Decarbonization Strategies and Drivers to Achieve Carbon Neutrality for Sustainability

Edited by
Majeti Narasimha Vara Prasad, Larry E. Erickson, Fabio Carvalho Nunes and Bimastyaji Surya Ramadan

Highlights the importance of different strategies for decarbonization

Decarbonization Strategies and Drivers to Achieve Carbon Neutrality for Sustainability emphasizes the significance of various decarbonization strategies. It is expected to solve some of the problems centered around decarbonization and available technologies and to diversify renewable energy supply in different sectors contributing to energy security.

This book covers contribution of bioenergy to decarbonization, nonfossil energy targets, role of wind energy, hydrogen energy, potential of geothermal energy, nuclear energy, wind energy, role of electrification, and carbon capture, utilization, and storage (CCUS) technologies. This book aims to explain how reducing fossil fuel consumption and supplementing alternate sources of renewable fuels is vital and would strengthen decarbonization.

Key Features

- Provides strategies for the implementation of decarbonization
- Explores the possibilities for reducing the emission of greenhouse gases
- Suggests actions and possible solutions to counteract climate change and its consequences

About the Editors

Dr. Majeti Narasimha Vara Prasad
Professor (Retired), Department of Plant Sciences, School of Life Sciences, University of Hyderabad, India

Dr. Larry E. Erickson
Professor of Chemical Engineering, Kansas State University, Manhattan, USA

Dr. Fabio Carvalho Nunes
Professsor; Researcher; Federal Institute Baiano (IF BAIANO), Santa Inês, Bahia, Brazil

Dr. Bimastyaji Surya Ramadan
Assistant Professor, Environmental Engineering Department, Universitas Diponegoro, Indonesia; Researcher, Environmental Sustainability Research Group (ENSI-RG) Universitas Diponegoro, Indonesia

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Prasad • Erickson
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CHAPTER TWENTY THREE

c0023 Harnessing home gardens for sustainable agroforestry: A promising approach to reducing greenhouse gas emission

T.M. Paranavithana, W.A.D.D. Wasalamuni and R.R. Ratnayake
National Institute of Fundamental Studies, Kandy, Sri Lanka

s0010 1. Objective

p0010 Arable greenhouse gas emission significantly reduces potential carbon sinks while exacerbating global warming. Mitigating actions to combat global warming has focused on reducing arable greenhouse gas emissions through forest landscape restoration, thereby increasing carbon sequestration. It has been suggested that reducing carbon dioxide emissions and other greenhouse gases will mitigate the risk of global climate change. The idea of increasing the amount of carbon stored in soils is one method that has been proposed as a means of reducing atmospheric carbon dioxide. Carbon sequestration implies the process of transferring and securing storage of atmospheric CO_2 in other long-lived carbon pools such as vegetation and soil.

p0015 Interestingly, sequestered carbon can be secured within the soil as stable carbon pools (i.e., humus) for centuries or even thousands of years (Hayes and Swift, 2020). The total soil carbon pool of 2300 pg is three times that of the 770 pg atmospheric pool and 3.8 times that of the 610 pg vegetation pool (Iticha et al., 2017). Thus, soil serves as a huge carbon sink absorbing more carbon than any other terrestrial carbon pool. This effective carbon sequestration strategy aids in the reduction of anthropogenic CO_2 emissions while improving soil fertility and crop productivity (Nair et al., 2015). In fact, soil organic carbon (SOC) reserves nutrients and contaminants in the soil, which enhances plant growth by increasing essential nutrient intake while restricting pollutant uptake (Lehmann and Kleber, 2015). Among different CO_2 emission reduction strategies, agroforestry could be considered a promising approach to the sustainable utilization of terrestrial ecosystems for carbon sequestration.

p0020 Consequently, the main objective of this chapter is to provide an overview of agroforestry with a particular reference to traditional Kandyan home gardens in Sri Lanka and their role in controlling greenhouse gas emissions. Furthermore, the

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knowledge generated from the current study would be helpful in developing a model home garden system to enhance the carbon sequestration potential. Sustainable management of home gardens is crucial in addressing global warming and other related issues.

s0015
2. Audience

p0025 One of the major challenges confronting the world today is the supply of needs for the rapidly growing population. At the same time, urbanization continues to drive a vast majority of the world's population into cities. Home garden, one of the best-developed agroforestry systems, is a better option for local communities with limited land areas to make efficient carbon sinks by fine-tuning the carbon sequestration capacity. As a result, home gardens in the city are becoming increasingly important in climate change mitigation via carbon sequestration. These gardens are the last remnant of land that can capture CO_2 from the atmosphere after the decline of natural forests for human settlements. More importantly, this presents an excellent opportunity to sell carbon offsets generated by C sequestering agronomic methods in their home gardens to a C exchange market. Carbon trading, often called "cap and trade," is a system developed to cut down carbon emissions, contributing to global warming (Avi-Yonah and Uhlmann, 2009). The Kyoto Protocol of the United Nations (1998) established a clean development mechanism that allows all parties to trade carbon emissions (Breidenich et al., 1998). Accordingly, activities that reduce or absorb CO_2 in developing nations can be utilized to offset CO_2 emissions in developed countries that exceed the agreed limit of CO_2 emissions (Simone et al., 2017). In addition, smallholders in developing nations could benefit from this trading mechanism, which might help them improve rural livelihoods. This could be a financial incentive for landowners to implement soil-conserving and carbon-sequestering agronomic practices in their home gardens (Marland et al., 2001).

