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RESEARCH ARTICLES

Tree species composition, diversity and soil organic carbon stock in homegardens and shifting cultivation fallows of Mizoram, Northeast India

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Abstract

We examined tree species diversity and soil organic carbon (SOC) at different soil depth intervals (0–20, 20–50, 50–80, and 80–100 cm) of homegardens (HGs) and shifting cultivation fallows (SCFs) of Mizoram, Northeast India. Total tree species encountered in the sampled HGs and SCFs plots were 86 and 50 respectively. Significant differences ($p < 0.05$) in tree diversity and basal area was observed between different age categories of both land use systems. Tree diversity was inversely related to the age of homegardens, whereas a positive correlation (significant at $p < 0.05$) was observed with the increasing age in case of shifting cultivation fallows. On an average, SOC content in the older systems were significantly higher ($p < 0.05$) than the younger systems and small HGs had discernibly higher ($p < 0.05$) SOC than the large HGs. Highest SOC content was found in 0–20 cm and decreased with increasing soil depth. At 1 m soil depth, SOC stock was 183.42 and 123.24 Mg C ha^{-1} in HGs and SCFs respectively. Values of SOC content were higher in HGs than the SCFs as a result of higher tree species composition and density. The study demonstrate that both HGs and SCFs, being tree based systems can sequester carbon and contribute to climate change mitigation.

Keywords Biodiversity · Plant community · Species richness · Soil nutrients · Carbon pools

Introduction

Agroforestry systems are approved as greenhouse gas mitigation activity under the Kyoto Protocol, as the presence of trees or woody perennials along with agricultural crops, pastures or livestock plays an important role through carbon sequestration in vegetation, soils and biomass products (Montagini and Nair 2004; Nair et al. 2009). Globally, agroforestry systems are estimated to be 1.6 billion hectares of land and occupy the third largest C sink amongst the different land use types after primary forest followed by long term fallows or secondary forest (Mbow et al. 2014). Shifting cultivation and homegardens are two prominent tree-based land use systems widely practiced for thousands of years in the tropical regions of Latin America, Southeast Asia and Equatorial Africa, wherein humans have cultivated agricultural plants with trees in a number of different arrangements (Bos et al. 2020; Erni 2015; Peyre et al. 2006). Shifting cultivation practices with reduced jhum cycle (fallow period) from 20 to 30 years to 2–3 years and other form of human activity like logging in recent years have modified much of the tropical forests into secondary growth with severe ecological consequences such as decline in natural forest area, habitat fragmentation, extinction of native species and invasion by exotic weeds and other plants, etc. (Ranjan and Upadhyay 1999; Morris 2010). These regenerating secondary forests or shifting cultivation fallows (SCFs) do provide similar environmental benefits like the primary forests, but they differ quite heavily in terms of biodiversity (Gogoi et al. 2020; Bonner et al. 2013; Chazdon et al. 2009; Thong et al. 2020) which may be due to the changing nature of fallow landscapes, site specific heterogeneity and different management practices (Mukul and Herbohn 2016). Homegardens

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(HGs) agroforestry on the other hand are practiced around homesteads as intimate, multi-storied systems consisting of a mixture of several trees, fruits, crops and other species resembling a forest-like structure and composition (Fernandes and Nair 1986; Nair et al. 2009) that are ecologically, socially and economically more sustainable to village ecosystem (Sahoo et al. 2012; Gbedomon et al. 2017).

Soil organic carbon (SOC) acts as the major terrestrial carbon (C) pools with higher potential to sequester carbon than vegetation (Batjes 1996). SOC stock in terrestrial ecosystems is globally estimated at 684–724 Pg C and 1462–1548 Pg C in upper 30 cm and 100 cm respectively (Le Quere et al. 2012). However, different land use types exhibit differences in the accumulation of stable soil organic matter through atmospheric carbon dioxide (CO_2) sequestration due to variations in net primary production, rooting distribution, and litter accumulation (Connin et al. 1997; Tharammal et al. 2019). In homegarden agroforestry systems, the soil is believed to maintain its fertility as a result of vigorous organic matter additions, nutrient cycling, protection from soil erosion and the maintenance of nitrogen fixing trees (Stagnari et al. 2017). The roots of the tree component of homegardens also influence the physical properties of soil by penetrating the deeper layer and possibly breaking the compact sub-soil and pumping the nutrients from deep layers where the roots of agricultural components cannot reach, subsequently adding to the top soil (Warren et al. 2014). Several environmental factors including climatic and edaphic, stand characteristics (tree density, species richness, species diversity, etc.) and management practices influence the C sequestration in agroforestry systems by determining the nature of system, the structure and the function of the components (Albrecht and Kandji 2003).

