (C) sinks in the biosphere. The latter proposes storing of atmospheric C in the biosphere, and it is believed that this can be achieved by promoting land-use practices such as agroforestry (Montagnini and Nair, 2004). The IPCC special report on Land Use, Land-Use Change and Forestry (LULUCF) shows that net increase in global C stocks are estimated to be 0.026 Pg (billion tons) C year^{-1} for improved agroforest management and 0.39 Pg C year^{-1} for agroforestry-related land-use changes in 2010 (IPCC, 2007). With proper design and management, agroforestry systems can be effective C sinks (Montagnini and Nair, 2004). Global estimates of C stocks indicated that, 1.1 to 2.2 Pg C can be removed from the atmosphere globally within 50 years through proper implementation of agroforestry systems (Albrecht and Kandji, 2003). Wright et al. (2001) estimated that the goal of assimilating 3.3 Pg C yr year^{-1} would require 670 − 760 Mha area of improved maize (*Zea mays*) cultivation, whereas this goal could be achieved by adoption of 460 Mha of agroforestry. They even suggested that agroforestry is the only system that could realistically be implemented to mitigate the atmospheric CO_2 through terrestrial C sequestration. It may be logical to assume that agroforestry systems consisting of multiple plant species in intimate spatial and temporal (simultaneous or sequential) associations on the same unit of land have high C storage potential. In addition, the tree component of agroforestry systems, with its potential of high aboveground and belowground biomass production is a major promoter of soil C accumulation (Kursten, 2000). However, these potentials of agroforestry systems for sequestering C in soil remain little studied (Nair and Nair, 2003).

Trees can contribute substantially to soil C sequestration (Sanchez et al., 1985; Lal et al., 1999, Nair et al., 2008). Production of larger quantities of aboveground and belowground biomass compared to shrubs or herbs makes trees more efficient in promoting soil C sequestration (Brady and Weil, 2007). More biomass results in increased production of aboveground litter and belowground root activity. By adding trees in agricultural systems agroforestry can increase the C storage capacity of the system (Kursten, 2000). Research indicates that by adding trees in grassland or pasture systems the soil organic carbon (SOC) content can be increased considerably (Reyes-Reyes et al., 2002; Yelenik et al., 2004, Haile et al., 2008). According to Montagnini and Nair (2004) the tree components of agroforestry systems are potential sinks of atmospheric C due to their fast growth and productivity, high and long term biomass stock, and extensive root system. Depending on the land-use type, considerable amount of C can be accumulated at lower depths, because at lower depths soil is better protected from the disturbances leading to longer residence time (Fontaine, 2007). However, most of the soil C study investigates only top 50 cm or less, underestimating the potential of subsoil C sequestration. Considering the beneficial effects of individual trees on the SOC, it can also be argued that the increase in tree density should ensure the increased production of aboveground and belowground biomass, which could contribute to SOC accumulation through litter-and root-decomposition.

Soil plays a major role in global C sequestration (Lal, 2002) and has a higher capacity to store C compared to vegetation and atmosphere (Bellamy et al., 2005). The global soil C pool is

2300 Pg, which is 3 times the size of atmospheric C (770 Pg) and 3.8 times the size of biotic pools (610 Pg) (Lal, 2001). Soil aggregation (development of aggregates) is the process of retaining the SOC (Carter, 1996) and can be divided into short-term storage in macroaggregates and long-term storage in microaggregates (Six et al., 2002). The major and widely accepted particle size classes are > 250 µm diameter (macroaggregate) and < 250 µm diameter (microaggregate) (Edward and Bremener, 1967) and silt and clay size fractions (< 53 µm). Storage of SOC and aggregation is determined by the land-use, soil, climate, and management practices (Carter, 1996). Some studies have recently been initiated in agroforestry systems to investigate the partitioning of C storage among the soil fraction-size classes (Haile et al., 2008; Takimoto et al., 2008), but none in tropical homegarden systems.

Homegardens (HG) are intimate, multistory combinations of various trees and crops, sometimes in association with domestic animal, around the homesteads (Fernandes and Nair, 1986; Nair, 1993). Distributed in tropical areas of Asia, Africa, Central America, the Caribbean, and the Pacific Islands (Ruthenberg, 1980; Anderson, 1993; High and Shackleton, 2000; Nair and Kumar, 2006), the HGs are rich in plant diversity and have been ranked at the top among all manmade agro-ecosystems for their high biological diversity. Indeed in terms of plant diversity, the HGs are reported to be second only to natural forests (Swift and Anderson, 1993). Homegardens are considered to have high C sequestration potential (CSP) due to their high plant diversity and forest-like structure and composition; however no authentic data is available to validate this function, particularly in stocking C in the soil (Kumar, 2006). Factors such as plant population, species and tree density, size, and age of homegardens and the socioeconomic characteristics of the HG owner may have influence on carbon sequestration potential (CSP) of homegardens.

High species assemblages in HGs are likely to harbor species with strong resources-utilization characteristics compared with less species-intensive systems (Tilman et al., 1997) and may promote a greater net primary production (Vandermeer, 1989), which in turn promote C sequestration. Kirby and Potvin (2007) theorized that as more species are included in a system, more complete utilization of resources takes place and the system becomes more productive. These theories predict the possibility of a positive relationship between plant diversity and C sequestration, however very little research has been done to verify these claims in agroforestry in general, and no such study has been reported from homegardens.

The holding size and age of the HG may also influence its CSP. Previous research has shown that smaller homegardens had higher species diversity (Kumar et al., 1994) and higher species density (Mohan et al., 2007). Increase in number of species, may influence the accumulation of SOC and as a result small HGs that have higher species density may have greater soil CSP than larger HGs with lower species density. In addition, higher tree density may result in more SOC in small HGs. Age, may also be a critical factor in influencing the soil C storage capacity of HGs. The amount of SOC accumulation in HGs may also be influenced by factors such as permanence, reduced disturbance and effect of trees. The trees being present in HGs for relatively long periods of time, they are likely to develop their roots deeper in the soil and sequester more C at lower soil depths. The C at lower depths being better protected from the disturbances leads to longer residence time (Fontaine, 2007). Thus, the HG age may have a direct effect on SOC sequestration, especially at the lower soil depths.

The influence of agricultural practices on C sequestration is well-established (Six et al., 2002). Several farming practices such as tillage, plant residue management, and manure and fertilizer application have been identified as factors influencing the extent of C sequestration

(FAO, 2004); the extent of their influence depends on land-use type, crop species, ecological and social factors, and the management intensity of the practices. Socioeconomic and demographic factors such as income, education, age, and family size of the HG owner may also indirectly influence soil CSP of the HG; however, little information is available on the extent of influence of such factors.

Kerala state in southwestern India is well known for the abundance and diversity of HG agroforestry systems (Kumar and Nair 2006). In Kerala, there are 5.4 million small operational holdings (average size 0.33 ha) covering an area of 1.8 Mha and about 80% of these are homegardens (Govt. of Kerala, 2008), therefore this state is estimated to have 4.32 million homegardens covering 1.33 Mha of land (Kumar, 2006). With the high level of recognition of the ecological and socioeconomic sustainability values of homegardens in the state (Nair and Shreedharan, 1986; Jose and Shanmugaratnam, 1993; Kumar et al., 1994), Kerala offers a good opportunity to study the development trends of homegardens (Peyre et al., 2006).

Apart from HGs, other major tree-based land-use systems in Kerala include plantations (single-species stands) of rubber (*Hevea brasiliensis*) and mixed plantations of coconut (*Cocos nucifera*). This study included single-species stands of rubber and coconut along with HGs to represent three major tree-based tropical land-use systems. Furthermore, the study included a nearby natural forest as well as a rice (*Oryza sativa*) paddy system to provide a broad spectrum of land-use systems ranging from natural forest to rice paddy, with the three managed tree-based systems (HGs, and plantations of rubber and coconut) in between. These systems represent a range of ecological complexities as well as management intensities: e.g. high ecological complexity of natural forest to the low complexity of the rice paddy, and corresponding levels of management intensities in the reverse order (rice paddy with highest intensity and natural forest with the lowest).

Objectives

1. To investigate the soil C storage in the whole soil as well as fractionated size-classes of soils along a range of tree-based land-use systems from natural forests to homegardens, coconut groves, and rubber plantations, in comparison with a treeless agricultural system (rice-paddy), to one-meter depth in central Kerala, India.
2. To study the differences in soil C sequestration in homegardens of varying ecological characteristics, holding size, and age.
3. To investigate the effects of socioeconomic and demographic factors on soil C sequestration in homegardens.

Dissertation Outline

The dissertation contains seven chapters. Following this chapter (Chapter 1, Introduction), Chapter 2 presents a literature review, highlighting the potential for soil C sequestration in agroforestry systems, especially homegardens, and the role of socioeconomic factors on soil carbon sequestration. Chapter 3 provides the agro-climatic details of the study region and discusses about different land-use types under the study. Methodologies and results of the biophysical part of the study are presented in Chapters 4 and Chapter 5. Chapter 4 compares the selected land-use types in terms of their CSP in whole and fractionated soil-size classes. Chapter 5 documents the plant diversity of homegardens of various sizes (area) and calculates the biodiversity indices; it also presents the effects of homegarden age and plant diversity on soil C storage. Chapter 6 presents the effects of socioeconomic and demographic factors on homegarden management practices, and discuses the socioeconomic tools and methodologies used for the study and shows how farmers' decision on management practices affecting C sequestration are influenced by different social factors. Finally, Chapter 7 provides the summary and conclusions along with the suggestions for future research and management plans.

CHAPTER 2
LITERATURE REVIEW

Carbon sequestration is one of the most important environmental issues of this century and is an extensively researched topic in the recent past. Homegarden, on the other hand, though a popular and widely distributed tropical agroforestry system, has not been widely researched, especially in regard to its role in C sequestration. This chapter presents a review of relevant literature on soil C sequestration with an emphasis on homegardens. The chapter starts with an outline on the issue of C sequestration followed by an examination of its relation to agroforestry. Then, the studies discussing the relationship of C sequestration to soil and biodiversity are highlighted. Following this, literature on the scope and limitations of the carbon sequestration potential (CSP) of homegardens is presented. Finally, literature is reviewed to examine the relationship between socioeconomic characteristics of homegarden and C sequestration.

Carbon Sequestration

Global warming is undoubtedly one of the major environmental issues of this century. This phenomenon is affecting global climate by increasing earth's temperature and is caused primarily by the increase in atmospheric concentrations of greenhouse gases (GHGs) (Intergovernmental Panel on Climate Change (IPCC), 2007), the most common of which is carbon dioxide (CO_2). At the current rate of CO_2 emissions, its concentration in the atmosphere will be doubled by the end of 21st century. Realizing the threat of global warming, United Nations (UN) established the Intergovernmental Panel on Climate Change and created the Kyoto Protocol (by United Nations Framework Convention on Climate Change – UNFCCC) as the first international agreement on mitigating GHGs. The goal of this protocol is to reduce the GHGs of committed countries by at least 5% compared to the 1990 level by the period 2008 – 2012. In order to reduce the GHGs in the atmosphere, two key activities are relevant (IPCC, 2007): reduce the anthropogenic emissions of CO_2, and create or promote carbon (C) sinks in the biosphere. The second option proposes storing atmospheric C in the biosphere, and in that context, land-use systems such as agroforestry have considerable importance.

Agroforestry and Carbon Sequestration

Agroforestry involves the deliberate growing of trees and shrubs on the same unit of land as agricultural crops or animals, either in some form of spatial mixture or temporal sequence (Nair, 1993; 2001). As a leading tree-based system especially in the tropics, agroforestry has been suggested as one of the most appropriate land-management systems for mitigating atmospheric CO_2 (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004). In Article 3.3 of Kyoto Protocol, further clarified by the Marrakesh Accord in 2001, afforestation and reforestation have been identified as one of the means of mitigating GHGs. Clean Development Mechanism (CDM), defined in Article 12 of the Protocol allows industrialized nations to execute emission reduction projects in the developing countries (UNFCCC, 2007) and due to the wide distribution and high CSP, agroforestry has become an attractive choice for such projects under the umbrella of afforestation and reforestation.

Several studies have investigated the CSP of agroforestry systems. Wright et al. (2001) estimated that the goal of assimilating 3.3 Pg C year^{-1} would require 670 − 760 Mha area of improved maize cultivation, whereas this goal can be achieved by adoption of 460 Mha of agroforestry. They even suggested that agroforestry is the only system that could realistically be implemented to mitigate the atmospheric CO_2 through terrestrial C sequestration. Estimation of C stocks all over the world indicated that, with the proper implementation of agroforestry at the global scale 1.1 to 2.2 Pg C can be removed from the atmosphere within 50 years (Albrecht and Kandji, 2003). Agroforestry systems may also indirectly affect C sequestration by decreasing the pressure from the natural forests. It has been estimated that in the tropics one hectare of sustainable agroforestry may offset 5 – 20 hectares of deforestation (Dixon, 1995). Sharrow and Ismail (2004) reported C sequestration to be higher in silvopasture systems compared to forests and pastures. Silvopastures accumulated approximately 740 kg ha^{-1} year $^{-1}$ more C than forests and 520 kg ha^{-1} $year^{-1}$ more C than pastures in Oregon, USA. They concluded that agroforestry systems had both forest and grassland nutrient cycling patterns and would produce more total annual biomass. Haile et al. (2008) observed higher soil C in silvopastoral systems (slash pine (*Pinus elliottii*) + bahiagrass (*Paspalum notatum*) of Florida compared to the open pasture bahiagrass. Their results indicated that total soil organic carbon (SOC) content was higher by 33% in silvopastures near trees and by 28% in the alleys between tree rows than in adjacent open pastures. In Brazil, Schroth et al. (2002) observed that multi-strata systems had an aboveground biomass of 13.2 – 42.3 Mg ha^{-1} and a belowground biomass of 4.3 – 12.9 Mg ha^{-1} compared to those of monoculture at 7.7 – 56.7 Mg ha^{-1} and 3.2 – 17.1 Mg ha^{-1}, respectively. Woomer (1993) observed that at surface soil, rainforests had SOC (2.7 kg m^{-2}) very similar to agroforestry systems (2.6 kg m^{-2}). In West African Sahel, Takimoto et al. (2008) found higher amount of SOC (aboveground + belowground) in parkland agroforestry systems (*Faidherbia albida* and *Vitellaria paradoxa* trees as the dominant species), compared to live fence and fodder bank.

Earlier projections indicate that in near future, the area under agroforestry would increase worldwide. According to the IPCC report (IPCC, 2007) the existing area under agroforestry is 400 million hectares with an estimated C gain of 0.72 t C ha $year^{-1}$, with potential for sequestering 0.026 Pg C $year^{-1}$ by 2010 and 0.045 Pg C $year^{-1}$ by 2040. That report also indicates that 630 Mha of unproductive cropland and grasslands worldwide could be converted to agroforestry, with the capacity to sequester 0.39 Pg C $year^{-1}$ by 2010 and 0.586 Pg C $year^{-1}$ by

2040. This certainly would have an effect on long-term C storage in the biosphere. Some earlier estimates suggested the rate of total C emission from global deforestation as 1.6 Pg/ 17 Mha and assumed that one ha of agroforestry can save five ha of deforestation (Schroeder, 1994; Dixon, 1995). However, these claims have not been validated and detailed and dependable quantitative data on CSP of different agroforestry systems is not available (Nair and Nair, 2003).

Carbon Sequestration and Biodiversity

Conservation of biodiversity is another major environmental challenge of this century (United Nations Environment Program-UNEP, 2002; Convention on Biological Diversity-CBD, 2006). Biodiversity provides priceless ecosystem services to sustain human life and effective strategies should be adopted to conserve biodiversity in this changing world (Loreau et al., 2002; Díaz et al., 2006; CBD, 2006; Ives and Carpenter, 2007). The word ‘biodiversity’ is a contraction of biological diversity that includes any life form on earth. Several definitions of biodiversity are available, but the most widely accepted one seems to be that proposed by the US Congressional Biodiversity Act, HR1268 (1990) "biological diversity means the full range of variety and variability within and among living organisms and the ecological complexes in which they occur, and encompasses ecosystem or community diversity, species diversity, and genetic diversity" (The State of California, 2000).

At the 1992 Earth Summit in Rio de Janeiro, two key agreements were adopted, the formation of the UNFCCC and the Convention on Biological Diversity (CBD) (Walsh, 1999). The objective of the UNFCCC was to mitigate the greenhouse gases through means like sequestration of atmospheric C and the objective of CBD was to conserve the biological diversity. For a long period of time these two issues had been treated separately. With time scientists and policymakers realized the need of combining both the issues in a single plan, and some ventures started to explore both under a single project (Swingland, 2002; World Bank, 2002). Thus, scientists became interested in functional relationship between biodiversity (especially plant diversity) and C sequestration (Schwartz et al., 2000; Tilman et al., 2001; Srivastava and Vellend, 2005).

Existing theories argue that high species assemblages are likely to harbor species with strong response to the resources (soil nutrients, water etc.) compared to systems with limited species (Tilman et al., 1997) and may promote a resource use efficient system that favors greater net primary production (Vandermeer, 1989), which in turn promote C sequestration. In support of plant diversity, Huston and Marland (2003) reported that multiple species performing a particular function provide some insurance that the system will continue to function even if one species is lost. They also added that the action of multiple species can reduce the effects on environmental fluctuations and continue their ecological functions under different condition. These arguments indicate that high plant diversity in a system has the potential to alleviate disturbances. In support of this, Loreau et al. (2002) reported that high diversity should reduce temporal instabilities caused by climate change and other disturbances. On the other hand, it is widely agreed that more C is sequestered in systems with lesser disturbance (Six et al., 2002). Therefore, it may be logical to say that species-rich systems may promote C sequestration through mitigating the effects of disturbance. Kirby and Potvin (2007) theorized that as more species are included in a system, more complete utilization of resources takes place and the system becomes more productive. However, they also said that coincidental inclusion of functionally important species in diverse assemblages actually results in increase in productivity rather than just increase in diversity.

The mechanism of species driven C sequestration in soil is influenced by two major activities, aboveground litter decomposition and belowground root activity (Lemma et al., 2007).

Litter decomposition is one of the major sources of SOC and the quality of litter is very important in this regard (Mafongoya et al., 1998; Issac and Nair, 2006; Lemma et al., 2007). In systems with high plant diversity, it is likely that they would have litters with different degrees of chemical resistance, creating the possibility of longer residence of C through slower decomposition of litters from some species. Lignin in litter is highly resistant to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya et al., 1998). In contrast, litter with low lignin, phenols, and high N content would have faster rate of decomposition. Issac and Nair (2006) reported that lignin contents and the phenol + lignin: N have the highest correlation with the decay rates of the litter in the homegardens of Kerala. Plant species diversity influences the soil microbial activity through plant-specific differences in the release of root exudates in the rhizosphere (Vancura, 1964; Klein et al., 1988), which provide the nutrition source for microorganisms and in turn affects the SOC (Rees et al., 2005).

Homegardens are rich in plant diversity (Nair, 1993). Studies in different regions of Kerala, India, have reported the occurrence of 107 plant species (John and Nair, 1999), 127 woody species only (Kumar et al., 1994), and total 153 plant species (Mohan et al., 2007) in the homegardens. A detailed report on homegarden flora of different geographic regions is listed in Table 2-1. Although there are a series of studies documenting the plant diversity of homegardens, many of them lack information on the degree of heterogeneity in the study area (Kumar and Nair, 2004). To avoid this, some authors have suggested using the ecological diversity indices to analyze the plant diversity of homegardens (Rico-Gray et al., 1990; Kumar et al., 1994; Wezel and Bender, 2003). Analysis of homegarden flora with ecological indices indicates that results were comparable to adjacent forests (Gajaseni and Gajaseni, 1999). Mohan et al. (2007) estimated the mean Margalef value as 5.4 to 6.4 in the homegardens of Kerala, which were comparable to the value 7.07 reported from the wet evergreen forests of the southern Western Ghat Mountains of Kerala (Varghese and Balasubramanyan, 1998). The species richness of homegardens varies with the holding size (Kumar and Nair, 2004). Sankar and Chandrashekara (2002) observed that the smallest gardens had the highest Shannon index value followed by the medium and large gardens. Kumar et al. (1994) observed higher Simpson's diversity index value in smaller homegarden, which was 0.61, 0.44, and 0.46 in small (<0.4 ha), medium (0.4 – 2.0 ha), and large (>2.0 ha) homegardens, respectively.

The rich plant species diversity of homegardens, comparable to that of forests, suggests that, homegardens, like forests, may also have high potential to sequester soil C (Kumar, 2006). Based on the information presented above, it may also be claimed that smaller homegardens have higher C sequestration due to their greater species richness compared to the larger homegardens. However, adequate data are not available to verify these arguments. Roshetko et al. (2002) reported 60.8 Mg C ha^{-1} was obtained in the topsoil of homegardens of Sumatra, Indonesia. Rosalina et al. (1997) reported that a total of 104 Mg C ha^{-1} was found in homegardens of North Lampung, Indonesia, of which 60.32 Mg C ha^{-1} (58%) was obtained from soil. More elaborate studies are required from other parts of the tropics to establish the extent of CSP of homegardens.

Soil Carbon Sequestration

Soil plays a major role in global C sequestration (Lal, 2002). Out of the total stock of C in the soil + plant system, soils store significantly higher proportion of C than the vegetation. The global soil C pool is 2300 Pg, which is 3 times the size of atmospheric C (770 Pg) and 3.8 times the size of biotic pools (610 Pg) (Lal, 2001). However, the idea of soil C sequestration did not get adequate recognition due to inadequate understanding of the role of soil in global C cycle and the processes involved (Lal, 2002).

Land-use and Soil Organic Carbon

The SOC varies with the land-use system (Post and Mann, 1990; Davidson and Ackerman, 1993). Depending on land-use type, changes in vegetation change the SOC accumulation. Changes beneficial to SOC are: increase in the rate of organic matter production, changes in the decomposability of organic matter that increase organic C, placing of organic matter deeper in the soil, and enhancing physical protection and aggregation (Post and Kwon, 2000). Tree-based land-use systems have greater potential of soil CSP than agronomic crops (Post and Mann, 1990). Trees have the potential of producing larger quantities of aboveground and belowground biomass compared to shrubs or herbs. More biomass results in increased production of aboveground litter and belowground root activity and these make trees an important factor for SOC sequestration (Lemma et al., 2007). Inclusion of trees in a treeless system changes some functional mechanisms such as total productivity, rooting depth and distribution, and litter quantity and quality (Gill and Burke, 1999; Jackson et al., 2000; Jobbagy and Jackson, 2000). According to Montagnini and Nair (2004), the tree components of agroforestry systems are potential sinks of atmospheric C due to their fast growth and productivity, high and long-term biomass stock, and extensive root system. By adding trees in the agricultural systems, agroforestry can increase the C storage capacity of the system (Kursten, 2000). Research indicates that by adding trees in grassland or pasture systems the SOC content can be increased considerably (Reyes-Reyes et al., 2002; Yelenik et al., 2004; Haile et al., 2008). Forests are land-use systems with high tree population and play a major role in C sequestration (Lal, 2005). Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of all SOC (Batjes, 1996; Six et al., 2002). When forests are converted to treeless system they loose

SOC. The conversion of forest to agricultural system results in depletion of SOC by 20 – 50% (Post and Mann, 1990; Davidson and Ackerman, 1993). Trumbore et al. (1995) reported that, when tropical dry forest in eastern Amazonia were converted to pasture it lost 13 g SOC m^{-2} $year^{-1}$ within top 10 cm soil. In another part of eastern Amazonia, when tropical moist forest was converted to pasture it lost 30 g SOC m^{-2} $year^{-1}$ within top 40 cm (Desjardins et al., 1994). Similar results were observed by Veldkamp (1994) in tropical wet forests of Costa Rica, where it lost 90 g SOC m^{-2} $year^{-1}$ within top 50 cm, when replaced with pasture. Opposite results were observed when treeless pastures were converted to forest lands. Pregitzer and Palit (1996) observed that when an agricultural field was changed to oak forest in Great Lakes region, northern USA, the land gained 60 g SOC m^{-2} $year^{-1}$ within top 70 cm. Brown and Lugo (1990) reported that when agricultural fields of Puerto Rico and US Virgin Islands were replaced with secondary forest, after 35 years of this change, SOC increased 80 g m^{-2} $year^{-1}$ and 105 g m^{-2} $year^{-1}$ within top 25 and 50 cm of soil, respectively. Depending on the species diversity and plant density, considerable difference in SOC can also be observed between two tree-based systems. In the same study mentioned above Brown and Lugo (1990) observed when agricultural fields were replaced with Mahogany (*Swietenia macrophylla*) plantation, after 50 years of this conversion SOC increased only 40 g m^{-2} $year^{-1}$ within top 25 cm, which was half of the secondary forest. Jenkinsen (1971) reported that when moist temperate forest was converted to pine plantation it lost 6.3 g SOC m^{-2} $year^{-1}$ within top 40 cm soil. This clearly indicates that land-use type such as forests have higher potential to sequester soil C compared to tree populations or treeless systems. It can be argued that due to forest like structure and composition (Kumar, 2006), homegarden may also have the potential to sequester more soil C than tree plantation such as rubber (*Hevea brasiliensis*) and coconut (*Cocos nucifera*) and treeless systems such as rice (*Oryza sativa*)-

paddy field. Wauters et al. (2008) found 101 Mg ha^{-1} and 52 Mg ha^{-1} SOC within top 60 cm in rubber plantations of Brazil and Ghana, respectively. Zhang et al. (2007) reported that in China the SOC content of rice-paddy fields in a wide range of soil varied between 38.2 to 44.2 Mg ha^{-1} within 1m soil profile. The SOC values of forests from different geographic regions had higher values than both the rubber and rice-paddy (Lal, 2005). However, available SOC data are inadequate on homegardens to make a valid comparison with other land-use types.

Root Activity and Soil Carbon Sequestration

Roots make a significant contribution to SOC (Strand et al., 2008). About 50% of the C fixed in photosynthesis is transported belowground and partitioned among root growth, rhizosphere respiration, and assimilation to soil organic matter (Lynch and Whipps, 1990; Nguyen, 2003). Roots help in accumulation of SOC by their decomposition and supply C to soil through the process known as rhizodeposition (Rees et al., 2005; Weintraub et al., 2007). Increased production and turnover rates of roots lead to increased SOC accumulation following root decomposition (Matamala et al., 2003). Rhizodeposition, on the other hand is an activity of live roots and is a collective term for several activities such as exudation, secretion, sloughing and lysis (the breaking open of a cell by the destruction of its wall or cell membrane), and root tissue senescence (Rees et al., 2005). Rhizodeposition primarily affects soil organic C accumulation by influencing soil microbial activity (Weintraub et al., 2007). Root exudation is a mechanism under rhizodeposition (Rees et al., 2005) and in natural conditions, the largest source of labile C inputs to the soil comes from root exudates (Bertin et al., 2003; Hutsch et al., 2002; Kuzyakov, 2002).

Roots are the sources of SOC in deeper soil depth, where they are better protected. Some trees have rooting depth as deep as 60 m or more (Akinnifesi et al. 2004). The deeper root development accumulates C at lower depths and the soil at lower depths is better protected from the disturbances leading to longer residence time (Fontaine, 2007). Minimal physical disturbance and reduced microbial activity caused by lack of supply of fresh C, increases the mean residence time (MRT) of SOC at deeper depths (Fontaine, 2007). However, most of the soil C study investigates only top 50 cm or less, underestimating the potential of subsoil C sequestration.

Soil Carbon Fractions and Stability

The C sequestration capacity of a soil is determined by its structural stability, i.e, the ability of the soil to protect its unit forms from external forces (Six et al. 2002). Structural stability is related to the aggregation of soil particles. Depending on their size, soil aggregates are usually termed as macroaggregate (> 250 µm diameter) and microaggregates (< 250 µm diameter) (Edward and Bremener, 1967; Tisdall and Oades, 1982). The process of soil aggregation (development of aggregates) for retaining the soil organic C (Carter, 1996) can be divided into short-term storage in macroaggregates and long-term storage in microaggregates (Six et al., 2002). Macroaggregates are comparatively vulnerable to breakdown due to external forces. In contrast, microaggregates are more stable in storing C (Six et al. 2000). The well-known smallest size-fraction class is the silt- and clay fractions of the soil (< 53 µm). This class have more stable SOC than in larger-size fractions (macroaggregates > 250 µm diameter) (Tiessen and Stewart, 1983). Organic C inside the microaggregates have lower decomposition rate than the organic C inside the macroaggregates. This is primarily because the organic (humic) molecules become amalgamated with aluminum- and iron oxides, and clay minerals during the formation of microaggregates (Brady and Weil, 2007). Microaggregates are connected to each other or substances like sand or decomposing organic matter to form macroaggregates. Soil size-fractionation is associated with these aggregate sizes (Christensen, 1992). Storage of SOC and aggregation is determined by the land-use, soil, climate, and management practices (Carter, 1996). Depending on the organic matter quality (Martens, 2000) and aggregation (Six et al., 2000), the residence time of components varies (Carter, 1996).

Homegardens

Homegardens, defined as a land-use system where multipurpose trees are grown in intimate association with shrubs and herbaceous species and livestock around the homesteads (Fernandes and Nair, 1986), are one of the oldest and major forms of tropical agroforestry systems (Kumar and Nair, 2004). Homegardens are distributed in different part of the tropics, primarily in Asia, Africa and South America (Ruthenberg, 1980; Anderson, 1993; and High and Shackleton, 2000, Nair and Kumar, 2006). In Bangladesh, Sri Lanka, and Indonesia, homegardens cover 0.54, 1.05, and 5.13 Mha of land, respectively (Kumar, 2006). In Kerala, there are 5.4 million small operational holdings (average size 0.33 ha) covering an area of 1.8 Mha and about 80% of these are homegardens (Govt. of Kerala, 2008), therefore this state is estimated to have 4.32 million homegardens covering 1.33 Mha of land (Kumar, 2006).

The value and usefulness of homegardens are well accepted. They have provided sustenance to millions of farmers, and prosperity to some, around the world for centuries (Nair, 2001). The basic objective to maintain homegarden is to ensure the supply of products such as food, fuel, fodder, medicines, construction materials, besides providing monetary income to the owner (Soemarwoto, 1987; Kumar and Nair, 2004). Food production is a basic function of homegardens and they meet the basic staple food needs of the household (Kumar and Nair, 2004). Available data indicate homegarden food supply contributes 3 – 44% of total calorie and 4 – 32% of the protein intake (Torquebiau, 1992). Research shows that homegardens are also a significant source of timber, fuelwood, and non-timber forest products. For example, in Kerala, 74 – 84% of wood requirements come from the homegardens (Krishnakutty, 1990) and in Bangladesh 85 – 90% of the fuelwood collected come from homegardens (Leuschner and

Khaleque, 1987). Non-timber forest products such as medicines, gums, construction materials, resins, organic chemicals, and leaf manure are provided by the homegardens to sustain the households (Kumar and Nair, 2004). Generation of income and employment are the other major aspects of the homegardens. In West Java, Indonesia, up to two-thirds of the homegarden products were sold (Jensen, 1993) and 6.6 – 55.7 % of total family income was generated from homegardens (Soemarwoto, 1987).

Apart from the economic and ecological benefits, homegardens deserve recognition for their social services. Homegarden promote gender equality by providing *in situ* work environment. They provide cash income, nutrition, stability and integrity of the household and reflect the cultural and societal status of the owner. The spontaneous exchange and sharing of products of homegardens foster amiability among members of the local community and strengthen societal bonds. In spite of these advantages, homegardens have not received adequate appreciation among development planners and policy makers because of the single-commodity systems that have often been the focus of development projects.

The combined effects of social, economic and cultural changes that are affecting the biophysical and socioeconomic characteristics of the homegardens pose a threat of extinction of this age-old land use system (Kumar and Nair, 2004). The threat is multidimensional and ever-increasing leading from fragmentation of the homegarden to the replacement of it. Economic issues such as commercialization and changes in market demand and orientation are converting homegardens to lucrative monocultures. In Kerala, homegardens are being replaced by rubber and coconut stands for better economic return (Ashokan and Kumar, 1997). Abolition of homegardens is causing the loss of species, which is one of the major environmental issues of this century. Socio-cultural changes such as adoption of new patterns of behavior and changes in outlook due to globalization, industrialization, urban-employment opportunities, and altered views of societal prestige are causing disrespect to traditional ways of life of which homegardens are an integral component (Kumar and Nair, 2004). Due to a serious lack of adequate scientific information about the claimed benefits of the homegardens, this practice remains unable to protect itself from alterations and obliterations. Research on homegarden is required to investigate its "hidden" ecological benefits such as CSP and explore the ways to generate additional income.

Homegardens are believed to have higher CSP compared to many tropical land-use systems. High species diversity is claimed to promote C sequestration (Vandermeer, 1989; Tilman et al., 1997; Huston and Marland, 2003; Kirby and Potvin, 2007) and therefore, species-rich homegardens may have greater potential to sequester C than mono-crop production systems, primarily due to their high plant diversity resembling mature forests (Kumar, 2006). Carbon sequestration, carbon conservation, and carbon substitution are the three ways agroforestry can contribute to C sequestration (Montagnini and Nair 2004). Most agroforestry systems feature one or two of these mechanisms but, the homegardens are postulated to have the potential to contribute to C sequestration through all three mechanisms (Kumar, 2006). Homegardens have the potential of ex-situ storage of C in form of different products (Kumar et al., 1994) similar to managed plantations or forests. Homegardens also ensure the long-term storage of C s through their permanent and long-lasting nature. Permanence of the sequestered C is a major concern in LULUCF special report) (UNFCCC, 2007) and homegarden systems are permanent in nature with no complete removal of the biomass (Gajaseni and Gajaseni, 1999). Although homegardens promote C sequestration through multiple mechanisms, this study explores only the soil CSP of homegardens, which has remained understudied.

This study on soil CSP of homegardens may have some application in the context of Kyoto protocol. Clean Development Mechanism (CDM) under Kyoto protocol allows industrialized countries to develop GHG mitigation projects in developing and less developed countries (IPCC, 2007). Countries hosting such projects get economically benefitted, by selling the sequestered C to the developed industrialized nations who are under the agreement of the Kyoto protocol. Tropical homegardens may qualify as potential C sinks and draw external investments to help the society economically and environmentally and at the same time ensure its own future as well. With research generated information to support the CSP of homegardens, along with policy enablement, homegardens may reward the owners with carbon credits, followed by monetary prosperity.

