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Aboveground Carbon Stock and Economic Benefit of Homegardens in Ywangan Township, Southern Shan State, Myanmar

Win Win Nwe, Range Officer, Forest Research Institute

And

Nobuya Mizoue (Professor), Tetsuji Ota (Associate Professor), Faculty of Agriculture, Kyushu University

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Win Win Nwe, Range Officer

Forest Research Institute, Forest Department

Abstract

Homegarden is an agroforestry system with diverse benefits such as carbon sink and socio-economic function. This study focused on zones and fencing trees as the management practice and aimed to evaluate roles of zones and fencing trees in aboveground carbon stock of homegardens. It was conducted in three villages in Ywangan Township, Southern Shan State, Myanmar. 27 homegardens were chosen by stratified random sampling depending on size classes. We set up 1-3 sample plots in each zone, and 4 line transects along the fencing trees in each homegarden. Diameter measurements of tea and coffee species were carried out at while diameters of trees (≥5cm) and bamboo and banana were measured. Allometric equations were used to calculate aboveground biomass of each plant. Games Howell test was applied to identify the variability of aboveground carbon stock by homegarden size classes. Path analysis was also performed to observe the effect of homegarden size on aboveground carbon benefits indirectly through the zone area ratio and fencing length ratio. The results showed that there were no statistically significant differences by size classes. The proportion of tea, coffee and seasonal crop zones significantly negatively affected aboveground carbon stock per hectare ($p<0.05$). However, fencing ratio significantly positively affected aboveground carbon stock ($p<0.05$). In conclusion, homegarden size did not directly affect aboveground carbon of homegardens. Management practices including zones and fencing trees play a considerable role in aboveground carbon stock of homegardens. However, increasing proportion of single zones may result in reducing carbon values. Thus, we conclude that keeping multiple zones and fencing practice is important for homegardens.

Keywords: Agroforestry system, Management practices, Zones, Fencing, Proportion

မြန်မာနိုင်ငံ၊ ရှမ်းပြည်နယ်တောင်ပိုင်း၊ ရွာငံမြို့နယ်ရှိ ရိုးရာဓလေ့အစဉ်အလာအရ ထိန်းသိမ်းစောင့်ရှောက်လာခဲ့သော ဥယျာဉ်ခြံများ၏ ကာဗွန်သိုလှောင်မှုအား လေ့လာခြင်း

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ဥယျာဉ်ခြံသည် သီးနှံသစ်တော ရောနှောစိုက်ပျိုးခြင်းနည်းစနစ် တစ်ခုဖြစ်သည့် အကျိုးကျေးဇူးများစွာကို ထောက်ပံ့ပေးလျက်ရှိပါသည်။ ဤသုတေသနသည် ဥယျာဉ်ခြံများ၏ ကာဗွန်သိုလှောင်မှုတွင် စီမံအုပ်ချုပ်မှုနည်းလမ်းများဖြစ်သော ဇုန်အလိုက် စိုက်ပျိုးခြင်းနှင့်ခြံစည်းရိုးစိုက်ပျိုးခြင်း၏ အခန်းကဏ္ဍကို ဖော်ထုတ်လေ့လာရန်ဖြစ်ပါသည်။ ဤသုတေသနကို ရှမ်းပြည်နယ်တောင်ပိုင်း၊ ရွာငံမြို့နယ်ရှိ ဥယျာဉ်ခြံများတွင် ဆောင်ရွက်ခဲ့ပါသည်။ ဥယျာဉ်ခြံ ၂၇ကို အလွှာခွဲ ကျပန်းနည်းဖြင့် ရွေးချယ်ခဲ့ပြီး ဥယျာဉ်ခြံတစ်ခုတွင်ဇုန်တစ်ခုလျှင် နမူနာကွက် ၁-၃ ကွက်၊ ခြံစည်းရိုးတစ်ခုလျှင် နမူနာလိုင်း ၄ ခု ဖော်ဆောင်ခဲ့ပါသည်။ လက်ဖက်၊ ကော်ဖီ၊ ဝါး၊ ၄က်ပျောပင်နှင့် သစ်ပင်များ၏ အချင်းများကို တိုင်းတာ၍ ကာဗွန်သိုလှောင်မှုအား တွက်ချက်ခဲ့ပါသည်။ Games Howell test နှင့် Path analysis ကို အခြေခံ၍ စာရင်းအင်းတွက်ချက်မှုများကို ဆောင်ရွက်ခဲ့ပါသည်။ ရလဒ်များအရ ဥယျာဉ်ခြံ အရွယ်အစားအလိုက် ကာဗွန်သိုလှောင်မှု ကွဲပြားခြားနားမှု မရှိသော်လည်း လက်ဖက်၊ ကော်ဖီနှင့် ရာသီသီးနှံဇုန်များနှင့် ခြံစည်းရိုးစိုက်ပျိုးမှုသည် ဥယျာဉ်ခြံများ၏ ကာဗွန် သိုလှောင်မှုအပေါ် အကျိုးသက်ရောက်မှုရှိပါသည်။ သို့သော်လည်း ဇုန်တစ်ခုတည်း အကျယ်အဝန်းကြီးလာခြင်းသည် ကာဗွန်သိုလှောင်မှုကို လျော့နည်း စေသောကြောင့် ဥယျာဉ်ခြံ တစ်ခုအတွင်း ဇုန်အမျိုးအစားများ စုံလင်အောင်ထားရှိခြင်းနှင့် ခြံစည်းရိုးစိုက်ပျိုးခြင်းသည် ကာဗွန်သိုလှောင်မှုကို များစွာ အထောက်အကူပေးလျက်ရှိပါသည်။