Mizoram, a state located in the north east of India had undergone an abrupt land transformation due to deforestation owing to clearing of forest lands to temporary agriculture through adaptation of slash and burn method of cultivation on hill slopes. Shifting cultivation is the major widely practiced land use system in Mizoram followed next by the practice of traditional homegardens. Both the systems are of subsistence nature where food production is supplemented from shifting cultivation, while the trees, crops and animals are intergrated in the homegardens to meet the additional daily needs for household such as vegetables, fruits, spices, condiments, medicines, fodder, fuelwood, etc. Thus, HGs and SCFs land use types exhibit different tree composition and structure. The variation in tree stand characteristics is also observed within the land use systems depending on its management practices such as landholding size (small, medium or large) and age (young or old). Very few studies have been undertaken and research information on how tree stand characteristics influence SOC accumulation is limited in the HGs and SCFs from Mizoram. The present study aims to characterize the diversity of tree species, soil carbon storage and relate tree diversity with SOC stock across different aged and sized traditional homegardens and shifting cultivation fallow in Mizoram.

Materials and methods

Study area and land use types

Mizoram is a state in north eastern part of India having over 80% of total geographical area hilly. The undulated topography ranged from 21 to 2157 m above msl receiving an annual rainfall of 2000–3200 mm. Agriculture is the main occupation through shifting cultivation affecting more than 2618 km^2 (NRSC 2010). Soils in the hills are generally acidic with loam to clay loam. The state experience a humid and tropical climate characterized by short winter and long summer with heavy rainfall. Four villages, viz.. Durtlang, Sairang, Selesih and Tanhril located in Aizawl district, Mizoram were selected for the study where both land use types (HGs and SCFs) with varying age and size were available. On the basis of age, HGs were stratified as Young HGs (< 20 years; n = 12) and Old HGs (> 20 years; n = 12). Further, these stratified HGs were grouped to landholding size gradient as Small HGs (< 0.25 ha; n = 8); Medium HGs (0.25–0.5 ha; n = 8); and Large HGs (> 0.5 ha; n = 8). Similarly, the SCFs were stratified on the basis of the fallow age as Young SCFs (< 5 years; n = 4) and Old SCFs (> 5–20 years, n = 4). Altogether 32 (24 HGs + 8 SCFs) land use systems were selected in such a way that at least one category either from HGs or SCFs are represented from each study village. The area of each sampled HGs and SCFs were measured and permanent study plots were laid within and marked for reference. Geographical co-ordinates at the centre of these plots were taken using a hand held GPS.

Tree vegetation sampling

Information about the land use history and age were obtained from the owners through reconnaissance survey. Permanent plots were established randomly in different aged HGs and SCFs. In the HGs, a permanent plot of 40 m × 40 m continuous area was selected and four sample plots (quadrats) of 0.01 ha (10 m × 10 m) were marked within for sampling trees. While in case of SCFs, a permanent plot of 100 m × 100 m continuous area was selected and four sample plots (quadrats) of 0.04 ha (20 m × 20 m) were marked within for sampling trees. Permanent plot size in HGs was reduced to 0.16 ha by adjusting to the smallest HGs under survey and to maintain an uniform quadrat size for ease in phyto-sociological data analysis. However, the permanent plot size in SCFs is made for

1.0 ha for larger land availability extent and to encounter more vegetation during sampling. From each of these sample plots, all individual tree having more than 30 cm girth over bark at breast height (GBH) was identified and tagged. GBH measurements were done using a metal tape and tree height (H) by pole method (Goodwind 2004).

Tree species composition, diversity and community indices

Tree density (D), frequency (F), abundance (A), total basal area as dominance (D), and the relative values respectively were estimated by pooling together all data collected for a particular plot category (Misra 1968; Mueller-Dombois and Ellenberg 1974). The sum of relative values of density (RD), frequency (RF), and dominance (RD) was calculated as importance value index (IVI). Tree species richness (Margalef 1958) and species diversity index (Shannon and Wiener 1963) were calculated for the different categories of HGs and SCFs.