s0020
3. Rationale

p0030 The Earth is experiencing a temperature rise, making it the most alarming and debated environmental concern of this century. The rising atmospheric temperature level causes devastating damage to the Earth's habitats and its living creatures. Having recognized the accumulation of CO_2 and other greenhouse gases in the upper atmosphere as the primary reason for global climate change, the necessity of reducing CO_2 levels has become an important topic. Land-use changes have been considered a significant contributor to increasing atmospheric CO_2. Deforestation, biomass burning, forest conversion to agriculture and human settlements, intensive cropping, and drainage of wetlands are the fundamental causes of carbon emissions caused by land-use changes (Lal, 2004). Therefore, it is crucial to improve soil carbon contents in affected land parcels.

p0035 Managing agroforestry systems to sequester atmospheric carbon in soil has drawn scientific attention as a way of reducing global warming and improving soil quality. Agroforestry is a land use management system combining trees, crops, and/or livestock on the same land, establishing a sustainable and productive agricultural environment (Nair et al., 2021; Sharma et al., 2022). It is a traditional practice that has experienced a revived interest in recent years owing to its potential to address various environmental and social issues, such as climate change mitigation, biodiversity conservation, and sustainable food production (Murthy et al., 2013; Sharma et al., 2022). Several agroforestry practices are tailored to specific ecological and socioeconomic conditions. Some common types of agroforestry systems include silvopasture, forest gardens, windbreaks, and home gardens (EURAF, 2021). The benefits associated with agroforestry systems include the improvement of soil health, promote habitat diversity, providing refuge for a wide range of plants and animals, helping to combat climate change via sequestering more carbon (Dollinger and Jose, 2018), diversification in agroforestry provides more stable yields and greater resistance to pests, diseases, and extreme weather events and generate more income opportunities for farmers through diverse products such as fruits, nuts, timber and medicinal plants (Caballero-Serrano et al., 2016). Besides, agroforestry systems emerge as a highly favorable option for integrating food production with environmental services while fulfilling both climate change adaptation and mitigation goals. Even though agroforestry systems are not explicitly created for carbon sequestration, numerous recent studies support the idea that these systems can significantly contribute to storing carbon in aboveground and belowground biomass, as well as in the soil (Montagnini and Nair, 2004; Raczkowski et al., 2002). The tree components of agroforestry systems have the potential to act as significant sinks of atmospheric C due to their rapid growth and productivity, substantial and long-term biomass storage, as well as extensive root systems (Lorenz and Lal, 2018).

p0040 Home gardens are the best-developed agroforestry systems in tropical regions compared to the different agroforestry systems. These home gardens play an important role in C sequestration as forest resources are declining at an alarming rate in the tropics (Rajapaksha et al., 2020). These manmade ecosystems, comprising a diverse assortment of plant species, their low maintenance requirements, and, thereby, high C sequestration potential, have caught the attention of most of the researchers and policymakers in the world (Caballero-Serrano et al., 2016). Primarily, home gardens are occupied in tropical regions across Asia, Africa, and South America, attributed to favorable climatic conditions and the cultural significance of small-scale agriculture in these regions (Montagnini, 2006; Nair and Kumar, 2006). Furthermore, home gardens have served as a valuable tool to enhance household food security across various regions of the world (Galhena et al., 2013). Notably, international aid agencies, local governments, and nongovernment organizations have actively utilized and promoted home gardens in their educational and community outreach efforts. These gardens also play a crucial role in species domestication and conservation, and their high plant species diversity makes them significant resources for ethano-botanical studies (Idohou et al., 2014). Over time, home gardens have evolved to domesticate valuable species, as many of these plants are deliberately encouraged and cultivated within these systems. The efficient nutrient cycling observed in traditional home gardens is a key factor contributing to their ecological sustainability. This sustainability is further maintained through the optimal management and transfer of carbon, water, and nutrients, facilitated by the diversity of species and structures within these gardens (Caballero, 1992). Hence, tropical home gardens could be recognized as one of the oldest forms of managed land use systems with multispecies production systems and stand as prime examples of sustainability.

p0045 Kandyan home gardens, also known as Kandyan forest gardens in Sri Lanka, represent a traditional form of perennial cropping that has been practiced for several centuries (Perera and Rajapakse, 1991). These home gardens are unique in that they resemble natural forests other than typical manmade land use systems. They are characterized by a diverse mix of economically valuable tree crops, including spices, fruits, medicinal plants, and timber species (Jacob and Alles, 1987). They sustain soil cover and fertility within the landscape, and their massive impact on controlling microclimate and local hydrology is remarkable (Hochegger, 1998). Moreover, Kandyan home gardens significantly advance Sri Lanka's socioeconomic development and promote resource sustainability (Pushpakumara et al., 2010).

p0050 Therefore, studying the carbon sequestration potential of home gardens is highly useful for future applications such as developing and maintaining a sustainable home garden system with high carbon sequestration potential to achieve climate change mitigation and adaptation goals. In addition, a self-sufficient model home garden system can be designed to provide day-to-day household needs that ensure the food security of local residents.

s0025 4. Expected results and deliverables

p0055 The carbon sequestration potential of manmade ecosystems can be improved by implementing proper management strategies. Especially, the maintenance of SOC through organic amendments ensures that carbon remains are sequestered in the soil. Soil disturbance by tillage practices significantly contributes to the loss of SOC from the system. Hence adopting conservation or no-tillage practices would be favorable for promoting soil carbon sequestration (Baker et al., 2007). Further, vegetation structure, density, and diversity affect both above- and belowground soil carbon dynamics. For instance, introducing cover crops with deeper roots could maximize the amount of belowground carbon (Bell et al., 2020). Hence, the carbon sequestration potential is significantly higher in agroforestry than in monoculture agricultural systems. More importantly, the multispecies plant associations within the agroforestry systems are speculated to have high carbon sequestration potential due to their forest-like structure and composition (Nair et al., 2009).