Aboveground Carbon Stock of Homegardens in Ywangan Township, Southern Shan State, Myanmar

1. Introduction

Homegarden is a traditional agroforestry system and belongs to an agrisilvicultural or agrisilvopastoral agroforestry system according to the structural classification (Nair 1993). Homegarden is a complex sustainable land use system that combines multipurpose and multi-storied trees, shrubs and crops including annual or perennial crops sometimes with livestock and/or aquatic animals around a homestead (Kumar and Nair 2006; Weerahewa et al. 2012; Galheana 2013). Although definitions of homegardens differ from place to place according to local physical environment, and ecological, socio-economic and cultural characteristics (Kumar and Nair 2004; Kumar and Tripathi 2017), homegardens have a potential for ecological and socio-economic benefits (Linger 2014; Abdoellah et al. 2020).

Homegardens can directly decrease CO_2 emissions through carbon sequestration in plant components and soil, and indirectly conserve carbon by reducing pressure on adjacent forests by providing fuelwood, timber, and non-timber products (Kumar and Nair 2004; Kumar 2006; Muhammed et al. 2013; Mathewos et al. 2018) and generating income to households. It can store carbon for a long time with no complete removal of biomass (Roy 1999; Albrecht and Kandji 2003; Kumar 2011; Mattsson et al. 2013) in parallel with the permanent keeping by homegarden owners. So, homegardens have a potential for climate change mitigation through enhanced carbon sequestration (Verchot et al. 2007; Kumar 2011) and conservation. However, biomass carbon of homegardens varies with tree density and diversity, management practices, homegarden age and size, site characteristics, and plant composition (Kumar 2011; Mattsson et al. 2015; Singh and Sahoo 2018).

There were many studies about homegardens focusing on species diversity, structure, utilization of plant species (Whitney et al. 2018; Martin et al. 2019; Moh et al. 2019; Rayol et al. 2019; Vibhuti et al. 2019), effects of socio-economic factors on homegarden characteristics (Kabir et al. 2016), effects of homegarden size on carbon stock (Kumar 2011; Mattsson 2015; Singh and Sahoo 2018), and comparison of biomass carbon between homegardens and other land uses types (shifting cultivation, crop cultivation areas, woodlots, and pasture) (Henry et al. 2009; Singh and Sahoo 2018). Homegarden is not a simple structure but is complex with a spatial arrangement of different management practices (Méndez et al. 2001; Alam 2012). However, there is a little knowledge on management practices in the role of homegardens. Moreover, in Myanmar, there is no study about the aboveground carbon stock of homegardens except economic point of view. This chapter unpacked 1) the variability of aboveground carbon stock by homegarden size classes, and 2) the effect of homegarden size on aboveground carbon stock indirectly through zones and fencing trees as the management practices.