Assessment of soil organic carbon and other physico-chemical soil properties

Three sub samples per plot and depth class from 32 plots at 4 depths each (0–20, 20–50, 50–80, and 80–100 cm) collected randomly from the permanent plots were air-dried at room temperature. Air-dried soil was grounded, passed through 2 mm sieve and stored in air-tight plastic bags. The corresponding three sub-samples were mixed to get one composite sample for each plot per depth class and these composite soil samples (n = 128; 32 per depth class) were analyzed for various parameters. The composite soil samples were used to determine soil texture at different depth-class through hydrometer method. Soil corer method was used to assess the bulk density of soil (Abu-Hamdeh and Al-Jalil 1999). Soil pH and moisture content percentage were determined within 36 hours of sampling (Anderson and Ingram 1993). Walkley-Black rapid titration method was used to determine SOC concentration (Walkley and Black 1934). SOC stock (Mg C ha^{-1}) of each soil depth was computed by multiplying the SOC concentration (g C soil kg^{-1}) with the respective depth (m) and bulk density (Mg soil m^{-3}) and adjusting for the soil volume occupied by coarse fragments (IPCC 2003).

Relationship between carbon (SOC) and biodiversity

The relationship between SOC stock measures and tree diversity characteristics from all the land uses was established using a correlation analysis (non-parametric Spearman test). The relationship between SOC stock and biodiversity and species richness respectively was determined through regression analysis. Apart from categorization of HGs and SCFs into size and age, the selected land uses were categorized arbitrarily based on their tree-stand characteristics to investigate how they influence the SOC stock. Margalef Species Richness Index was categorized accordingly as low (< 5.2); medium (5.2 to 6) and high (> 6).

Data analysis

Data generated from tree vegetation survey and soil physico-chemical tests were compiled and arranged. Test of significant differences of tree stand characteristics (no. of species per plot, basal area, tree density, diversity index and species richness); SOC content and stock among the various categories of HGs and SCFs were determined through analysis of variance (ANOVA) and Fisher's least significant difference (LSD) post-hoc test. A significant difference between two means is indicated when the absolute difference of means is greater than the LSD value (Fisher 1935). Microsoft EXCEL and SPSS version 17 was used for data compilation, analysis and the corresponding figures were also prepared.

Results and discussion

Tree species diversity and characteristics

From 24 HGs plots, a total of 1424 tree individuals (79 genera, 86 species, and 35 families) and from 8 SCFs plots, 344 tree individuals (44 genera, 50 species and 27 families) were encountered (Appendix I). In HGs, Fabaceae (11 species), Moraceae (8 species) and Euphorbiaceae (7 species) were the species rich families. The dominant family of Fabaceae in HGs represented high species richness accounting 12.79% of the total recorded species. The dominance of Fabaceae indicate that HGs have the characteristics of most of tropical lowland rainforests (Gentry 1988; Valencia et al. 1994). Along an age gradient, a total of 83 and 70 tree species were recorded in Old HGs and Young HGs respectively. The importance value index (IVI) indicates the ecological importance of a species in the community and provide an overview of the social structure of a species (Gogoi et al. 2020). The dominant species based on the IVI in the HGs were *Magnifera indica* (IVI-28.68), *Areca catechu* (IVI-20.92), *Artocarpus lakoocha* (IVI-16.93), *Carica papaya* (IVI-10.77), *Trevisia palmata* (IVI-7.36). In SCFs, Euphorbiaceae (6 species), Fabaceae and Moraceae (5 species each) and Verbenaceae (4 species) were the dominant families.

The most dominant tree species in the SCFs were *Schima wallichi* (IVI-26.25), *Trema orientalis* (IVI-18.92), *Wendlandia grandis* (IVI-16.94), *Tectona grandis* (IVI-17.18), *Toona ciliata* (IVI-12.05), *Castanopsis tribuloides* (IVI-11.96), *Bombax insigne* (IVI-11.79), *Ficus hispida* (IVI-10.76) and *Litsea monopetala* (IVI-9.67). A total of 46 and 37 tree species were recorded in Old SCFs and Young SCFs respectively indicating regenerating secondary forests where stands are still growing and have not reached maturity/climax. In different sized homegardens, total number of tree species recorded was 52, 69 and 76 in large, medium and small homegardens respectively which might be primarily due to choice of species by the farmers where some gardens are specifically chosen for food and numerous vegetables to meet the household requirements according to several geographic and socioeconomic factors (Sahoo 2009). In comparison with similar studies from India, 87 tree species from a survey of 50 homegardens from Barak valley of Assam (Das and Das 2005); 70 tree species from 150 homegardens in the Khasi Hills homegarden of Meghalaya (Tynsong and Tiwari 2010); and 142 tree species from 80 homegardens of Upper Assam (Saikia et al. 2012) have been reported. In another study Sahoo (2009) reported 105 tree species from 45 homegardens. Different types of tree species occurred in HGs is much higher compared to the SCFs under study, which also clearly indicate the contribution of these tree based systems in biodiversity conservation (Bardhan et al. 2012).