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s0030 4.1 Potential of soil carbon sequestration in home gardens

s0035 *4.1.1 Plant diversity and soil carbon sequestration*

p0060 High plant diversity enhances SOC storage by elevating carbon inputs (particularly belowground carbon inputs) and increasing the diversity and activity of microbial communities by suppressing carbon losses from decomposition (Fornara and Tilman, 2008; Lange et al., 2015). Therefore, the number of trees (Kursten, 2000) and species richness (Lemma et al., 2007) in a system is claimed to boost its carbon storage capacity. Home gardens comprise high biodiversity as an intrinsic feature (Kumar and Nair, 2004), which is believed to create favorable conditions for greater net primary production (Vandermeer, 1989) and enhanced capacity for carbon sequestration compared to monocrop production systems. Specifically, in monoculture cultivation, competitive interactions (asymmetric competition), which involves individuals of mixture acquiring resources at different rates, can hinder the productive potential of some competing elements. Besides, the dominant component of the mixture may engage resource preemption, further impacting productivity (Wedin and Tilman, 1993). In addition to the considerable variation of vegetation, the superior performance of multistrata systems in home gardens resembling natural forest ecosystems controls the natural competition of the plant community (Beyene et al., 2018). Apart from that, these species mixtures provide increased resistance to insect infestation or disease outbreaks, which improves the plant community's survival over environmental challenges (Jactel et al., 2005). The distinct ground layer (GL) vegetation community in home gardens, comprising shrubs, forbs, graminoids, and seedlings, plays a crucial role in interacting with and influencing plant diversity, ecosystem productivity, and nutrient cycling. This GL vegetation covers the land, protecting against soil erosion, and contributes to soil stability by promoting soil aggregation (Tisdall and Oades, 1982). Moreover, they also add to the aesthetic value of the environment.

p0065 The interplay of the structure of vegetation, species composition, and biodiversity emerges as a vital determinant in enhancing the system's ability to sequester carbon and contribute to environmental sustainability.

s0040 *4.1.2 Litter characteristics and soil carbon sequestration*

p0070 Litter layer is a vital component of terrestrial ecosystems as it serves as a source of soil organic matter and acts as a substrate for essential soil biological processes, including decomposition and nutrient cycling. Furthermore, it represents one of the two primary energy sources in the soil, making it of utmost importance for sustaining soil organisms and preserving the vast biodiversity found in these ecosystems (EFSA, 2010). Therefore, litter decomposition is one of the significant sources of SOC, and the quality of the litter itself influences the decomposition process (Mafongoya et al., 1998). The litter quality, in turn, varies depending on the plant species (Lemma et al., 2007). In forest ecosystems, both litter production and litter quality are crucial factors affecting the carbon sequestration process in soil (Giweta, 2020). The tree species producing litter that are rich in lignin content contribute to increased carbon stabilization in the soil (Austin and Ballare, 2010). Furthermore, the abundance of litter diversity resulting from high species diversity positively influences soil carbon sequestration, specifically the microbial biomass carbon content in the soil (Bastida et al., 2021; Zak et al., 2003). The storage of SOC is influenced by two main factors: the amount of litter present (Lemma et al., 2007) and the activity of roots, including rhizo deposition and decomposition (Rees et al., 2005). As a result, trees highly contribute to soil C sequestration with their larger aboveground and belowground biomass compared to shrubs or herbs. In summary, the quantity and quality of litter produced by different plant species in a diverse ecosystem significantly impact on soil C sequestration.

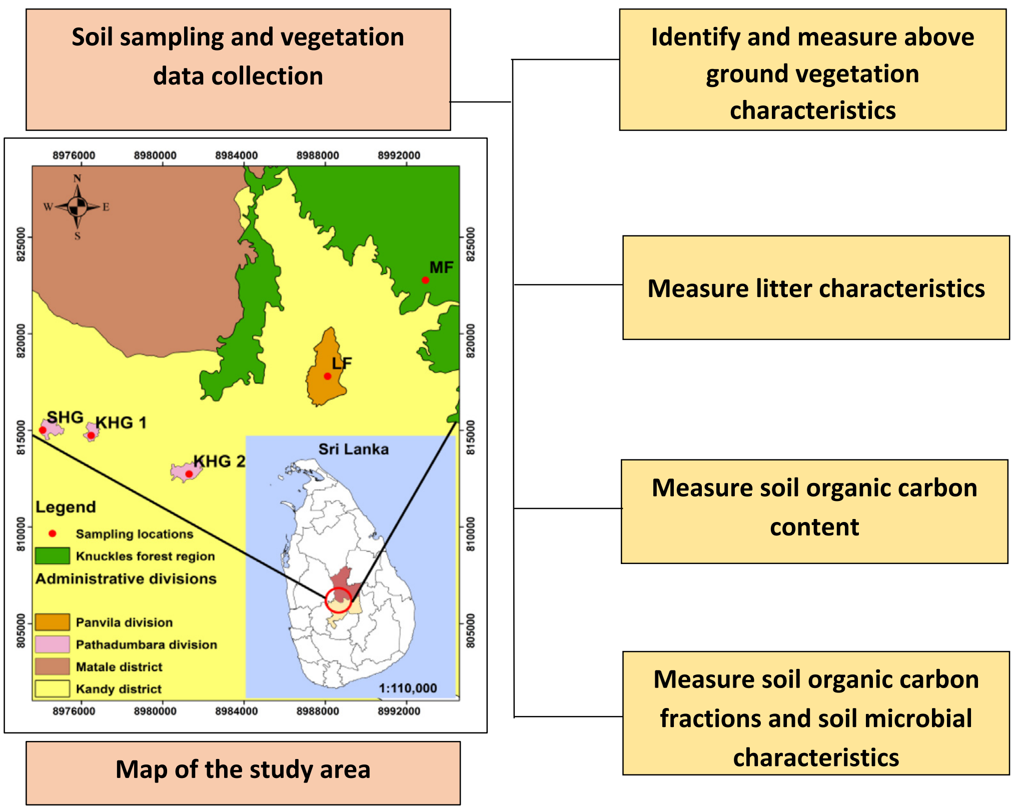
s0045 *4.1.3 Soil microbial activity and soil carbon sequestration*