Socioeconomic Factors, Farming Practices, and Carbon Sequestration

Several agricultural practices such as tillage, plant residue management, and manure and fertilizer application have been identified to affect C sequestration (FAO, 2004). The extent of influence of these practices on C sequestration depends on land-use type, crop species, ecological and social factors, and the management intensity of the practices. Several studies have been conducted to explore the effects of these agricultural practices on C sequestration and the biophysical factors that affect these practices (Lal et al., 1989; Li et al., 1994; Lal et al., 1999; Whalen and Chang, 2002). However, little information is available about the role of underlying social factors in influencing the farmers' decision with these practices. Socioeconomic and demographic factors affect agricultural management decisions (Seabrook, 2008). Factors such as income, education, age, size of family, and connection to stakeholders are important in this regard. However, in commercial agricultural systems the effects of social factors on management practices are difficult to measure. In such systems, the management decisions are made with a goal of higher production and profit maximization, which undermines the influence of socioeconomic and demographic factors. An ideal place for a study like this would be an agricultural system, which is not solely done for commercial production, but still has an economic purpose and the goal of subsistence use. Homegarden is one such system, where profit maximization by selling its products is not the primary objective and socioeconomic and demographic factors have a strong effect on farmers' decision with the management practices.

Most homegardens in Kerala are not the only source of income to the farmers' family. Unlike rice-paddy and other labor-intensive land-use systems, most of the homegardens need comparatively less labor input, leaving the farmers' spare time and other resources to generate additional income from other sources. Where homegardens are not the main source of income, farmers may not follow the extensive and expensive recommended package of practices. Some of the farming practices that might affect C sequestration are discussed below.

Tillage

Tillage is an important practice that decreases C stocks in agricultural soils (Lal et al., 1989; Carter, 1993). Soil aggregates are vital for soil C storage (Six et al., 2000), but tillage causes destruction of aggregates and release of soil C. The effects of tillage vary from site to site (Buschiazzo et al., 2001). In homegardens, tillage is common where farmers grow vegetables and non perennial/non-woody crops like banana or medicinal/spice crops. This practice is more predominant in the homegardens used for commercial or semi-commercial purposes and needs labor input. On the other hand, if homegarden is not the primary source of income economically constrained homegarden owners may neglect tillage. This way soil C storage can be affected by socioeconomic factors like sources of income and economic condition of the farmer.

Plant Residue

Plant residues provide resources for the production of soil organic matter (Payan et al., 2007; Marhan et al., 2008). Lal (1997) reported about 15 % of plant residues get converted to

SOC. Campbell et al. (2000) observed that 9% (frequently fallowed systems) to 29 % (continuously cropped systems) of residue C converted to SOC in semiarid regions of Canada. However, this conversion rate depends on several factors like temperature, moisture, type of crop, and quantity of residue. Applying plant residues as well as removing them is common in the homegardens of Kerala. However, it primarily depends on factors such as the traditional belief and economic state of the farmer.

Manure

Manure application increases the formation and stabilization of soil macroaggregates (Whalen and Chang, 2002) and development of particulate organic matter (Kapkiyai et al. 1999). Manure is more resistant to microbial decomposition than plant residues, thus for the same quantity of C input, C storage could be higher with manure application (Jenkinson, 1990). Li et al. (1994) found that manure yielded the largest amount of C sequestered over a range of soils and climatic conditions, although factors like donor species and soil texture were important. In the homegardens, farm animals are common and their dung and litter are the main raw materials for the production of the Farmyard Manure (FYM) (termed as manure henceforth). The supply of raw materials in the HGs ensures the application of manure to some extent. However, some farmers apply more manures that is purchased from outside. These decisions, therefore, might be influenced by factors like economic importance of homegardens, sources of income, influence of stakeholders, and ownership of cattle.

Inorganic Fertilizer

The primary goal of fertilizer application is to increase plant production; but any increase in biomass promotes the scope of C sequestration. Therefore, fertilizer application has proved to be a successful method for enhancing C sequestration (Lal et al., 1999). In contrast, application of nitrogenous fertilizers is considered as a source of GHGs, because they generate nitrous oxide

(N_2O), which is a GHG (Robertson, 2000). In Kerala homegardens, three distinct classes of farmers are observed in terms of the extent of fertilizer application to their homegardens: those who apply inorganic fertilizers at high and moderate rates and those who do not apply any. The decisions of fertilizer application are influenced by factors such as the level of education and economic status of the farmers, and the role of the stakeholders. Generally, educated farmers, who have sources of income other than homegarden, have a tendency to neglect their homegardens and avoid applying fertilizers to homegardens. On the other hand, less educated farmers with a commercial goal may apply surplus fertilizer. Therefore, factors such as education and income from homegarden may play a decisive role in the amount of fertilizer applied.

Selection of Species

The CSP of a system varies according to the type of plants included in it (Post and Kwon, 2000). The more the biomass, the more will be the C storage, thus trees may have a better CSP than annual herbs. Montagnini and Nair (2004) reported that the tree component of agricultural systems is a potential sink for atmospheric C due to their fast growth and productivity. According to Kursten (2000), by adding trees, the system can increase the C storage capacity of the system. Carbon sequestration is also influenced by the tree species (Lemma, 2007). Chen (2006) observed that C sequestration increased with tree species diversity; however, Kirby and Potvin (2007) could not find any such effect. Different tree species influence soil C sequestration through the differences in litter production and root activity. Issac and Nair (2006) observed differences in litter production among the six tree species from Kerala homegardens. Several researchers have observed difference in rooting pattern among trees species (Huiquan et al., 1992; Etoh et al., 2002; Crow and Houston, 2004), which could explain differences in soil CSP.

Synthesis

Literature indicates the importance of tropical agroforestry systems such as homegardens in mitigating global warming through soil C sequestration. Due to the relative newness of agroforestry, only limited information is available about soil CSP of different agroforestry systems and almost no information is available on the role of homegardens in stocking C in soil. Various authors have suggested that homegarden characteristics such as species richness, permanence, and presence of significant numbers of trees may result in high rates of C storage in homegardens compared to monocultures. Due to the difference in species richness in homegardens of various size classes, their CSP may also vary with holding size. In addition, the effects of socioeconomic factors on farmers' decision with respect to management practices are well established; however, no information is available as to how these practices affect soil C sequestration. The potential of C sequestration can be beneficial both environmentally and economically and may provide a win-win situation for a large number of stakeholders. The wide distribution of homegardens throughout the tropics and the opportunity from CDM encourage the study by extrapolating and extending the applicability of results for the benefit of the individual homegarden owner as well as to the entire homegarden community. Based on the current state of literature and knowledge gaps, several hypotheses can be formulated. They are,

1. Soil CSP of homegardens is comparable to that of tree-based land-use systems, but higher than that of treeless monocultures.

2. Soil C accumulation potential of homegardens is directly proportional to plant species density; consequently, smaller homegardens that have higher species density have higher soil CSP compared to larger homegardens.

3. Socioeconomic factors influence farmers' decisions with the homegarden management practices that have an influence on soil C sequestration.

Table 2-1. Floristic elements reported from homegardens of tropical regions of the world.

Region/location and the floristic spectrum samples	Number of species		Source
	per garden	Total for geographic location	
South Asia			
Pitikele, Sri Lanka (edible species)	–	55	Caron (1995)
Kandy, Sri Lanka (woody species)	4–18	27	Jacob and Alles (1987)
Thiruvananthapuram, Kerala, India	–	107	John and Nair (1999)
Kerala, India (woody species)	3–25	127	Kumar et al. (1994)
Bangladesh (perennial species)	–	92	Millat-e-Mustafa et al. (1996)
Kerala, India	–	65	Nair and Sreedharan (1986)
Southeast Asia			
Northeastern Thailand	15–60	230	Black et al. (1996)
Chao Phraya Basin, Thailand	26–53	–	Gajaseni and Gajaseni (1999)
West Java	–	602	Karyono (1990)
Central Sulawesi, Indonesia	28–37	149	Kehlenbeck and Maas (2004)
Cilangkap, Java	42–58	–	Yamamoto et al. (1991)
South/Central America & the Caribbean			
Quintan Roo, Mexico	39	150	De Clerck and Negreros-Castillo (2000)
Cuba	–	80	Esquivel and Hammer (1992)
Central Amazon (woody species)	–	60	Guillaumet et al. (1990)
Belize	30	164	Levasseur and Olivier (2000)
Masaya, Nicaragua	–	324	M´endez et al. (2001)
Santa Rosa, Peruvian Amazon	18–74	168	Padoch and de Jong (1991)
Yucatan, Mexico	–	133–135	Rico-Gray et al. (1990)
Cuba	18–24	101	Wezel and Bender (2003)
Other regions			
Southern Ethiopia	14.4	60	Asfaw and Woldu (1997)
Bungoma, Western Kenya	–	253	Backes (2001)
Soqotra island, Yemen	3.9–8.4	–	Ceccolini (2002)
Bukoba, Tanzania (woody species)	–	53	Rugalema et al. (1994)
Central, eastern, western and southern Ethiopia	–	162	Zemede and Ayele (1995)

Source: Kumar and Nair (2004)

CHAPTER 3
STUDY AREA AND LAND-USE TYPES

Description of the Region

Location

This study was conducted in the state of Kerala, India. With the high level of recognition of the ecological and socioeconomic sustainability values of homegardens in this state (Nair and Shreedharan 1986; Jose and Shanmugaratnam 1993; Kumar et al. 1994), Kerala offers a good opportunity to study the development trends in homegardens (Peyre et al. 2006). There are about 5.4 million small operational holdings covering a total area of 1.8 Mha in Kerala, and apparently about 80% of them are homegardens (Govt. of Kerala, 2008), therefore the state is estimated to have 4.32 million HGs covering 1.33 Mha of land (Kumar, 2006). Other major land-use types of Kerala include forest, rice (*Oryza sativa*) -paddy fields, rubber (*Hevea brasiliensis*) plantations, and mixed plantations of coconut (*Cocos nucifera*).

Kerala state is located in southwestern part of peninsular India (Fig. 3-1) and covers an area of 38,863 km^2, which is approximately 1.18% of the whole country. Forested land covers 10,292 km^2 including 1887 km^2 of private forests (The Government of India, 1993). The forests in Kerala are classified as tropical wet and semi-evergreen, tropical moist deciduous, tropical dry deciduous, montane sub-tropical, and forest plantations. The normal average annual rainfall of Kerala state is 3107.5 mm. The coastline, bounded by the Arabian Sea to the west, runs 580 km. The soils of Kerala state can be broadly classified as Oxisols (50% by area), Inceptisols (25%), Entisols (20%), and Alfisols (5%) (Nair and Sreedharan, 1986). The state is administratively divided into 14 districts, and each district subdivided into various '*Panchayats*' (subdivisions). Madakkathara *Panchayat* in the district of Thrissur in the central part of the state, where the Kerala Agricultural University (KAU) is located, was selected for this study. Thrissur district is bordered by Malappuram district in the north, Palakkad district to the east, and Ernakulam district to the south. It lies between 10º 0’ and 10º 47’ north latitudes, and 75º 55’ and 76º 54’ east longitudes. Madakkathara *Panchayat*, located at the northeast part of Thrissur district, extends over an area of 2504 ha and lies between 10º 32’ and 10º 36’ north latitudes, and 76º 14’ and 76º 18’ east longitudes. Within the Madakkathara *Panchayat*, three villages (Pandiparambu, Chirakkakode, and Vellanikkara) were chosen for the study based on the availability of various land-use types that were considered important for the study.

Soil

The parent material of the soils of Madakkathara *Panchayat* is granite gneissic rocks formed by the weathering of charnokites, laterites transported and deposited as soils of sedimentary origin that are low in bases. The soils of Madakkathara *Panchayat* have been classified into eight different local series (Govt. of Kerala, 2005). Four of the series (Kozhukkuly, Kottala, Mulayam, and Maraickal) fall under the order Inceptisols that covers 75% of the land. Two of the series, Velappaya and Anjur are Ultisols covering 7% of the land. Series Madakkathara is under Alfisol and series Kolazy comes under the order Entisol, cover 17.5% and 0.5%, respectively (Table 3-1). The soils of the study areas selected from the three villages (primarily Kozukkuly and Kottala series), as well as the coconut grove at KAU campus and the sampling sites from the forest fall under the order Inceptisols. Detailed soil taxonomy and characteristic are presented in Table 3-1.

Topography

Madakkathara *Panchayat* consists of lowlands (< 20m above mean sea level (MSL)), mid-lands (20 to 100 m above MSL), mid-uplands (100 to 300 m above MSL), and uplands (100 to 300 m above MSL). The highest point is 396 m above MSL and lowest point 4 m above MSL (Govt. of Kerala, 2005). The slope is from NE to SW. The study villages and the KAU coconut plantation are located in the lowland area with slopes varying from 1 – 5 %, but the forest is located in the mid-uplands and uplands region.

Climate

Madakkathara *Panchayat* has a humid tropical climate with two monsoon seasons. About 65% of the rainfall is received from the so-called "southwest monsoon" during June to August and 30% from the "northeast" monsoon during October − November. Mean annual rainfall is 2783 mm. Mean maximum and minimum temperature is 32º C and 23.3 º C, respectively, with the average annual temperature of 27.7 º C. The mean humidity and evaporation of the area are 74.83% and 105.35 mm, respectively (Govt. of Kerala, 2005).

Land-Use and Vegetation

The *Panchayat* has diverse types of vegetation and a wide range of land-use types. Out of the total area of the *Panchayat*, 588 ha are under forest, 1421 ha are dry lands and rest (495 ha) are wetland. The major crops and land-use types are rice-paddy fields, rubber plantations, intercropped coconut groves, and homegardens. Crop-wise land-use statistics are presented in Table 3-2. Majority of the land holding is marginal and only 30% of the population actually depends entirely on agriculture for their livelihood. The total number of agricultural holdings in the *Panchayat* is 3100, of which 2956 are less than 1 ha, 102 are between 1− 2 ha, and 42 are more than 2 ha (Govt. of Kerala, 2005).

Socio-cultural Conditions

The population of the Madakkathara *Panchayat* is 20964 (1991 census), of which 10176 are male and 10788 are female (male: female = 1: 1.06) (Govt. of Kerala, 2005). The Panchayat and the whole Thrissur district have been inhabited since time immemorial. Followers of three major religions (Hinduism, Islam, and Christianity) have lived there for generations, all maintaining their own cultural and religious customs and traditions and yet all living in complete social and communal harmony. The city of Thrissur, the capital of Thrissur district, is known as the cultural capital of Kerala. Madakkathara *Panchayat*, where the main the campus of Kerala Agricultural University is located in close proximity to the city, and is influenced by the city's cultural environment. The literacy rate of the *Panchayat* is 85.4%, which is fairly high compared to other parts of India. The local language is Malayalam, which is also the state language of Kerala. The main occupation of the people of Madakkathara *Panchayat* is agriculture: about 15% farmers and 30% agricultural laborers. Other sources of income include industries such as textile, engineering wood, rubber, plastic, and food processing.

Description of Land-use Systems of Kerala

In addition to the homegardens, the major land-use in Madakkathara *Panchayat* in terms of total land used consists of cultivation of coconut, rice-paddy, and rubber (Table 3-2).

Homegarden (HG)

Homegarden (Fig. 3-2A) is the most important agroforestry system in Kerala. The area statistics on the extent of HGs in Thrissur district are not available; however, the local experts estimate that in this district 74% of cultivated land falls under homegardens (B. M. Kumar, personal communication, June, 2006). By definition, homegardens are intimate, multistory combinations of various trees and crops, sometimes in association with domestic animals, around the homesteads (Fernandes and Nair, 1986; Kumar and Nair, 2004) and are rich in plant diversity next to natural forests (Swift and Anderson, 1993). The multilayered canopy configurations and a mixture of diverse but compatible plant species are the most prominent characteristics of homegardens (Fernandes and Nair, 1986). Although the arrangement of species apparently looks random, the HG structures are planned carefully with specific objectives. The canopy structure generally followed the descriptions as set forth by Fernandes and Nair (1986) and Nair (1993). Homegardens generally have 3 layers or canopies, lower, intermediate, and the upper. The lower layer consists of herbaceous plants, which may again be divided in two categories. The lowermost layer consists of vegetable and medicinal herbs that are below 1 m. Layer above that contains plants that are within 1 – 3 m in height, such as banana (*Musa* spp.), cassava (*Manihot esculenta*), yams etc. The intermediate level that is within 5 – 10 m is dominated by fruit trees like mango (*Mangifera indica)*, cacao (*Theobroma cacao*) and short varieties of palms etc. that are grown or still growing. The upper layer consists of two strata: the uppermost stratum that contains trees over 25 m and the upper-medium stratum that contains trees between 10 – 20 m. Trees such as coconut and arecanut (*Areca catechu*) are common in the uppermost layer and trees such as jackfruit (*Artocarpus heterophyllus*) and breadfruit (*Artocarpus altilis*) are common in the upper medium layer. However, the structure of HGs is not uniform or static; it changes with the growth and replacement pattern of species.

Plant species in homegardens are chosen carefully for their utility value, and almost every species in a HG is useful in some way based on the need of the homeowner. The utility value categories may include food, timber, medicinal, fuelwood, aesthetic value, and special products (gum, resin, bark etc.). Some examples of different crops are given (below) from the homegardens of Kerala, India. The most important category is the food producing crops that can again be divided in two major categories, vegetables (herbaceous crop) and fruits (mostly tree crops). Some common homegarden vegetables of Kerala are beans, cassava (*Manihot esculenta*), chillies (*Capsicum* spp.), ginger (*Zingiber officinale*), okra (*Abelmoschus esculentus*), sweet potatoes (*Ipomoea batatas*), turmeric (*Curcuma longa*), yams etc. Common fruit (and nut) crops found in HGs are arecanut, banana, cashew (*Anacardium occidentale*), coconut, jackfruit, and mango. In addition, there are some crops that are not consumed directly and cultivated primarily for cash generation. The crops under this category are black pepper (*Piper nigrum*), cardamom

(*Elettaria cardamomum*), clove (*Syzygium aromaticum*), nutmeg (*Myristica fragrans*), and vanilla (*Vanilla planifolia*). Timber producing trees such as *kodampuli* (*Garcinia cambogia*), mahogany (*Swietennia macrophylla*), *maruthu* (*Terminalia paniculata*), *matti* (*Ailanthus triphysa*, teak (*Tectona grandis*), and *veeti* (Rosewood) (*Dalbergia latifolia*) are very common. Medicinal plants include species such as *ashoka* (*Saraca asoca*), *brahmi* (*Bacopa monnieri*), *chakkarakolli* (*Gymnema sylvestre*), long pepper (*Piper longum*), neem (*Azadirachta indica*), *nitya kalyani* (*Catharanthus roseus*), *poovamkurinnila pacha* (*Vernonia cineraria*), *tulasi* (*Ocimum sanctum*), *ung* (*Pongamia pinnata*), and *vicks ela* (*Mentha piperita*). The majority of the tree species in homegardens have multiple uses. Trees used for obtaining fuelwood and other products generally have other uses such as fruit and nut production. Some trees with special products are rubber (*Hevea brasiliensis*) (latex), ornamental palms (leaves), sandalwood (*Santalum album*) (oil), etc. Aesthetic plants are generally planted in the front yard of the HGs, near the entrance to the home. Popular ornamental or aesthetically valued plants are *Coleus* spp., *Croton* spp., *Dieffenbachia* spp., *Hibiscus* spp., *Ixora* spp., ornamental palms, and numerous flowering annuals.

Owners of all selected HGs were surveyed to gather information about the history, management practices, and the biodiversity of their gardens (detailed methodology of the survey is discussed in Chapter 5 and Chapter 6). Intensity of management practices varied with the surveyed HGs. Almost all of the homegarden owners apply plant residue, manures, and fertilizer. The plant residues are generally obtained from the HG itself and if needed external sources are also exploited. Manure is primarily produced at home. Most of the HGs have household animals and that makes the production of cattle manure (or Farmyard Manure) convenient. However, buying manure from the market and obtaining it from the peers are also very common. Fertilizer application is an important practice in the HGs. Use of fertilizer varies with the type of crop, soil, and the economic condition of the farmers. Generally, the amount of fertilizer applied to HGs is lesser than that for field crops. The total fertilizer consumption for the state of Kerala for 1999 – 2000 was 211,632 Mg, of which 87,061 Mg was N, 43,975 Mg was P_2O_5 and 80,326 Mg was K_2O (Kerala Department of Agriculture, 1999 – 2000). No statistics were found for the fertilizer usage specifically in HGs. Tillage is another important management practice in the homegardens. However, the intensity of tillage varies from homegarden to homegarden. Tillage in HGs is generally done manually. In addition, manual weeding is also a common practice in the HGs.

The size of HGs of Kerala varies widely (Nair, 1993; Mohan et al., 2007). The holding size of HGs is likely to affect the amount of C sequestered in the system. Previous research indicates that smaller homegardens had higher species diversity (Kumar et al., 1994) and higher species density (Mohan et al., 2007). High species assemblage are likely to harbor species with strong response to the resources compared to systems with limited species richness (Tilman et al. 1997) and may promote a resource use efficient system that favors greater net primary production (Vandermeer, 1989), which in turn promote C sequestration in homegardens (Kumar, 2006). However, how HG size affects C sequestration is not well understood.

Forest (FR)

Approximately 25% of the state (940,000 ha) is under forest (Fig. 3-2B) (Land Resources of Kerala State, 1995). Madakkathara *Panchayat* has 588 ha of forest land located in its northeastern region. The type of the forest is moist deciduous. Forest in the region is reported to contain more than 100 tree species (B. M. Kumar, personal communication, June, 2006). Some common deciduous species are *Dillenia pentagyna, Tabernaemontana heyneana, Tectona grandis*, and *Xylia xylocarpa.* In the dense forests, often there is dominance of evergreen species such as *Bridelia* spp., *Grewia* spp., *Lagertroemia* spp., *and Terminalia* spp. (Kumar and Deepu, 1992). The sites surveyed were 175m high from MSL and were in close proximity to the study villages.

Rubber Plantation (HB)

Rubber (Fig. 3-2C) is the economically most attractive cash crop in Kerala. In Madakkathara *Panchayat* 280 ha (Table 3-2) (20% of total cultivable dry land area) of land is under rubber cultivation. The sites selected for this study had mature rubber trees (under tapping) in plantations that were more than 50 years old. However, the rotation length varied among plantations. The rubber trees are usually cultivated in rotations of 35 years and at the end of each rotation, the land is cleared and the area is replanted after six months. The felled logs are moved out and sold, but the small branches, leaves, and, of course, the roots are left on site to decompose (or in some cases removed by firewood collectors). The tree density varied from 450 to 500 trees per hectare and accordingly the spacing was about 4.5 m × 4.5 m. Most of the rubber farmers follow the KAU- recommended package of practices (RPP) for cultivation. General fertilizer recommendation for mature rubber under tapping is 10:10:10 (N: P_2O_5: K_2O) mixture at 300 kg ha^{-1}, but the popular trend in the study areas was to use complex fertilizers of grades 17:17:17 at 175 kg ha^{-1}. Fertilizer is applied in single dose or two split doses. In some plantations cover cropping is practiced and common cover crops in Madakkathara region are *Calapagonium mucanoides* and *Pueraria phaseoloides.* Weeds such as *Chromolaena odorata, Lantana aculeata, Mimosa pudica,* and *Imperata cylindrica* are common in rubber plantations. Growing cover crops is a measure of controlling weeds at the early stages of rotation, but in mature plantations weeds are controlled manually or chemically. Common herbicides are Diuron, Simazine, Cotoran (pre-emergent) and Paraquat, 2, 4-D, Glyphosate (post-emergent). Mechanical tillage is practiced once before the planting of a crop (at the beginning of a new rotation). All of the selected rubber plantations had histories of tree cultivation in the land.

However, the type of species varied and included teak, cashew, and coconut. Average yield is 1400 kg dry rubber ha^{-1}.

Coconut Grove (CN)

Kerala derives its name from coconut (*kera* in Sanskrit). It is the land of coconut palms (Fig. 3-2D), which are ubiquitous throughout the state including in almost all HGs. Coconut production, mostly in small holdings of less than 1 ha in size, is an important land-use in Kerala with approximately 23% of the total area of the state (0.9 Mha) under coconut cultivation (Land Resources of Kerala State, 1995). The area under coconut in Madakkathara *Panchayat* is reported to be 608 ha (43% of total cultivable dry land area) (Table 3-2). However, coconuts are seldom cultivated as a single-species stand and much of that area represents coconuts in HGs and other plant associations. Indeed, sole stands of coconuts are difficult to find in Thrissur district. Therefore, a coconut plantation of KAU at Vellanikkara was used for this study. Information about the history and management practices of the plantation was collected from the university. These plantations were 30 years old; the palms planted at 8 m × 8 m spacing had been maintained according to the guidelines of KAU recommended package of cultivation practices. The square planting system was followed that contained 150-160 plants per hectare. Recommendation for planting is to dig pits of 1.2 m ×1.2 m × 1.2 m size for each seedling and mixing the husk, silt, sand and topsoil to entire bole of palm. This pit forms a basin around the palm and further management takes place based on the basin. Mulching the basin is done using external plant residues and coconut plant parts, which in turn generates soil organic matter. The fertilizer recommendation followed is application of 0.34 kg N, 0.17 kg P_2O_5, and 0.68 kg K_2O per palm/year. Fertilizers are applied in one or two split doses. Periodic manual weeding is practiced in the coconut basins of the selected sites. Average annual yield per palm is 42 nuts.

Rice-Paddy Fields (OS)

Rice-Paddy (Fig. 3-2E) is the main cereal crop in Kerala covering 14% of total land area of Kerala (537610 ha) (Land Resources of Kerala State, 1995). In Madakkathara *Panchayat*, rice is mostly cultivated in wetlands and lowlands covering an area of 278 ha. Owners of all selected rice-paddy fields were surveyed to acquire information about the history, demography, and management practices of their fields. In all of the study sites, rice-paddy cultivation had been practiced for 100 years or more, and land-holdings ranged from 0.12 ha to 0.4 ha or more. Soil sampling was done in December, when the cropping season was *Mundakan* (winter crop), which lasts from September to early January. Before planting of rice-paddy, tillage is practiced 2-3 times using tractors or bullocks. The farmers more or less follow KAU RPP and apply both inorganic fertilizer and organic manure to their crop. The recommended dose for organic manure in the form of farmyard manure or compost is 5 Mg ha^{-1}, which is mixed in the soil while tilling the soil. The recommended dose for fertilizers is 70 kg N, 35 kg P2O5, and 35 kg K2O per ha per season. Five cm of irrigation once in 6 days is adequate. Common weeds include *Cyperus iria, Echinochloa* spp, *Ludwigia presnnis*, *Monochoria vaginalis*, and *Oryza rufipogon*. Weeds are controlled chemically; common herbicides are Butachlor, Thiobencarb, Oxyfluorfen, and Pretilachlor. The average grain yield for the *Mundakan* crop is 2000 kg ha^{-1}.

Table 3-1. Soil taxonomy and characteristics (averaged up to 1 m) of Madakkathara *Panchayat*, Thrissur, Kerala, India.

Series	Order	Suborder	Percentage of total area	Soil Organic Carbon (g $100g^{-1}$)	pH	Soil Particles (g $100g^{-1}$)		
						Sand‡	Silt	Clay
Kozhukkuly	Inceptisols	Tropepets	45	0.99	5.2	35.8	11.4	52.8
Kottala	Inceptisols	Tropepets	22	0.47	5.6	48	17.5	34.5
Mulayam	Inceptisols	Tropepets	6	0.31	6	62	12.5	25.5
Maraickal	Inceptisols	Tropepets	2	0.35	6.1	46	22.5	31.5
			Total **75**					
Velappaya	Ultisols	Ustults	4	0.45	5.6	45.5	25.8	28.7
Anjur	Ultisols	Humults	3	1.2	5.5	49.6	16.8	33.6
			Total **7**					
Madakkathara	Alfisols	Ustalfs	17.5	0.9	5.4	38.3	21.0	40.7
Kolazhy	Entisols	Aquic Ustifluvents	0.5	0.08	6.2	36.3	26.0	37.7

Source: Govt. of Kerala, 2005.

‡ According to the standard classification, sand is particle between 0.05 – 2 mm in equivalent diameter, silt is particle between 0.002 – 0.05 mm in equivalent diameter, and silt is >0.002 mm in equivalent diameter (Brady and Weil, 2007).

Table 3-2. Crop-wise land-use in Madakkathara *Panchayat*, Thrissur, Kerala, India.

	Crop	Scientific Name	Area (ha)
1	Rice-Paddy	*Oryza sativa*	278
2	Coconut	*Cocos nucifera*	608
3	Rubber	*Hevea brasiliensis*	280
4	Pepper	*Piper nigrum*	42
5	Arecanut	*Areca catechu*	112
6	Cassava	*Manihot esculenta*	65
7	Vegetables	-	80
8	Banana	*Musa* spp.	72
9	Pulses	-	25
10	Cashew	*Anacardium occidentale*	80
11	Ginger	*Zingiber officinale*	40
12	Mango	*Mangifera indica*	10
13	Pineapple	*Ananas comosus*	12
14	Sesame	*Sesamum indicum*	45
15	Nutmeg	*Myristica fragrans*	12
16	Turmeric	*Curcuma longa*	32
17	Sweet Potato	*Ipomoea batatas*	9

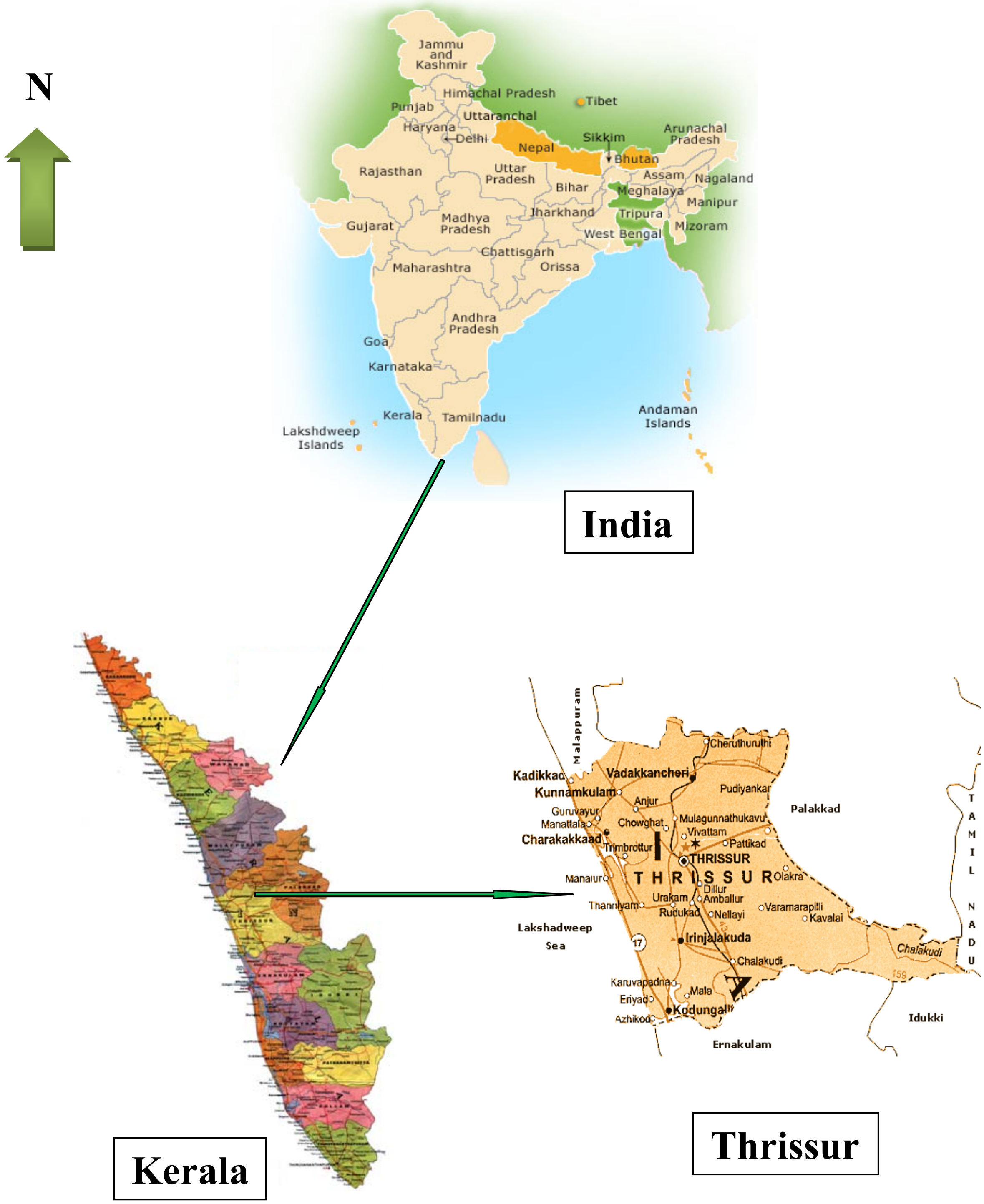


Figure 3-1. Location of the study in India. Source: http://maps.locateindia.com, http://hikerala.googlepages.com. Last accessed July 2008.

Figure 3-2. Images of selected land-use types of Kerala, India. A) Homegarden, B) Forest, C) Rubber Plantation, D) Coconut Grove, E) Rice-Paddy Field. Source: Photograph by author.

CHAPTER 4
SOIL CARBON STORAGE UNDER TROPICAL HOMEGARDENS AND RELATED LAND-USE SYSTEMS IN KERALA, INDIA

Introduction

Global warming is undoubtedly one of the major environmental issues of this century. The increasing concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere is the primary cause of global warming (Intergovernmental Panel on Climate Change -IPCC, 2007). Creation or promotion of carbon (C) sinks in the biosphere is widely accepted as a strategy for reducing the GHG concentrations in the atmosphere. This entails storing of atmospheric C in the biosphere, and it is believed that this can be achieved by promoting land-use practices such as afforestation and reforestation including agroforestry (Montagnini and Nair, 2004). The IPCC special report on Land Use, Land-Use Change and Forestry (LULUCF) shows that net increase in global C stocks are estimated to be 0.026 Pg (billion tons) C year^{-1} for improved agroforest management and 0.39Pg C year^{-1} for agroforestry-related land-use changes in 2010 (IPCC, 2007). Montagnini and Nair (2004) claimed that with proper design and management, agroforestry systems could be effective C sinks. Wright et al. (2001) even suggested that agroforestry would be the only system that could realistically be implemented to mitigate the atmospheric CO_2 through terrestrial C sequestration. In spite of these postulated benefits, the C sequestration potential (CSP) of agroforestry systems remains largely unexplored (Nair and Nair, 2003), especially in stocking soil C.

Soil is an important part of the biosphere in sequestering C (Lal, 2002) and has a higher potential to store C compared to vegetation and atmosphere (Bellamy et al., 2005). Different land-use types have different net primary production, rooting distribution, and quality and quantity of litter (Connin et al., 1997; Jackson et al., 2000), and these factors affect the soil organic carbon (SOC) storage dynamics (Schlesinger et al., 1990). However, the effect of tropical agroforestry systems such as homegardens on soil C sequestration is not well understood. Most of the C sequestration studies have focused on the aboveground biomass such that soil C has remained little studied. A majority of available studies on soil C have addressed the C in top 50 cm of soil (Certini et al., 2004) and C storage below 50 cm remained rather unexplored and are often inadequately quantified in assessments (Sharrow and Ismail, 2004). However, soil sampling depth is an important factor for accounting the CSP of a system (Fontaine, 2007). In a study in West African Sahel investigating SOC up to 1m depth, Takimoto et al. (2008) found substantial amounts of C in lower depths of all land-use systems (parkland, live fence, fodder bank, and abandoned land). Due to lesser disturbance, lack of fresh C and reduced microbial activity C is better protected in deeper soil (Fontaine, 2007). But, little or no information is available about soil C storage in deeper soil layers of systems such as homegardens.