Tree density and basal area of different categories of HGs and SCFs are presented in Table 1. HGs had tree density of 1188 trees ha^{-1} with a basal area of 19.74 m^2 ha^{-1} while SCFs recorded 269 trees ha^{-1} with a basal area of 5.41 m^2 ha^{-1}. Small HGs had significantly ($p < 0.05$) higher tree density and basal area than the Medium and Large HGs which might be the result from farmers maintaining more trees to fulfill their needs from within the limited available land. More number of trees in terms of species and individuals were observed in Young HGs than Old HGs; however tree basal area cover is higher in the Old HGs. This could reflect the presence of bigger trees and practice of farmers if less number of trees is planted back after the death or felling in Old HGs. In SCFs, tree density and basal area were higher in the Old SCFs as compared to Young SCFs which might be due to disturbances in establishment of tree saplings or growth in young fallow lands due to suppression by shrubs (Klanderud et al. 2010; Schmook 2010). The biodiversity indices of HGs and SCFs under study (Table 1) are influenced by variations in habitats, biogeography, competition and disturbances (Gentry 1988; Padalia et al. 2004). The Shannon-Wiener diversity usually range from 1.5 to 3.5 and seldom exceeds 4.5 (Kent and Coker 1992) and in our study we find this index varying from 2.35 to 3.42 in HGs and 2.72 to 3.35 in SCFs. Our results on diversity index were comparable to the values reported by several workers in the region (Saikia and Khan 2016). The Shannon's diversity index reported in Attappady valley homegarden

Table 1 Tree species characteristics and ecological indices in homegardens (HGs) and shifting cultivation fallow (SCFs) in Mizoram

Land-use types and category	Basal area (m^2/ha)	Tree density (stem/ha)	Shannon's Diversity Index (H')	Marglef's species richness (SRI)
HGs				
Large HGs	16.66 ± 1.51 (9.19–22.12)	1031.25 ± 76.52 (760–1200)	2.59 ± 0.09 (2.35–2.97)	3.89 ± 0.31 (2.93–4.99)
Medium HGs	19.98 ± 1.12 (16.20–24.62)	1242.5 ± 53.38 (1120–1560)	3.01 ± 0.05 (2.82–3.17)	5.55 ± 0.21 (4.68–6.21)
Small HGs	22.59 ± 0.75 (19.28–26.14)	1290 ± 84.35 (940–1620)	3.13 ± 0.06 (2.84–3.42)	6.17 ± 0.33 (5.01–7.87)
LSD ($p < 0.05$)	3.43	213.56	0.20	0.84
Old HGs	21.79 ± 0.80 (16.80–26.14)	1060.83 ± 49.43 (760–1280)	2.83 ± 0.08 (2.35–3.16)	4.99 ± 0.33 (3.24–6.49)
Young HGs	17.70 ± 1.18 (9.19–23.46)	1315.00 ± 60.26 (900–1620)	2.99 ± 0.09 (2.41–3.42)	5.41 ± 0.40 (2.93–7.87)
LSD ($p < 0.05$)	2.96	161.63	0.25	1.06
All HGs (average)	14.33 ± 0.78 (9.19–26.14)	1187.75 ± 46.42 (760–1620)	2.91 ± 0.06 (2.35–3.42)	5.20 ± 0.25 (2.93–7.87)
SCFs				
Old SCFs	6.32 ± 0.84 (5.07–8.69)	326.56 ± 23.44 (282–388)	3.22 ± 0.05 (3.12–3.35)	6.91 ± 0.31 (6.30–7.52)
Young SCFs	4.50 ± 0.54 (3.50–5.86)	210.94 ± 16.61 (175–250)	2.89 ± 0.09 (2.72–3.08)	5.69 ± 0.35 (4.66–6.23)
LSD ($p < 0.05$)	2.45	70.29	0.31	1.15
All SCFs (average)	5.41 ± 0.58 (3.50–8.69)	268.75 ± 25.58 (175–388)	3.05 ± 0.08 (2.72–3.35)	6.30 ± 0.32 (4.66–7.52)