p0075 Microbes play a vital role in the soil carbon cycle and are key contributors to soil carbon sequestration. Understanding and supporting their beneficial functions can improve soil health and alleviate climate change impacts by storing more carbon in the soil. The activity of soil microbes in carbon sequestration is influenced by climatic factors (temperature, moisture levels) and vegetation type, as well as soil properties like pH, texture, and nutrient content (Paranavithana et al., 2023). Optimal conditions for microbial activity can lead to increased carbon storage in soils. Sustainable land management practices like reduced tillage, cover cropping, and agroforestry can improve microbial activity and help to combat climate change through carbon sequestration. Therefore, managing agricultural practices to promote a healthy and diverse soil microbial community is vital for maximizing soil carbon sequestration capacity. For instance, Microbes produce substances like glomalin, a glycoprotein produced by mycorrhizal fungi, which plays a crucial role in soil aggregation (Paranavithana et al., 2021; Six et al., 2004; Wilson et al., 2009). Soil aggregation refers to binding soil particles into stable aggregates, creating pore spaces, and enhancing soil structure. These aggregates help protect soil organic matter from rapid decomposition and create physical protection for microbes (Grandy and Robertson, 2006, 2007). Therefore, microbes help to protect organic carbon from further decomposition and mineralization by forming physical and chemical associations with soil particles. This process, known as microbial carbon protection, contributes to the enduring carbon retention within the soil.

p0080 Microbes, mainly bacteria and fungi, are responsible for breaking down dead plant and animal material (organic matter) into simpler compounds. During this decomposition process, some of the carbon from the organic matter is converted into stable forms of organic carbon, such as humus, which can persist in the soil over long periods (Lehmann and Kleber, 2015). Therefore soil bacteria and fungi have a critical function in maintaining the balance of SOC levels and serve as key regulators of C sequestration within the ecosystem. Hence, the determination of microbial biomass carbon (MBMC) and microbial biomass nitrogen (MBMN) contents, along with the total soil carbon content and different soil carbon fractions, help to reveal information about fertility and C cycling within a particular ecosystem.

s0050 5. Actions taken/workflow/tools used/simulations and analyses

p0085 In this study, soil C sequestration potential in home garden systems of different species compositions, including traditional home gardens and traditional home gardens incorporated with spice crops in the Central province of Sri Lanka, were studied (Figs. 23.1 and 23.2) while comparing their C sequestration potential with a lowland rain forest and montane forest as controls. We studied aboveground vegetation characteristics, litter characteristics, soil microbial characteristics, SOC, and SOC fractions variations related to C sequestration in the studied ecosystems.



f0010 **Figure 23.1** Schematic diagram for the workflow of the current study.

f0015 **Figure 23.2** View of the Kandyan home garden, Sri Lanka.

s0055 5.1 Description of the study sites

p0090 The Research was conducted in Central Province Sri Lanka, which experiences a tropical climate and is situated between 5°54′N–9°52′N latitude and 79°39′E–81°53′E longitude (National Atlas, 2007). Three home gardens were selected for the study, each with a considerably large area for soil sampling. Those home gardens were categorized as follows: Traditional Kandyan home garden 1 (KHG1), Traditional Kandyan home garden 2 (KHG2), and home garden incorporated with spice crops (SHG). The primary purpose of selecting the home garden interspersed with spice crops was to compare it with the traditional Kandyan home gardens. The chosen home gardens share similarities in slope gradient, age, area, and environmental conditions. This careful selection aimed to minimize the impact of variations in the aforementioned characteristics on soil C sequestration and the potential error associated with comparing soil C sequestration in home gardens with different species compositions. In addition to the home gardens, two control sites were chosen for soil sampling: a lowland rain forest (Moraella) and a montane forest (knuckles) within the same agroecological zone. These control sites were selected to compare the C sequestration potential of the home gardens with the nearby forest types.

s0060 5.2 Soil and litter sampling

p0095 In each of the selected locations, three 20 m × 20 m plots were established for soil and litter sampling. Edges of the lands and slopes were avoided to minimize the microclimatic variations among the plots and field sites. For soil sampling, the superficial litter layer was removed, and soil samples were randomly collected from two depths: 0−15 cm and 15−30 cm. Litter samples were collected randomly in a 1 m × 1 m area within the main study plot.