2. Material and Methods

2.1 Study Sites

Southern Shan State is a hilly region in Myanmar where mixed deciduous forest, evergreen forest, dry hill forest, indaing forest and pine forest are found (Sharma et al. 2019). Ywangan Township is a Danu Self-Administered Zone which is located in Taunggyi District, Southern Shan State, and between North latitude 20˚ 45′ and 21˚ 45′ and East longitude 96˚ 15′ and 96˚ 45′, including 125 villages of 28 village tracts inhabited by 82532 people (2014 Myanmar Population and Housing Census). Three villages were randomly selected from Ywangan Township. Wapoeyae village is situated at 1518 m altitude (N 20˚ 59′ and E 96˚ 34′), Hsatchan village at 997 m (N 21˚ 02′ and E 96˚ 27′), and Myaechar village at 1373 m (N 20˚ 53′ and E 96˚ 34′). Figure 4 shows the location of study area in Ywangan Township, Southern Shan State. In Wapoeyae village with the total population of 333 people, mostly PaO ethnic group dominates while the majority of ethnic groups in Hsatchan and Myaechar villages inhabited by 510 and 450 people respectively is Danu. Figure 5 shows the number of households of ethnic groups found in Wapoeyae, Hsatchan and Myaechar villages.

Although different villages occupy different land uses with the variety of site characteristics, common village landscapes are organized by mosaics of (1) homegardens where trees, and permanent and seasonal crops are planted in a mixture around homesteads; agroforestry type farmlands where trees are planted on the farm boundaries, or in rows or in a scattered design with permanent or seasonal crops in the farmlands,(2) agricultural farmlands where local people plant seasonal crops without mixing with trees or permanent crops (tea, coffee, and orange), and (3) community forests or spring forests that conserved mainly for water sources. Table 5 shows the estimated areas of land uses found in study villages. Local people mainly rely on homegardens (especially in Wapoeyae and Myaechar villages), agroforestry type farmlands (in Wapoeyae and Myaechar villages) and unclassed forests (in Hsatchan village) for their fuelwood sources needed for cooking and steaming tea leaves.

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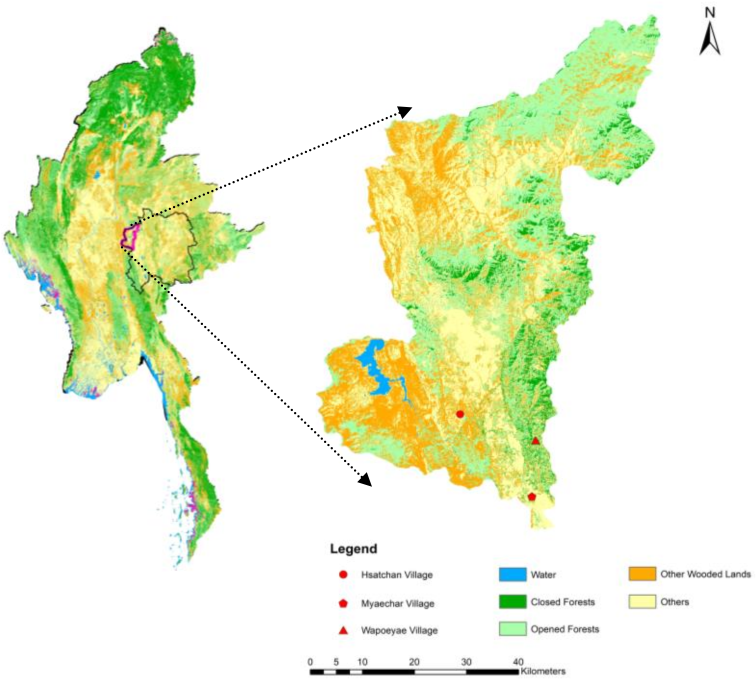

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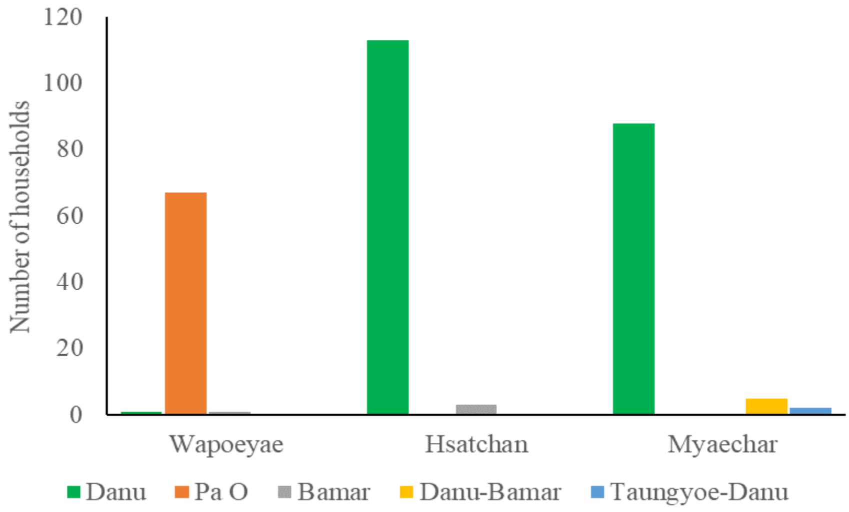