± SEM; values within parenthesis indicate range

(2.18) by George and Christopher (2020) were lower than the present findings, however, higher values of Shannon's Diversity index from Small HGs than the Large HGs were reported from Kerala (Mohan et al. 2007). Studies from HGs in Kerala, India reported Marglef's index value ranged from 3.4 to 7.4 (Kumar et al. 1994) which is in conformity with results of the present study. The higher evenness value indicates more consistency in species distribution (Magurran 2004). Higher species diversity has been reported for many small homegardens across tropics (Mohan et al. 2007; Sahoo et al. 2010). High species assemblages in HGs with a variety of multipurpose trees (MPTs) respond stronger in terms of litter and nutrient re-cycling dynamics as compared to the limited species richness in SCFs (Tilman et al. 1997). In the case of SCFs, Shannon's diversity and Marglef's Species Richness with higher values were observed in the old than the young fallows. Following Spearman's correlation test, tree diversity was inversely proportional with the age of homegardens, whereas a significant positive correlation ($p<0.05$, $r=0.78$) was observed with the increasing age in case of shifting cultivation fallows (Fig. 1).

Soil physico-chemical properties and soil organic carbon

Physico-chemical properties at different soil depths in various categories of homegarden and shifting cultivation fallows showed variations across space and time (Table 2). Soil bulk density was higher in HGs than SCFs in all soil depth classes and it increased with depth. The soil moisture content in homegardens and shifting cultivation fallows also increased with soil depth. Higher soil moisture content in the HGs compared to SCFs may be due to relatively denser litter floor in the former than the later. Homegardens are better managed with soil and water conservation practices, such as mulching than the shifting cultivation fallows. The average soil pH values in older categories of homegardens and shifting cultivation fallows showed higher pH values than the younger ones. Also, the smaller HGs has more soil pH values than the larger HGs. Soil pH values decreased with increasing depth class indicating more acidic soils in the deeper layers. The decreasing pH values with depth might be due to reducing organic matter content and nutrient availability in the deeper layers of soil. According to Reddy et al. (2012) the variation in topography, climate, vegetation cover, weathering process and biota may influence the soil physico-chemical properties in a given site. Besides, the soil may also vary due to land use systems, age of land use, cultivation practices, tillage, soil management systems with soil inputs like residue management, fertilizer application, etc. The soil of selected plots in both HGs and SCFs in Aizawl district of Mizoram were sandy loam in texture. The less clay and silt values were most probably due to leaching and run off of the fine particles due to heavy rainfall. The higher values of bulk density may be attributed to higher sand percentage in the soil (Guerrero et al. 2000; Pernitsky et al. 2015). Soil bulk density values are higher in the homegardens than the shifting cultivation fallows which may be attributed by the frequent cultural operations in homegardens resulting more soil compaction (Kotto-Same et al. 2002). Soil moisture content is reportedly influenced by soil properties, vegetation type and density, topography, solar radiation, water table and precipitation depth (Vashisth et al. 2020). Soil organic carbon concentration was found higher in older system than the younger systems in both type land use. Higher SOC values in the older systems than the younger systems might be explained due to the presence of perennial tree crops for longer duration. Higher SOC content in top layers compared to the lower layers and decreasing with increasing depth are commonly reported in all mineral soils (Brady and Weil 2008). The root growth and activity of shrubs and herbs at the upper soil layers gives higher organic matter and more microbial activities, whereas the tree roots are distributed to deeper layers beyond 50 cm depth (Van Noordwijket al. 1996). Comparatively, higher SOC content in HGs than SCFs may be explained by the presence of more quantity of litter and root activity such as rhizodeposition and decomposition (Defrenet et al. 2016). This difference in SOC stock of HGs and SCFs may, however, not same in all situations, as SOC stock can be influenced by various location and system specific factors (Kirby and Porviu 2007). Regression analysis showed a positive but very weak relationship between SOC stock and tree species richness in the HGs and SCFs under study, whereby Saha et al. (2009) found that species richness could provide greater stability of SOC in homegardens of Kerala. HGs systems are resource-use-efficient system and favours greater net primary production (Vandermeer 1989) and higher C sequestration. Similarly, older HGs and SCFs stored higher SOC than younger HGs and SCFs respectively. These soil carbon stocks serves