Soil aggregation (development of aggregates) is the process of retaining the SOCC (Carter, 1996) and can be divided in short-term storage in macroaggregates and long term storage in microaggregates (Six et al., 2002). The major and widely accepted particle size classes are > 250 μm diameter (macroaggregate) and < 250 μm diameter (microaggregate) (Edward and Bremener, 1967). Widely accepted smallest size class is silt and clay size fractions (< 53 μm). Storage of SOC and aggregation is determined by the land-use, soil, climate, and management practices (Carter, 1996). Several studies have been done to investigate the partitioning of C storage among the soil fraction-size classes. Some such studies have recently been initiated in agroforestry systems too (Takimoto et al., 2008), but none in tropical homegarden systems.

The accumulation of SOCC depends on the quantity of litter (Lemma et al., 2007) and root activity such as rhizodeposition and decomposition (Rees et al. 2005). Trees with their greater aboveground and belowground biomass compared to shrubs or herbs contributes more to the soil C sequestration. According to Montagnini and Nair (2004) the tree components of agroforestry systems are potential sinks of atmospheric C due to their fast growth and productivity, high and long term biomass stock, and extensive root system. More than half of the C assimilated by trees is eventually transported below ground via root growth and turn over, root exudates, and litter deposition, making soil a significant sink of C. Research indicates that by adding trees in grassland or pasture systems the SOC content can be increased considerably (Reyes-Reyes et al., 2002; Yelenik et al., 2004, Haile et al., 2008). However, the potential of trees in sequestering soil C in systems like homegardens is not well documented.

Homegardens are intimate, multistory combinations of various trees and crops, sometimes in association with domestic animals, around the homesteads (Fernandes and Nair, 1986; Kumar and Nair, 2004). Homegardens are rich in plant diversity and have been ranked top among all manmade agro-ecosystems for their high biological diversity after natural forest by Swift and Anderson (1993). Homegardens have a major contribution in the local subsistence economy and food security in India (Kumar and Nair, 2004) and other tropical areas like Africa, Central America, the Caribbean, and the Pacific Islands (Ruthenberg, 1980; Anderson, 1993; and High and Shackleton, 2000; Nair and Kumar, 2006). Homegardens are speculated to have high CSP due to their forest-like structure and composition, however no research result is available to verify this function (Kumar, 2006), particularly in accumulating C in the soil. High species assemblage of HGs are likely to harbor species with strong resources-utilization characteristics compared with less species-intensive systems (Tilman et al., 1997; Kirby and Potvin, 2007) and may promote a greater net primary production (Vandermeer, 1989), which in turn promote C sequestration. In addition extended growth due to competition among spices (Kumar and

Divakara, 2001), species specific effects on soil microbial community through differences in root exudates (Klein et al., 1988; Vancura ,1964) and litter quality (Gallardo and Merino, 1993), influence the C sequestration (Rees et al., 2005).

Kerala state in the southwestern part of India is well known for its traditional homegardens. With the high level of recognition of the ecological and socioeconomic sustainability values of homegardens in the state (Nair and Shreedharan, 1986; Jose and Shanmugaratnam, 1993; Kumar et al. 1994), Kerala offers a good opportunity to study the development trends of homegardens (Peyre et al. 2006). There are about 5.4 million small operational holdings covering a total area of 1.8 Mha in Kerala, and apparently about 80% of it is homegarden (Govt. of Kerala, 2008), therefore the state is estimated to have 4.32 million HGs covering 1.33 Mha of land (Kumar, 2006). Apart from homegardens other common tropical land-use systems in Kerala are forest, rubber (*Hevea brasiliensis*) plantations, mixed plantations of coconut (*Cocos nucifera*), and rice (*Oryza sativa*)-paddy fields. According to reports of Govt. of Kerala (2008), in out of total 3886300 ha of Kerala (including water bodies), forest area is 1112500 ha, of which 410000 ha (10.5 % of the state) is under moist deciduous forest. Coconut (in mixed cropping) and rubber covers an area of 899000 ha (23% of the state), and 473000 ha (12% of the state), respectively. In Kerala, rice-paddy covers an area of 350000 ha (9% of the state) (Govt. of Kerala, 2008). In spite of their wide distribution in Kerala, soil CSP of these land-use systems is inadequately investigated. These four land-use systems along with the homegardens globally cover a considerable portion of the land and hold a potential of storing a great amount of soil C. However, no study has compared them to see to what extent their C sequestration capacity differs. The study locations in Kerala offer all the above mentioned land-use systems in the same vicinity under the similar agro-climatic conditions. Therefore, the study from such a location would give a better opportunity to assess the influence of land-use systems on soil C compared with studies involving different systems from locations of diverse agro-ecological conditions. The overall objective of this study was to investigate the soil C storage in the whole soil as well as fractionated size-classes of soils in homegardens, coconut groves, rubber plantations, forests, and rice-paddy fields across four soil layers to a depth of 1 m at three sites in Kerala, India. The basic hypotheses of the study were,

1. Land-use systems involving trees store relatively higher quantities of soil C (and therefore possess higher soil CSP), compared to treeless systems, at lower soil depths (up to 1 m from surface).
2. Soil C is more stable in smaller size-fractions (< 53 um) of soil.

Materials and Methods

Study Area

This study was conducted in the state of Kerala, India. The Madakkathara subdivision (*Panchayat*) in the district of Thrissur in the central part of the State (Fig. 3-1), where the Kerala Agricultural University (KAU) is located, was selected for this study. Thrissur district, bordered by Malappuram district in the north, Palakkad district to the east, and Ernakulam district to the south, lies between 10º 0’ and 10º 47’ north latitudes, and 75º 55’ and 76º 54’ east longitudes. Madakkathara *Panchayat*, located at the northeast part of Thrissur district, extends over an area of 2504 ha and lies between 10º 32’ and 10º 36’ north latitudes, and 76º 14’ and 76º 18’ east longitudes. Within the Madakkathara *Panchayat*, three villages (Pandiparambu, Chirakkakode, and Vellanikkara) were chosen based on the availability of various land-use types that were considered important for the study. Homegarden is popular land-use in Kerala (Nair, 1993; Kumar et al. 1994) and this state offers a good opportunity to study the development trends in homegardens (Peyre et al., 2006). The other major land-use types of Kerala include forest, rice paddy fields, rubber plantations, and mixed plantations of coconut. Madakkathara *Panchayat* has diverse types of vegetation and a wide range of land-use types. Out of the total area of the *Panchayat*, 588 ha are under forest, 1421 ha are dry land and the rest (495 ha) is wetlands (Govt. of Kerala, 2005). The major land-use types of Madakkathara *Panchayat* are rice-paddy fields, rubber plantations, intercropped coconut groves, and homegardens. Crop-wise land-use statistics of Madakkathara *Panchayat* is presented in Table 3-2. The majority of the land holding is marginal and only 30% of the population actually depends entirely on agriculture for their livelihood.

Climate and Soil

Madakkathara *Panchayat* has a humid tropical climate with two monsoon seasons. About 65% of the rainfall is received from the so-called “southwest monsoon” during June to August and 30% from the “northeast” monsoon during October −November. Mean annual rainfall is 2783 mm. The average annual temperature is 27.7° C with a mean maximum temperature of 32° C and a mean minimum temperature of 23.3° C. The mean humidity and evaporation of the area are 74.8% and 105.4 mm, respectively (Govt. of Kerala, 2005).

The parent material of the soils in Madakkathara *Panchayat* is granite gneissic rocks formed by the weathering of charnokites and laterites, which were transported and deposited as soils of sedimentary origin that are low in bases. The soils of Madakkathara *Panchayat* have been classified into eight different local series (Govt. of Kerala, 2005). Four of the series (Kozhukkuly, Kottala, Mulayam, and Maraickal) fall under the order Inceptisol, which covers 75% of the land. Two of the series (Velappaya and Anjur) are Ultisols covering 7% of the land. Series Madakkathara is under Alfisol and series Kolazy comes under the order Entisol, covering 17.5% and 0.5%, respectively (Table 3-1). The soils of the study areas selected from the three villages (primarily Kozukkuly and Kottala series), as well as the coconut grove at KAU campus and the sampling sites from the forest fall under the order Inceptisol. Detailed soil taxonomy and characteristic are presented in Table 3-1. Madakkathara *Panchayat* consists of lowlands (< 20m above mean sea level (MSL)), mid lands (20 to 100 m above MSL), mid uplands (100 to 300 m above MSL), and uplands (100 to 300 m above MSL); the highest point is 396 m above MSL and lowest point is 4 m above MSL (Govt. of Kerala, 2005). The slope is from NE to SW. The study villages and the KAU coconut plantation are located in the lowland area with slopes varying from 1 – 5 %, but the forest is located in the mid-uplands and uplands region.

Selected Land-use Types

Basic information of homegardens, forests, coconut groves, rubber plantations, and rice-paddy are presented below. Cultivation details of these systems have been discussed in Chapter 2.

Homegarden (HG)

Homegarden is the most important agroforestry system in Kerala (Fig. 3-2A). Homegardens are diverse in nature in terms of species composition, size, use, and age (Mohan, 2007). Holding size of HGs is likely to affect the amount of C sequestration in the system. Previous research indicates that smaller homegardens had higher species diversity (Kumar et al., 1994) and higher species density (Mohan et al., 2007). High species assemblage are likely to harbor species with strong response to the resources compared to systems with limited species richness (Tilman et al., 1997) and may promote a resource use efficient system that favors greater net primary production (Vandermeer, 1989), which in turn promote C sequestration in homegardens (Kumar, 2006). However, how HG size affects C sequestration is not well understood. This study categorizes homegarden in two size groups and considers them as two different land-use types for statistical calculations. The purpose of this categorization is to investigate how soil C stock is being affected by holding size. The two size groups are ‘Small

Homegarden" (HGS), which were less than 0.4 ha (1.0 acre) and 'Large Homegarden' (HGL), which were more than 0.4 ha (1.0 acre).

Forest (FR)

Approximately 25% of the state (940,000 ha) is under forest (Fig. 3-2B) (Land Resources of Kerala State, 1995). The Madakkathara *Panchayat* has 588 ha of forest land located in its northeastern part and the type of forest is moist deciduous. Forest in this region is reported to contain more than 100 tree species (B. M. Kumar, personal communication, June, 2006). The sites surveyed were 175m high from MSL and were in close proximity to the study villages.

Rubber plantation (HB)

The rubber tree (*Hevea brasiliensis*) is economically most attractive cash crop in Kerala (Fig. 3-2C). In Madakkathara *Panchayat* 280 ha (Table 3-2) (20% of total cultivable dry land area) of land are under rubber cultivation. The selected plantations were under rubber cultivation for more than 50 years and the sites selected for the study had mature rubber trees (under tapping) with varied age class. The tree density varied from 450 to 500 trees per hectare and accordingly the spacing was about 4.5 m × 4.5 m at all sites. All farmers more or less followed the KAU- recommended package of cultivation practices.

Coconut grove (CN)

Kerala that derives its very name from coconut (*Cocos nucifera*; *kera* in Sanskrit) is the land of coconuts and coconut palms are ubiquitous throughout the state and are present in almost all HGs. The area under coconut in Madakkathara *Panchayat* is reported to be 608 ha (43% of total cultivable dry land area) (Table 3-2). But coconuts are seldom cultivated in single-species stands, and a major fraction of the area statistics for coconuts represents coconuts in HGs and other plant associations. Indeed, sole stands of coconuts are difficult to find in Thrissur district, therefore, a coconut plantation of KAU at Vellanikkara was used for this study (Fig. 3-2D).

These plantations were 30 years old; the palms planted at 8 m × 8 m spacing had been maintained according to KAU recommended package of cultivation practices.

Rice-Paddy field (OS)

Rice (*Oryza sativa*)-Paddy (Fig. 3-2E) is the main cereal crop of Kerala and covers 14% of total land area of the state (537610 ha) (Land Resources of Kerala State, 1995). In Madakkathara *Panchayat*, this crop covers an area of 278 ha and is mostly cultivated in wetlands and lowlands. In all of the study sites rice-paddy cultivation was done for more than 100 years and land-holdings varied from 0.12 to 0.4 ha or more.

Land-Use Survey

Owners of all selected HGs were surveyed to gather detailed information about the history, demography, management practices, and the biodiversity of their gardens. In addition the owners of all selected rubber plantations and rice-paddy fields were surveyed to acquire basic information about the history, and management practices of their lands. The information about the coconut groves and forest was collected from the KAU and the Madakkathara Forest Department, respectively.

Soil Sampling

Soil samples were collected in November – December 2006. Four plots of each land-use system (small homegarden (< 0.4 ha), large homegarden (> 0.4 ha), rubber plantation, and rice-paddy field) were selected in each of the three villages, totaling 12 plots of each land-use type. Soil samples were also collected from four plots randomly selected from the forest adjacent to the villages, as well as from the coconut grove of KAU campus. In each plot, three sampling points were selected randomly and from each point, soils were collected from four depths 0 – 20, 20 – 50, 50 – 80, and 80 – 100 cm. The three sub-samples at each location and depth class were composited to get one composite sample for each depth class per plot. Thus, there were a total of

192 samples (4 land-use types × 3 villages × 4 replications/plots × 4 depths) from the three villages and 16 samples each from (1 location × 4 replications/plots × 4 depths) forest and coconut grove, totaling 224 samples. Soil sampling for bulk density measurement was done using a 178 cm^3 steel cylinder. Pits of 1 m × 1 m × 1 m size were dug and the steel cylinder was inserted horizontally on the wall of the pits at the center of each depth class. Soil collected inside the cylinder was collected, dried, and weighed. All samples were air-dried and sieved (2 mm sieve) at the KAU soils laboratory, bagged, and sent to University of Florida, Gainesville, FL.

Soil Preparation and Analysis

The soil samples were manually fractionated into three aggregate size classes (250 − 2000 µm, 53 − 250 µm, <53 µm) at the Soil and Water Science Department laboratory, University of Florida, according to a procedure from Elliott (1986), Six et al. (1998), and Six (2002), adapted as follows by Haile et al. (2008). Following a procedure from Elliott (1986), the soil samples were physically fractionated by wet-sieving using disruptive forces of slaking and wet-sieving through a series of two sieve sizes (250 and 53 µm) to obtain three fraction size classes: macro (250 – 2000 µm), micro (53 – 250 µm), and silt- and clay- sized fraction (<53 µm). The procedure was modified by submerging a sub-sample of 100 g of the composite soil sample in a 500 mL beaker of de-ionized water as disruptive forces of slaking for about 5 min prior to placing it on top of 250 µm sieve to release the air that is trapped inside soil pores. The sieving was done manually. Comparable energy input was used by moving the sieve up and down approximately 50 times in 2 minutes. The fraction remaining on the top of a 250 µm sieve was collected in a hard plastic pan and allowed to oven-dry at 65^{o}C and weighed. Water plus soil < 250 µm was poured through a 53µm sieve and the same sieving procedure was repeated. The overall procedure yielded a water-stable, macro-sized fraction 250 − 2000 µm; a micro-sized fraction 53 − 250 μm, and silt +clay fraction size <53 μm. The overall average recovery mass percentage of soil fractions after wet sieving procedure was 97.5% of the initial soil mass (Haile et al., 2008). In this study, the recovery of mass soil fractions after overall wet sieving procedure ranged from 95 to 99% of the initial soil mass. For further analysis, whole and fractionated soil was oven-dried at 60°C for 72 h, and crushed to fine powder using a QM-3A High Speed Vibrating Ball Mill (Cianflone Scientific Instruments, Pittsburgh, Pa.). Total nitrogen and SOC concentration were determined for both whole and fractionated soil samples by dry combustion and gas chromatography on an automated FLASH EA 1112 N C elemental analyzer (LECO Corporation, St. Joseph, Mich.). Soil pH and particle- size density were also determined at the Soil and Water Science Department laboratory. The C storage was calculated as:

C storage = C concentration x BD x Depth x weight fraction (Eq. 4-1)

where,

C storage = C expressed in Mg ha^{-1} in 1 m vertical depth of fraction-size classes,

C concentration = C in fraction size, g per kg of soil of that fraction size,

BD = Bulk density, kg m^{-3}

Depth = Depth of soil profile, cm, and

Fraction weight = % weight of the fraction in the whole soil

In the absence of a time-sequence study involving long time intervals, the C stock data were considered as an indicator of the CSP of the systems.

Statistical Methods

A split-plot design with land-use as a factor was employed. The tropical land-use systems were considered as subplots (i.e. total 6 subplots) and three study villages were considered as whole plots (i.e. total 3 whole plots). The model equation is,

$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_{ij} + (\beta\gamma)_{i(jk)} + \varepsilon_{ijk}$ (Eq. 4-2)

where,

μ = General mean
α_i = Soil depth (i = 1,2,3,4)
β_j = Whole plot (j = 1,2,3)
γ_k = Sub plot (k = 1,2,3,4,5,6)
δ_{ij} = Interaction between soil depth and whole plot
$(\beta\gamma)_{i(jk)}$ = Interaction between whole plot and sub plot (nested with soil depth)
ε_{ijk} = Error

Multiple linear test was performed using the general linear model (GLM) and analysis of variance (ANOVA). Waller Duncan K-ratio test was used to compare the mean differences between land-management practices on SOC in whole soil, macro-sized, micro-sized and silt- and clay- sized fractions for all sites. All statistical tests were performed with SAS 9.0 (SAS Institute Inc., 2004) and differences were considered significant when $p<0.05$.

Results

Soil Organic Carbon Storage in Whole Soil

The amount of SOC varied with the land-use system (Fig. 4-1). Among all land-use systems, SOC was highest in FR (forest) and lowest in OS (rice-paddy); the amount of SOC in FR (176.6 Mg ha^{-1}) was more than three times higher than in OS (55.6 Mg ha^{-1}). In addition, HGS (small HG) and HB (rubber plantation) had higher SOC values compared to CN (coconut grove). The levels of SOC in homegardens were in between FR and OS; the small homegardens had 30% and 114% more SOC than in CN and OS, respectively, whereas for HGL (large HG), the corresponding numbers were 18% and 94%. Between the two homegarden size classes, HGS showed 10% greater SOC content than HGL. The overall results for SOC content within 1m depth were in the following order: FR > (HGS = HB) > CN > OS; HGL = HGS, HB; HGL = CN (Fig. 4-1).

In general, the depth class comparison of SOC showed similarities with the overall ranking results of the land-use systems (Figure 4-2). The forest had a higher value of SOC (49.99 Mg ha^{-1}) than HGL, HGS, CN, and OS at the upper-most soil layer (0 − 20 cm). At the upper-medium soil layer (20 − 50 cm), SOC of FR and OS remained highest (58.19 Mg ha^{-1}) and lowest (15.3 Mg ha^{-1}), respectively. At the lower- medium soil layer (50 − 80 cm) again, the SOC value for FR was the highest (47.23 Mg ha^{-1}) compared to other land-use systems. At this depth, OS followed by CN had lower amounts of SOC than the rest of the systems. Finally, at the lower-most soil layer studied (80 − 100 cm), the pattern remained the same like lower- medium layer and the SOC decreased in the following order: FR > HGS = HB = HGL > CN > OS (Figure 4-2).

Soil Organic Carbon in Macro-Sized Fraction (250 µm − 2000 µm)

The total SOC of the macro-sized fraction within 1m soil profile were 55.4, 43.73, 37.78, 32.65, 26.42, and 17.74 Mg ha^{-1} in FR, HB, HGS, HGL, CN, and OS, respectively (Table 4-2). The mean values for SOC content of all sites indicate that at all depth classes forest had higher SOC content than HGL, CN, and OS (Table 4-2). The SOC content of rice-paddy was lower compared to FR and HB at all depths. The HB plots had higher SOC than that of CN throughout the 1m soil profile. However, SOC content in HB did not differ from that in HG (except with HGL at the upper medium layer). The two homegarden size classes did not differ from each other in SOC content at any depth. Furthermore, at the lower-most depth studied, SOC content in HGs (HGL and HGS) was higher than that of CN.

Soil Organic Carbon in Micro-Sized Fraction (53 μm − 250 μm)

The total SOC of the micro-sized fraction within 1m soil profile were 58.72, 40.13, 37.09, 36.95, 28.58, and 13.56 Mg ha^{-1} in FR, HB, HGS, HGL, CN, and OS, respectively (Table 4-3). Below 20 cm the SOC content of FR and OS were highest and lowest, respectively The SOC contents of HB, HGL, and HGS were higher than that of CN at all depths, but the upper-most layer. The SOC content of HB, HGL, and HGS did not differ among themselves.

Soil Organic Carbon in Silt and Clay-Sized Fraction (<53 μm)

The total SOC of the silt and clay sized fraction within 1m soil profile were 55.36, 34.46, 32.21, 31.09, 29.84, and 19.05 Mg ha^{-1} in FR, HGS, HGL, HB, CN, and OS, respectively (Table 4-4). Statistical differences were observed only in depth classes below 20 cm. In depth classes below 20 cm, SOC content in FR and OS remained highest and lowest compared to the other land-use systems No differences were observed among HGs, HB, and CN.

Discussion

Soil Organic Carbon in Whole Soil

The total amount of SOC within 1 m soil profile varied significantly among six selected land-use types (Fig. 4-1). The land-use types with highest and lowest SOC, forest and rice-paddy respectively, had completely different plant compositions. Plant C is added to soil by deposition and incorporation of aboveground plant parts (litter decomposition) and belowground root activity (Schlesinger et al., 1990; Lemma et al., 2007). The intensity of litter production and root activity varies with different compositions of plants and land-use types (Connin et al., 1997; Jackson et al., 2000). Among plant types, trees with their large size and higher biomass production contain higher stocks of atmospheric C. More than half of the C assimilated by trees is eventually transported belowground via root growth and turnover, root exudates and litter deposition, making soil a significant sink of C (Montagnini and Nair, 2004). Addition of trees to treeless systems is reported to increase the belowground C stock; for example an increase on SOC was observed when grass dominated ecosystems were invaded by tree population in central highlands of Mexico (Reyes-Reyes et al., 2002) and South Africa (Yelenik et al., 2004). Similarly, silvopasture systems were observed to have more SOC when compared with adjacent tree- less pastures in Florida (Haile et al., 2008). Thus, it is logical to believe that the presence of trees is one of the main sources of higher SOC in FR and is one of the main factors responsible for the high values in FR within 1m profile. By extension, absence of trees could be the reason for the lowest SOC values in the rice-paddy soils among all the systems studied.

Soil organic carbon in whole soil decreased with soil depth for all land-use types (Fig. 4-3). This is common in all mineral soils (Brady Weil, 2007). The major sources of SOC accumulation are belowground plant root activity (Tate et al., 1993) and aboveground plant residue decomposition. The combined effects of herbs, shrubs, and trees result in high root density in the top soil, but this root density is expected to decrease with depth. Furthermore, the decomposition of plant residue (litter) on the soil surface enriches primarily the top soil with C. The combined effects of these two factors explain why all selected land-use systems in this study showed the high SOC values in the top soil, which gradually decreased with depth (Fig. 4-3). However, the decline in SOC varied with the land-use type. The amount of SOC in the top half of the 1m soil profile (0 − 50 cm) was greater than in the lower half (50 − 100 cm) by 37%, 28%, and 36% in FR, HGL, and HGS, respectively. However, this difference was higher in CN and HB with values of 54% and 43%, respectively. Diverse tree species of different age groups were present in FR and HGs. These encompassed a wide range of root growth patterns. It is expected that root density at the lower depths would be higher in FR and HGs compared to monocultures such as CN and HB with comparatively shallower rooting pattern. The difference in rooting density at lower depths is probably the underlying cause for the difference in C content. For example, Dea et al. (2001) reported that the main taproot of a 3-year old rubber tree went 100 cm deep but the lateral roots were restricted within 70 cm with a higher density above 30 cm. This could explain why the SOC difference between top half and lower half of 1m was greater in these HB systems. The difference in SOC between top and bottom half of 1 m was highest (71%) in OS. This was primarily because majority of the rice-paddy roots are restricted well above the 50 cm range (Kusnarta et al., 2004) resulting limited or no root activity at the bottom half of the 1m profile. This reconfirms the importance of tree-roots in promoting SOC accumulation.

Forest had the highest amount of SOC compared to the other land-use types within 1 m soil depth in all three sites (Fig. C-1). The SOC content of forest soils was 48%, 63%, 93%, and 217% more than that of (HGS and HB), HGL, CN, and OS, respectively (Fig. 4-1). Higher tree population and relatively lesser disturbances (both anthropogenic and environmental) in forests compared to other land-use systems under study were probably the major reasons for the forests to accumulate more SOC. The tree density was higher in the FR compared to all land-use types. Due to increase in numbers of trees, net primary production, rooting distribution and activity, and litter production increased, which probably promoted accumulation of SOC. In addition, with reduction in disturbance, the process of soil aggregation increased (Six et al., 2000) and aggregation is known to facilitate SOC retention (Carter, 1996). Survey reports (Kerala Forest Department, personal communication and survey, October, 2006) indicate that selected forest areas experienced none to minimal forest management (anthropogenic disturbance) and no severe natural disturbances that may alter the SOC such as forest fire, draught, and pest infestation took place in the selected area.

The only treeless system in the study, rice-paddy, had the lowest SOC stock (55 Mg ha^{-1}) within the top 1 m of soil profile (Fig 4-1). This is comparable to 38.2 to 44.2 Mg ha^{-1} SOC within 1 m soil profile of rice-paddy systems in a range of soils in China (Zhang et al., 2007). Limited root activity and heavy anthropogenic disturbance in rice-paddy systems are probably the major underlying causes for the reduced accumulation of SOC. Unlike tree based systems, rice-paddy roots generally go up to 15− 20 cm, with density gradually decreasing with depth (Kusnarta et al., 2004). In addition, rice-paddy systems also experienced the higher anthropogenic disturbance (e.g. tillage) compared to the other land-use types in study. Tillage decreases C stocks in soils (Lal et al., 1989; Carter, 1993) by exposing SOC to microbial activity through destruction of aggregates and the release of soil C (Six, et al., 2000). Below 20 cm, OS systems had less SOC than that of rest of the land-use systems (Figure 4-2).

In all three sites the total SOC contents within 1 m profile of HGs were lower than in FR and were higher than in OS (Fig. C-1). The difference in SOC content between FR and HG can be explained by the differences in tree population and anthropogenic differences. Overall plant density and especially tree density was higher in the FR compared to the HGs. The pattern of root growth and development is also important for SOC accumulation. In Kerala HGs, coconuts and arecanuts (*Areca catechu*) are the major tree species. These are palms (monocots) with shallow fibrous root system. In contrast, in the FR the majority of the trees are hardwoods (dicots) (B. M. Kumar, personal communication, June, 2006; Chandrashekara and Ramakrishnan, 1994) with taproots that can extend to deeper soil depths. Amount of litter fall was also high in forests compared to HGs. Issac and Nair (2006), reported the litter fall from the six tree species of Kerala HG ranged from 3.8 to 8.6 Mg ha^{-1} $year^{-1}$, which were comparable to that of different species grown in agroforestry combinations. However, the range of value remained lower compared to the litter fall (12 -14 Mg ha^{-1} $year^{-1}$) of moist deciduous forests of Kerala (Kumar and Deepu, 1992). Unlike FR, HGs experience disturbances such as tillage, manual weeding, and removal of trees, all of which affect the process of SOC accumulation. Trees in HGs are generally not retained beyond their economic life span, but in FR trees generally stay until they senesce and provide a good source of SOC after they die and decompose. Although Kerala forests are not free from the effects of grazing, forest fires, and illicit felling (Kumar, 2005), the life span of trees generally is higher than that of homegardens. These factors explain why SOC in HGs was lower compared to the FR at all soil-depth classes up to 1 m. This difference in SOC contents between forest and HGs may, however, not hold good under all conditions. For example, Kirby and Potvin (2007) observed no difference in SOC content between forests and agroforests (home and outfield gardens, consisting of perennial tree crops that include fruit, timber and medicinal species) up to 40 cm soil depth in Inceptisols and Vertisols of eastern Panama province, Panama. Obviously, the SOC content in any system is determined by a large number of location- and system-specific factors.

The mean difference in SOC of HGS and HGL across the three sites was 10% within top 1 m soil (Fig. 4-1). This difference is probably due to the difference in species and plant (especially tree) density between HGL and HGS. Smaller homegardens are reported to have higher species diversity (Kumar et al., 1994) and higher species density (Mohan et al., 2007). Plant diversity survey of the HGs under this study indicated that HGS had higher species density (1.61 species 100 m^{-2}) than HGL (0.71 species 100 m^{-2}) (Table 5-2). Furthermore, plant density (especially tree density) was also higher in the HGS (7.5 trees 100 m^{-2}) compared to HGL (5.8 trees 100 m^{-2}) (Table 5-2). High species assemblage are likely to harbor species with strong response to the resources compared to systems with limited species richness (Tilman et al., 1997) and may promote a resource-use-efficient system that favors greater net primary production (Vandermeer, 1989), which in turn promote C sequestration in homegardens (Kumar, 2006). The SOC difference between HGS and HGL are more pronounced when compared with the SOC of CN. The SOC difference between HGS and CN (30%) was significant, whereas the difference between HGL and CN (18%) was not (Fig. 4-1).

Within top 50 cm of soil, the amount of SOC in HB was 76 Mg ha^{-1}. This value is in between the SOC contents found in the top 60 cm soil of rubber plantations of Mato Grosso, Brazil (101 Mg ha^{-1}), where age of the plantation varied from 16 to 29 years and western Ghana (52 Mg ha^{-1}), where age of the plantation varied from 5 – 17 years) (Wauters et al., 2008). The total amount of SOC within top 1 m of soil in HB was lower (33%) than that of FR. Similar results have been reported from Malaysia, where SOC content in HB was lower than in FR by 55% (Sanchez et al., 1985). The SOC values of HB and HGs were somewhat similar. The SOC in top soil of HGs are affected by disturbances such as tillage, manual weeding, and partial removal of plant residue. In contrast, HBs had reduced soil management disturbances (no annual tillage, reduced mechanical weeding etc.). It is likely that diverse assemblage of trees in the HGs can grow their roots in deeper soil than rubber trees. This may facilitate more C accumulation on deeper soil of HGs compared to HB. Earlier findings estimated the litter fall from the six HG tree species ranged from 3.8 to 8.6 Mg ha^{-1} $year^{-1}$ (average 6.2 Mg ha^{-1} $year^{-1}$) (Issac and Nair (2006), which is comparable to the leaf litter production (6 Mg ha^{-1} $year^{-1}$) in rubber plantations as reported by Krishnakumar and Potty (1992). Overall, these differences between HGs and HB evened out such that total SOC from all soil depths yielded similar SOC values for both HGs and HB.

Soil Organic Carbon in Fraction Size Classes

The study showed differences among land-use systems in terms of storage of SOC in different soil fraction-size classes (Tables 4-2, 4-3, 4-4). Macro-sized class (250 − 2000 μm) (macroaggregates) contains the active pool of C, which is influenced by the land-use and soil management (Six et al., 2002). The class contains the recent C depositions in soil (Carter, 1996) and the C content in this class is sensitive to changes in organic matter dynamics and may show variation depending on the land-use system. Thus, the SOC contents of this size class may vary significantly with the land-use changes within short period of time. This is evident by the differences among CN, HGs, and HB in the SOC contents of macro-sized fraction (Table 4-2). In this size class, SOC content of CN was lower than those of HB and HGs at all depth classes. This indicates that the SOC content in this fraction-size class was influenced by the changes in land-use types within a period of may be >100 years (when the HGs have been in existence), with comparatively older land-use systems like FR and OS showing more differences in the SOC stock in this class than in the relatively newer systems such as HB and HGs.

Micro-sized class (53 − 250 μm) (microaggregates) is the building block of soil structure and more stable in storing C (Tiessen and Stewart, 1983). Organic C inside this class has lower decomposition rate and can store C for a longer terms than in higher- size fractions (Six et al., 2000). In other words, the micro-sized class would be in between the macro-sized class and the silt and clay-sized class in terms of SOC stability. The SOC differences among CN, HGL, HGS, and HB in this fraction-size class remained lower than those in the macro-sized class (Tables 4-3, 4-2), but was higher than those of the silt + clay-sized class (Tables 4-3, 4-4). This suggests that the effects of land-use changes on the SOC of micro-sized class are less than that on macro-sized class, but more than that on silt and clay-sized class. As expected, comparatively older land-use systems like FR and OS showed more differences in the SOC stock than in “newer” systems such as HB and HGs in this fraction-size class too just as in the case of the macro-size class.

The SOC content in silt + clay-sized class (>53 μm) , which is considered to be more stable than larger soil fractions (Six et al. 2002), showed a clear trend of increasing amount with increasing tree density, with the lowest value in the rice paddy and highest value in the forest soils (Table 4-4). The SOC contents under this silt and clay size class below 20 cm were in the following order: FR > HGS = HGL= HB = CN > OS (Table 4-4), with no difference in SOC content among CN, HGL, HGS, and HB at any depth class below 20 cm. The age of all these land-use types varied from 20 to 100 years, which may not be long enough to reflect the effects of land-use change on C content in the silt and clay fraction of soil, which is expected to be the most stable. In contrast, FR had higher and OS had lower SOC in the silt and clay size fraction compared to rest of the systems. This could be a reflection of the residence time of SOC in these systems: forest have been there for a very long period of time and the rice paddies under the same land-use type for possibly hundreds of years. The results thus support the idea that SOC in silt + clay-sized class is more stable compared to that of macro-sized class and are not affected by any short-term changes in land-use.

Conclusions

Land-use systems with higher tree density and less soil disturbance contributed to greater soil C storage is an indicator of higher C sequestration in soils. Highest SOC stock was found in the forest and the lowest in the rice-paddy system. Soil organic carbon contents of homegardens and rubber plantations did not vary significantly. There were difference between the SOC contents of large and small homegardens, and it is probably due to the individual or combined effects of species density and plant density (especially tree density). Carbon content in soil profiles decreased with soil depth; but lower depths up to 1 m contained substantial amount of C, indicating the importance of considering the soils below the surface horizon in soil C studies. Comparatively more SOC was found in the lower half of 1m depth in forest and homegardens than the other land-use systems. Soil organic carbon contents in macro-sized class (250 − 2000 μm) showed more difference among land-use types followed by those of micro-sized (53 − 250 μm) and silt and clay-sized (>53 μm) classes suggesting that changes in land-use types in course of time are reflected first in macro-sized class followed by micro-sized and then the silt + clay sized fractions. Due to the structural stability of silt and clay-sized class, more time is required to observe any effect of land-use changes on this size class. These results, however, are inconclusive; more detailed research is needed on a number of aspects to make valid conclusions; these include net primary production over time, litter quality and quantity, root development, and microbial dynamics.