s0065 5.3 Vegetation data recording

p0100 To assess the horizontal structure of home gardens, the number of trees (diameter >5 cm) in each subplot (20 m × 20 m) was counted, and tree density per hectare was calculated for each home garden. The percentage cover of the ground layer (GL) was estimated by using 12 (1 m × 1 m) quadrats per home garden. To evaluate the floristic composition of studied home gardens, all the dominant tree species within each subplot (20 m × 20 m) were identified and recorded. The Shannon−Wiener diversity index (H) (Eq. 23.1), species richness (Menhinick's index (D), (Eq. 23.2)) and Shannon's equitability of evenness (E_H) (Eq. 23.3) were calculated.

$$H = -\Sigma\,(Pi \ln Pi) \tag{23.1}$$

$$D = S/N^{1/2} \tag{23.2}$$

$$E_H = H/\,Hmax(Hmax = \ln\ S) \tag{23.3}$$

Pi is the proportion of individuals that species i contribute to the total number of species, S is the number of different species represented in the sample, and N is the total number of individual organisms in the sample.

s0070 5.4 Laboratory analyses

p0105 The soil samples were sieved using a 2 mm mesh sieve. The fresh soil samples were analyzed for MBMC using the chloroform fumigation and extraction method (Vance et al., 1987). Similarly, MBMN was extracted using the Chloroform fumigation and extraction method and extracted MBMN was analyzed using the total Organic carbon (TOC) analyzer (analytikjena, multi N/C 2100/2100S). TOC content was analyzed using dried and ground soils (<0.15 mm) using the modified Walkley's oxidation method (Anderson and Ingram, 1993). Additionally, soil organic C fractions, including water-soluble carbon (WSC) (Anderson and Ingram, 1993), and permanganate oxidizable carbon (POC) (Weil et al., 2003) were measured.

s0075 6. Results

s0080 6.1 Aboveground vegetation structures

s0085 *6.1.1 Vertical structures of vegetation*

p0110 The agroforestry systems typically present 3−4, or in certain instances, even five principal layers or niches (Hochegger, 1998). The tree layer in the home garden

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consists of woody species that reach heights ranging from 5 to 30 m, constituting the overarching canopy. In general, the canopy layer spans a height of 25–30 m, the subcanopy layer extends between 10 and 15 m, and the understory Layer encompasses heights of 4–5 m.

p0115 Accordingly, both KHG1 and KHG2 exhibited four distinct strata, namely canopy, subcanopy, understory, and ground layer (<1 m in height). However, the stratification observed in KHG1 and KHG2 was not clearly observed in SHG, primarily due to the dominance of *M.fragrans* trees in the latter. The canopy layer of *M. fragrans* trees with dense crowns limits the sunlight to the ground layers, which inhibits the growth of ground layer vegetation. Furthermore, in KHG1, the ground layer was occasionally cleared, resulting in a reduction in the number of strata present. Therefore, among the three home gardens studied, KHG2 exhibited the closest resemblance to a natural forest structure due to its relatively undisturbed and multilayered composition.

s0090 6.1.2 Horizontal structure of vegetation

p0120 Home gardens and other smallholder systems characterized by an abundant presence of trees possess significant potential for C storage due to their high woody biomass (Haile et al., 2008; Takimoto et al., 2008). As tree density increases, the woody biomass of the trees concurrently increases. Over half of the C assimilated by trees is eventually transported below ground through root growth and turnover, root exudates, and litter deposition, promoting more SOC sequestration (Montagnini and Nair, 2004).

p0125 Tree density of the trees higher than 5 cm diameter at breast height (DBH) in home gardens varied in the decreasing order of KHG2 > KHG1 > SHG (Table 23.1). KHG2 had significantly higher tree density ($P < .05$) than the rest of the sites and greater potential for soil C sequestration. The spaces between incorporated *M. fragrans* trees in SHG are the main reason for the recorded low tree density compared to the other two sites.

t0010 **Table 23.1** Vegetation characteristics across the studied home gardens.

Home garden	Tree density ha^{-1} (DBH>5 cm)	Average cover % (ground layer)	Species richness (D)	Shannon–Weiner diversity index (H)	Shannon's equitability (EH)
KHG1	1500 ± 6.1[a]	55.1 ± 7.2[a]	1.65 ± 0.08[a]	2.37 ± 0.12[ab]	0.81[a]
KHG2	1941 ± 7.3[b]	63.3 ± 10.6[a]	1.80 ± 0.11[a]	2.71 ± 0.16[a]	0.85[a]
SHG	975 ± 5.4[c]	25% ± 5.4[b]	1.56 ± 0.07[b]	2.07 ± 0.09[b]	0.73[b]

KHG1, Kandyan home garden 1, *KHG2*, Kandyan home garden 2, *SHG: SHG*, Kandyan home garden incorporated with *M. fragrans* (SHG). Different superscript letters [a,b,c] indicate statistically different means at the $P < .05$ significance level.

s0095 *6.1.3 Ground layer vegetation*

p0130 The ground layer (GL), composed of shrubs, forbs, graminoids, and seedlings, plays a key role in ecosystem function and the terrestrial carbon cycle (Hou et al., 2015; Saitoh et al., 2015). The plant community in GL exerts a better contribution to plant diversity, ecosystem productivity, and nutrient cycling (Gilliam, 2007; Moore et al., 2007) and, thus, plays a crucial role in regulating soil C and N cycles.