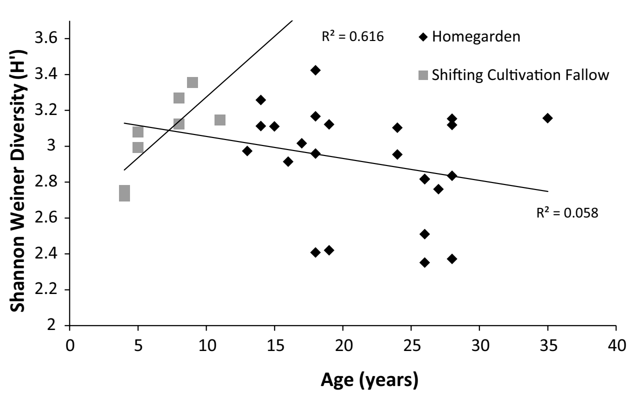

Fig. 1 Relationship between tree diversity and age of homegardens and shifting cultivation fallow

Table 2 Soil physico-chemical properties at different depths of homegardens (HGs) and shifting cultivation fallows (SCFs) in Mizoram

Land-use types	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Bulk density(g cm^{-3})	Soil moisture (%)	Soil pH	SOC (%)
Large HGs	0–20	20.9 ± 0.7	22.9 ± 1.2	56.2 ± 1.7	1.05 ± 0.01	13.82 ± 2.08	5.33 ± 0.11	2.07 ± 0.07[a]
	20–50	14.2 ± 0.7	20.8 ± 2.0	65.1 ± 1.5	1.07 ± 0.01	15.48 ± 1.94	5.21 ± 0.11	1.77 ± 0.06[b]
	50–80	14.2 ± 0.7	20.8 ± 2.0	65.1 ± 1.5	1.08 ± 0.01	17.74 ± 1.79	5.13 ± 0.11	1.42 ± 0.06[c]
	80–100	20.9 ± 0.7	22.9 ± 1.1	56.2 ± 1.7	1.11 ± 0.01	19.49 ± 1.71	5.04 ± 0.11	1.16 ± 0.05[d]
Medium HGs	0–20	20.4 ± 0.9	25.3 ± 1.0	54.2 ± 1.9	1.07 ± 0.01	15.58 ± 1.34	5.40 ± 0.06	2.25 ± 0.07[ab]
	20–50	14.3 ± 0.8	20.6 ± 1.4	65.2 ± 1.7	1.10 ± 0.01	17.06 ± 1.25	5.30 ± 0.06	2.12 ± 0.09[ab]
	50–80	15.3 ± 1.5	22.3 ± 1.8	62.4 ± 3.0	1.13 ± 0.01	19.35 ± 1.17	5.20 ± 0.06	1.61 ± 0.05[cd]
	80–100	19.6 ± 0.9	24.2 ± 1.2	56.2 ± 2.0	1.15 ± 0.01	20.84 ± 1.08	5.09 ± 0.06	1.48 ± 0.06[cd]
Small HGs	0–20	20.0 ± 1.2	26.1 ± 1.8	53.9 ± 2.5	1.14 ± 0.01	16.03 ± 1.34	5.55 ± 0.07	2.65 ± 0.08[ab]
	20–50	12.6 ± 0.5	18.7 ± 0.9	68.7 ± 0.6	1.16 ± 0.01	17.57 ± 1.28	5.36 ± 0.06	2.54 ± 0.10[ab]
	50–80	12.6 ± 0.5	18.7 ± 0.9	68.7 ± 0.6	1.18 ± 0.01	20.32 ± 1.16	5.27 ± 0.06	2.15 ± 0.07[c]
	80–100	20.0 ± 1.2	26.1 ± 1	53.9 ± 2.5	1.21 ± 0.004	22.20 ± 1.14	5.07 ± 0.06	1.67 ± 0.06[d]