Table 4-1. Depth-wise soil particle size classes and pH for the soil in six land-use systems in Madakkathara *Panchayat*, Thrissur, Kerala, India.

Land-use Types	Depth (cm)	Soil Particle Size Density	(g $100g^{-1}$ soil)		pH
		Sand‡	Silt	Clay	
Forest	0 – 20	46.41	21.46	32.13	6.1
	20 – 50	40.00	20.76	39.24	5.9
	50 – 80	40.95	20.23	38.82	5.8
	80 – 100	41.57	20.94	37.49	5.7
Coconut Grove	0 – 20	50.08	13.91	36.01	5.8
	20 – 50	36.60	15.21	48.19	5.7
	50 – 80	32.34	17.22	50.44	5.7
	80 – 100	35.03	16.89	48.08	5.6
Large Homegarden	0 – 20	60.93	15.44	23.63	6.2
	20 – 50	54.01	12.25	33.74	6
	50 – 80	50.18	15.50	34.32	5.8
	80 – 100	47.94	10.91	41.15	5.9
Small Homegarden	0 – 20	62.04	12.36	25.60	6.2
	20 – 50	54.92	11.53	33.54	6
	50 – 80	52.00	12.45	35.55	6.1
	80 – 100	50.23	11.74	38.03	5.9
Rubber Plantation	0 – 20	62.51	13.07	24.42	5.9
	20 – 50	55.90	12.74	31.36	6.1
	50 – 80	51.10	11.52	37.39	5.9
	80 – 100	49.58	11.98	38.44	5.8
Rice-Paddy Field	0 – 20	72.50	11.89	15.61	5.8
	20 – 50	76.01	10.99	13.00	5.9
	50 – 80	70.21	12.92	16.87	6.1
	80 – 100	65.31	12.28	22.42	6

‡According to the standard classification, sand is particle between 0.05 – 2 mm in equivalent diameter, silt is particle between 0.002 – 0.05 mm in equivalent diameter, and silt is >0.002 mm in equivalent diameter (Brady and Weil, 2007).

Table 4-2. Soil organic carbon (SOC) in macro-sized fraction (250 µm − 2000 µm) at different soil depths of six tropical land-use systems (mean of all three sites) in Madakkathara *Panchayat*, Thrissur, Kerala, India.

			Mg ha^{-1}			
Depth (cm)	FR	CN	HGL	HGS	HB	OS
0 – 20	14.63 [a] ‡	7.35 [c]	8.86 [bc]	10.21 [abc]	13.18 [ab]	5.82 [c]
20 – 50	18.25 [a]	10.04 [cd]	9.54 [cd]	12.55 [bc]	15.22 [ab]	6.72 [d]
50 – 80	14.46 [a]	5.67 [cd]	8.37 [bc]	9.1 [b]	9.65 [b]	3.76 [d]
80 – 100	8.06 [a]	3.36 [c]	5.88 [b]	5.92 [b]	5.68 [b]	1.44 [d]

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class).
FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

Table 4-3. Soil organic carbon (SOC) in micro-sized fraction (53 µm − 250 µm) at different soil depths of six tropical land-use systems (mean of all three sites) in Madakkathara *Panchayat*, Thrissur, Kerala, India.

			Mg ha^{-1}			
Depth (cm)	FR	CN	HGL	HGS	HB	OS
0 – 20	16.11 [a] ‡	8.42 [c]	10.1 [bc]	10.01 [bc]	12.73 [ab]	7.71 [c]
20 – 50	20.68 [a]	10.04 [b]	11.51 [b]	11.75 [b]	12.86 [b]	2.78 [c]
50 – 80	13.6 [a]	6.88 [c]	9.66 [b]	9.5 [b]	9.73 [b]	1.9 [d]
80 – 100	8.33 [a]	3.24 [c]	5.68 [b]	5.83 [b]	4.81 [b]	1.17 [d]

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class).
FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

Table 4-4. Soil organic carbon (SOC) in silt + clay-sized fraction (<53 µm) at different soil depths of six tropical land-use systems (mean of all three sites) in Madakkathara *Panchayat*, Thrissur, Kerala, India.

			Mg ha^{-1}			
Depth (cm)	FR	CN	HGL	HGS	HB	OS
0 – 20	13.62	9.04	9.1	10.2	9.78	9.07
20 – 50	16.95 [a]‡	10.65 [b]	10.45 [b]	10.64 [b]	10.7 [b]	5.06 [c]
50 – 80	16.69 [a]	6.62 [b]	7.76 [b]	8.74 [b]	7.1 [b]	3.04 [c]
80 – 100	8.1 [a]	3.53 [b]	4.9 [b]	4.88 [b]	3.51 [b]	1.88 [c]

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class).
FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

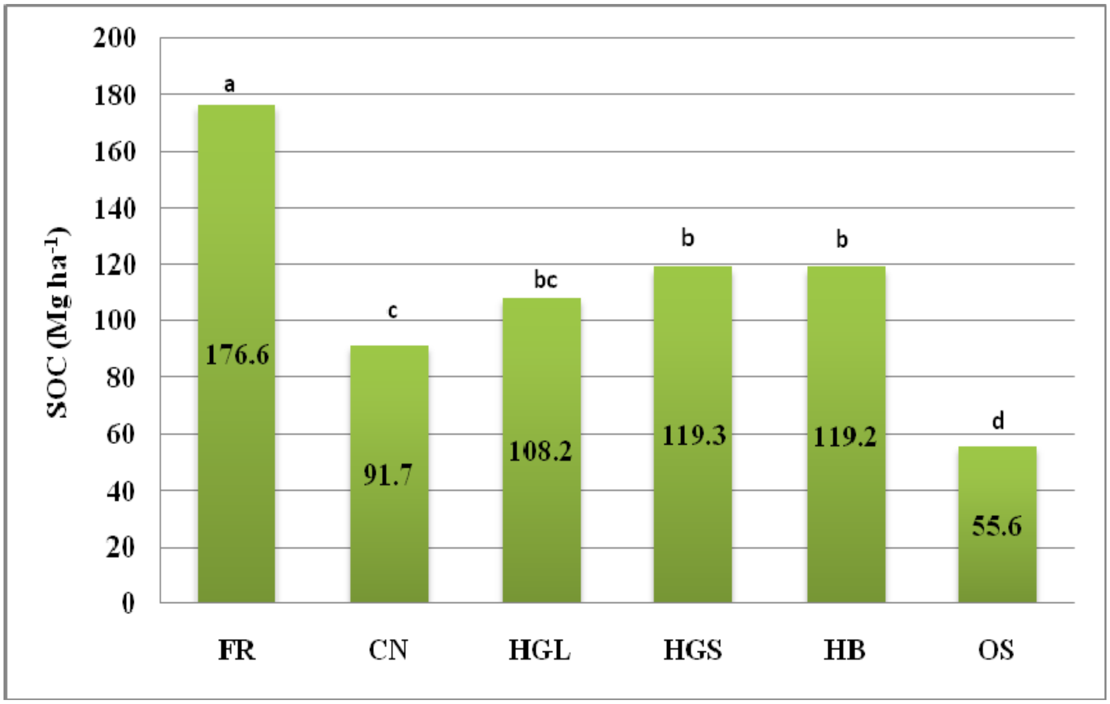
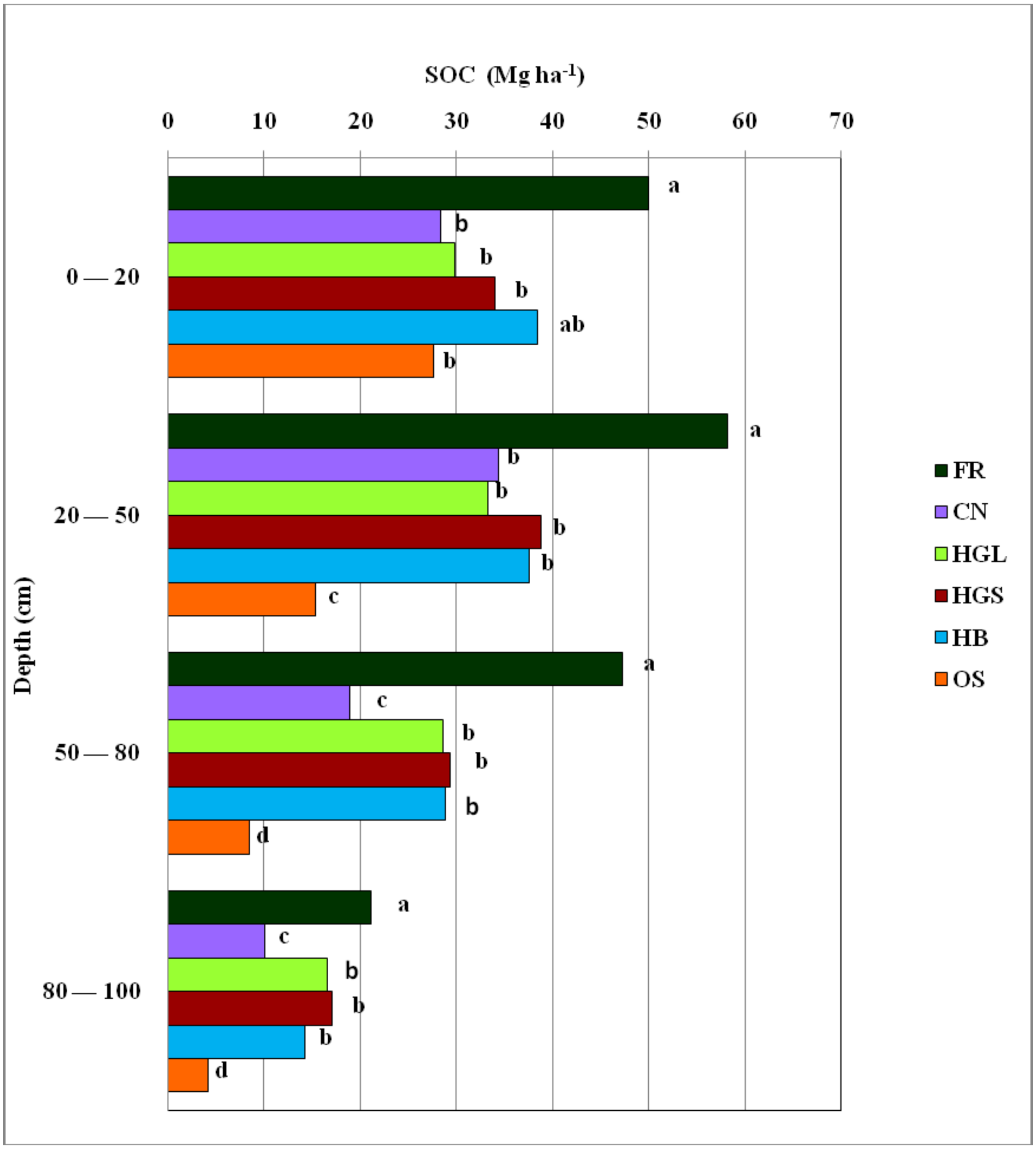
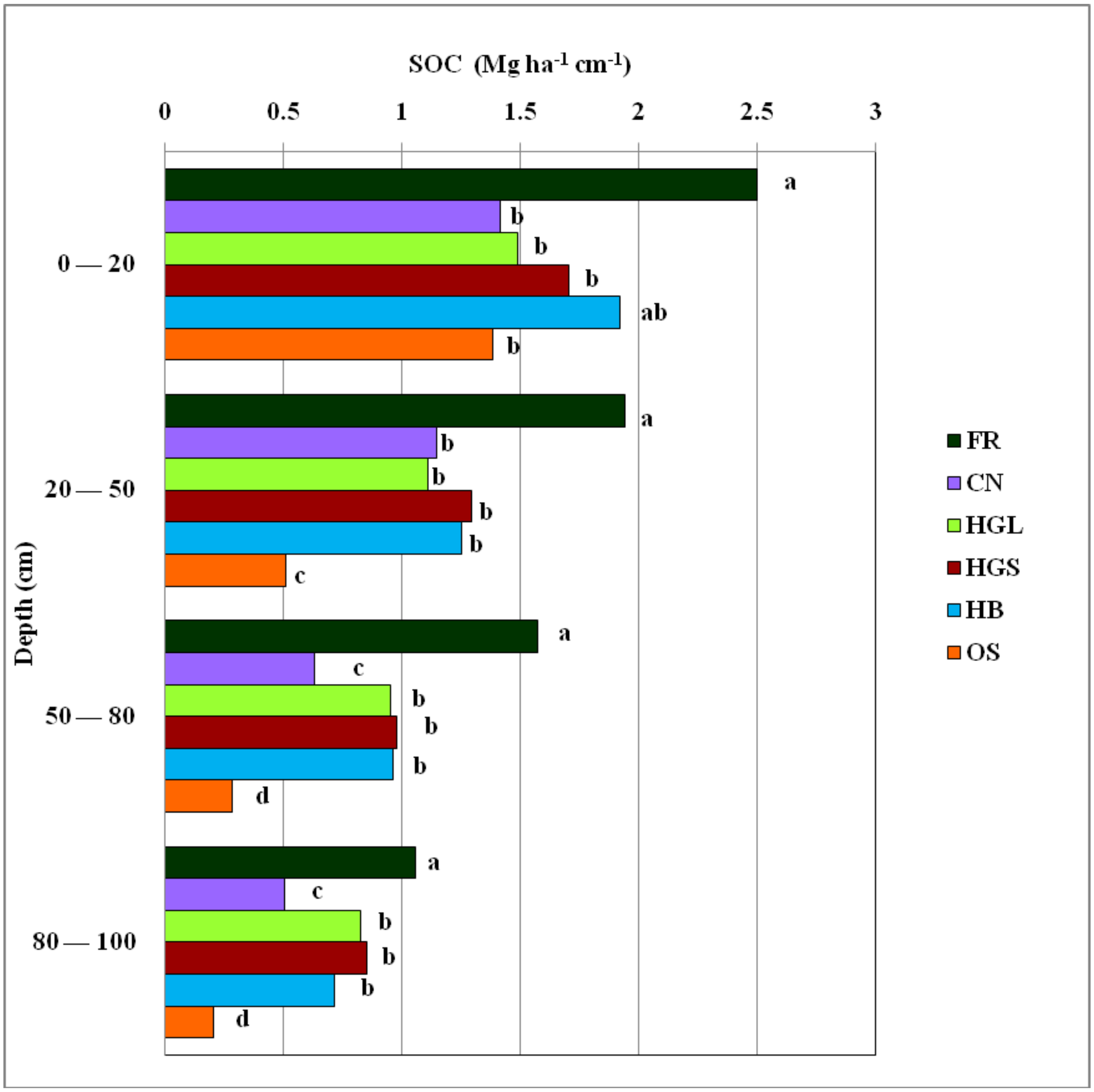


Figure 4-1. Total soil organic carbon (SOC) within 1 m depth in six tropical land-use systems for whole soil in Madakkathara *Panchayat*, Thrissur, Kerala, India. Lower case letters indicate differences (at the 0.05 probability level) in SOC among land-use systems within 1m soil depth. FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.



A

Figure 4-2. Mean soil organic carbon (SOC) in the whole soil of six tropical land-use systems across soil depth classes in Madakkathara *Panchayat*, Thrissur, Kerala India. A) SOC calculated per ha, B) SOC calculated per ha per cm. Lower case letters indicate differences (at the 0.05 probability level) in SOC among land-use systems compared within each depth class. FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.



B

Figure 4-2. Continued

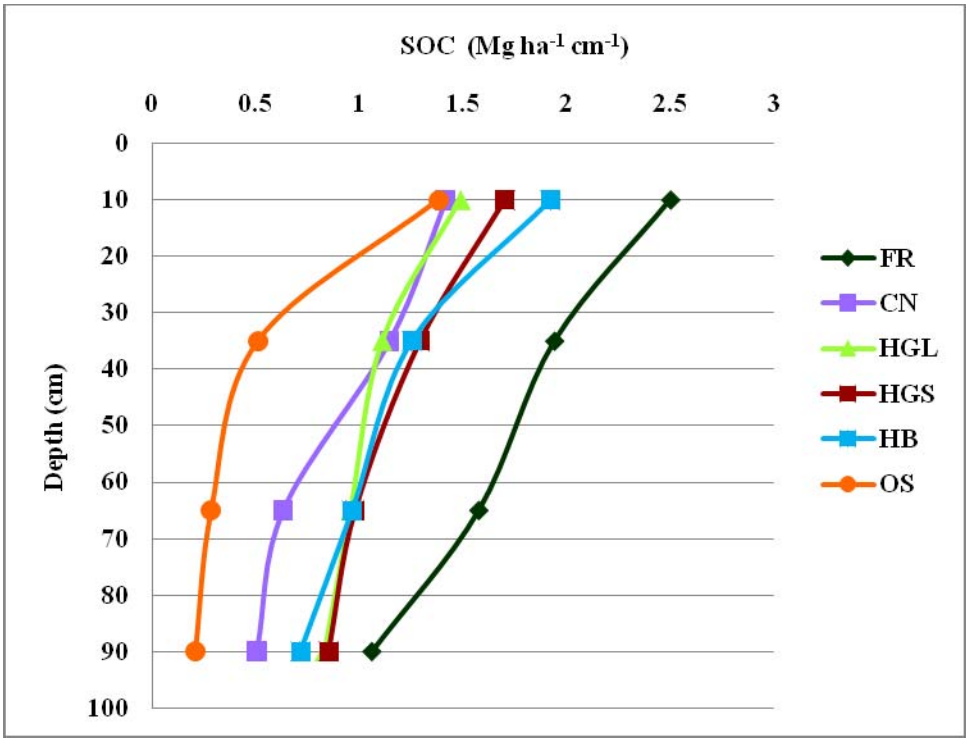


Figure 4-3. Depth-wise averaged (per ha per cm) mean soil organic carbon (SOC) in the whole soil of six tropical land-use systems in Madakkathara *Panchayat*, Thrissur, Kerala India. FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

CHAPTER 5
SOIL CARBON STOCK IN RELATION TO PLANT-STAND AND OPERATIONAL CHARACTERISTICS IN HOMEGARDEN SYSTEMS IN KERALA, INDIA

Introduction

Depletion of biodiversity and global warming are two major environmental issues of the world today. Biodiversity[1] incorporates all the living beings of the world. It is estimated that human activity is causing species extinction at a rate of 100 −1000 times the natural rate of extinction (Convention on Biological Diversity (CBD), 2006). Global warming that refers to an increase in temperature in the earth's atmosphere is caused primarily by the increase in atmospheric concentrations of greenhouse gases (GHGs), the most common of which is carbon dioxide (CO_2). The current GHG concentrations are estimated to be 30% more than the pre-industrial level (Intergovernmental Panel on Climate change (IPCC), 2007).These two major environmental issues have been the subject of several international summits and conventions, leading to a number of major global declarations and covenants. Important among these are the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD) that were formulated at the 1992 Earth Summit in Rio de Janeiro, Brazil. The UNFCCC aims to mitigate GHG effects through means like sequestration of atmospheric carbon (C), and the CBD aims to conserve biological diversity. In course of time, ventures to explore the potential of sequestering C and conserving biodiversity under a single project have emerged (Swingland, 2002; World Bank, 2002). The functional relationship between biodiversity (especially plant diversity) and C sequestration thus became a subject of

[1] As defined in the proposed US Congressional Biodiversity Act, HR1268 (1990), "biological diversity means the full range of variety and variability within and among living organisms and the ecological complexes in which they occur, and encompasses ecosystem or community diversity, species diversity, and genetic diversity."

major scientific interest (Schwartz et al., 2000; Tilman et al., 2001; Srivastava and Vellend, 2005).

Biodiversity encompasses more than plant species diversity; but from the point of view of C sequestration, plant species diversity is the most important if not the only aspect of biodiversity to be considered. The relationship between plant species diversity and C sequestration has not been investigated in detail, although some conjectures have been reported. For example, several researchers (Tilman et al., 1997; Kirby and Potvin, 2007) have suggested that plant assemblages with high species-diversity may promote more efficient use of resources compared with those of lesser species diversity and thus lead to greater net primary production (Vandermeer, 1989), and consequently higher C sequestration. High plant diversity in a system may alleviate disturbances (Huston and Marland, 2003) such as temporal instabilities caused by climate change (Loreau et al., 2001). On the other hand, it is widely agreed that more C is better sequestered in systems with lesser disturbance (Six et al. 2002). Litter decomposition is one of the major sources of soil organic carbon (SOC) and the decomposition process depends on quality of litter (Mafongoya et al., 1998) and the quality of litter varies with the plant species (Lemma et al., 2007). In the homegarden (HG) agroforestry systems of Kerala, for example, litter quality varied considerably with tree species (Issac and Nair, 2006). In addition, plant species diversity also influences the soil microbial activity through plant-specific differences in the release of root exudates in rhizosphere (Klein et al., 1988, Vancura, 1964), which in turn could affect C sequestration (Rees et al., 2005). All these considerations suggest the possibility of a positive relationship between plant-species diversity and C sequestration. However, no research has been reported on this topic. The high plant-species-diversity of HGs offers a good ground for investigating this hypothesis.

Homegardens are intimate, multistory combinations of various trees and crops, sometimes in association with domestic animal, around the homesteads (Fernandes and Nair, 1986; Kumar and Nair, 2004). They constitute a very common land-use system in the tropics and are regarded as 'the epitome of sustainability' (Torquebiau, 1992). Homegardens are distributed throughout the tropics in Africa, Asia, Central and South America, the Caribbean, and the Pacific Islands (Ruthenberg, 1980; Anderson, 1993; High and Shackleton, 2000; Nair and Kumar, 2006). The high plant-species diversity of tropical homegardens has been amply illustrated in a series of reports (Swift and Anderson, 1993; Kumar et al., 1994; John and Nair, 1999; Mohan et al., 2007). Some studies that have estimated the diversity indices from ecological points of view have indicated that HG plant diversity indices are comparable to that of adjacent forest (Kumar et al. 1994; Gajaseni and Gajaseni, 1999; Wezel and Bender, 2003).

Homegardens are speculated to have high C sequestration potential (CSP) due to their forest-like structure and composition (Kumar, 2006), particularly in stocking C in the soil. This conjecture is based on the premise that trees play an important role in soil C sequestration (Haile et al., 2008; Nair et al., 2008; Takimoto et al., 2008). More than half of the C assimilated by trees is eventually transported below ground via root growth and turn over, root exudates, and litter deposition, making soil a significant sink of C (Montagnini and Nair, 2004). By adding trees in the agricultural systems agroforestry can, increase the C storage capacity of the system (Kursten, 2000). It is logical to assume that with the increase in number of trees (or tree density) in a system; the overall biomass production per unit area of land will be higher, which in turn may promote more SOC sequestration.

The term "Plant-stand characteristics" coined in this study include the homegarden plant-stand related characteristics such as plant species density, plant density, tree and tree species density and ecological index parameters like species richness (Margalef index) and Species diversity (Shannon index).

Operational attributes of HGs such as size of the holding and age of the system may have influence on CSP. For example, plant-species diversity in HGs is inversely proportional to the holding size (Kumar et al., 1994; Mohan et al., 2007); therefore, smaller-sized HGs are likely to sequester more soil C per unit area of land compared to larger-sized ones. Furthermore, the mean residence time (MRT) of SOC at lower soil depths is influenced by the permanence of the system (indicated by their age) and the extent of soil disturbance (Fontaine, 2007); therefore, older systems can be expected to store more quantities of soil C than younger ones. Again, no research reports are available on these topics.

In this background, the present study was conducted in the state of Kerala, India, a region that is rich in homegardens of various size classes and varying species diversity (Nair and Shreedharan, 1986; Jose and Shanmugaratnam, 1993; Nair, 1993) with the overall objective of examining the relationship between plant (tree) species diversity and soil C sequestration. It is expected that the results of this study will have applicability in other parts of the world and for other integrated multispecies systems.

The specific objectives of the study are to,

1. Examine the relationship between plant-stand characteristics and soil C sequestration in homegardens.
2. Examine the relationship between operational characteristics and soil C sequestration in homegardens.

Materials and Methods

Study Area

The study was conducted in the state of Kerala, India (Fig. 3-1). The Madakkathara subdivision (*Panchayat*) in the district of Thrissur in the central part of the state where the Kerala

Agricultural University (KAU) is located was selected for this study. Thrissur district, bordered by Malappuram district in the north, Palakkad district to the east, and Ernakulam district to the south, lies between 10º 0' and 10º 47' north latitudes, and 75º 55' and 76º 54' east longitudes. Madakkathara *Panchayat*, located at the northeast part of Thrissur district, extends over an area of 2504 ha and lies between 10º 32' and 10º 36' north latitudes, and 76º 14' and 76º 18' east longitudes. Within the Madakkathara *Panchayat*, three villages (Pandiparambu, Chirakkakode, and Vellanikkara) were chosen for the study based on the availability of homegardens. Homegarden is a popular land-use in Kerala (Nair, 1993, Kumar et al., 1994) and this state offers a good opportunity to study the development trends in homegardens (Peyre et al., 2006). Details of structure and function of homegardens has been discussed chapter 3.

Climate and Soil

Madakkathara *Panchayat* has a humid tropical climate with two monsoon seasons. About 65% of the rainfall is received from the so-called "southwest monsoon" during June − August and 30% from the "northeast" monsoon during October − November. Mean annual rainfall is 2783 mm. The average annual temperature is 27.7° C with a mean maximum temperature of 32° C and a mean minimum temperature of 23.3° C. The mean humidity and evaporation of the area are 74.8% and 105.4 mm, respectively (Govt. of Kerala, 2005).

The parent material of the soils in Madakkathara *Panchayat* is granite gneissic rocks formed by the weathering of charnokites and laterites, which were transported and deposited as soils of sedimentary origin that are low in bases. The soils of Madakkathara *Panchayat* have been classified into eight different local series (Govt. of Kerala, 2005). Four of the series (Kozhukkuly, Kottala, Mulayam, and Maraickal) fall under the order Inceptisols, which covers 75% of the land. Two of the series (Velappaya and Anjur) are Ultisols covering 7% of the land. Series Madakkathara is under Alfisol and series Kolazy comes under the order Entisol, covering

17.5% and 0.5%, respectively (Table 3-1). The soils of the study areas selected from the three villages (primarily Kozukkuly and Kottala series) fall under the order Inceptisol. Detailed soil taxonomy and characteristic are presented in (Table 3-1). Madakkathara *Panchayat* consists of lowlands (< 20m above mean sea level (MSL), mid lands (20 to 100 m above MSL), mid uplands (100 to 300 m above MSL), and uplands (100 to 300 m above MSL) (Govt. of Kerala, 2005). The slope is from Northeast to Southwest. The study villages and the KAU coconut plantation are located in the lowland area with slopes varying from 1 – 5 %, but the forest is located in the mid-uplands and uplands region.

Homegardens

Homegardens constitute the most important agroforestry system in Kerala (Fig. 3-2A). They are diverse in nature in terms of species composition, size, and age (Mohan et al. 2007). The HGs of the study sites were categorized arbitrarily into two classes: "Small Homegarden" (HGS), less than 0.4 ha (1.0 acre) in area; and "Large Homegarden" (HGL), more than 0.4 ha (1.0 acre) in area.

A total of 24 homegardens were selected of which, half were HGL and rest HGS. Eight gardens, four each of HGL and HGS, were selected from each of the three study villages. Each HG was unique in terms of its size, age, plant diversity, and management practices. Indeed, it is difficult, if not impossible, to find two HGs that are identical in all the above parameters, although the plant diversity and management practices may be somewhat similar among the HGs within a location. Within the Madakkathara *Panchayat*, for example, HG owners follow similar traditional management practices in their gardens and share any new information they might be getting from government agricultural extension sources. Owners of all 24 homegardens were surveyed for their demographic and socioeconomic information according to a questionnaire (Appendix B) and information was gathered on items such as age, education, annual income of the head of the household; size, age class, and sex ratio of the family; and information on livestock and occupational details of the owner. Size and the age of the HGs can vary regardless of the location; special attention was given to these factors during the survey. In addition, information was collected on plant diversity parameters (number and species of trees, shrubs, and herbs – including ornamentals and medicinal plants, but excluding weeds – in the garden; and management practices such as nutrient application, tillage, weed management, and irrigation. Taxonomic identification of plant species was obtained when needed from the Kerala Agricultural University.

Soil Sampling and Analysis

Soil samples were collected in November – December 2006 from eight HGs from each of three study villages. In each HG (plot), three sampling points were selected randomly and from each point soils were collected from four depths 0 – 20, 20 – 50, 50 – 80, and 80 – 100 cm. A composite sample for each depth interval was prepared by mixing soils from three sampling points, resulting in one sample per depth level from each study plot. Thus, there were a total of 96 samples (1 land-use type × 3 villages × 8 replications/plots × 4 depths) from the three villages. Soil sampling for bulk density measurement was done using a 178 cm^3 steel cylinder. For bulk density measurement soil pits of 1 m × 1 m × 1 m size was dug and the cylinder was horizontally inserted on the wall of the pit at the center of each depth class to collect the samples. All samples were air-dried, sieved (passed through 2 mm sieve), bagged, and sent to University of Florida, Gainesville, FL.

The soil samples were analyzed at the Soil and Water Science Department laboratory at the University of Florida, Gainesville, FL. The samples were oven-dried at 60° C for 72 hours and crushed to fine powder using a QM-3A High Speed Vibrating Ball Mill (Cianflone Scientific Instruments, Pittsburgh, Pa). Total nitrogen and SOC concentrations were determined on an automated FLASH EA 1112 N C elemental analyzer (LECO Corporation, St. Joseph, MI). Soil pH and particle size density were also determined. The C storage (Mg ha^{-1} in 1 m vertical depth) was calculated by multiplying the C concentration (g per kg of soil in fraction size) with bulk density of depth interval (kg m^{-3}) and the depth of respective class.

Ecological Indices

Plant species richness of the HGs was estimated according to the Margalef Index (Margalef, 1958) and plant species diversity by the Shannon index (Krebs, 1985). Sorenson's index of similarity (Sorenson, 1948) was used to estimate the magnitude of similarity in plant species between homegardens. Detailed procedure of each index is presented below.

Species richness

This index calculates the number of species in an area divided by the log of the total number of individuals sampled, added over species. The higher the Margalef index value, the higher the species richness of the population.

$$\text{Margalef Index} = (N-1) / \ln (n) \qquad \text{(Eq. 5-1)}$$

Where, N is the number of species, and n is the total number of individuals in the sample.

Species diversity

Species diversity is the product of its richness and evenness. Richness refers to the presence or absence of species and evenness is the balance between the numbers of individual members of species. There are several ecological indices to measure species diversity, of which Shannon index is most commonly used. Equation 5.2 is the mathematical expression of Shannon index (Krebs 1985).

Shannon Index (H)

$$H = -\sum_{i=1}^{n} p_i \ln p_i \qquad \text{(Eq. 5-2)}$$

where, n = Number of species p*i* = Proportion of total sample belonging to *i*th species

The proportion of species relative to the total number of species is calculated and multiplied by the natural logarithm of this proportion. The resulting product is summed across species and multiplied by negative one (–1).

Similarity

The vegetative similarity was estimated using Sorensen's index of similarity and presented in percentage.

$$S_s = \left[\frac{\textbf{Number of common species}}{\mathbf{(S_x + S_y)/\ 2}} \right] \times \mathbf{100} \qquad \text{(Eq. 5-3)}$$

S_s = Sorenson's Index
S_x= Number of species in homegarden X
S_y = Number of species in homegarden Y

Relative Difference in SOC Contents

The difference between the SOC contents of two groups (within the same parameter class, e.g. low and high species density) expressed as a percentage of the lower value.

Δ Relative Difference (%)
= (Difference between the higher and lower values /Lower value) × 100 (Eq. 5-4)

Categorization of Homegardens

Apart from the size classification, the selected HGs were categorized arbitrarily in different groups based on their age and plant-stand characteristics as described below to investigate how they influenced the SOC content.

- **HG size (ha):** HGS (<0.4 ha) and HGL (>0.4 ha): 0.4 ha = 1 acre, which is the common measure of land area in the study location.

- **HG age (years):** Young (35 – 50 years), Medium-aged (51- 79 years) and Old (80 – 100 years).
- **HG species density (no. of species100m^{-2}):** Low (<0.66 species), Medium (0.66 – 1.1 species) and High (>1.1 species).
- **HG species richness (Margalef index value):** Low (< 5.2), Medium (5.2 – 6) and High (> 6).
- **HG tree density (no. of trees 100m^{-2}):** Low (<5.5), Medium (5.5 – 7.5) and High (>7.5).

Notes:

1. The age of HG refers to the length of the period when the land has been managed as a homegarden, and was assessed based on discussion with its owners. While annuals are replanted every season, perennial plants including trees, are removed and replanted only when they become senile or unproductive.
2. Based on taxonomic identification of species (with the help of KAU professionals) and experience of local farmers, the plants were categorized as trees, shrubs, and herbs. .
3. In the absence of a time-sequence study involving long time intervals, the C stock data were considered as a reliable indicator of the CSP of the homegardens.

Statistical Methods

Multiple linear test was performed using the general linear model (GLM) and analysis of variance (ANOVA). Waller Duncan K-ratio test was used to compare the mean differences between effects of plant-stand characteristics and HG operational characteristics such as age and size on SOC for all sites. All statistical tests were performed with SAS 9.0 (SAS Institute Inc., 2004) and differences were considered significant when p<0.05.

Results

Homegarden Size, Age, and Soil C Sequestration

The size of HGs varied from 0.1 ha to 1.1 ha, with mean values of 0.22 ha for HGS and 0.55 ha for HGL. The HGS had higher SOC content (119.3 Mg ha^{-1}) than the HGL (108.2 Mg ha^{-1}) throughout the 1 m soil profile and the difference between the two size classes being more conspicuous in the upper 50 cm soil depth (Fig. 5-1).

The age of HGs ranged from 35 to 100 years with 74 and 67 years as the mean values for HGS and HGL respectively. The SOC content increased with the age of the HGs: older HGs (80 – 100 year) had higher SOC than younger ones (35 – 50 year) throughout the 1m soil profile; the differences were significant at the lower most depth class (80 – 100 cm) (Fig. 5-2B). The SOC content between the young and medium-aged (51 – 79 year) HGs were different below 50 cm, although not statistically significant (Fig. 5-2A).

Plant-stand Characteristics and Soil Carbon Stock in Homegardens

A total of 106 plant species were found and taxonomically identified. Average number of total species among all HGLs and HGSs were 37 and 33.5, respectively. The HGS had higher plant density, plant species density, tree, and tree species density compared with HGL (Tables 5-1 and 5-2). Plant density varied from 4.6 to 23.3 plants 100 m^{-2}, with a mean of 11.1 and 14.4 in HGL and HGS, respectively. Plant species density varied from 0.38 – 2.4 species 100 m^{-2}, with the HGS having higher mean value (1.6) than for HGL (0.7). Tree density varied from 1.55 – 13.5 trees 100 m^{-2}, with a mean of 5.8 and 7.5 in HGL and HGS, respectively. Tree species density varied from 0.25 – 1.25 species 100 m^{-2}; the mean value for HGS (0.95) being higher than that for HGL (0.4).