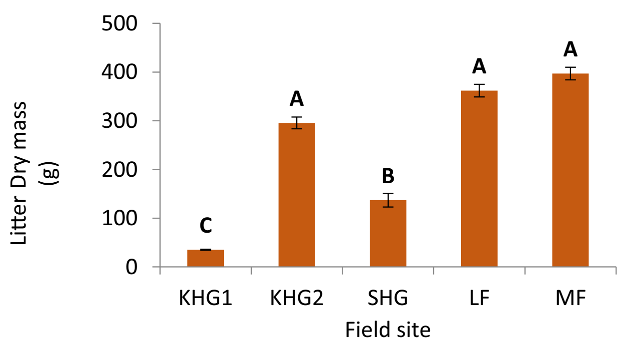
p0135 The average cover of ground layer (AC%) varied in the following descending order: KHG2 > KHG1 > SHG. The KHG2 recorded the highest AC%, which was significantly exceeding the value recorded for SHG. Moreover, KHG2 had the highest moisture content (MC%), encouraging more GL communities, and thereby contributing to the overall aboveground carbon stocks. However, the GL measurements may fluctuate significantly over time due to management practices associated with home gardens, such as GL clearing and weeding.

s0100 *6.1.4 Species diversity and richness*

p0140 Home gardens with a rich diversity of species can be distinguished from less species-intensive systems from their robust resource utilization traits (Tilman et al., 1997; Kirby and Potvin, 2007). Consequently, these diverse home gardens may promote higher net primary production (Vandermeer, 1989), ultimately contributing to above- and belowground C sequestration. Therefore, studying species diversity, species richness, and species equitability within home gardens becomes imperative to understand their C sequestration potential comprehensively.

p0145 As indicated by the present findings, the species richness (D) and Shannon's equitability (EH) were significantly greater in KHG2 compared to SHG, whereas no significant difference was observed between KHG1 and KHG2 (Table 23.1). As represented by elevated species and family richness, as well as species diversity in both KHG1 and KHG2, it can be inferred that they have a higher potential for aboveground C sequestration than SHG. The Shannon—Weiner diversity index (H) considers both the species' quantity and their dominance or evenness relative to each other. A higher value of the H indicates that plant species are more abundant and evenly distributed. This even distribution is also reflected in the higher value obtained for EH. Hence, the lower value of EH in SHG may be attributed to the high density of *M. fragrans* trees within the site, which limits the even distribution of other plant species.

p0150 In conclusion, studies on aboveground vegetation revealed that traditional Kandyan home gardens (KHG1 and KHG2) have a structure (stratification) and composition (species richness, tree density) much similar to natural forests. At the same time, in SHG, some deviations could be observed due to incorporating spice crops.



f0020 **Figure 23.3** Litter dry weight variation across study sites. *KHG1*, traditional Kandyan home garden 1; *KHG2*, traditional Kandyan home garden 2, *SHG*, Kandyan home garden incorporated with *M. fragrans*; *LF*, lowland rain forest; *MF*, Montane Forest. Means denoted by different letters are significantly different at $P < .05$.

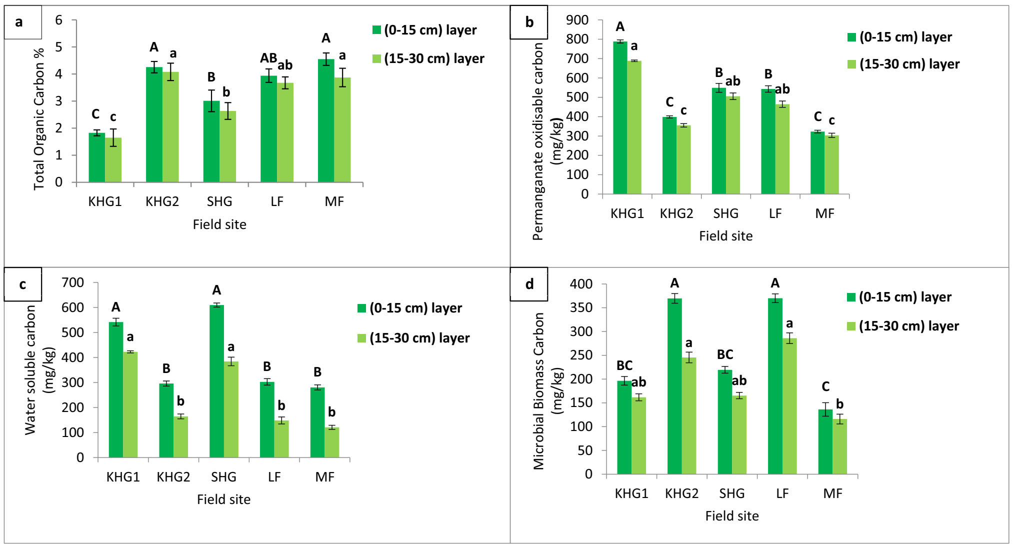
s0105 *6.1.5 Litter characteristics*

p0155 Among the studied home gardens, the KHG2 is characterized by a higher tree density, species diversity, minimal management interventions, and an undisturbed ground layer, resulting in litter dry mass (LDM) levels comparable to those found in natural forests (Fig. 23.3). In contrast, KHG1, which was subjected to frequent management practices such as litter sweeping and burning, demonstrated the lowest LDM. Consequently, the limited litter decomposition in KHG1 leads to reduced incorporation of litter-derived carbon into the soil during decomposition. This observation underscores the pivotal role of litter debris in directly influencing the accumulation of SOC (Fig. 23.6).