Old HGs	0–20	17.4 ± 1.4	23.1 ± 1.1	59.5 ± 2.3	1.13 ± 0.01	15.95 ± 1.10	5.50 ± 0.06	2.67 ± 0.06[ab]
	20–50	19.7 ± 1.7	26.5 ± 1.7	53.9 ± 4.0	1.15 ± 0.01	17.43 ± 1.02	5.34 ± 0.05	2.54 ± 0.06[ab]
	50–80	20.7 ± 1.6	23.6 ± 1.6	55.7 ± 2.9	1.17 ± 0.01	20.07 ± 0.96	5.22 ± 0.05	2.01 ± 0.05[c]
	80–100	21.2 ± 1.4	26.0 ± 1.4	52.9 ± 3.4	1.18 ± 0.01	22.17 ± 0.92	5.07 ± 0.05	1.71 ± 0.08[d]
Young HGs	0–20	15.4 ± 1.0	21.7 ± 0.9	62.9 ± 1.0	1.05 ± 0.01	14.33 ± 1.00	5.35 ± 0.05	1.97 ± 0.05[a]
	20–50	17.4 ± 1.0	22.0 ± 0.9	60.6 ± 1.3	1.08 ± 0.01	15.97 ± 0.95	5.25 ± 0.05	1.75 ± 0.04[b]
	50–80	18.2 ± 0.8	22.0 ± 0.5	59.8 ± 1.1	1.10 ± 0.01	18.20 ± 0.87	5.18 ± 0.05	1.44 ± 0.04[c]
	80–100	19.9 ± 1.2	23.7 ± 1.2	56.5 ± 2.2	1.13 ± 0.01	19.52 ± 0.79	5.06 ± 0.05	1.16 ± 0.03[d]
Old SCFs	0–20	22.76 ± 1.39	22.95 ± 0.99	54.29 ± 1.83	1.07 ± 0.003	16.08 ± 1.83	5.51 ± 0.11	2.12 ± 0.06[a]
	20–50	15.01 ± 0.61	16.30 ± 0.33	68.69 ± 0.89	1.09 ± 0.003	17.52 ± 1.67	5.49 ± 0.12	1.67 ± 0.06[b]
	50–80	15.26 ± 0.98	17.05 ± 0.43	67.69 ± 0.89	1.11 ± 0.003	18.95 ± 1.63	5.23 ± 0.10	1.42 ± 0.06[c]
	80–100	24.76 ± 1.86	18.95 ± 0.81	56.29 ± 1.10	1.13 ± 0.003	20.99 ± 1.49	5.05 ± 0.10	1.14 ± 0.05[d]
Young SCFs	0–20	19.76 ± 0.37	20.55 ± 1.21	59.69 ± 1.54	1.01 ± 0.003	15.17 ± 1.93	5.25 ± 0.10	1.42 ± 0.04[ab]
	20–50	13.86 ± 1.36	26.45 ± 0.51	59.69 ± 0.87	1.03 ± 0.003	16.69 ± 1.77	5.16 ± 0.10	1.54 ± 0.04[ab]
	50–80	14.61 ± 2.00	25.2 ± 1.46	60.19 ± 0.61	1.04 ± 0.003	19.24 ± 1.65	5.07 ± 0.10	1.25 ± 0.04[c]
	80–100	18.51 ± 1.08	21.8 ± 0.49	59.69 ± 1.54	1.06 ± 0.003	20.17 ± 1.62	4.94 ± 0.10	1.00 ± 0.05[d]