Mean Margalef index value was slightly higher (5.94) in HGS than in HGL (5.74), indicating higher species richness in HGS than in HGL. Although statistically not significant, HGS had slightly higher Shannon index value (2.38) than of HGL (2.27).

Sorenson's index of similarity showed that the similarity of plant species among three study villages varied from 86 – 88% (Table 5-4) and mean similarity between the HGS and HGL was 91.4%.

The SOC varied with the plant species density. Homegardens with high species density had the highest SOC (119.3 Mg ha^{-1}) within 1m soil profile (Fig. 5-3A). Homegardens with medium and low species density had 7% and 14% less SOC, respectively, than the HG with high species density. The SOC varied also with tree density: HGs with high tree density had the highest SOC (126 Mg ha^{-1}) within 1m soil profile and those with medium and low tree density had 10% and 20% lower SOC, respectively (Fig. 5-4A). The SOC difference among tree density categories was prevalent at all depth classes. The relative difference between low and high tree density category was lower in bottom half of 1m than that of top half of 1m soil (although not statistically different) (Table 5-3). Homegardens with high species richness (Margalef index) had the highest SOC (127.4 Mg ha^{-1}) within 1m soil profile; those with medium and low species richness had 16% and 17% lower SOC, respectively (Fig. 5-5A). The SOC per unit depth (Mg ha^{-1} cm^{-1}) was higher in HGs with high species richness than HGs with low species richness in the upper 50 cm depth; however, the difference in SOC content among three categories reduced with depth below 50 cm. No clear difference in SOC was observed due to the overall plant density, tree species density, and Shannon index parameter.

Discussion

Soil Carbon Stock in Relation to Operational Characteristics of Homegardens

Any effect of operational characteristics of HGs such as garden size and age on SOC stock can be explained in terms of the effect of these parameters on the plant-stand characteristics such as plant species density and tree density, and in turn, their effect on SOC stock. For example, smaller HGs have higher (though not always statistically different) species density, richness, and diversity compared to larger HGs (Table 5-2). Consequently, the higher SOC content in HGS compared to HGL can be taken as a direct reflection of the species density, richness and diversity associated with HGS. In this study the mean Margalef index (species richness) value was slightly higher (5.94) in HGS than in HGL (5.74), indicating higher species richness in HGS than in HGL. Previous research in Kerala also had indicated that smaller homegardens had higher species diversity and higher species density. Kumar et al. (1994) reported that Margalef index value ranged from 3.4 to 7.4 in Kerala HGs, which is similar to the results (3.4 to 7.8) of a study conducted on Kerala HGs by Mohan et al. (2007). The Shannon index (species diversity) value was also slightly higher (but statistically not significant) for HGSs (2.38) than for HGLs (2.27). Sankar and Chandrashekhara (2002) found similar differences between small and large HGs in Kerala, but their values were fairly low. Studies from Thailand (Gajaseni and Gajaseni, 1999) showed that Shannon index values of HGs ranged from 1.9 to 2.7, which are comparable to the range of values (1.45 to 3.14) of the present study.

The increase in SOC content in older HGs (Fig. 5-2B) can be explained in terms of the impact of disturbance to the system and the mean residence time (MRT) of SOC. In this study the age of homegardens varied from 35 to 100 years, with an average of 70 years. The flora of homegardens includes trees, herbs, and shrubs and all of them contribute to the soil C sequestration. However, shrubs and herbs are comparatively short-lived but trees can survive as high as 100 years or more. The HGs selected for this study had trees with varied age distribution with trees as old as the HG itself. Indeed, most HGs have certain tree species that are indicators of homegarden age. Longer life of trees in HGs ensures prolonged SOC accumulation. With increase in age, above- and below-ground volume of trees also increase (to a certain age) and this contributes to continued and prolonged addition of leaf and fine root biomass to the soil. However, the growth rates of trees do not stay the same forever, depending on species it decreases with age and the rate levels off after a certain period of time. But, even at that stage, although the rate of growth is zero or close to it, trees continue to add leaf and root litter throughout their life.. When mature trees are removed from homegardens, their roots are left in the soils, which upon subsequent decomposition could contribute substantially to SOC accumulation. Therefore, the older a HG, the higher are the chances for SOC accumulation. This also explains why older HGs had higher SOC stock than the younger ones at the lowermost soil depth class studied (80 – 100 cm). Reduced microbial activity caused by lack of supply of aeration and minimal physical disturbance would probably have contributed to the increase in the MRT of SOC at lower depths (Fontaine, 2007). Thus, it is likely that SOC accumulation at lower depths will be more prominent in older than in younger HGs. This also explains why SOC below 50 cm was higher in medium-aged HGs compared to young HGs, whereas there was no difference within top 50 cm (Fig. 5-2B).

Soil Carbon Stock in Relation to Plant-stand Characteristics

The SOC stock increased with the increase in plant species density (Fig. 5-3) and species richness (Margalef index) (Fig. 5-5). Both these parameters are associated with the number of plant species and their values increase with an increase in the number of species in a system. In a study on wet evergreen forests of southern Western Ghat mountains of Kerala the Margalef index value of 7.07 was reported (Varghese and Balasubramaniyan, 1998), which is fairly close to the values found in this study (Table 5-1). This supports Swift and Anderson (1993)'s ranking of homegardens, based on biological diversity, as the highest among all human-made agroecosystems, next only to natural forest. Kirby and Potvin (2007) suggested that, in general, as more species are included in a system, more complete utilization of resources takes place and the system becomes more productive. High species assemblage of HGs is likely to harbor species with strong resources-utilization characteristics compared with less species-intensive systems (Tilman et al., 1997) and may promote a greater net primary production (Vandermeer, 1989), which in turn could contribute to higher C sequestration.

In general, across all treatments, the SOC stock decreased with soil depth. This is common in almost all mineral soils and is a reflection of the accumulation of higher quantities of litter and other organic materials on the surface and their rapid decomposition. The SOC stocks in HGs in relation to both species density and species richness were also higher in the upper, than in the lower, soil layer (Figures 5-3B, 5-5B). This can be explained by the plant composition of HGs. Homegarden are comprised of trees, shrubs, and herbs and these plant classes have different belowground growth pattern. The majority of root growth and activity of shrubs and herbs are expected to be restricted within the upper 50 cm of the soil. In contrast, tree roots are distributed to deeper soil layers (1m depth and lower). Increase in number of species means increase in the number of species from all three plant classes and this promotes the higher SOC accumulation in the upper soil. On the other hand, the relative differences in SOC stock between HGs with high and low tree density were more conspicuous at the lower depth than in the upper depth (Table 5-3), suggesting the existence of increased root activity in the lower soil layers in tree-based compared to treeless systems.

Soil organic C content did not change with increase in tree species. Although SOC content of HGs showed a positive relationship with overall species density, no clear relationship was observed between SOC and tree species density at any depth. The relationship between ree species composition and diversity and SOC accumulation is however not clearly established. While some have reported a positive relationship between tree species and SOC above 30 cm depth (Simard et al., 1997; Chen. 2006) others (e.g., Kirby and Potvin, 2007) did not find any relationship between tree species diversity and SOC accumulation 0 – 10 cm and 30 – 40 cm soil depths.

The SOC content increased with increasing tree density of the HGs. Throughout the 1m soil profile the SOC of the HGs with high tree density remained higher compared to HGs with medium and low tree density (Fig. 5-4B). This is a clear indication of the influence of trees on

SOC accumulation throughout the soil profile through increased biomass production both above and below ground, as discussed previously.

Conclusions

Overall, the study showed that in a tropical homegarden system, the C stock in soil increased with the increase in number of plant species. There were differences between smaller and larger homegardens in terms of their plant-stand characteristics such as tree and tree-species density, and overall plant and species density. Perhaps because of the differences in plant-stand characteristics, SOC content also varied with the size of e homegardens: smaller-sized homegardens had more SOC per unit volume of soil than larger-sized homegardens. Furthermore, homegardens with higher number of species retained more C in the soil compared to those with lower number of plant species. The species influence on SOC was prominent at the top 50 cm of soil and decreased with depth below 50 cm. The C stock estimates are considered as approximations to CSP. Therefore, it is logical to infer that increase in plant species increases the CSP of HGs. Viewed in context of their high plant-species diversity (a surrogate of biodiversity), this enhanced C sequestration (GHG mitigation) potential of homegardens could be useful for the emerging scientific interest on understanding the relationship between species diversity and C sequestration. The main limitation of this study is that, it evaluated only a rather small number (24) of homegardens. More elaborate studies are needed with larger number of homegardens at study locations with varying soil and agro-climatic conditions. Furthermore, different patterns of plant-species compositions should be compared for their C sequestration characteristics to develop C sequestration-friendly species-composition models for different situations.

Table 5-1. Operational and plant-stand characteristics and depth-wise soil organic carbon in the homegardens of Madakkathara *Panchayat*, Thrissur, Kerala, India.

Homegarden			Density (no. of items 100 m^{-2})				Margalef Index	Shannon Index	Soil Organic Carbon (Mg ha^{-1})			
Sl.#	Size (ha)	Age (Years)	Plant	Plant Species	Tree	Tree Species			0 – 20 cm	20 – 50 cm	50 – 80 cm	80 – 100 cm
1	0.10	50	11.40	2.40	6.40	1.20	4.85	2.39	30.92	29.08	21.28	13.64
2	0.12	60	15.33	2.33	6.58	1.17	5.18	2.69	17.94	26.81	20.71	14.40
3	0.15	100	10.81	1.35	5.88	0.88	3.74	2.37	26.76	38.15	25.98	18.37
4	0.20	70	8.15	1.50	4.75	0.85	5.70	2.48	36.84	32.87	30.63	17.86
5	0.20	60	16.50	2.15	7.50	0.85	7.24	2.45	32.66	35.23	25.19	14.86
6	0.22	70	14.50	1.32	7.59	0.95	4.86	2.00	37.14	31.74	34.91	17.71
7	0.24	100	22.08	1.96	5.79	1.25	7.34	3.14	37.45	49.05	37.06	18.88
8	0.24	60	12.58	1.21	8.58	0.79	4.90	1.94	35.70	44.27	40.23	27.11
9	0.24	90	17.13	1.43	10.98	0.82	5.63	2.49	20.80	36.54	24.85	14.37
10	0.27	85	10.56	1.34	8.62	0.97	6.19	2.00	43.44	45.64	34.16	20.32
11	0.30	50	18.67	1.40	10.30	0.87	6.48	2.10	37.38	36.84	24.29	8.34
12	0.35	100	17.39	1.11	8.15	0.74	9.20	2.54	51.80	59.50	33.23	18.38
13	0.40	55	14.38	0.58	5.45	0.33	3.46	1.80	22.10	27.13	19.67	14.04
14	0.40	50	7.20	1.08	1.55	0.60	7.42	2.93	24.24	24.44	21.12	16.92
15	0.40	100	12.53	0.65	7.40	0.33	4.02	2.44	26.06	27.65	30.34	11.72
16	0.44	100	12.02	0.77	9.39	0.32	5.26	1.79	24.89	29.04	33.41	22.27
17	0.44	50	10.84	0.84	4.36	0.43	5.83	2.64	25.55	20.79	25.12	14.72
18	0.50	70	9.38	1.02	4.16	0.48	8.13	3.03	30.69	35.10	28.41	14.93
19	0.52	80	9.60	0.69	3.60	0.44	5.64	2.61	34.89	36.72	28.46	23.47
20	0.52	35	11.08	0.75	4.56	0.35	5.97	2.39	25.33	40.82	29.45	11.94
21	0.56	60	4.59	0.61	3.36	0.46	5.95	1.91	28.60	30.78	23.49	15.06
22	0.60	50	7.95	0.52	5.77	0.30	4.86	1.86	35.87	35.03	33.31	16.12
23	0.68	100	12.35	0.72	6.37	0.32	7.13	2.33	44.06	51.78	42.32	21.43
24	1.10	50	23.31	0.38	13.48	0.25	5.22	1.45	35.15	39.88	28.46	16.13

Table 5-2. Plant-stand characteristics of homegardens selected for the study in Madakkathara *Panchayat*, Thrissur, Kerala, India

Plant-Stand Characteristics	Large Homegarden (>0.4 ha)	Small Homegarden (<0.4 ha)
Total no. of Species	105	96
Mean no. of Species/ homegarden	37	33.5
Mean Plant Density (no. of plants 100 m^{-2})	11.14	14.42
Mean Species Density (no. of species 100 m^{-2})	0.71b‡	1.61a
Mean Tree Density (no. of trees100 m^{-2})	5.84	7.51
Mean Tree Species Density (no. of tree species 100 m^{-2})	0.41b	0.95a
Mean Margalef Index	5.74	5.94
Mean Shannon Index	2.27	2.38

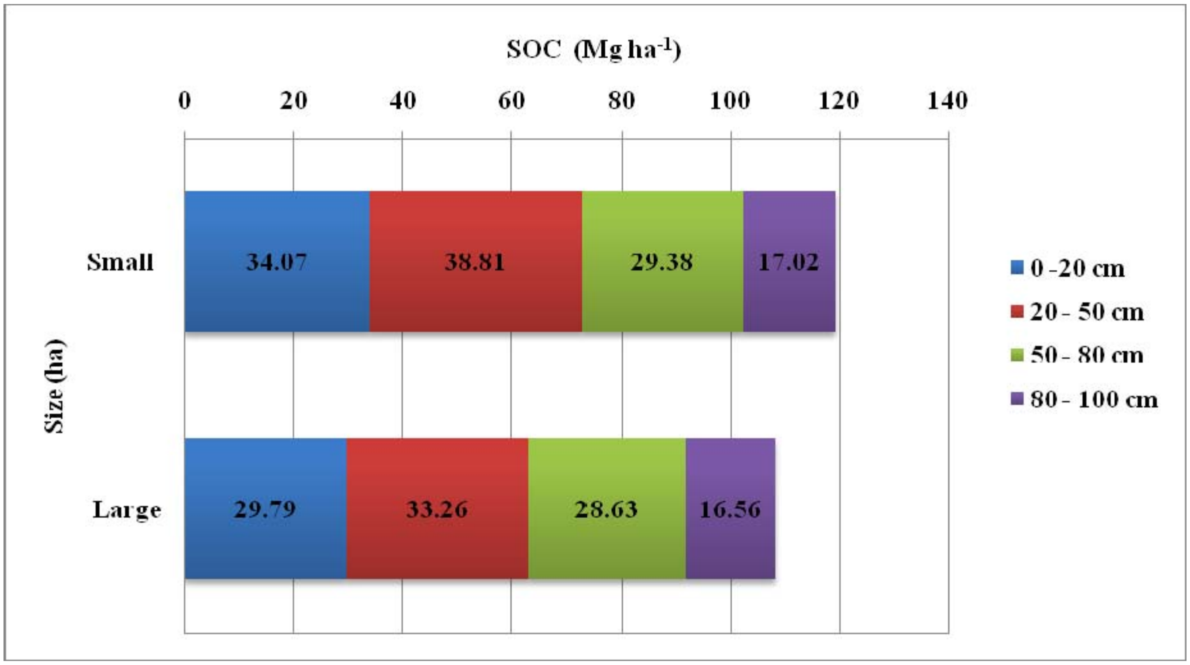
‡ a or b following the mean value indicates a statistically significant difference (at $p<0.05$), between means of different plant-stand characteristics.

Table 5-3. Relative difference of soil organic carbon between low and high tree density at different soil depth classes in homegardens of Madakkathara *Panchayat*, Thrissur, Kerala, India.

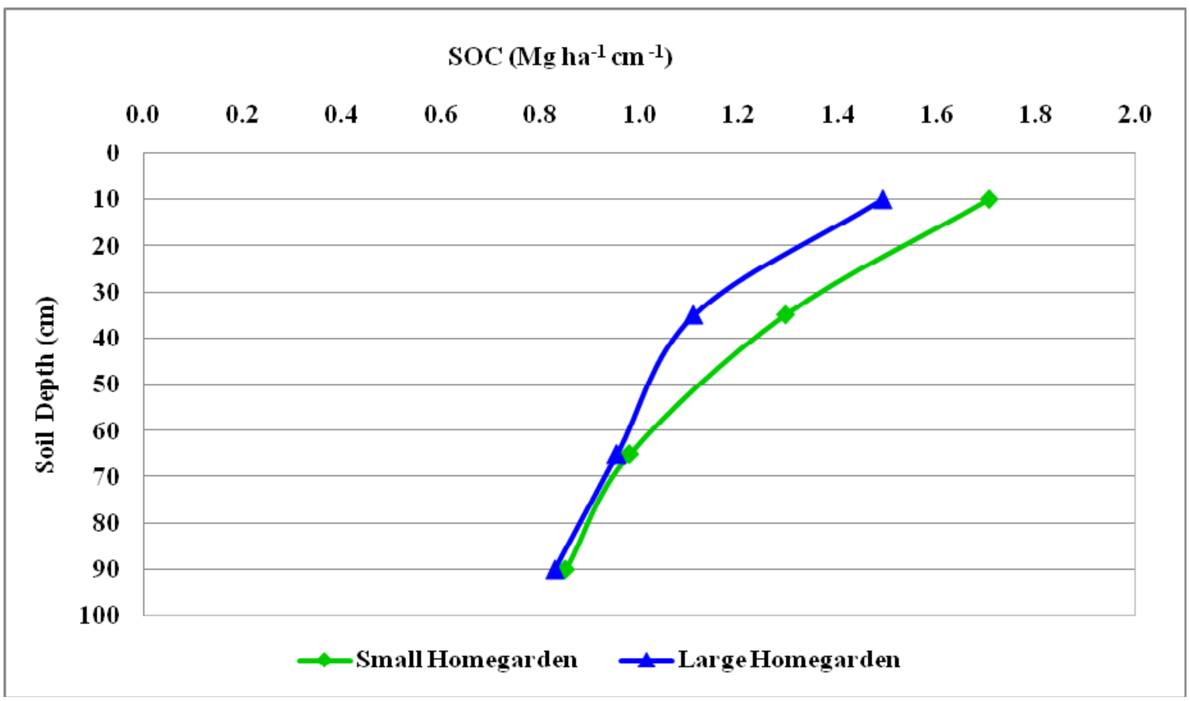
Depth	Low Tree Density Value (LTDV)	High Tree Density Value (HTDV)	Δ Relative Difference = (HTDV – LTDV)/LTDV	Relative Difference (%)
0 -20 cm	1.43	1.79	0.2561	25.61
20 - 50 cm	1.04	1.35	0.2948	29.48
50 - 80 cm	0.86	1.06	0.2334	23.34
80 - 100 cm	0.81	0.91	0.1242	12.42

Table 5-4. Percentage of similarity of species richness using Sorenson's index for across the homegardens of three study locations in Madakkathara *Panchayat*, Thrissur, Kerala, India.

Study Sites	Pandiparambu	Chirakkakode	Vellanikkara
Pandiparambu	—	86.3	88
Chirakkakode	86.3	—	86.96
Vellanikkara	88	86.96	—

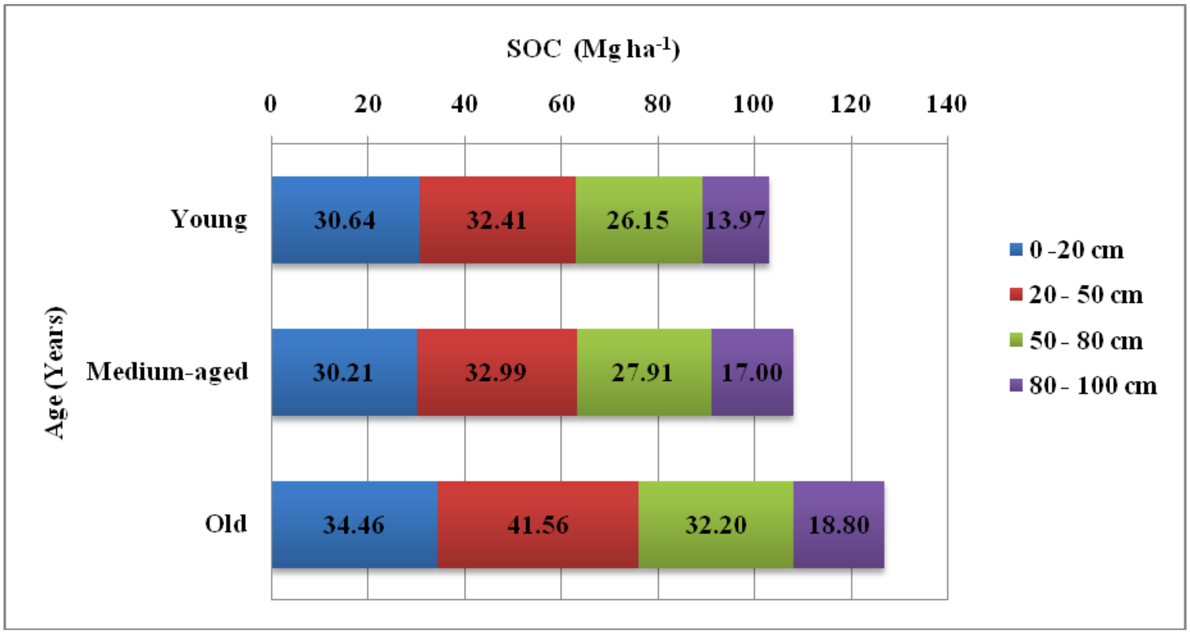


A



B

Figure 5-1. Soil organic carbon (SOC) content across soil depths in homegardens with two different size classes in Madakkathara *Panchayat*, Thrissur, Kerala, India. A) SOC calculated per ha, B) SOC calculated per ha per cm. Size classes(ha): Small (<0.4) and Large (> 0.4).



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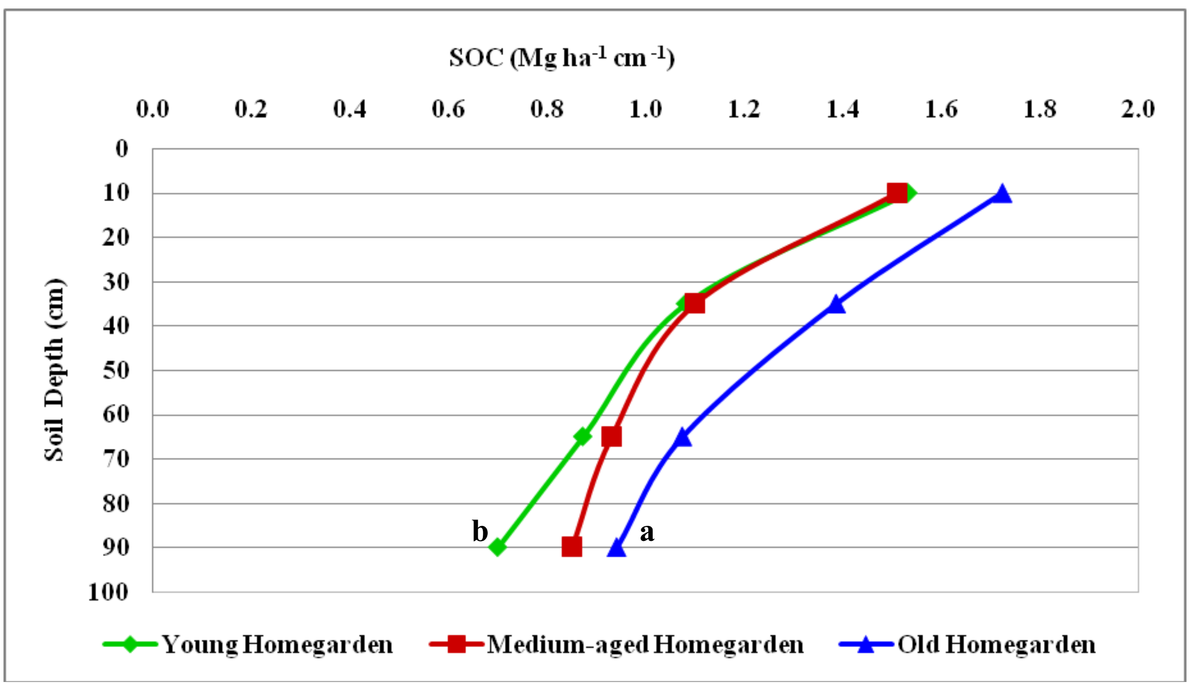
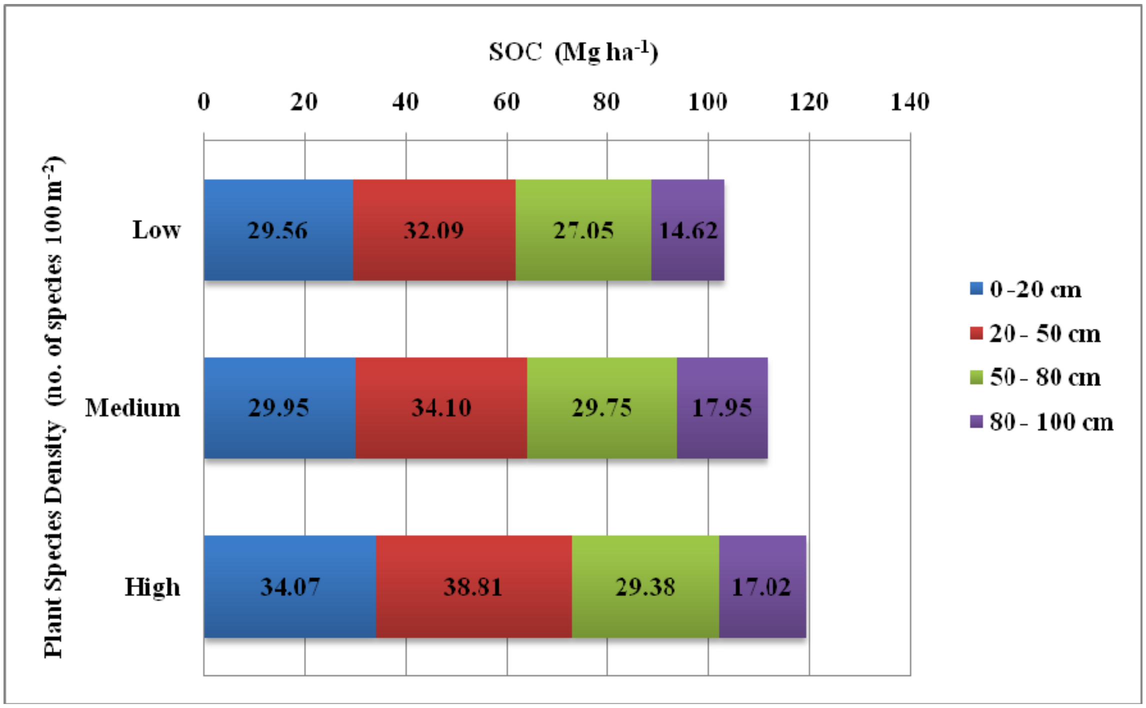


B

Figure 5-2. Soil organic carbon content (SOC) across soil depths in homegardens with different age classes in Madakkathara *Panchayat*, Thrissur, Kerala, India. A) SOC calculated per ha, B) SOC calculated per ha per cm. The presence of a and b indicates a statistically significant difference (at $p<0.05$), between SOC of different age classes at any given depth. Age classes (years): Young (35 – 50), Medium (51 to 79) and Old (80 to 100).



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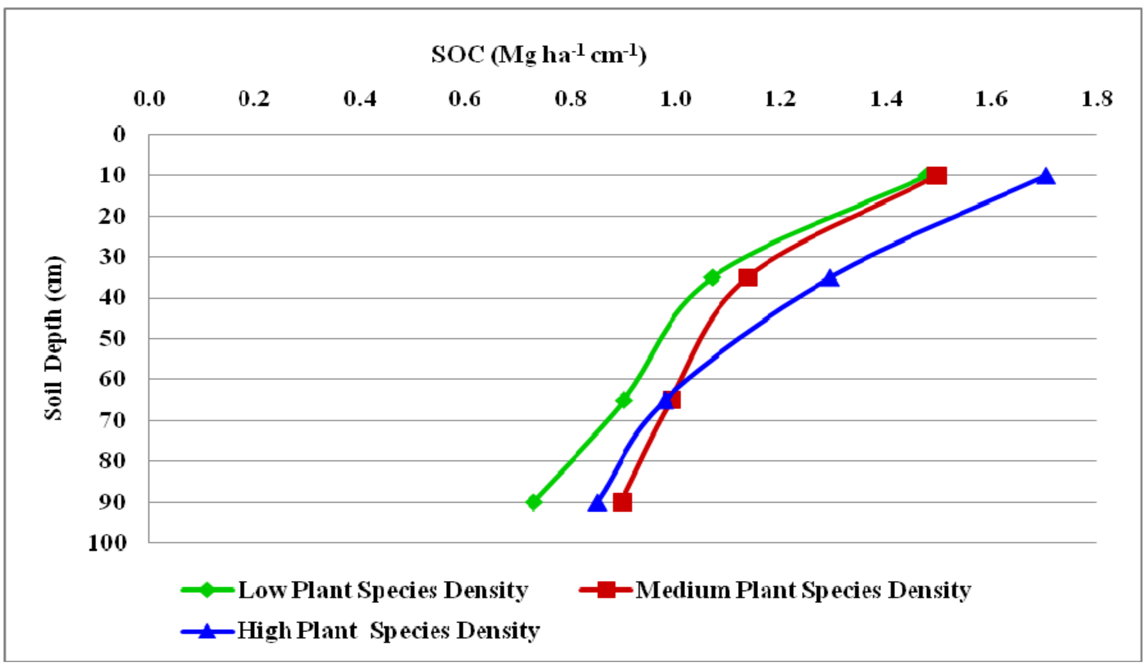
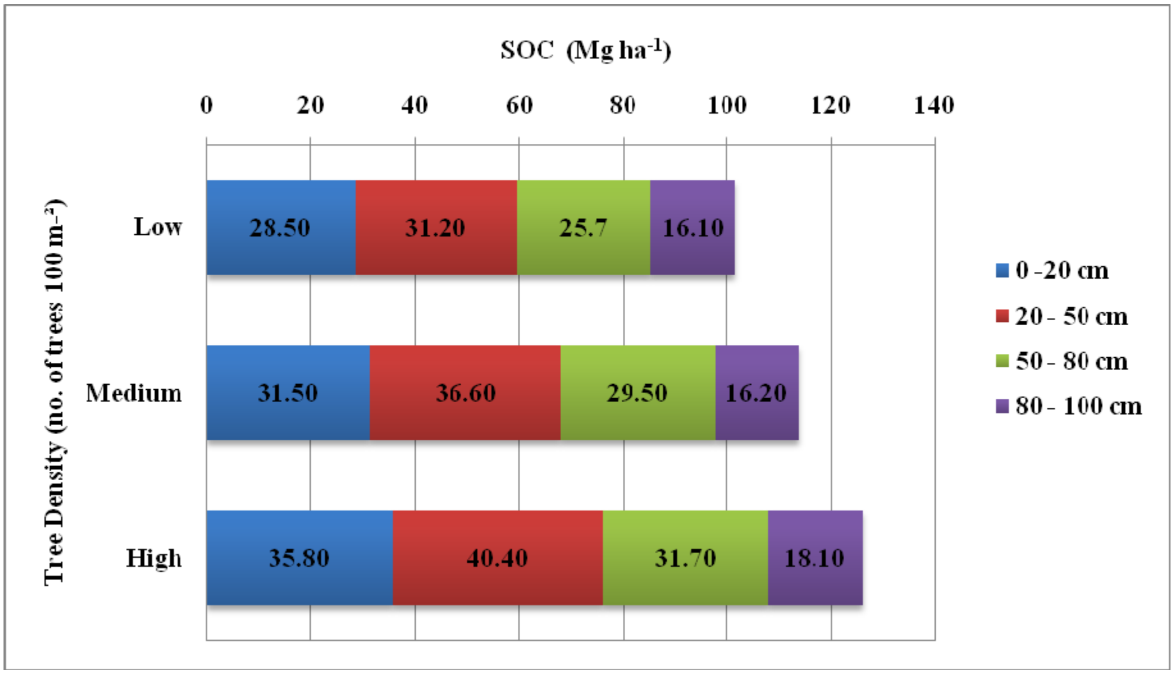


B

Figure 5-3. Soil organic carbon content (SOC) across soil depths in homegardens with different plant species densities in Madakkathara *Panchayat*, Thrissur, Kerala, India. A) SOC calculated per ha, B) SOC calculated per ha per cm. Plant species density classes (species 100 $m^{-2)}$: Low (<0.66), Medium (0.66 – 1.1), High (>1.1).