s0110 *6.1.6 Soil organic carbon content*

p0160 Natural forest ecosystems are crucial for storing atmospheric carbon, both in the vegetation and soil. Soil carbon sequestration primarily transpires through microbial processes, where organic matter is broken down and incorporated into the soil as the SOC. The current research indicated that the MF forest had the highest concentration of TOC due to the accumulation of organic materials from diverse plant residues on the soil surface (Seely et al., 2010). The low-temperature levels experienced in MF ecosystems caused decomposition rates to slow down, leading to greater retention of SOC. The LF, renowned for its dense tree population and wide variety of species, is largely attributed to the high-quality litter cover, which facilitates storing a significant amount of TOC. More importantly, these pristine forests faced fewer disturbances, resulting in minimal human-induced SOM turnover and higher levels of TOC.

p0165 Interestingly, the KHG2 with the highest species density, richness and highest litter mass exhibited elevated SOC levels, which is statistically similar to both of the above-discussed natural forests (Fig. 23.4A). Compared to KHG2, both KHG1 and SHG recorded low TOC levels. The KHG1 employing additional management practices such



f0025 **Figure 23.4** Total organic carbon and carbon fractions variation across study sites: (A) total organic carbon, (B) permanganate oxidizable carbon, (C) water-soluble carbon, (D) Microbial biomass carbon. *KHG1*, traditional Kandyan home garden 1; *KHG2*, traditional Kandyan home garden 2; *SHG*, Kandyan home garden incorporated with *M. fragrans*; *LF*, lowland rain forest; *MF*, Montane Forest. Means denoted by different letters are significantly different at $P < .05$.

as ground-layer clearance and tree thinning exhibited reduced litter mass and lower TOC concentration. On the other hand, SHG, where spice crops and frequent management practices were employed, showed lower TOC levels than KHG2. The results also indicated that the TOC concentration in the 0–15 cm layer surpassed that in the 15–30 cm layer, as the decomposition of leaf litter directly enriches the topsoil with organic carbon.

s0115 *6.1.7 Soil organic carbon fractions*

p0170 The soil carbon fractions represent the labile C pool (active soil C) in the soil is mainly derived from the degradation of plant materials and animal wastes, root exudates, and dead microorganisms (Bongiorno et al., 2019). Hence, the continuous supplement of labile carbon to soil relies on organic amendments. This fraction is essential to control soil quality because it stabilizes the soil structure and is directly related to the mineralization of soil C by enhancing the capacity of microbes to release nutrients (Lucas and Weil, 2012). More importantly, mineral protection, water solubility, and microbial degradation are critical in determining the persistence and mobility of organic compounds (Lehmann and Kleber, 2015). The labile fractions of organic carbon may considerably influence soil quality, making them more sensitive indicators of the effects of land-use changes or management techniques than the TOC pool (Ramesh et al., 2019).

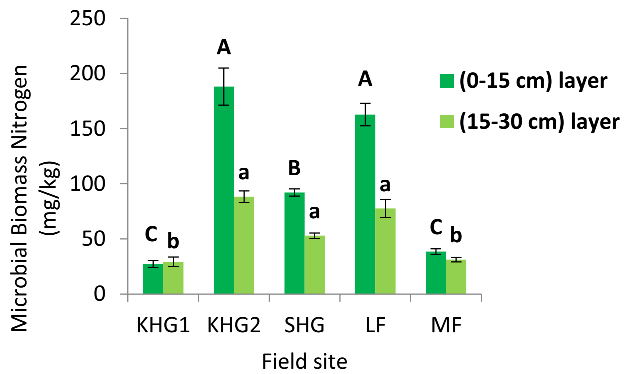
p0175 The easily oxidizable carbon or the permanganate oxidizable carbon (POC) is one of the labile carbon fractions that also can be used as an indicator of soil health and is sensitive to intensive management practices (Pal et al., 2015). Further, these oxidizable carbon fraction is recognized as a primary energy source for soil microbes (Bongiorno et al., 2019). Therefore, MBMC accomplices with other oxidizable C fractions can be added as the preferable ecological indicator to assess SOC fluctuations in a particular ecosystem. More frequent implementation of management practices and disturbances leads to an increase in POC content. The study found that both MF and LF forests had lower POC levels, indicating fewer disruptions to the soil system (Fig. 23.4B). Among the sites examined, KHG1, which experienced more frequent management practices, showed the highest POC level, while KHG2, with fewer disturbances, had a lower POC content. The POC content was generally higher in the topsoil (0–15 cm) than in the deeper soil layer (15–30 cm), reflecting the greater disturbances in the topsoil.

p0180 The WSC fraction is the most mobile and reactive form in soil organic carbon pools, modulating many chemical, physical, and biological processes (Gmach et al., 2019). Usually, WSC is either absorbed by soil particles or dissolved in soil pore water (Ghani et al., 2003). The WSC is proposed as an indicator to evaluate various agricultural management strategies as they are susceptible to short-term changes in land use patterns. Similar to the patterns observed in POC, the KHG1, and SHG subjected to more frequent management practices exhibited the most elevated levels of WSC. In contrast, KHG2, characterized by fewer disturbances, recorded low WSC levels with no significant differences from that of the two natural forests (Fig. 23.4C). Our findings highlighted that the WSC could serve as an indicator of human-induced impacts on the soil C pool. More importantly, the study emphasized the strong positive correlation between the POC and WSC (Fig. 23.6).