± SEM; n = 8 large, medium and small HGs, and 12 old and young HGs; n = 4 young and old SCFs; different letters indicate significant difference ($p < 0.05$)

as good indicators of soil carbon sequestration potential of the systems (Haile et al. 2008; Kumar and Nair 2004).

SOC concentration in different categories of HGs and SCFs (Table 2) indicated higher SOC values in the older systems than the younger systems. Similarly, SOC values were highest in Small HGs than the large HGs. SOC content in the upper soil layers (0–50 cm) of all study sites were higher than the deeper soil layers (50–100 cm) (Table 2). SOC stock in homegardens and shifting cultivation fallows were assessed as 142.24 and 94.44 Mg C ha^{-1} respectively up to 1 m soil depth (Fig. 2). Higher tree population in HGs when compared to SCFs contributed more SOC through increased net primary production, root distribution and litter dynamics. SOC stock decreased with increasing depth across different categories of HGs and SCFs (Table 3). SOC stocks was in the order of Small HGs > Medium HGs > Large HGs mainly attributed by the difference of tree densities in various HGs land holding sizes in conformity with results reported by

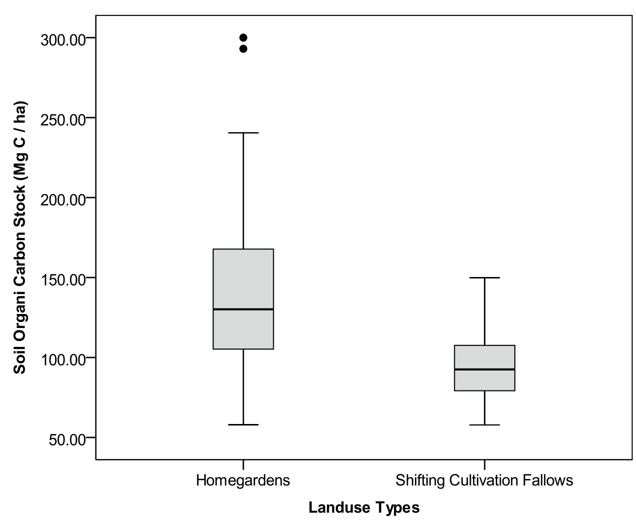

Fig. 2 Box plot representing SOC stock (Mg C ha^{-1}) in homegardens and shifting cultivation fallows in Mizoram

Table 3 SOC stock (Mg C ha^{-1}) distribution at different soil depths in various categories of homegardens (HGs) and shifting cultivation fallows (SCFs) in Mizoram

Land use categories	Soil depth class (cm)			
	0–20	20–50	50–80	80–100
HGs				
Small HGs	42.17 ± 2.32	60.98 ± 4.40	49.20 ± 3.02	25.41 ± 1.78
Medium HGs	33.63 ± 1.88	46.17 ± 3.55	36.37 + 2.39	20.95 ± 1.39
Large HGs	29.57 ± 1.97	37.70 ± 2.50	28.82 ± 2.32	15.76 ± 1.23
LSD@5%	5.83	10.07	7.32	4.19
Old HGs	41.90 ± 1.75	59.00 ± 3.48	46.92 ± 2.37	25.92 ± 1.24
Young HGs	28.34 ± 1.23	37.57 ± 1.84	29.34 ± 1.99	15.50 ± 0.83
LSD@5%	4.26	7.84	5.81	2.98
All HGs (average)	35.12 ± 4.14	48.28 ± 5.69	38.13 ± 4.49	20.71 ± 2.44
SCFs				
Old SCFs	28.77 ± 1.41	34.89 ± 1.94	28.03 ± 1.97	14.68 ± 1.13
Young SCFs	22.70 ± 1.09	27.52 ± 1.56	22.37 ± 1.61	11.83 ± 0.96
LSD@5%	3.70	7.84	5.27	3.07
All SCFs (average)	25.73 ± 5.25	31.20 ± 6.37	25.20 ± 5.14	13.26 ± 2.71

±SEM; n = 8 large, medium and small HG, 12 old and young HG, and 4 old and young SCF

Saha et al. (2009) from homegardens in Kerala. The variation is SOC stocks is attributed by higher SOC content in higher tree density stands. By regulating litter inputs (Fernandes-Nunez et al. 2010) management practices such as tillage operations, application of fertilizers common in Large HGs also might reduce SOC content (Matos et al. 2010), and on the other hand the addition of organic FYM and sewage sludge common in Small HGs could increase SOC content (Mosquera-Losada et al. 2011).

Conclusions

Our study suggests that homegardens and shifting cultivation fallows of Mizoram harbors 86 and 50 tree species respectively, which are of both ecological and economic significance. Tree diversity in HGs differs with age and size with higher values in the smaller and older ones. Older shifting cultivation fallow had recorded more tree species diversity. In both HGs and SCFs, SOC concentration and stock increased with soil depth and were greater in older systems than the younger ones, and on an average values were significantly ($p < 0.05$) higher in HGs than the SCFs. Study results indicate that both HGs and SCFs systems store considerable amount of organic carbon in the soil compartment, maintaining soil health and mitigate enhanced greenhouse effect. Although, shifting cultivation followed by short fallow periods degrade ecological systems, tribes still continue the practice of slash and burn to sustain themselves and their families. Longer fallow period required for SCFs to revive to natural forest needs institutional and policy interventions in these region. The practice of HGs can be promoted through ameliorative agroforestry measures and solutions such as improved tree fallows, intercropping, alley cropping, etc. Good management practices need to be developed for conservation of species diversity, whilst increasing SOC and biomass C stock. Further studies to consider the different aspects of tree base agroforestry systems in carbon sequestration and climate change mitigation should be conducted.

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Availability of data and materials The data will be available from the corresponding author on reasonable request.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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