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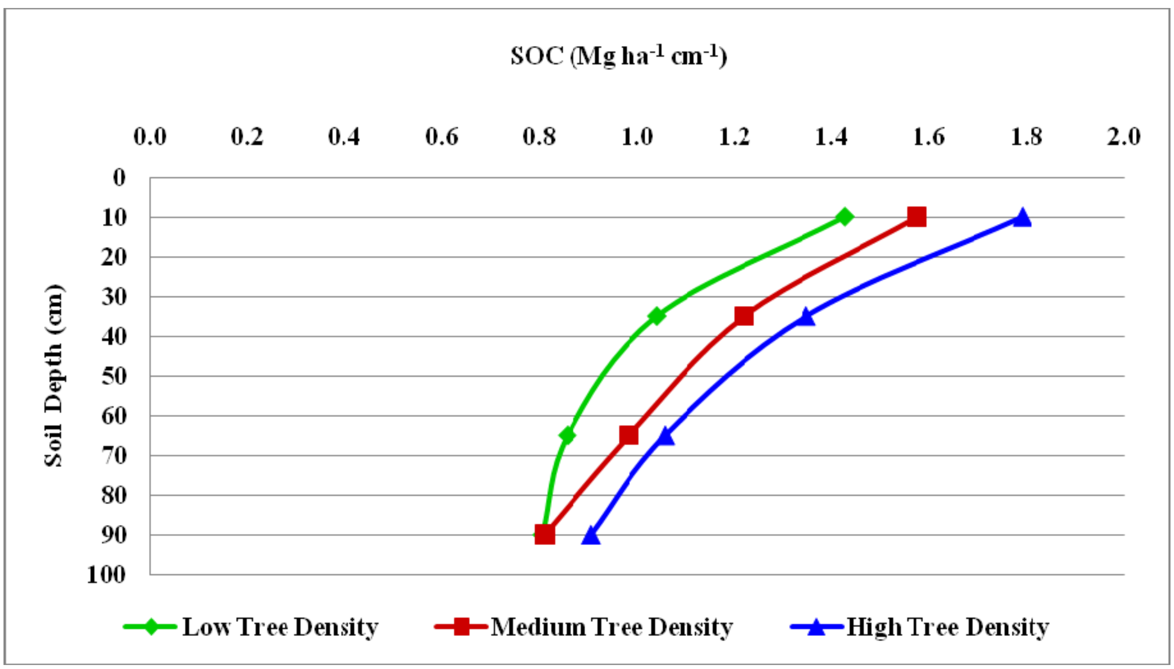
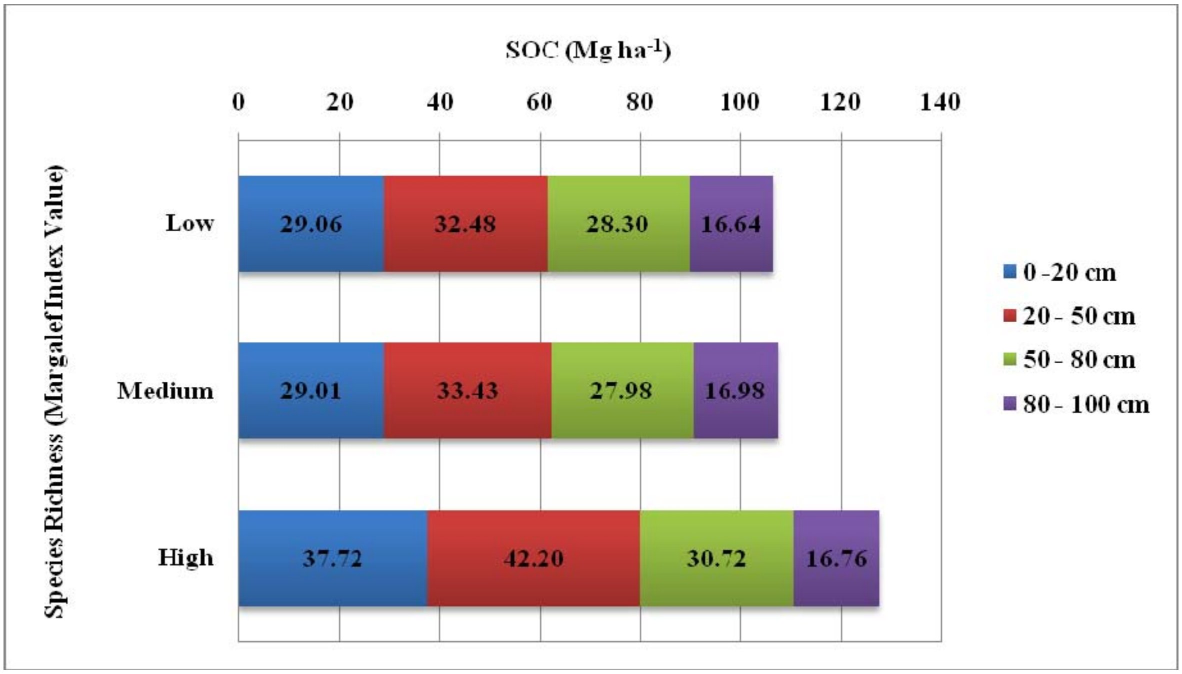


B

Figure 5-4. Soil organic carbon (SOC) content across soil depths in homegardens with different tree densities in Madakkathara *Panchayat*, Thrissur, Kerala, India. A) SOC calculated per ha, B) SOC calculated per ha per cm. Tree density classes (trees 100 m^{-2}): Low (<5.5), Medium (5.5 to 7.5) and High (>7.5).



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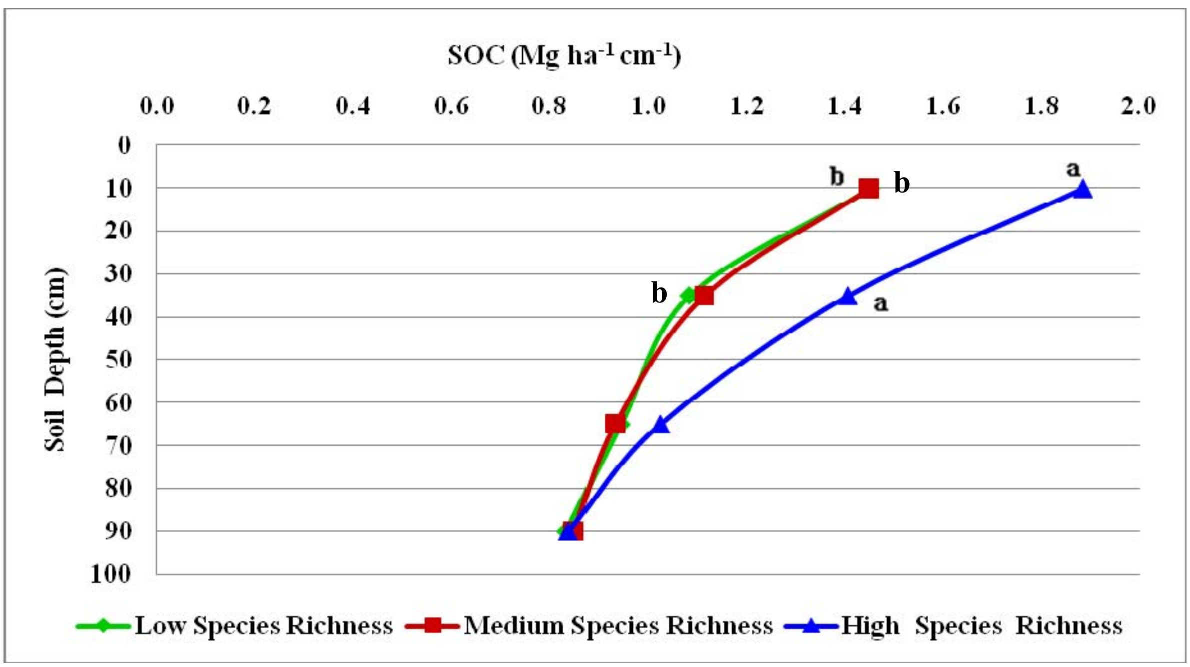

B

Figure 5-5. Soil organic carbon (SOC) content across soil depths in homegardens with different species richness in Madakkathara *Panchayat*, Thrissur, Kerala, India. A) SOC calculated per ha, B) SOC calculated per ha per cm. The presence of a and b indicates a statistically significant difference (at p<0.05), between SOC of different species richness classes at any given depth. Plant Species Richness classes based on Margalef Index (MI) values: Low (< 5.2), Medium (5.2 to 6) and High (> 6).

CHAPTER 6
SOCIAL CONTEXT OF FARMERS' DECISION ON HOMEGARDEN MANAGEMENT PRACTICES THAT MAY IMPACT SOIL CARBON SEQUESTRATION

Introduction

In agricultural systems, the extent of carbon stored (or sequestered) in the components of biosphere such as vegetation and soils is influenced by a number of agricultural practices. However, the magnitude of this effect on soil C sequestration is still not clear: while some agricultural practices promote sequestration of C, some may adversely affect it. Farming practices that are reported to affect C sequestration include tillage, plant residue management, manure usage, and fertilizer application (FAO, 2004). In addition, tree planting is recognized as a practice that contributes to C sequestration (Montagnini and Nair, 2004, Yelenik et al., 2004; Haile et al., 2008).

Farming Practices

Tillage is an important practice that decreases C stocks in agricultural soils (Lal et al., 1989; Carter, 1993). Soil aggregates are vital for soil C storage (Six et al., 2000), but tillage causes destruction of aggregates and exposure of stored C to microbial degradation. The effect of tillage varies from site to site (Buschiazzo et al., 2001) and the no-tillage approach may be beneficial for soil C storage (Phillips et al., 1980; Reicosky et al., 1995). Plant residues provide resources for the production of soil organic C. About 15% of the plant residue is converted to passive soil organic C (SOC) (Lal, 1997). Campbell et al. (2000) observed that 9% (frequently fallowed systems) to 29 % (continuously cropped systems) of residue C converted to SOC in semiarid regions of Canada. However, this conversion depends on several factors like temperature, moisture, type of crop, and quality of residues. Manure application increases the formation and stabilization of soil macroaggregates (Whalen and Chang, 2002) and particulate organic matter (Kapkiyai et al., 1999). Formation of macroaggregates and particulate organic matter are beneficial to the storage of soil C (Six et al., 2002). Manure is more resistant to microbial decomposition than plant residues, thus for the same input, C storage is higher with the manure application (Jenkinson, 1990). Li et al., (1994) reported that application of manure yielded the largest amount of C accumulated over a range of soils and climatic conditions. The primary goal of fertilizer application is to increase the yield and any increase in biomass promotes the scope of C sequestration. Therefore, fertilizer application has been proved to be a successful method of enhancing C sequestration (Lal et al., 1999). In contrast, application of nitrogenous fertilizers is considered as a source of GHGs, because they generate nitrous oxide (N_2O), which is a GHG (Robertson, 2000). The carbon sequestration potential (CSP) of a system varies according to the type of plants included in it. More the biomass more will be the C storage, thus trees may have a better CSP than annual herbs. According to Montagnini and Nair (2004) the tree component of the agricultural systems are potential sinks of atmospheric C due to fast growth and productivity and by adding trees, the system can increase the C storage capacity of the system (Kursten, 2000).

The extent of influence of these practices on C sequestration depends on the intensity of the management. The farmers' decision on the intensity of management is influenced by a large number of factors including socioeconomic and demographic factors (Seabrook et al., 2008), as well as the financial condition, education, age and gender of the farmer, land holding-size, availability of resources, and extension contact (Anjichi et al., 2007; Matata et al., 2008).

Agricultural decisions made by individuals are often influenced by his/her economic opportunities (Lambin et al., 2001). Chuma et al. (2000) and Campbell et al. (1997) reported that wealth (or financial solvency) of the farmers was an important factor for choosing soil fertility management practices in Zimbabwe. Lompo et al. (2000) reported that the resource endowment of the farmers influenced the adoption of composting. Education of the farmer plays a major role in making farm management decisions. Farmers with more education are most likely aware of the wide range of information sources and are more efficient at processing information and reaching decisions (Huffman, 1974). Farmers with more education can adopt and adjust to changes more quickly and accurately (Oram, 1988; Huffman, 1974). Therefore, it may be logical to think that any new agricultural development or environmental friendly recommendations would be adopted faster by the educated farmers. Pichon (1997) and Geoghegan et al. (2001) observed that higher education had a negative effect on the levels of cutting trees in South America. Anjichi et al. (2007) observed that formal education was a critical factor in influencing the efficacy of the farmers’ decision to adopt the farm soil conservation measures in Kenya. Matata et al. (2008) reported that almost all the farmers participated in new agroforestry activities in Tanzania had primary education. Welch (1970) observed that increase in the level of formal education resulted in selecting a more accurate quantity of nitrogenous fertilizers.

Size of the land-holding is also an important factor that influences the farmers’ decision to implement certain management practices management practices. Resource-poor farmers can be inversely influenced by the size of the farm and may have a tendency to not apply manure, plant residues, or fertilizers uniformly and adequately to the farm. Williams (1999) observed that application of manure was inversely influenced by the farm size in semi-arid West Africa. Size of the land-holding influences the plant species density and tree density (especially in HGs), which in turn may affect the stocking of soil C. Smaller homegardens had higher species diversity (Kumar et al., 1994) and higher species density (Mohan et al., 2007). High species assemblage of HGs are likely to harbor species with strong resources-utilization characteristics compared with less species-intensive systems (Tilman et al., 1997) and may promote a greater net primary production (Vandermeer, 1989), which in turn promotes C stocking in homegardens (Kumar, 2006). Identifying any difference in management intensities of selected practices due to the size of the homegardens and social factors related to size may strengthen our understanding about the social factor and C sequestration interrelationship.

Age of the farmer is another important factor for making farm decisions. Age affects farmers' knowledge and ability to adopt changes (Anjichi et al., 2007). Older farmers may be inflexible with many new developments or may take more time to adopt new technologies. Matata et al. (2008) reported that more young (20 – 40 years) farmers participated in agroforestry activities than older farmers (45 – 70 years) in Tanzania. Similar results were observed by Alavalapati et al. (1995) in India and Ayuk (1997) in Burkina Faso, where they observed younger farmers were more inclined to participate in agroforestry practices.

The role of gender in HG decision-making is still under debate. Phiri et al. (2003) observed that men planted more trees than women in the improved tree fallows in Zambia. They explained that it was primarily because women are dependent on men for making agricultural decisions. In contrary, Anjichi et al. (2007) observed that gender was not a critical issue in adopting soil conservation methods in Kenya.

Availability of resources such as raw materials, labor, household cattle etc. influenced the farmers' decision with the management practice. Williams (1999) observed that application of manure in semiarid West Africa was dependent on the number of farm animals and available labor. He observed that manure application contracts with external labors or seasonal participation of household members increased the probability of manure application by 15.7% and 8%, respectively.

Contacts with peers and organizations may also influence farmers' decision with farming practices. Thangata and Alavalapati (2003) reported that contacts with extension agents promoted mixed intercropping in Malawi. Somda et al. (2002) observed that farmers' participation in extension workshops influenced the adoption of composting technology in Burkina Faso. However, little information is available about the role of underlying socioeconomic and demographic (or social) factors in influencing the farmers' decision with practices such as tillage, application of plant residue, manure, and fertilizer, and planting trees. Mercer and Miller (1997) reported that one of the main reasons for the failure of agroforestry development projects in developing nations was lack of attention to the socioeconomic issues during the development of the systems.

Scope of Homegardens

In commercial agricultural systems, the effects of social factors on management practices are difficult to measure. In such systems, the management decisions are made with a goal of higher production and profit maximization, which undermines the influence of socioeconomic and demographic factors. An ideal place for the proposed study would be an agricultural system, which is not solitarily for commercial production, but still has an economic purpose and goal at the subsistence level. The homegarden is one such system, where profit maximization, in most of the instances, is not the main objective and social factors have strong effects on farmers' decision with the management practices.

Homegardens are intimate, multistory combinations of various trees and crops, sometimes in association with domestic animals, around the homesteads (Fernandes and Nair, 1986; Kumar and Nair, 2004). Homegardens are distributed in tropical areas like Asia, Africa, Central America, the Caribbean, and the Pacific Islands (Ruthenberg, 1980; Anderson, 1993; High and Shackleton, 2000; Nair and Kumar, 2006). The social importance of homegardens is very high

(Nair, 1993; Kumar, 2006) and there are several socioeconomic and demographic factors that influence the famers' behavior with management decisions. The objectives of the study are to,

1. Identify farming practices (and their intensities) that influence C sequestration in the HG systems.

2. Understand the effects of socioeconomic and demographic factors on farmers' decisions with homegarden management practices that influence C sequestration.

Conceptual Framework

The "Theory of Planned Behavior" (TPB) (Ajzen, 1981; 1985), a popular theory on human behavioral science, has been used as a conceptual framework of this study. This theory assumes that people behave in accordance to their belief and the beliefs are based on experiences, social or peer influence, and availability of resources. The underlying beliefs of TPB are associated with the social factors that influence the human behavior. Any demographic, social, or economic differences between farmers should, if relevant to the behavior, be reflected in differences in their beliefs (Beedell and Rehman, 1999). The idea of using TPB as the conceptual framework was to see if the differences in their beliefs (or social factors) can explain the differences in their behavior. Numerous social, psychological, and economic studies have used TPB to understand the human behavior. However, few studies (Beedell and Rehman, 2000; Burton, 2004; Colemont and Van den Broucke, 2008) have applied this theory in the field of agriculture to explain the farmer behavior.

Theory of Planned Behavior

The basic research question in this study was do demographic and socioeconomic factors influence HG-owners' decisions with farm management practices, which eventually affect C sequestration. Farmers' behavior in making a decision on any management practice is influenced by several factors such as his personal beliefs, social pressure, and availability of resources. At this point, the basic idea of this study reflects a connection with the "Theory of Planned

Behavior", a popular concept developed by Icek Ajzen (Ajzen 1985). In this study TPB has been viewed as the underlying thread to understand behaviors such as tilling the land, applying plant residue, applying fertilizers, applying manure, and planting trees. The framework of this study is inspired by this theory (Ajzen 1985, 1991).

Ajzen identified three basic beliefs that influence the outcome of a behavior: behavioral belief, normative belief, and control belief (Fig. 6-1). Behavioral belief is the belief or concept that the behavior will produce a given outcome (e.g. application of manure will help plants to grow and develop). This in combination with subjective values of expected outcomes determine the attitude towards the behavior. Attitude toward the behavior is the degree to which performance of the behavior is positively or negatively valued. Factors such as education and experience of the farmer built up his behavioral beliefs.

Normative belief refers to the perceived behavioral expectations of such important referent individuals or groups (e.g. my father applied manure and my friends apply it, too). It is assumed that these normative beliefs in combination with the person's motivation to comply with the different referents, determine the prevailing subjective norm. Subjective norm is the perceived social pressure to engage or not to engage in a behavior. In this study normative beliefs refer to referent individuals or groups such as ancestors, friends, agricultural extension agents, experts from the farmers' club etc. These factors create the perceived social pressure to engage or not to engage in a behavior, which is basically the subjective norm.

Control beliefs have to do with the perceived presence of factors that may facilitate or impede performance of a behavior (e.g. I have household cattle, so I will have supply of manure). It is assumed that these control beliefs, in combination with the perceived power of each control factor determine the prevailing perceived behavioral control. Perceived behavioral control refers to people's perceptions of their ability to perform a given behavior. It is assumed that perceived behavioral control is determined by the total set of accessible control beliefs (i.e., beliefs about the presence of factors that may facilitate or impede performance of the behavior). Control beliefs in this study refer to the financial condition, e.g. availability of funds to perform an action, availability of family labor, cattle and raw materials such as plant residue and manure. These factors influence the perceived behavioral control and facilitate the process of decision - making.

Actual behavioral control is similar to the perceived behavioral control refers to the extent to which a person has the skills, resources, and other prerequisites needed to perform a given behavior. Successful performance of the behavior depends not only on a favorable intention but also on a sufficient level of behavioral control. To the extent that perceived behavioral control is accurate, it can serve as a proxy of actual control and can be used for the prediction of behavior.

Theory of Planned Behavior can be better explained with an example of manure application to homegarden, where the owner positively adopts the practice. The behavioral belief (education/experience) of the farmer will contribute to the intention of applying manure and attitude toward the behavior will act positively. This is because the farmer knows plants get nutrition through manure, which in turn promotes growth and yield. Therefore, the farmer will apply (positive attitude toward the behavior) manure if the other factors remain constant. The normative belief refers to the referents like farmers' ancestors, friends, and agricultural extension agents. The farmer will evaluate his decision by observing what his peers are doing, what his ancestors have done, and what is suggested by the agricultural office. These factors will create a perceived social pressure (subjective norm) on him to make a positive or negative decision. In this case it was assumed that peers and agricultural extension agents suggest application of manure and ancestors did the same, as well. Thus, the subjective norm will be positive. Control beliefs in this case will relate to the perceived presence of factors like availability funds, labor, manure and cattle. Perceived behavioral control will refer to a farmer's idea about his ability to perform the behavior. Assuming the farmer has cattle, producing manure free of cost, or sufficient funds to buy manure and family labor to apply manure; this will give him the idea that he is able to perform the behavior (positive perceived behavioral control). Assuming all three beliefs result positively, the intention will be positive and the farmer will apply manure to the crop. Now, if some of the factors result positively and some of the factors act negatively then the farmer has to compare between the entire set of factors and make the decision. If the influence of positive factors suppresses the effects of negative factors then only the farmer will apply manure and vise versa.

Materials and Methods

Study Area

This study was conducted in the state of Kerala, India. The Madakkathara subdivision (*Panchayat*) in the district of Thrissur in the central part of the State (Fig. 2-1), where the Kerala Agricultural University (KAU) is located, was selected for this study. Thrissur district, bordered by Malappuram district in the north, Palakkad district to the east, and Ernakulam district to the south, lies between 10º 0' and 10º 47' north latitudes, and 75º 55' and 76º 54' east longitudes. Madakkathara *Panchayat*, located at the northeast part of Thrissur district, extends over an area of 2504 ha and lies between 10º 32' and 10º 36' north latitudes, and 76º 14' and 76º 18' east longitudes. Within the Madakkathara *Panchayat*, three villages (Pandiparambu, Chirakkakode, and Vellanikkara) were chosen for the study based on the availability of various land-use types that were considered important for the study. With the high level of recognition of the ecological and socioeconomic sustainability values of homegardens in this state (Nair and Shreedharan, 1986; Jose and Shanmugaratnam, 1993; Kumar et al., 1994), Kerala offers a good opportunity to study the development trends in homegardens (Peyre et al., 2006). There are about 5.4 million small operational holdings covering a total area of 1.8 Mha in Kerala, and apparently about 80% of it is homegarden (Govt. of Kerala, 2005). Thus, Kerala is estimated to have 4.32 million HGs covering 1.33 Mha of land (Kumar, 2006) covering 35% of the total land area of the state (Kerala State Land Use Board, 1995). The study was conducted in collaboration with the Kerala Agricultural University (KAU), Kerala, India.

Focus Group Meeting

A focus group meeting was arranged at the agricultural office of Madakkathara *Panchayat* involving people from the study villages. It was conducted to develop and modify the household survey questionnaire, which was the primary data gathering tool, on the effects of socioeconomic and demographic factors related to HG management decision. The local agricultural office provided the contacts of the HG-owners and allowed us to use their facilities to conduct the meeting. There were ten HG-owners (eight male, two female) present in the meeting; in addition, the KAU personnel, government agricultural officer and some office employees were present in the meeting (total of seven). At the beginning, demographic information of the participants were collected followed by a discussion session on open-ended questions. Two interpreters (KAU personnel) asked the questions in the local language and translated responses back in English. Dr. B.M. Kumar, Head of the Department of Silviculture and Agroforestry, KAU, monitored the translation. All responses were tape recorded for future reference. Open-ended questions were asked and active responses were obtained from the participants. The focus group meeting generated information that enriched the knowledge base as well as helped in fine-tuning the survey questionnaire. The modified questionnaire set was done under the supervision of the associated faculty members of University of Florida.

Household Survey

Sixty-five households with homegardens were selected randomly for the survey from the three study villages, Pandiparambu, Chirakkakode, and Vellanikkara. Homegarden owners are basically farmers of their own garden and would be referred to as "farmers" in rest of the paper. All the households surveyed had male members as the head of the family. Head of the household (male) and other male members of the family answered the questions and female members did participate in the survey. The questionnaire sets included general questions and questions in Likert scale. The Likert scale is a type of response measurement system or scale where respondents specify their level of agreement to a statement (Likert, 1932). The complete set of questions is given in Appendix B. The entire questionnaire was translated to *Malayalam* (local language of Kerala, India) by KAU personnel and was approved by Dr. B. M. Kumar. An explanation of Likert-scale grading system was also made in *Malayalam* to help the farmers understand how it works. Owners of randomly selected households were asked questions from the questionnaire set and answers were recorded. Each interview lasted for approximately half an hour; a local contact of the KAU and an interpreter accompanied in the survey. Due to incomplete response by the interviewees and inadequate information, six of the survey responses were discarded and information received from 59 respondents was analyzed.

Socioeconomic and Demographic Factors

The socioeconomic and demographic factors that were significant for influencing the farmers' decision with the HG management were identified through the focus group meeting. Based on the responses from meeting attendees and the TPB framework, factors were selected in relation to the five HG management practices that are known to influence C sequestration. The identified factors are listed below.

Ancestors (ANC)

This factor designates the effects of traditional knowledge and lessons learned from ancestors. In India, farmers generally receive their agricultural education from their ancestors and continue the traditional practices from generation to generation (Kumar, 2008). Certainly, new agricultural practices are incorporated in their package of practices in each generation.

Friends (FRN)

Several management decisions of HG are made by imitating friends, relatives, and neighbors. Farmers learn the consequences of a behavior from theirs peer and make the decision to carry out the behavior. In Kerala, HG-owners are well connected through social ties and depend on each other for several practices and decisions.

Agricultural office (AOF)

Local government agricultural offices are important stakeholders who influence farmers' decision-making. These offices and their agents play a major role in controlling the trend of agriculture by supplying inputs (e.g. information, seed, bio-pesticide, and so on). Farmers generally visit agricultural offices to resolve their agricultural problems and also to learn about modern technology. Not all farmers, however, visit the agricultural offices, but they collect the information through the neighbors and friends and make several decisions based on the suggestion provided through this office.

Education (EDU)

This factor primarily indicates the academic qualification of respondents. Also education incorporates the respondents' outlook/knowledge about modern agricultural developments. The education of the farmer makes a huge difference in decision-making. In Kerala, homegarden owners are now adopting organic agriculture. Education gives the farmers exposure to modern agricultural developments.

Financial condition (FIN)

The financial condition of the farmers affects the management decisions (e.g. buying expensive fertilizer or manure and employing external labor for tillage). However, financial condition does not necessarily promote all management practices. In some cases it may also negatively impact how and when farmers use certain practices.

Economic importance of the homegarden (ECN)

The share of total income contributed from the homegardens varies from 0% to 100%. The economic importance of a homegardens depends on the percentage of the total income generated from it and the existence of other sources of income. It is rational to believe that farmer's willingness to invest time, energy, and money in the HG may depend on its economic importance (Lambin et al., 2001).

Farmers' club (FCB)

Farmers' clubs are informal village organizations formed by farmers based on common interests (e.g. cultivation of any specific crop) or agricultural issues in general. In these clubs farmers discuss different agricultural issues and learn from experienced farmers. Therefore, it is logical to believe that several farming decisions are based on the suggestions from the farmers' clubs. In the study villages of Kerala, the clubs existed permanently or seasonally (e.g. Tuberose farmers' club) and people were aware of it.

Availability of family labor (FLB)

Family members serve as laborers in the agricultural trade. In general, the more family members in a household, the less need for external laborers. In Kerala, generally farmers who are not economically well off, depend on family members (both male and female) to perform the homegarden management practices and laborers are rarely hired from outside.

Availability of plant residue (PRD)

The availability of plant residues is a determining factor for its application to the HG. The main sources of plant residue are the HGs and public areas. The more available are plant residues, the more likely farmers will apply them to their HG.

Ownership of cattle (CTL)

Homegarden owners traditionally make farmyard manure (termed as manure henceforth) from cattle dung (excretory product). The presence of household cattle may ensure supply of the raw materials for making manure. This reduces the need to purchase manure. It may be reasonable to say that the ownership of cattle may boost the farmers' decision with frequency and intensity of manure application.

Location (LCH)

The location of the HG is important in terms of plant residue application. The requirements of plant residues are high and the supply from only the HG may not meet a farmer's need. The next available source is any public land (e.g. forests, plantations) or unattended private property. Thus, proximity of the HG to sources of plant residue may encourage the farmer to perform this practice with higher frequency and intensity.

Forest department (FDP)

Forest department is an important stakeholder, who encourages planting of trees and occasionally distributes tree seedling/saplings to the villagers. The promotion and seedling distribution by the forest department agents may encourage the farmers to make decisions in favor of planting trees.

Environmental awareness (ENV)

The level of environmental awareness or the ecological concept of the farmers may encourage them to plant more trees.

Categorization of Management Intensity

The selected HG management practices were grouped into categories with varying intensities of application. Different categories are,

- Tillage: "No tillage" (owner did not practice any tillage) and "Tillage" (owner practiced tillage).

- Plant Residue: Amount of plant residue applied/ area under homegarden = Plant residue applied per unit area (kg ha^{-1}).

  Scale Range: 0 – 1000 kg ha^{-1} = Low
  1001 – 2500 kg ha^{-1} = Medium
  2501 – 10000 kg ha^{-1} =High

- Manure: Amount of manure applied/area under homegarden = Manure applied per unit area (kg ha^{-1}).

  Scale Range: 0 – 1000 kg ha^{-1} = Low
  1001 – 2500 kg ha^{-1} = Medium
  2501 – 7500 kg ha^{-1} =High

- Fertilizer: Amount of fertilizer applied/area under homegarden = Fertilizer applied per unit area (kg ha^{-1}).

  Scale Range: 0 – 100 kg ha^{-1} = Low
  101 – 250 kg ha^{-1} = Medium
  251 – 800 kg ha^{-1} =High

- Tree: Percentage of tree from the total plant population (%).

  Scale Range: 0 – 30 % = Low
  31 – 60% = Medium
  61 -100% = High

Statistical Analysis

A regression analysis was performed to determine the significance levels of the independent factors. Independent factors were socioeconomic and demographic factors (ancestors, friends, education, availability of objects etc.) and the dependent factor was the intensity of the farm management activity. There were five dependent factors (one for each selected management practice). Statistical tests were performed with software package SPSS (Version 9) and differences were considered significant at p value < 0.1.

Results

The basic information about the HGs, HG-owners, and the management practices are listed in Table 6-1. The age of the surveyed homegardens varied from 10 to 200 years (Fig. 6-2). The age of the homegarden owner varied from 24 years to 82 years (Fig. 6-3). Kerala is the Indian state with highest literacy rate. Almost all the HG-owners surveyed had basic education and some of them had higher education (Fig. 6-4). Homegardens provide sources of income (Kumar and Nair, 2004). There are HGs that are the only source of household income and there are HGs that generate no income. In this study, 5% of HG-owners informed they had no income from the HG and 12% indicated that they were solely dependent on the income from HG for their survival (Fig. 6-5). Size of the homegarden inversely affected the decision to apply the plant residue (p = 0.006) and manure (p = 0.032). The intensity of five selected management practices varied with homegardens (Figs. 6-6 – 6-10) and this indicates that the decisional behavior also varied farmer to farmer. Survey results indicate that 13.6% HG-owners do not till their land (Fig. 6-6). Out of 59 surveyed HG-owners, 95% applied plant residue, 93% applied manure and 53% applied fertilizer to their HG in last one year. Tree cover in selected HGs varied from 20 – 90%.

All five of the selected management practices (tillage, planting of trees, and application of plant residue, manures and fertilizers) were found to be influenced (positively or negatively) by the socioeconomic and demographic factors (Table 6-2). Tillage was positively influenced by participants' ancestors (p = 0.001), economic importance of the HG (p = 0.025), friends/relatives (p = 0.075) and was inversely influenced by participants' education (p = 0.082) (Table 6-2). Plant residue application was positively influenced by participants' ancestors (p = 0.018), friends (p = 0.05), and availability of plant residue (p = 0.053) and was inversely influenced by the financial solvency ($p = 0.01$) of the participants (Table 6-2). Application of manure was positively influenced by the availability of manure ($p = 0.019$) and cattle ($p = 0.022$). Fertilizer application was positively influenced by the economic importance ($p = 0.005$) of the HG and participants' ancestors ($p = 0.089$), but was inversely influenced by the education of the participants ($p = 0.008$). Planting of trees was positively influenced by the education of the participants ($p = 0.053$) and their friends ($p = 0.088$) (Table 6-2).

Overall comparison of social factors indicated (Fig. 6-11) that among the selected social factors "Ancestor" had the most influence on the farmers' decision about the HG management practices in general. This was followed by the factor "Education" and influenced practices both positively and negatively. Following these factors, "Friends", "Financial Condition", and "Economic Importance of Homegarden" carried equal importance in influencing farmers' decision. Finally, the "Agricultural Office" followed by "Farmers' Club" resulted in comparatively less effects on the farmers' decision with HG management practices

Discussion

Social factors have significant influence on farmers' decision with all five of the selected homegarden management practices. The implementation of the TPB in the context of socioeconomic and demographic factors on farmer behavior has shown that the differences in beliefs can explain the differences in behavior. Beliefs are developed and influenced by the socioeconomic and demographic factors and thus they influence the process of decision-making.

Tillage Operations

Tillage is a popular traditional practice in the homegardens of Kerala. However, not every HG-owner in Kerala practices tillage, 13.6% of the HG-owners surveyed informed that they did not practice tillage. This decision on whether to practice tillage seemed to be significantly influenced by ancestors ($p = 0.001$) and friends ($p = 0.075$) (Table 6-2). These two factors come under normative beliefs and shows how social norms, mentioned in the TPB, influence farmer behavior. As mentioned earlier, tillage is a traditional concept, and the current generation of farmers have observed their ancestors performing this practice for conspicuous reasons such as soil aeration, better root growth and improved plant health Therefore, it is likely that recommendations from the ancestors would have an influence on the farming decisions of today's farmers. On the other hand, if neighbors do practice tillage on their land, the peer pressure would influence the farmer to till his garden. A vast majority of farmers (86.4% of the surveyed HG-owners – Fig. 6-6) who till their land said that they tilled once a year. The intensity of tillage may vary depending on peer pressure.

Decision on practice of tillage was also positively influenced by the "Economic Importance of the Homegarden" ($p = 0.025$). This indicates that, the more economically important the HG, the more likely the farmer will till the land. Most of the HG-owners who said that they did not till earned little income from the HG. Out of eight farmers, who negatively responded about tilling six had less than 12% and two had less than 47% of their total income coming from homegardens (data not presented).

The decision to till was inversely influenced by the factor "Education" ($p = 0.082$). This is supported by the results of Anjichi et al. (2007), who observed that formal education was a critical factor in influencing the efficacy of the farmers' decision to adopt the soil conservation measures in Kenya. Our results indicated that the more the education (or exposure to new developments), the less the farmer was likely to till. This may have several explanations. A farmer who is exposed to new agricultural developments and environmental issues may be aware of the negative impacts of tillage such as soil erosion or alteration of stored soil C. According to Huffman (1974), farmers with more education are most likely aware of a wide range of information sources and can adopt and adjust to changes more quickly and accurately than those with less or no education. On the other hand the more the educated the farmer, the more likely is that, he will have other sources of employment. Other sources of income may reduce the economic importance of HG to the farmer, which in turn might affect the resource-consumptive (money and labor) homegarden practices such as tillage.

Plant Residue Application

The factors ancestors ($p = 0.018$) and friends ($p = 0.05$) positively influenced the decision of plant residue application (Table 6-2). The application of plant residue is a traditional age-old practice in the HGs. Generally, there is no external purchase of plant residues. Thus, irrespective of the economic importance of the HG, farmers apply the residues. In this study, 95% of the surveyed farmers were reported to be performing this practice. However, the amount of plant residues applied varied from homegarden to homegarden.

The availability of plant residues is also a factor significantly influencing ($p = 0.053$) (Table 6-2) farmers' decision with its application. The main source of plant residue is the HG itself, however due to smaller size or lesser plant density (especially tree), a HG may not be able to generate sufficient plant residues. In such cases, farmers collect residues from external sources such as nearby public lands or from the neighbors. There is no organized way of buying or selling plant residues. On the other hand, the amount of applied plant residues is much higher than manures and fertilizers (Table 6-1). Therefore, the balance in demand and supply of plant residue is very important in making a decision about the intensity of its application. The more easily plant residue is available (e.g. abundant supply from own HG, nearby forest, neighbors.), the more likely it will encourage the farmers to apply it to their HG. The availability factor is associated with the control belief of the TPB and influences the farmer behavior.