Figure 2. Number of Households of Ethnic Groups found in Wapoeyae, Hsatchan, and Myaechar Villages

Table 1. Description of Estimated Areas (Hectare) of Land Uses by Study Villages

Village name	**Total number of households**	**HG (ha)**	**Agro (ha)**	**Afram (ha)**	**CF (ha)**	**SF (ha)**
	69	47.64	62.73	-	-	-
Hsatchan	116	75.97	29.34	240.70	-	4.45
Myaechar	95	58.52	47.61	128.49	20.72	-

Note: “HG” denotes homegardens; “Agro” agroforestry type farmlands; “Afarm” agricultural farmlands; “CF” community forests; “SF” spring forests; “ha” hectare.

2.2 Climate Condition of Ywangan Township

As Myanmar is one of the tropical monsoonal regions, Ywangan Township receives rainfall from June to October with average annual rainfall of 1554.5 mm and experiences average minimum and maximum temperatures of 14.45 °C to 29.27 °C, respectively. Figure 6 shows the annual rainfall and annual temperature of Ywangan Township for one decade (2010-2019) (Forest Department, Myanmar, 2010 to 2019 data).

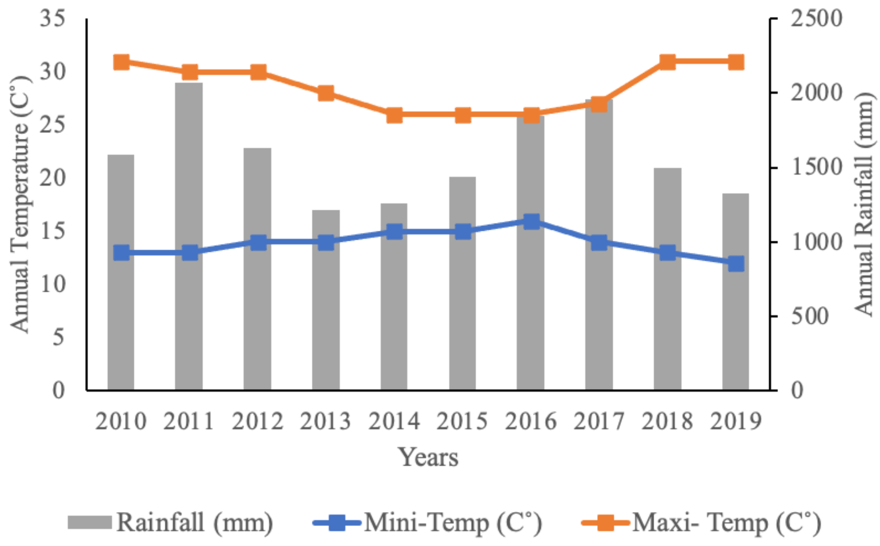


Figure 3. Annual Rainfall and Annual Temperature of Ywangan Township for One Decade (2010-2019)

Note: "Mini-Temp" means minimum temperature; "Maxi-Temp" maximum temperature.

2.3 Zones and Spatial Arrangements of Zones in Homegardens

"Zone" is a spatial area deliberately allocated to specific species and management (Méndez et al. 2001). "Tea zone" is an area where people grow tea plants with trees including fruit and timber trees. "Coffee zone" is an area where coffee cultivation is found with trees. "Natural forest zone" is an area maintained by local people to conserve soil and water sources. "Fruit tree zone" is an area allocated for fruit tree plantation. "Seasonal crop zone" is an area allocated only for seasonal crop cultivation. "Seasonal crop zone with trees" is an area where people grow seasonal crops with trees. "Fencing" is a kind of management practices and fencing trees are kept on the homestead boundary by local people for demarcation and fuelwood sources.