s0120 *6.1.8 Microbial biomass carbon and microbial biomass nitrogen*

p0185 Both MBMC and MBMN contents serve as an important indication of a well-functioning soil environment (Liu et al., 2010). Soil microbes use organic matter to get energy, and in this decomposition process, nutrients that are in the plant-unavailable form are converted into plant-available form (Dwivedi and Soni, 2011).

p0190 The highest MBMC and MBMN contents are recorded in the LF and the KHG2, which are directly proportionate to the recorded TOC contents across these sites (Fig. 23.6). In these productive ecosystems, the presence of organic-rich soil fosters a thriving community of bacteria and fungi, effectively engaging in the degradation process of substantial quantities of SOM (Six et al., 2006). In addition to the contribution of SOM, minimal disturbances of LF and KHG2 also may enrich the MBMC and MBMN levels. On the contrary, it has been observed that KHG1 and SHG, which are subjected to intensified management practices, exhibit diminished levels of MBMC (Fig. 23.4D) and MBMN (Fig. 23.5). The decline in MBMC, particularly in the deeper



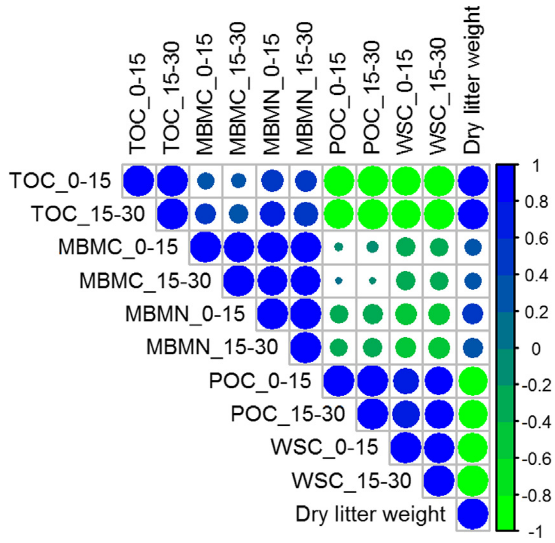
f0030 **Figure 23.5** Microbial biomass nitrogen variation across study sites. *KHG1*, traditional Kandyan home garden 1; *KHG2*, traditional Kandyan home garden 2; *SHG*, Kandyan home garden incorporated with *M. fragrans*; *LF*, lowland rain forest; *MF*, Montane Forest. Means denoted by different letters are significantly different at $P < .05$.

soil strata, can be attributed to the reduction in TOC and impaired air diffusion due to soil compaction. Additionally, soil pH, prevailing climatic conditions, and moisture levels exert significant influences on MBMC dynamics (Paranavithana et al., 2023). In fact, both MBMC and MBMN can be considered as paramount indicators for soil C management, as they demonstrate considerable variability contingent upon environmental factors and microbial activity.

p0195 In summary, the findings of this study indicate a positive correlation between soil C content and high litter dry mass (Fig. 23.6). Conversely, intensified management practices adversely affect the potential for soil C sequestration. Moreover, the investigation identifies labile carbon pools, including MBMC, POC, and WSC, as reliable indicators for detecting minor alterations in the soil C pool over anthropogenic interferences. Notably, the results highlight the remarkable soil carbon storage capacity of traditional home gardens, comparable to that of lowland rainforests and surpassing that of montane forests in tropical Sri Lanka.

s0125 7. Learning and knowledge outcomes

p0200 Agroforestry systems, including home gardens filled with a diverse array of plant species and requiring minimal management, possess a remarkable potential for C sequestration similar to vast forest stands in the same region. As a result, the sustainable management of these manmade ecosystems is crucial for the battle against global climate change. This community-based approach opens doors to earning valuable foreign exchange through C trading and sustaining people's livelihood through increasing crop productivity. The data generated from this study can serve as a valuable source in



f0035 **Figure 23.6** Figure 5 Correlation between considered soil parameters. *POC*, permanganate oxidizable carbon; *WSC*, water-soluble carbon; *TOC*, total organic carbon; *MBMC*, microbial biomass carbon; *MBMN*, microbial biomass nitrogen, 0–15 cm soil depth (0–15), 15–30 cm soil depth (15–30).

designing and implementing sustainable home gardens and future carbon trading programs. In conclusion, emphasizing sustainable home gardening practices becomes crucial in climate change mitigation and provides an opportunity to address global challenges while promoting local and community-based efforts to tackle carbon emissions.

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Non-Print Items

Abstract

Greenhouse gas emissions are accelerating due to rapid land use changes. Carbon sequestration involves the process of transferring and securely storing atmospheric CO_2 in other long-lived carbon pools, such as vegetation and soil. Agroforestry has excellent potential to enhance people's livelihoods by integrating food production and environmental protection. Due to the forest-like structure, composition, and multispecies plant association, agroforestry systems are speculated to have high carbon sequestration potential. Therefore, the potential for above- and belowground carbon sequestration is greater in agroforestry than in monoculture agricultural systems. Among various agroforestry systems, home gardens are the best-developed systems in tropical regions and play an essential role in C sequestration. The current chapter provides an overview of agroforestry, with a particular focus on home gardens and their role in controlling greenhouse gas emissions, by considering the traditional Kandyan home garden in Sri Lanka as a case study. The study depicted that soil C sequestration is positively affected by increasing species richness and tree density with minimum disturbances, which will be useful in developing model home garden systems to optimize the C sequestration capacity.

Keywords:

Global warming; Home garden; Management practices; Soil organic carbon; Species richness.