Financial solvency of the farmer was observed to negatively influence the decision on plant residue application ($p = 0.01$) (Table 6-2). This could be because of two reasons. First, with more money, farmers can afford to buy more organic manure and the nutritional contribution of plant residue is replaced by more effective manure. Second, rich HG-owners may actually have other sources of employment and the income from the HG may be little or none, which would discourage farmers from investing time and labor with activities such as plant residue application. However, this may not mean that the perceived adverse effects stop the rich HG-owners to apply any plant residue. More logical would be just to consider that their affluence inversely influence a part of their decision, because there are several other reasons for applying (or not applying) plant residues.

Size of the homegarden inversely affected the decision to apply plant residues ($p = 0.006$). The bigger the homegarden, the more the raw material, labor and time are required to maintain regular and uniform application of plant residue. Therefore, farmers with less family labor or other sources of income may be discouraged about the application of plant residue in larger HGs. Plant residue is an important source of soil organic C. Therefore, it can be said that smaller HGs will benefit more from the plant residue than large HGs in stocking soil C. It indicates that the tendency of applying plant residue to the whole garden increases with decreasing size of the HG.

Manure Application

Manure application is a traditional agricultural practice that is predominant in the HGs of Kerala. However, the intensity of this practice varies and the results indicated, 6.8% of the farmers in the study villages did not apply any manure to their HG in the past one year. Factors that significantly affected the farmer's decision with manure application, were the availability of manure ($p = 0.019$) and ownership of household cattle ($p = 0.022$) (Table 6-2). This is consistent with the finding of Williams (1999), who observed that in semiarid West Africa the likelihood of applying manure increased with the herd size of animals. Traditionally, manures are produced in the homegardens and the raw materials such as animal litter and leaf litter are obtained from the HG itself. Manure is also procured from friends, neighbors, and relatives, and sometimes purchased from stores. However, most of the farmers, who are not economically well-off or have less economically important HG, prefer to make or collect manures rather than buying it. Therefore, the availability of homemade manure is an important factor influencing farmers' decision with manure application. Cattle dung is one of the raw materials for manure and the presence of household cattle ensures the raw materials for making manure and also saves money from external purchase. Therefore, it may be reasonable to say that the ownership of cattle may boost the farmers' decision with frequency and intensity of manure application. Both the availability of the manure and the cattle falls under the control belief of the TPB. Size of the homegarden inversely affected the decision to apply the manures ($p = 0.032$). Similar results were observed by Williams (1999), who reported that in semi-arid West Africa the application of manure was inversely influenced by the farm size. Supply of manure involves labor and time (if homemade) and cost (if purchased). Therefore, for the resource-poor farmers it may not be worthwhile to apply manure adequately and uniformly throughout the HG. Thus, increase in the size of land holding can adversely affect the decision of application of manures. Manure is an important source of SOC (Jenkinson, 1990; Li et al., 1994). As the size of homegarden negatively affects the manure application, the smaller HGs can be benefitted in stocking more SOC than larger HGs.

Inorganic Fertilizer Application

Application of fertilizers promotes growth and development of plants and more C gets sequestered in the biomass. In contrast, it is argued that nitrogenous fertilizers generate GHGs through volatilization (Robertson, 2000). Thus, fertilizer application contributes to the global warming both negatively (C sequestration) and positively (GHGs emission). Therefore, investigating the impacts of social factors on fertilizer application would in turn help us better understand the indirect causes of global warming. Results of this study indicated that factors such as economic importance of HG, ancestors, and education significantly impact fertilizer application in the HGs. Results showed that the decision of fertilizer application is positively influenced by the economic importance of the homegarden (p = 0.005) (Table 6-2). As mentioned earlier, the share of total income contributed from the homegardens varied from none to 100% (Table 6-1). The economic importance of a homegardens depends on the percentage of the total income generated from it and the existence other sources of income of the owner. It is rational to believe that farmers' willingness to invest time, energy, and money into the HG may depend on its economic importance. The more the economic importance (i.e. more the expectation of monetary return from the HG), the more is the investment into the HG. Unlike plant residue and sometimes manure, fertilizer has to be purchased at a price. To meet the recommended dosage of fertilizers for any crop, the farmer may have to spend a considerable amount of money. It is reasonable to believe that most of the farmers would make decisions to spend funds for a complete package of fertilizers only if he is expecting economic returns from the HG. In other words, the decision of fertilizer application would depend on the economic importance of the HG. This is in concordance with what Lambin et al. (2001) observed, the agricultural decision made by individuals are often influenced by economic opportunities.

Results also indicate that the ancestors (p = 0.089) (Table 6-2) have an influence of the farmers' decision with fertilizer application. Application of fertilizer is an old practice and survey information indicates that the majority of the farmers have observed older generations practicing fertilizer application. Farmers have learned and experienced the benefits of fertilizer from their parents and that encouraged them to make a decision in favor of this traditional practice. Therefore, it can reasonably be assumed that ancestors influence the farmers' decision with fertilizer application.

The decision to apply fertilizer is inversely associated with the education of the farmer (p = 0.082). This means the more education (or exposure to new developments) the farmer has, the more he is likely to apply reduced amount of fertilizer. However, this should not be construed as the more educated farmers necessarily will stop the application of fertilizers. It is more reasonable to say that being aware of the negative effects of fertilizers the farmer might apply it more judiciously and avoid applying fertilizer unnecessarily. Welch (1970) observed that increase in the level of education resulted selecting a more correct quantity of nitrogenous fertilizers.

Tree Planting

Trees are an integral part of the HGs (Nair, 1993). Results show that tree cover percentage in selected HGs varied from 20% to as high as 90%. Trees play a major role in sequestering C both in above ground biomass and through belowground root activity (Montagnini and Nair, 2004). Therefore, the decision of planting trees by the owner indirectly affects the total CSP of the HG. Therefore, the socioeconomic and demographic factors influencing farmer's decisions with planting trees are important in terms of C sequestration.

Results show that the decision to plant trees is influenced by the education of the farmer (p = 0.053) (Table 6-2). The reports from Pichon (1997) and Geoghegan et al. (2001) support the findings of this study. In South America, they observed that higher education had a negative effect on the levels of cutting trees. Matata et al. (2008) reported that almost all the participants in new agroforestry activities (and planting trees) in Tanzania had primary education. The education of the farmer influencing tree planting may mean that the more educated the farmer is, it is more likely is that he will be inclined to plant more trees. It is possible that farmers who are educated and exposed to new developments understand the additional environmental benefits of trees. However, it should not be concluded that uneducated farmers are unaware of the environmental benefits of the trees. More reasonable to say would be educated farmers receive external scientific information from various sources, which strengthens their knowledge base and increases scientific awareness.

The other factor that significantly influenced the decision to plant trees was friends (p = 0.088). Several management decisions of HG are made by imitating friends, relatives, and neighbors. The profitability from a tree species does not remain the same forever, and selection of potential new species with a market demand takes place quickly. Kerala homegardens are highly responsive to this changes and the cropping patterns change depending on the market demand. For example, cacao (*Theobroma cacao*) was once a profitable species in Kerala HGs but, with time it was replaced by nutmeg (*Myristica fragrans*) (however, they still coexist in some places). This change in trend and selection of a new species is mostly influenced by the friends and relatives. Typically, a few farmers introduce a new species and the rest of the farmers learn from the consequences and make a similar the decision. Therefore, it may be logical to think that when it comes to select any type of species (in this case tree) the decision of the farmer gets influenced by the peers. In addition to that, farmers learn about the additional environmental benefits of the trees from their educated peers and this may affect their decision with planting trees.

Conclusions

The objective of this study was to explore the effects of social factors on farmers' decision with homegarden management practices. The intensity of selected practices varied with different aspects of the TPB, such as behavioral belief (e.g. education), normative belief (e.g. ancestors, friends), and control belief (e.g. availability or resources). These beliefs significantly influenced to varying degrees the farmers' decision to implement a variety of HG management practices. Ancestors (normative belief) had the highest influence on decision-making and it significantly influenced practices such as tillage, plant residue application, and fertilizer application. This was followed by the factor education (behavioral belief), which influenced the decision with tree planting in a positive manner and affected the decision with tillage and fertilizer application in a negative manner. Other important factors influencing the farmer behavior were friends (normative belief), financial condition (control belief) of the farmer, and economic importance of the HG. The size of the HGs inversely influenced the decision to apply manure and plant residue. This suggests that smaller HGs may be benefitted more in stocking more soil C via application of relatively more plant residues and manures on a unit area basis. The results of this study may have application in understanding the strength of socioeconomic and demographic factors in influencing the C management and can be used as a baseline study for further research on HG socioeconomics and C storage. More research is required to understand the detailed effects of individual socioeconomic and demographic factors on management practices and the TPB should be applied to explain the process of decision-making in agriculture.

Table 6-1. Basic information about the household and homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India

Factors	Mean	Median	Mode	Lowest	Highest
Age of HG (years)	71.75	60	100	10	200
Area of HG (ha)	0.22	0.12	0.04	0.016	2.4
Total Annual Income (USD)	679.7	375	250	75	7500
Annual Income from HG (USD)	166.4	125	125	0	2500
Age of the HG-owner (years)	54.37	58	60	24	82
Size of Family	4.57	4	4	2	12
Male Members in Family	2.07	2	2	0	6
Annual Plant Residue Application /Unit Area (kg ha^{-1})	2306	1339	1250	0	10000
Annual Manure Application /Unit Area (kg ha^{-1})	1742	1250	1250	0	7500
Annual Fertilizer Application /Unit Area (kg ha^{-1})	172.5	93.75	0	0	781.3
Tree Cover in HG (%)	48.5	40	40	20	90

Table 6-2. Influence of social factors on homegarden management decisions in Madakkathara *Panchayat*, Thrissur, Kerala, India

Management Practices	R^2 Values	Positive Effects				Negative Effects
		Importance level 1	Importance level 2	Importance level 3	Importance level 4	
Tillage	0.4	ANC (p = 0.018) (Normative belief)	ECN (p = 0.025)	FRN (p = 0.075) (Normative belief)	FLB (NS)	EDU (p = 0.082) (Behavioral belief)
Plant Residue Application	0.4	ANC (p = 0.018) (Normative belief)	FRN (p = 0.05) (Normative belief)	PRD (p = 0.053) (Control belief)	EDU (NS)	FIN (p = 0.01) (Control belief)
Manure Application	0.3	MNR (p = 0.019) (Control belief)	CTL (p = 0.022) (Control belief)	FRN (NS)	ANC (NS)	-
Fertilizer Application	0.3	ECN (p = 0.005)	ANC (p = 0.089) (Normative belief)	PLT (NS)	FIN (NS)	EDU (p = 0.008) (Behavioral belief)
Planting Trees	0.3	EDU (p = 0.053) (Behavioral belief)	FRN (p = 0.088) (Normative belief)	ENV (NS)	AOF (NS)	-

AOF = Agricultural Office, ANC = Ancestors, AST = Aesthetic Sense of Farmer, CTL = Cattle Availability, ECN = Economic Importance of Homegarden, EDU = Education, FIN = Financial Solvency of the Farmer, FLB = Family Labor, FRN = Friends/Relatives, MNR = Manure Availability, PLT = Plant Type, PRD = Plant Residue Availability, NS = Statistically not significant

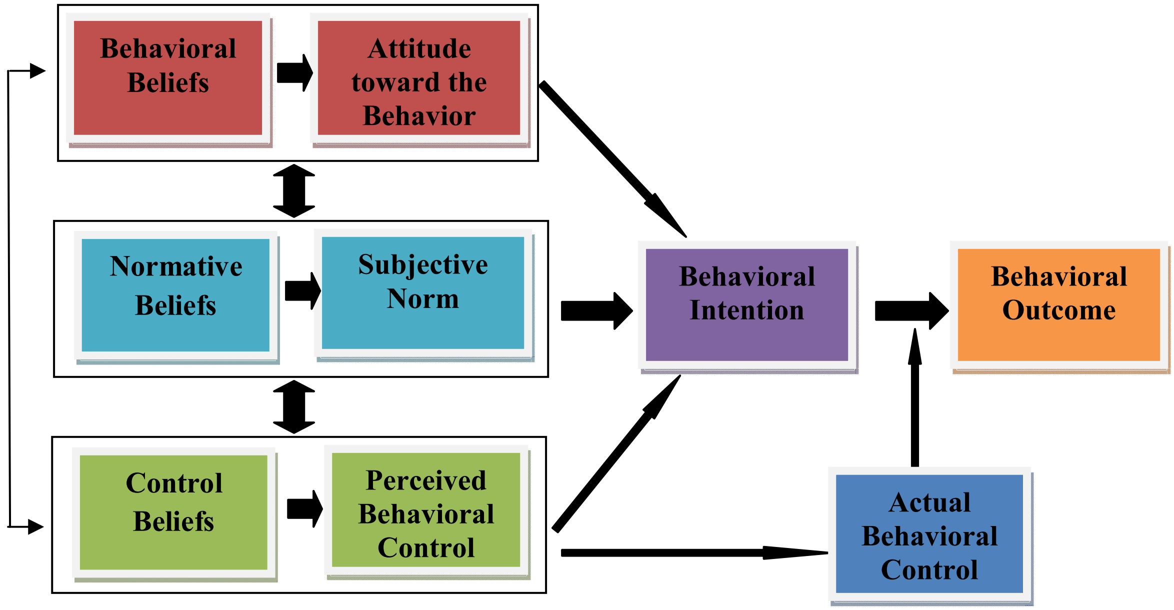

Figure 6-1. Schematic diagram of the Theory of Planned Behavior (Ajzen, 1991).

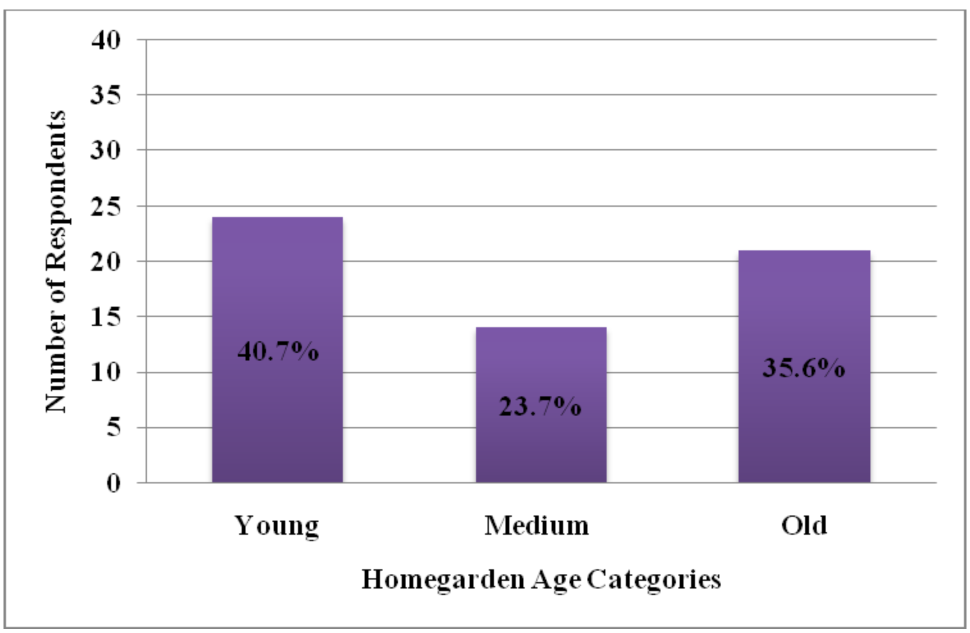

Figure 6-2. Age distribution of the homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. Age category (years): Young = 10 – 50, Medium = 51 – 80, Old = 81 – 200.

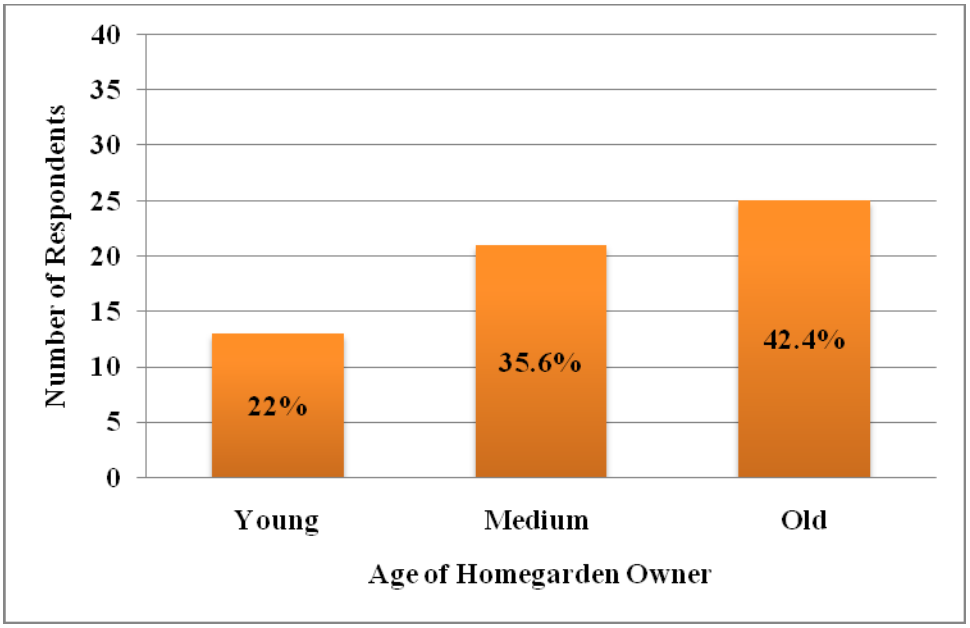

Figure 6-3. Age distribution of the homegarden-owners in Madakkathara *Panchayat*, Thrissur, Kerala, India. Age category (years): Young = 24 – 40, Medium = 41 – 59, Old = 60 – 82.

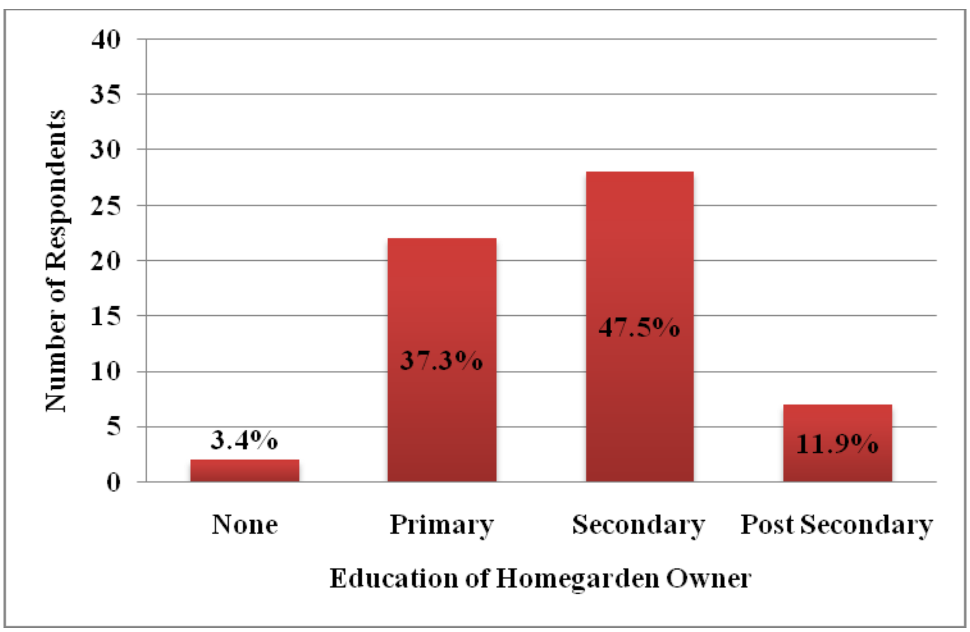

Figure 6-4. Educational qualification of the homegarden-owners in Madakkathara *Panchayat*, Thrissur, Kerala, India. Education Category: None = No formal education, Primary = 1st – 5th Standard, Secondary = 6th – 10th Standard, Post Secondary = 11th Standard or more.

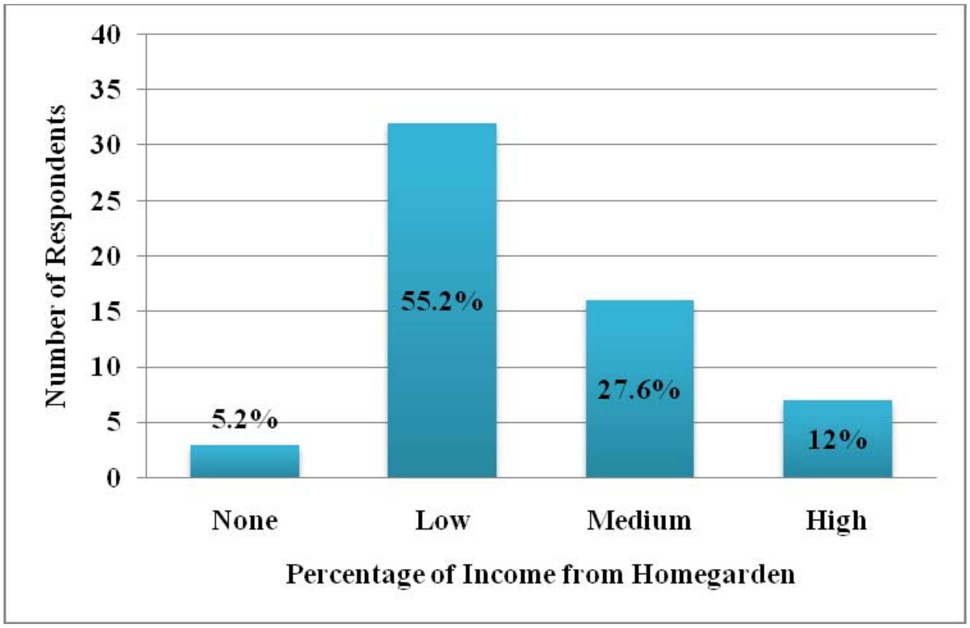

Figure 6-5. Distribution of percentage of total income from the homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. Income Percentage Category: None = No income from HG, Low = 1 – 33.33% of total income, Medium = 33.33 – 66.66% of total income, High = 66.66 – 100% of total income.

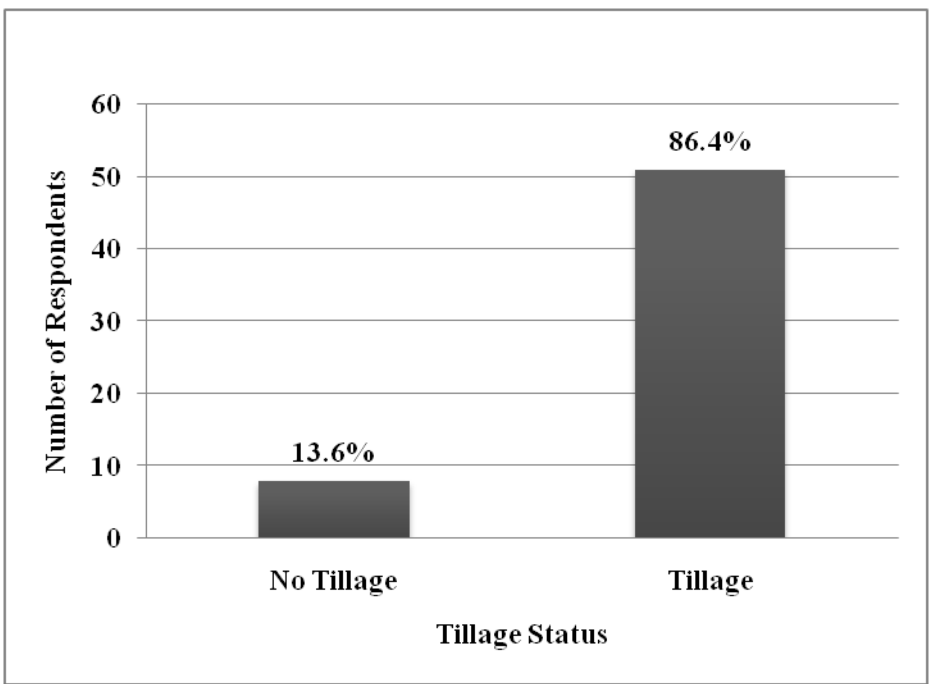

Figure 6-6. Tillage status in homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. No Tillage = Tillage is not practiced, Tillage = Tillage is practiced.

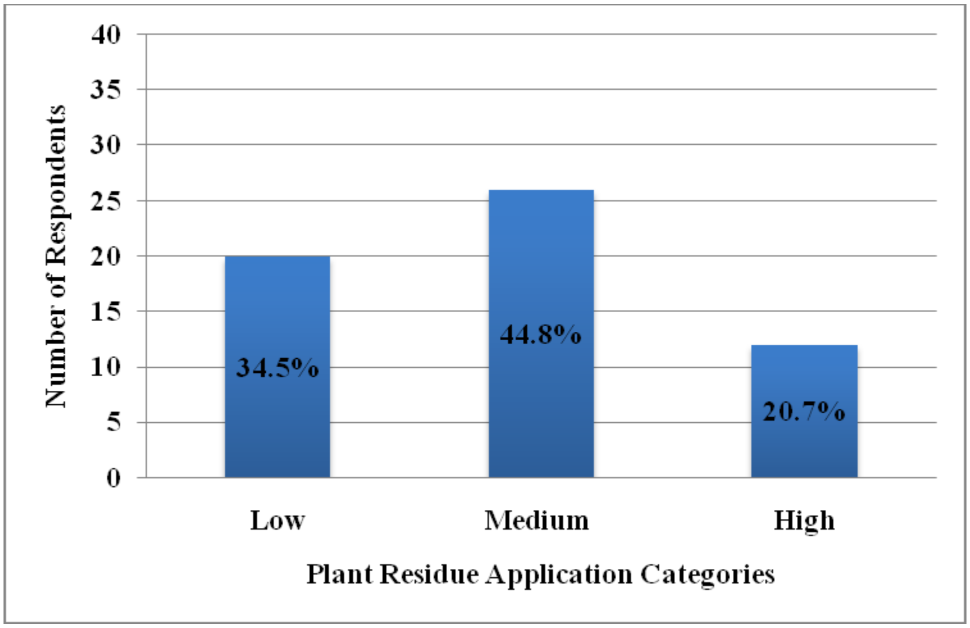

Figure 6-7. Plant residue application in homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India**.** Category (kg ha^{-1}): Low = 0 – 1000, Medium = 1001 – 2500, High = 2501 – 10000.

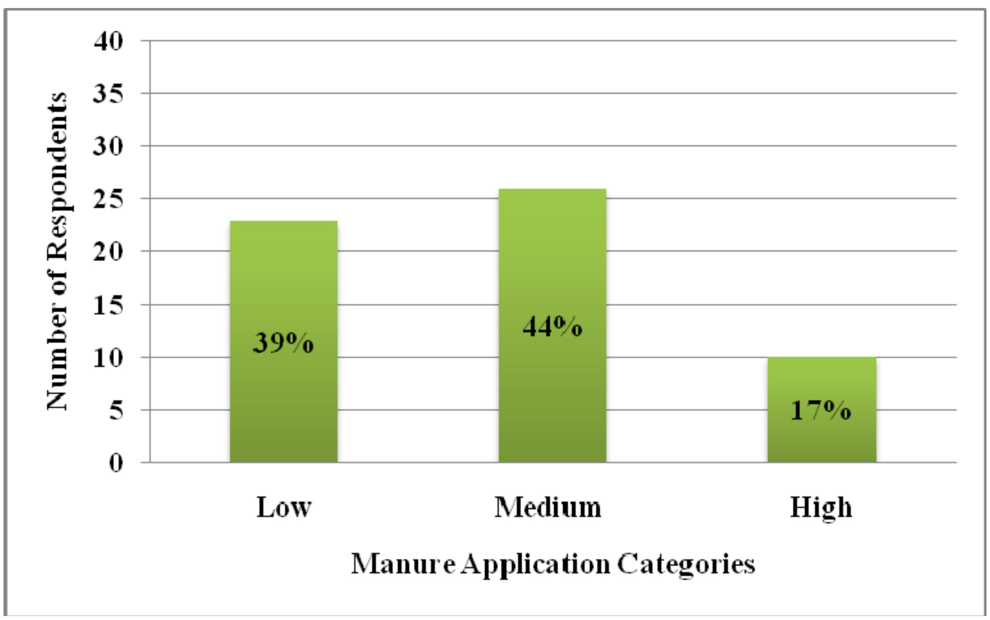

Figure 6-8. Manure application in homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. Category (kg ha^{-1}): Low = 0 – 1000, Medium = 1001 – 2500, High = 2501 – 7500.

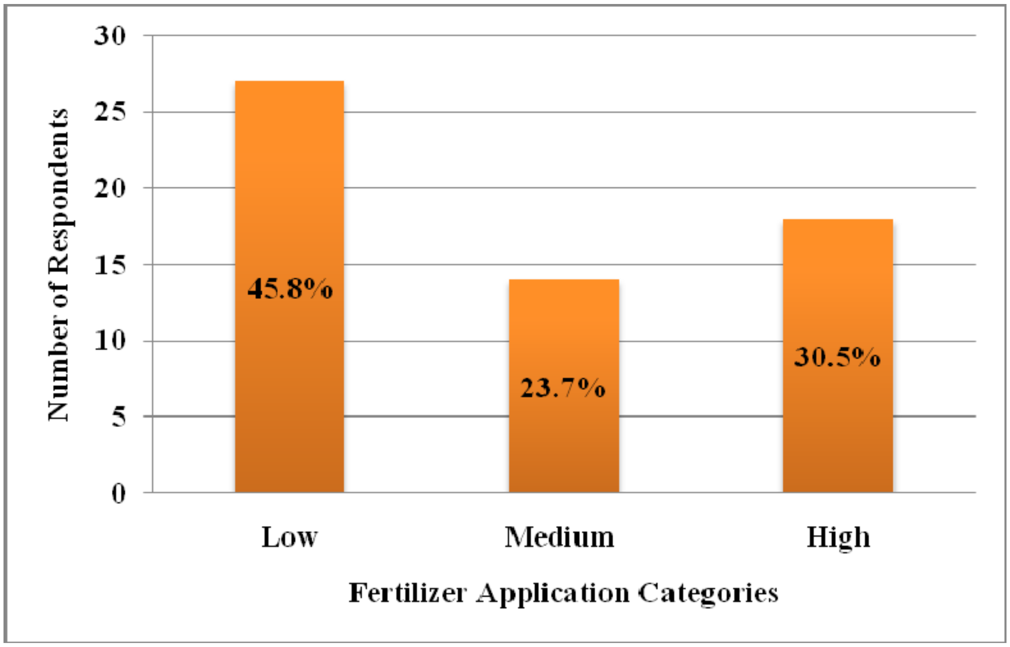

Figure 6-9. Fertilizer application in homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. Category (kg ha^{-1}): Low = 0 – 100, Medium = 101 – 250, High = 251 – 800.

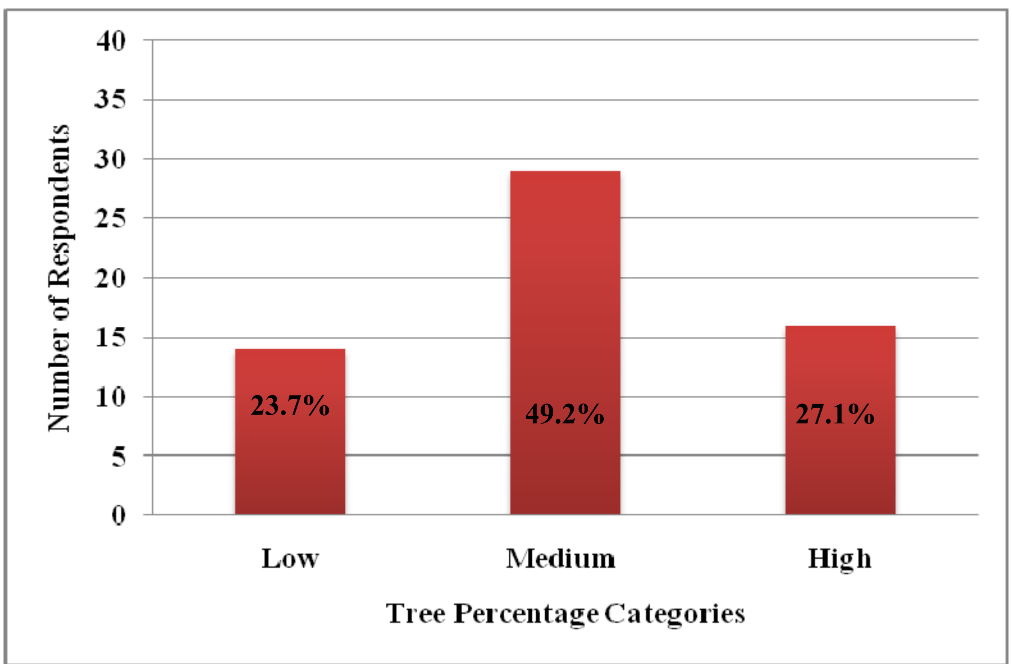

Figure 6-10. Tree-cover percentage categories in homegardens in Madakkathara *Panchayat*, Thrissur, Kerala, India. Tree Cover Category (% of tree cover): Low = 0 – 30, Medium = 31 – 60, High = 61 – 100.

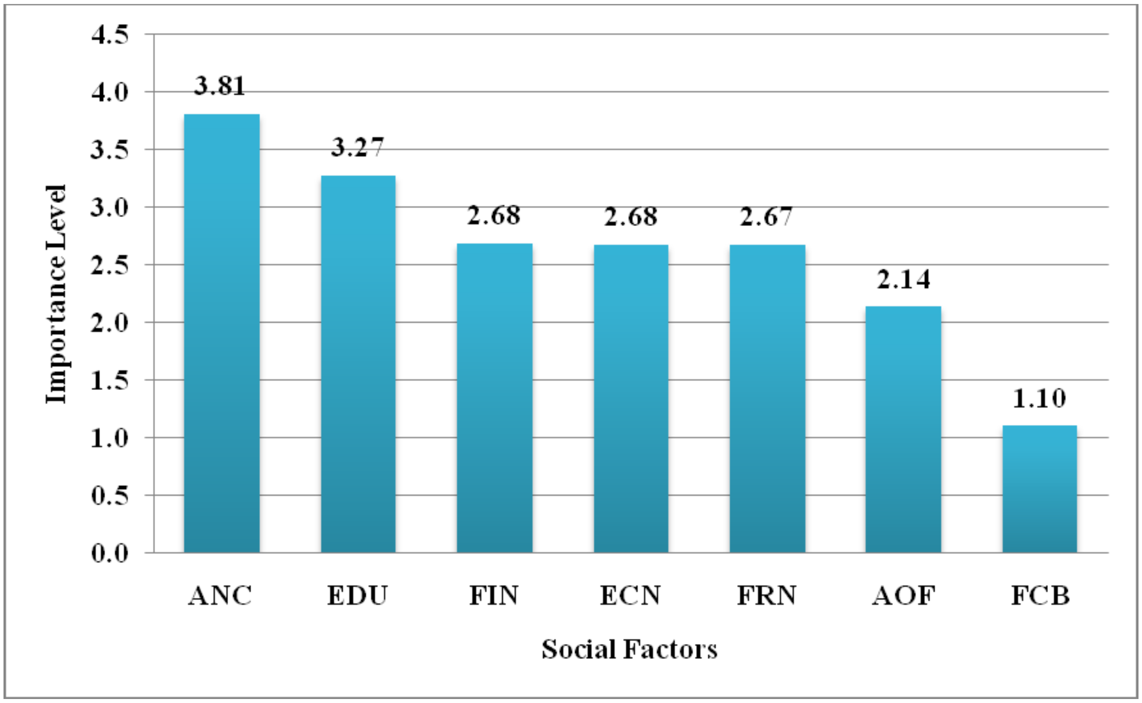

Figure 6-20. Importance of social factors in homegarden management decision in Madakkathara *Panchayat*, Thrissur, Kerala, India. AOF = Agricultural Office, ANC = Ancestors, ECN = Economic Importance of Homegarden, EDU = Education, FIN = Financial Solvency of the Farmer, FRN = Friends/Relatives, FCB = Farmers' Club.

CHAPTER 7
SUMMARY AND CONCLUSIONS

The sequestration of atmospheric carbon dioxide (CO_2) is an effective strategy for mitigating its build-up and reducing global warming. The soil is considered to be a major pool of carbon (C) in the biosphere; however, it has received rather little attention in terms of sequestration of C. The tropical homegardens (HGs), a widespread agroforestry system in the tropics, with their high plant-species density and often forest-like structure can be expected to have a high potential for sequestering C and impacting the global C budget. However, the soil C sequestration potential (CSP) of HGs has remained unexplored.

This study was conducted based on the premises that,

1. Land-use systems involving trees store relatively higher quantities of soil C (and therefore possess higher soil CSP), compared to treeless systems, at lower soil depths (up to 1 m from surface).
2. The amount of C stored in soils is directly related to plant- and tree density, implying that smaller homegardens that have higher plant- and tree density will store more C in soil compared to larger homegardens.
3. Social factors influence farmers' decision with the HG management practices, which in turn affect the CSP of the HGs.

With this background, the study investigated the soil C stock up to 1 m depth in homegardens and a spectrum of tropical land-use systems in Kerala, India. In addition to the HG, a natural system (moist deciduous forest), two common monoculture tree plantations (Rubber-Hevea brasiliensis and Coconut-Cocos nucifera), and one agronomic crop (rice (Oryza sativa)-paddy) were selected for the study.

Soil samples were collected from three villages (Pandiparambu, Chirakkakode, and Vellanikkara) of Madakkathara *Panchayat* (subdivision) of Thrissur district in Kerala. The soil in the study sites was of the order Inceptisols. From the selected land-use systems, soil samples were collected from four depths 0 – 20, 20 – 50, 50 – 80, and 80 – 100 cm. Collected soil samples were physically fractionated by wet-sieving through a series of two sieve sizes into three size fractions: (macro-sized class (250 – 2000 µm), micro-sized class (53 – 250 µm) and silt and clay-sized class (<53 µm), and their C contents were determined. In the absence of a time-sequence study involving long time intervals, the C stock data were considered as reliable indicators of the CSP of the systems. For the socioeconomic part of the study, five HG management practices (tillage, plant residue management, manure usage, fertilizer application, and tree planting) that are known to affect C sequestration were selected. Information about the social factors and HG-owners' preferences were collected through a focus-group meeting and a questionnaire survey.

The results suggest that tree-based systems have greater soil CSP than the treeless system up to a meter depth. Land-use systems with greater number of trees and less soil disturbance had higher stock of soil C. Soil C stock was highest in the forest and lowest in rice-paddy fields, with homegardens and the tree monocultures of rubber and coconut coming in between. Soils under HGs had higher C stock than in rice-paddy fields, but it was lower than in the forests. Homegardens and rubber plantations did not differ significantly in terms of their soil C contents. Carbon content in soil profiles decreased with soil depth; but lower depths up to 1 m contained substantial amount of C, indicating the importance of considering the soils below the surface horizon in soil C studies. Comparatively more soil C had accumulated in the lower half of 1m depth in forest and homegardens than in the other land-use systems. Soil C contents in macro-sized class (250 – 2000 µm) showed more difference among land-use types followed by micro-sized class (53 – 250 µm) and silt and clay-sized class < 53 µm)., This suggests that the changes in land-use types in course of time first reflected in macro-sized class followed by micro-sized class.

Values of plant-stand characteristics such as the tree density, tree species density, overall plants population, and overall plant species density were higher in the smaller homegardens (<0.4 ha) compared to larger homegardens (>0.4 ha). Further, homegardens with higher number of plant species and trees retained more C in the soil. Thus, soils of smaller-sized homegardens contained higher stocks of C than those of larger-sized gardens. Overall, the homegardens seem to have the unique distinction of high biodiversity (at least, plant diversity) and CSP. By extension of this observation, it can be surmised that integrated land-use systems consisting of assemblages of various plant forms (trees, shrubs, herbs) tend to provide the environmental benefits of biodiversity conservation and C sequestration.

Farmers' decision with the HG management practices were influenced by socioeconomic and demographic factors. The Theory of Planned Behavior (TPB) used as the conceptual framework for this study indicated that the differences in beliefs (or social factors) resulted in differences in outcome of behavior. The factor 'ancestors' had the highest influence on decision-making and it significantly influenced practices such as tillage, plant residue application, and fertilizer application. This was followed by education, which influenced the decision with tree planting in a positive manner and the decision with tillage and fertilizer application in an inverse manner. Other important factors influencing the farmer behavior were friends, economic importance of the HG and the financial condition of the farmer, Friends influenced the decision on tillage, plant residue application, and planting trees positively. Economic importance of the HG influenced farmers' decision on fertilizer application and tillage in a positive manner, but the financial condition of the farmer inversely influenced the decision on plant residue application. The results of this study may have application in understanding the strength of socioeconomic and demographic factors in influencing the C management and can be used as a baseline study for further research on HG socioeconomics and C storage.

Admittedly, this study has had some limitations. Information on several important issues was missing and it was not feasible to collect most, if not any, of them. To estimate the capacity of a system to sequester C, ideally the rate of C accumulation should be documented in a temporal scale. However, such a study that demands several years of observation and data collection were beyond the scope of this time-constrained graduate-study program. As a more realistic approach, this study estimated the C stocks of the land-use systems one time only and those estimates were considered as approximations to CSP. Each homegarden is a unique unit in terms of its dynamic structure and plant composition; unlike monocultures, it is impossible to find "identical" HGs to treat as homogeneous blocks for statistical analysis. The size and age of trees can significantly influence the CSP of HGs; however, information about the age and allometric information of the individual trees of the HGs were not available. In addition, information on the root distribution patterns of the HGs selected for the study was unknown. Given the major role of roots in soil C sequestration, the results of the study could have been better explained with in-depth information about the anatomy and architecture of roots. It has been reported that increase in species diversity influences C sequestration through a corresponding increase in net primary production. To support this claim, evidences were required about the net primary production of the HGs. Quantitative data were not available, nor could be collected, on litter input and microbial activity, two factors that are important in estimating the soil CSP of a system. Furthermore, only 24 homegardens were evaluated for determining the effects of HG management and plant-stand characteristics on soil C sequestration; a larger sample size could have increased the rigor and precision of the study. In the socioeconomic study, the survey questionnaire was developed based on the information received from the focus group meeting and personal communication. Multiple focus group meetings with different sets of farmers from different geographic locations could have generated a more refined set of questions. But, conducting multiple meetings in multiple locations was beyond the scope of the study. Homegarden management decisions are made both by the male and female members of the household. However, the randomly selected households for the survey had males as head of the family who answered the questions and female members did not take part in the survey. This may have generated results based on males' points of view and veiled the females' perspective of the HG management practices. Interviewing female members of the household to understand their role and outlook may have enriched the study. These and other limitations of the study may impose some restrictions on extrapolating the results to a broader scale to establish the role of HG in mitigating GHGs. Nevertheless, I believe that these limitations do not diminish the importance and value of the results of such a study of pioneering nature and the potential for extrapolating them to larger contexts.

APPENDIX A
HOMEGARDEN SURVEY 1

HG Code # GPS Co-ordinate: Date:

Name of Owner:

Address:

Size of the Homegarden:

Age of the Homegarden:

Situation of the garden (low/medium/high):

History of the Homegarden:

Description of Adjacent areas:

Livestock Information:

Management Practices of the Homegarden:

Fertilizer:
Manure:
Plant Residue:
Tillage:
Irrigation:
Weeding:

Cropping pattern in the Homegarden:

Memorable major change in the Homegarden:

Education of owner: Age of owner:

Main sources of income:

Annual income of the owner:

Percent of the income coming from the Homegarden:

Man-hours spent after the garden:

Sources of labor:

Size of the family:

Species	No.	Species	No.	Species	No.
Trees & Shrubs		**Trees & Shrubs**		**Herbaceous Crops**	
Coconut		Sandalwood		Turmeric	
Arecanut		Asoka maram		Arrowroot	
Mango		Poola		Taro *Colocasia*	
Jackfruit		Kaatu chembakam		Elephant foot yam	
Rubber		Aini		Greater yam	
Coffee		Pana (palmyra)		Bitter gourd	
Nutmeg		Talipot		Ash gourd	
Clove		Fish-tail palm		Spinach	
Tamarind		Thippili		Snake gourd	
Matti		Pali		Beans	
Teak		Rubber tree		Vanilla	
Maruthu		Breadfruit		Pineapple	
Veeti		Guava *Psidium*		Mango ginger	
Kodampuli		*Louvi-Louvi*		Pigeon pea	
Kaini		Papaya		Red pumpkin	
Mahogany		*Cherunarakam*		Chillies	
Cashew		*Irimbampuli bilimbi*		Eggplant	
Poomaram		Cacao		Ivy gourd	
Irumullu		Neem		Okra	
Venga		Indian gooseberry		Snow pea	
Cinnamon		*Kattaadi*		*kaavath (kaachal)*	
Rose apple		Custard apple		*Vellarikka*	
Sapota		Allspice		*Veliya chembu*	
Indian almond		*Bablus*		*Cheru kazhungu*	
Camphor		Eggfruit		*Pichinga*	
Ylang Ylang				Indian Pennywort	
Curry leaf		**Herbaceous Crops**		*Koorka*	
Chadchi (Grewia)		Banana		*Tulsi*	
Mulberry		Black pepper		Jasmine	
Venga /Kino		Ginger		*Vettla*	

List of Weeds in the Homegarden:

List of other Plants (including medicinal):

Remarks:

Sketch of the garden and photo:

APPENDIX B
HOMEGARDEN SURVEY 2

1. Do you have a homegarden (HG)?
2. How old is your HG?
3. How old big is your HG?
4. What is your annual income?
5. What is your income from the HG?
6. Do you have other sources of income?
7. If, so where does the income from HG stand (primary, secondary, tertiary etc.)?
8. How old are you?
9. How many family members do you have and how many of them are males?
10. Do family members help you in garden management?
11. Up to what grade have you studied?
12. What are the sources of your information about new agricultural technology?
13. Do you visit the agricultural office for information? If so, how many times do you see them in a year?
14. Are you associated with any farmers' club? If so, how many times do you go there in a year?

Farming Practices: Quantification

1. Tillage:

How much land area of your homegarden do you till?

How many times do you till in a year?

2. Application of Plant Residue:

How much plant residue do you return to the homegarden?

3. Application of Manure:

How much manure did you apply in last one year (in kg)?

4. Application of Inorganic Fertilizers:

How much fertilizer did you apply in last one year (in kg)?

5. Selection of Species:

What percentage of your homegarden plants are woody perennial/tree?

Number of woody perennials per unit area = Number of woody perennials/ area of homegarden

Ratio of woody perennial: non-woody plants in the garden

Tillage

1. Do you till your homegarden? Yes No

2. How important are the following factors in affecting your decision to till or not to till?

Factors	Not important	Little important	Important	Very important	Extremely important
Traditional/ Ancestors (Do you follow what they did?)	1	2	3	4	5
Friends/ Relatives (Do they do this?)	1	2	3	4	5
Agricultural office (Do they suggest it?)	1	2	3	4	5
Your Education/Experience	1	2	3	4	5
Your Financial Condition	1	2	3	4	5
Economic Importance of the Homegarden	1	2	3	4	5
Availability of Family Labor	1	2	3	4	5
Farmers' Club (e.g. Parishad)	1	2	3	4	5

What other factors may affect your decision with tillage?

Plant Residue

1. Do you apply plant residue to your homegarden? Yes No
2. How important are the factors below in affecting your decision to apply plant residues or not to apply plant residue?

Factors	Not important	Little important	Important	Very important	Extremely important
Traditional/ Ancestors (Do you follow what they did?)	1	2	3	4	5
Friends/ Relatives (Do they do this?)	1	2	3	4	5
Agricultural office (Do they suggest it?)	1	2	3	4	5
Your Education/Experience	1	2	3	4	5
Availability of Plant Residue	1	2	3	4	5
Your Financial Condition (If you buy it)	1	2	3	4	5
Location of the House (e.g. proximity to the forest)	1	2	3	4	5
Farmers' Club (e.g. Parishad)	1	2	3	4	5

What other factors may affect your decision with applying plant residues?

Manure

1. Do you apply manure to your homegarden? Yes No
2. How important are the factors below in affecting your decision to apply manure or not to apply manure?

Factors	Not important	Little important	Important	Very important	Extremely important
Traditional/ Ancestors (Do you follow what they did?)	1	2	3	4	5
Friends/ Relatives (Do they do this?)	1	2	3	4	5
Agricultural office (Do they suggest it?)	1	2	3	4	5
Your Education/Experience	1	2	3	4	5
Ownership of Cattle	1	2	3	4	5
Availability of Manure (e.g. ash etc.)	1	2	3	4	5
Economic Importance of the Homegarden	1	2	3	4	5
New technology	1	2	3	4	5
Farmers' Club (e.g. Parishad)	1	2	3	4	5

What other factors may affect your decision with applying manures?

Fertilizer

1. Do you apply fertilizer to your homegarden? **Yes** **No**
2. How important are the factors below in affecting your decision to apply fertilizer or not to apply fertilizer?

Factors	Not important	Little important	Important	Very important	Extremely important
Traditional/ Ancestors (Do you follow what they did?)	1	2	3	4	5
Friends/ Relatives (Do they do this?)	1	2	3	4	5
Agricultural office (Do they suggest it?)	1	2	3	4	5
Your Education/Experience	1	2	3	4	5
Your Financial Condition	1	2	3	4	5
Economic Importance of the Homegarden	1	2	3	4	5
Type of Plants	1	2	3	4	5
Farmers' Club (e.g. Parishad)	1	2	3	4	5

What other factors may affect your decision with applying fertilizers?

Tree Species

1. Do you have ≥50% tree to your homegarden? Yes No
2. How important are the factors in affecting your decision to plant trees or not to plant trees?

Factors	Not important	Little important	Important	Very important	Extremely important
Traditional/ Ancestors (Do you follow what they did?)	1	2	3	4	5
Friends/ Relatives (Do they do this?)	1	2	3	4	5
Agricultural office (Do they suggest it?)	1	2	3	4	5
Your Education/Experience	1	2	3	4	5
Forest Department (Do they suggest it?)	1	2	3	4	5
Farmers' Club (e.g. Parishad)	1	2	3	4	5
Your aesthetic values/ecological concept	1	2	3	4	5

What other factors may affect your decision with planting more trees?

Overall, what are the major factors that affect tour decision with all these practice?

APPENDIX C
ADDITIONAL TABLES AND FIGURES

Table C-1. Soil organic carbon (SOC) in macro-sized fraction (250 µm − 2000 µm) at different soil depths of six tropical land-use systems in three sites, Site 1 (Pandiparambu), Site 2 (Chirakkakode), Site 3 (Vellanikkara), and mean of all sites in Kerala, India.

	SOC (Mg ha^{-1})											
	Site 1						Site 2					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	14.63	7.35	8.92	11.86	12.8	7.43	14.63	7.35	11	10.85	13.52	5.73
20 – 50	18.25 ^{a} ‡	10.04 ^{b}	10.4 ^{b}	12.02 ^{ab}	16.12 ^{ab}	9.96 ^{b}	18.25 ^{a}	10.04 ^{bc}	10.59 ^{bc}	14.14 ^{ab}	11.96 ^{abc}	5.42 ^{c}
50 – 80	14.46 ^{a}	5.67 ^{bc}	8.48 ^{bc}	9.62 ^{abc}	10.24 ^{ab}	5.2 ^{c}	14.46 ^{a}	5.67 ^{bc}	9.03 ^{ab}	9.84 ^{ab}	8.84 ^{b}	3.23 ^{c}
80 – 100	8.06 ^{a}	3.36 ^{bc}	6.46 ^{a}	5.78 ^{ab}	6.35 ^{a}	2.27 ^{c}	8.06 ^{a}	3.36 ^{cd}	6.27 ^{ab}	6.57 ^{ab}	4.94 ^{bc}	1.08 ^{d}

	Site 3						Mean of all sites					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	14.63 ^{a}	7.35 ^{c}	6.66 ^{c}	7.91 ^{bc}	13.21 ^{ab}	4.31 ^{c}	14.63 ^{a}	7.35 ^{c}	8.86 ^{bc}	10.21 ^{abc}	13.18 ^{ab}	5.82 ^{c}
20 – 50	18.25 ^{a}	10.04 ^{b}	7.65 ^{bc}	11.47 ^{b}	17.6 ^{a}	4.77 ^{c}	18.25 ^{a}	10.04 ^{cd}	9.54 ^{cd}	12.55 ^{bc}	15.22 ^{ab}	6.72 ^{d}
50 – 80	14.46 ^{a}	5.76 ^{c}	7.6 ^{bc}	7.86 ^{bc}	9.87 ^{b}	2.86 ^{d}	14.46 ^{a}	5.67 ^{cd}	8.37 ^{bc}	9.1 ^{b}	9.65 ^{b}	3.76 ^{d}
80 – 100	8.06 ^{a}	3.36 ^{c}	4.9 ^{bc}	5.42^{b}	5.75 ^{b}	0.98 ^{d}	8.06 ^{a}	3.36 ^{c}	5.88 ^{b}	5.92 ^{b}	5.68 ^{b}	1.44 ^{d}

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class). FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

Table C-2. Soil organic carbon (SOC) in micro-sized fraction (53 μm − 250 μm) at different soil depths of six tropical land-use systems on three sites Site 1 (Pandiparambu), Site 2 (Chirakkakode), Site 3 (Vellanikkara), and mean of all sites in Kerala, India.

	SOC (Mg ha^{-1})											
	Site 1						Site 2					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	16.11 ^{ab}‡	8.42 ^{c}	11.51 ^{bc}	13.43 ^{ab}	16.85 ^{a}	11 ^{bc}	16.11 ^{a}	8.42 ^{bc}	10.83 ^{bc}	8 ^{c}	12.44 ^{ab}	9.95 ^{bc}
20 – 50	20.69 ^{a}	10.75 ^{b}	11.35 ^{b}	10.92 ^{b}	16.38 ^{a}	4.52 ^{c}	20.69 ^{a}	10.75 ^{b}	13.64 ^{b}	12.2 ^{b}	12.38 ^{b}	2.4 ^{c}
50 – 80	13..6 ^{a}	6.88 ^{b}	9.95 ^{ab}	10.27 ^{ab}	13.46 ^{a}	1.64 ^{c}	13..6 ^{a}	6.88 ^{c}	10.49 ^{ab}	7.9 ^{bc}	8.84 ^{bc}	1.35 ^{d}
80 – 100	8.33 ^{a}	3.23 ^{c}	6.25 ^{b}	6.34 ^{b}	5.85 ^{b}	0.91 ^{d}	8.33 ^{a}	3.23 ^{bc}	6.33 ^{b}	5.12 ^{b}	4.66 ^{bc}	0.9 ^{d}

	Site 3						Mean of all sites					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	16.11 ^{a} ‡	8.42 ^{b}	7.94 ^{b}	8.3 ^{b}	8.88 ^{b}	2.2 ^{c}	16.11 ^{a} ‡	8.42 ^{c}	10.1 ^{bc}	10.01 ^{bc}	12.73 ^{ab}	7.71 ^{c}
20 – 50	20.68 ^{a}	10.76 ^{b}	9.55 ^{b}	12.4 ^{b}	9.82 ^{a}	1.43 ^{c}	20.68 ^{a}	10.04 ^{b}	11.51 ^{b}	11.75 ^{b}	12.86 ^{b}	2.78 ^{c}
50 – 80	13.6 ^{a}	6.88 ^{bc}	8.54 ^{b}	10.34 ^{ab}	6.94 ^{bc}	2.74 ^{c}	13.6 ^{a}	6.88 ^{c}	9.66 ^{b}	9.5 ^{b}	9.73 ^{b}	1.9 ^{d}
80 – 100	8.33 ^{a}	3.24 ^{cd}	4.48 ^{bc}	6.044 ^{ab}	3.92 ^{bcd}	1.64 ^{d}	8.33 ^{a}	3.24 ^{c}	5.68 ^{b}	5.83 ^{b}	4.81^{b}	1.17 ^{d}

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class). FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

Table C-3. Soil organic carbon (SOC) in silt + clay-sized fraction (< 53 µm) at different soil depths of six tropical land-use systems on three sites Pandiparambu (Site 1), Chirakkakode (Site 2), Vellanikkara (Site 3), and mean of all sites in Kerala, India.

	SOC, (Mg ha^{-1})											
	Site 1						Site 2					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	13.62	9.04	8.45	11.46	12.91	12.69	13.62 ^{a}	9.04 ^{ab}	8.73 ^{ab}	8.8 ^{ab}	7.84 ^{b}	9.34 ^{ab}
20 – 50	16.95 ^{a}‡	10.65 ^{abc}	9.93 ^{bc}	10.57 ^{abc}	14.2 ^{ab}	5.96 ^{c}	16.95 ^{a}	10.65 ^{bc}	11.51 ^{b}	9.26 ^{bcd}	6.9 ^{cd}	5.71 ^{d}
50 – 80	16.69 ^{a}	6.62 ^{bc}	7.83 ^{b}	8.11 ^{b}	10.78 ^{b}	3.13 ^{c}	16.69 ^{a}	6.62 ^{bc}	8 ^{bc}	9.27 ^{bc}	5.26 ^{cd}	3.1 ^{d}
80 – 100	8.1 ^{a}	3.53 ^{bc}	4.92 ^{b}	5 ^{b}	4.66 ^{b}	1.6 ^{c}	8.1 ^{a}	3.53 ^{bc}	4.72 ^{b}	3.68 ^{b}	3.2 ^{bc}	1.95 ^{c}

	Site 3						Mean of all sites					
Depth (cm)	FR	CN	HGL	HGS	HB	OS	FR	CN	HGL	HGS	HB	OS
0 – 20	13.62 ^{a}	9.04 ^{b}	10.05 ^{b}	10.35 ^{ab}	7.18 ^{bc}	5.18 ^{c}	13.62	9.04	9.1	10.2	9.78	9.07
20 – 50	16.95 ^{a}	10.65 ^{b}	9.9 ^{b}	12.08 ^{b}	9.22 ^{b}	3.51 ^{c}	16.95 ^{a}	10.65 ^{b}	10.45 ^{b}	10.64 ^{b}	10.7 ^{b}	5.06 ^{c}
50 – 80	16.69 ^{a}	6.62 ^{bc}	7.44 ^{b}	8.83 ^{b}	3.9 ^{cd}	2.88 ^{d}	16.69 ^{a}	6.62 ^{b}	7.76 ^{b}	8.74 ^{b}	7.1 ^{b}	3.04 ^{c}
80 – 100	8.1 ^{a}	3.53 ^{cd}	5.07 ^{bc}	5.96 ^{ab}	2.21 ^{d}	2.9 ^{d}	8.1 ^{a}	3.53 ^{b}	4.9 ^{b}	4.88 ^{b}	3.51 ^{b}	1.88 ^{c}

‡Means for SOC in land-use systems at a given depth followed by different letters designate statistical significance at the 0.05 probability level (compared within each depth class). FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field.

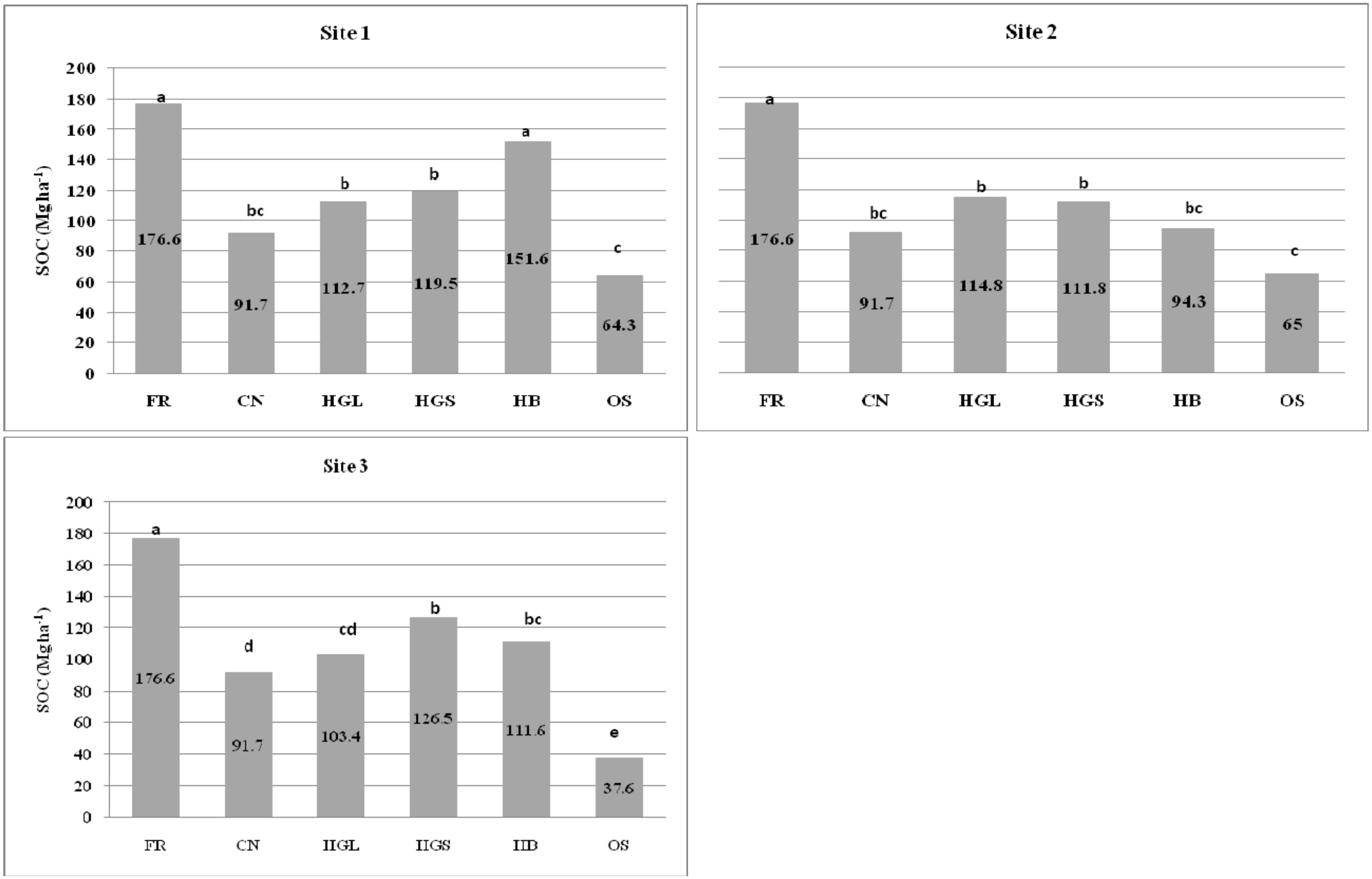

Figure C-1. Total Soil organic carbon (SOC) within 1 m depth in six tropical land-use systems for whole soil of Site 1 (Pandiparambu), Site 2 (Chirakkakode), Site 3 (Vellanikkara) in Kerala, India. Lower case letters indicate significant differences (at the 0.05 probability level) in SOC among land-use systems at a given depth class. FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field

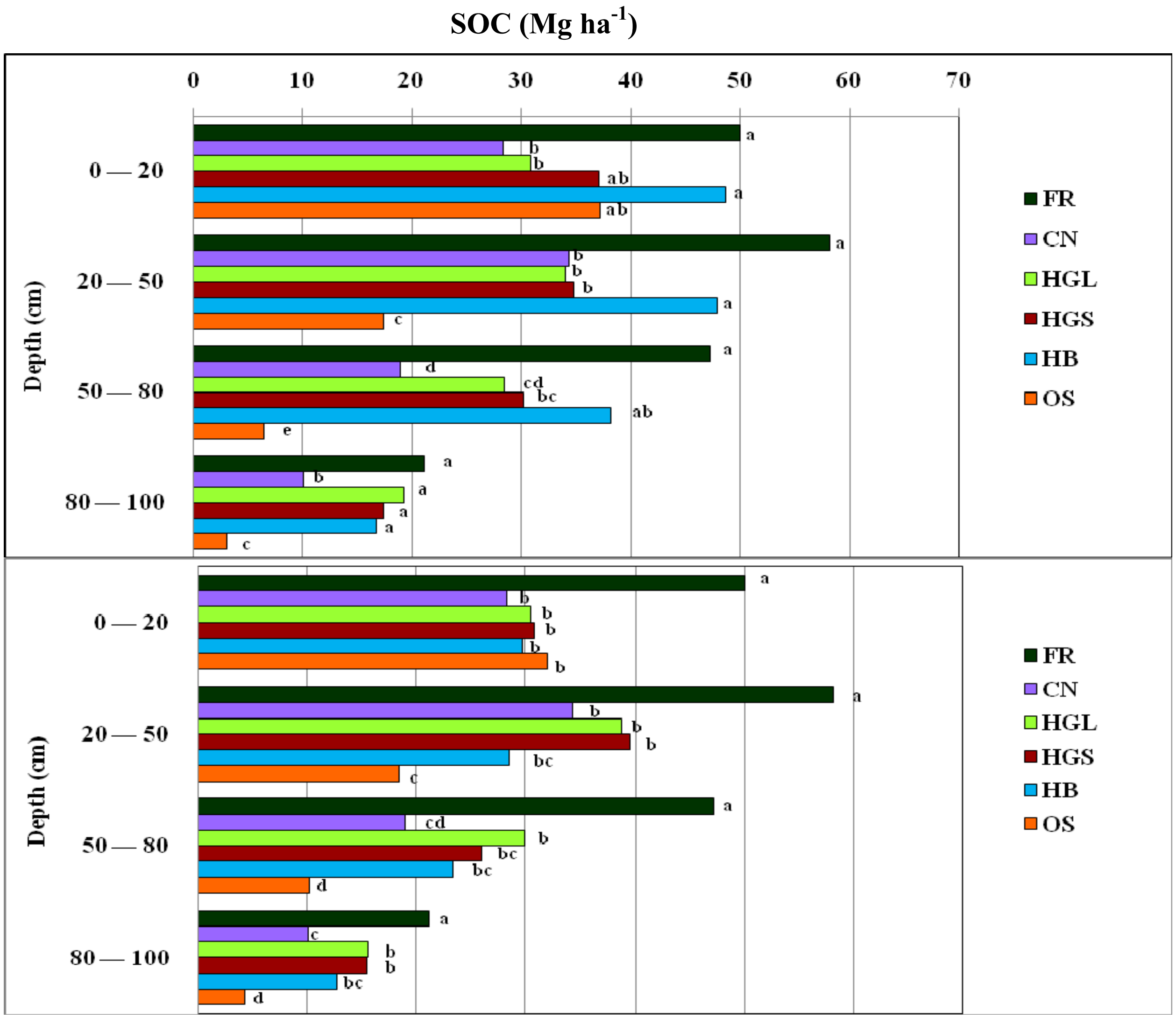

Figure C-2. Soil organic carbon (SOC) with depth at six tropical land-use systems for whole soil of the Site 1 (Pandiparambu), Site 2 (Chirakkakode), and Site 3 (Vellanikkara) in Kerala, India. Lower case letters indicate significant differences (at the 0.05 probability level) in SOC among land-use systems at a given depth class. FR = Forest, CN = Coconut Grove, HGL = Large Homegarden, HGS = Small Homegarden, HB = Rubber Plantation, and OS = Rice-Paddy Field

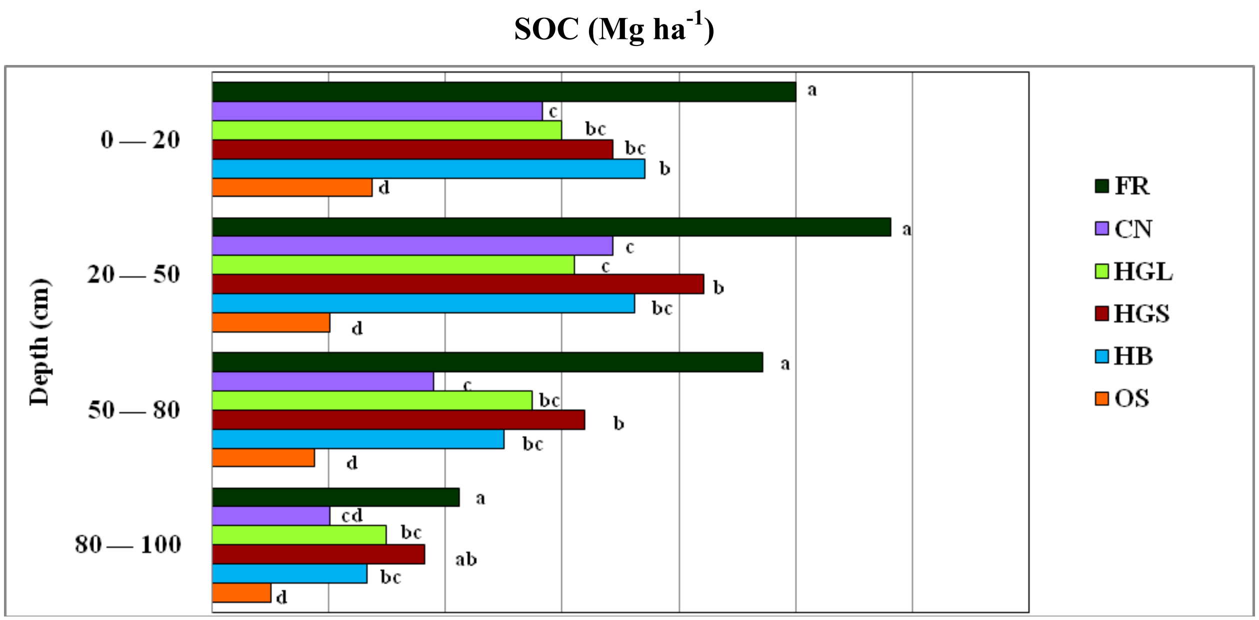

Figure C-2. Continued

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BIOGRAPHICAL SKETCH

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