Fencing practices can be found in all homegardens while spatial arrangements of zones were different among homegardens. In Wapoeyae village, which is located at high elevation, there were two distinct spatial arrangements of zones: 1) a spatial arrangement of tea zone and seasonal crop zone and 2) a spatial arrangement of tea zone, seasonal crop zone and natural forest zone; the latter was mostly found in very steep slope area. In Hsatchan village, there were 3 spatial arrangements of zones where a spatial arrangement of coffee zone and seasonal crop zone with trees is common while sometimes, a spatial arrangement of tea zone, coffee zone and seasonal crop zone with trees, and pure coffee zone were observed. In Myaechar village, more diverse spatial arrangements of zones were characterized: spatial arrangements of 1) tea zone and coffee zone, 2) tea zone, coffee zone and seasonal crop zone, 3) tea zone, coffee zone, seasonal crop zone and natural forest zone, 4) tea zone, coffee zone, seasonal crop zone and fruit tree zone, and

5) pure coffee zone. Figure 7 shows some examples of spatial arrangements of zones in homegardens.

2.4 Data Collection

A total of 27 homegardens was chosen by stratified random sampling depending on size classes (large, medium, and small) from three villages. The average homegarden area is 0.71 ± 0.10 ha ranging from 0.08 to 1.84 ha. Homegarden sizes were categorized into three classes based on the classification of local villagers. Large homegardens had a mean value of 1.35 ± 0.12 ha ranging from 0.90 to 1.84 ha, medium homegardens were with a mean value of 0.58 ± 005 ha ranging from 0.43 to 0.81 ha and small homegardens were with a mean value of 0.02 ± 0.03 ha ranging from 0.08 to 0.35 ha. Table 6 shows areas of homegardens by size classes in study villages. Because each homegarden included several management practices, the management practices were classified into 6 zones which were tea zone, coffee zone, natural forest zone, fruit tree zone, seasonal crop zone with trees and seasonal crop zone, and fencing practice. The area of each zone, fencing length, and total length of the perimeter of each homegarden were measured by Laser 360˚ Truepluse.

Comment [MN1]: If possible, plea explain how to classify into large, mideum and small. Of it is difficult t explain, it's OK

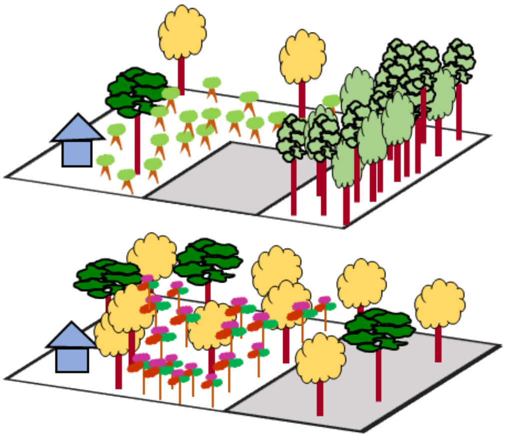
The number of sample plots of each homegarden were determined according to size classes. In small homegardens, one sample plot was set up in each zone, in medium homegardens, 1-2 sample plots were set up, and in large homegardens, 1-3 sample plots were set up, where the first sample plot was located at the center of the zone, and the second and third sample plots were placed at 10 m apart from the first; but it cannot be followed in steep slopes of natural forest zones. Sample plots were not set up in seasonal crop zones because there were no trees and permanent crops in these zones. Table 7 shows number of sample plots of homegardens by size classes and study villages. Four line transects (10 m) were set up at the center of each side of fencing. In tea and coffee zones, the area of sample plots was 10 m × 10 m (100 m^2) and in natural forest zones, the area of sample plots was 10 m × 5 m (50 m^2). The whole area or half of the area of zones was assumed as a sample plot especially in fruit tree zones and seasonal crop zones with trees.

In tea and coffee zones, 10 bushes or plants of tea and coffee were selected at the center of each sample plot. Diameter measurements of tea and coffee plants were carried out by Vernier caliper at 5 cm and 15 cm above the ground respectively and then number of plants in each sample plot were recorded. Diameter of trees (diameter at breast height ≥ 5 cm) was measured at 1.3 m above the ground by diameter tapes; total height was measured by vertex; and local names and ages were also recorded. For bamboo and banana plants, diameters of largest and smallest plants, which are mature, were measured at 1.3 m above the ground by diameter tapes, and number of plants were also counted.

Table 2. Areas of Homegardens by Size Classes in Study Villages

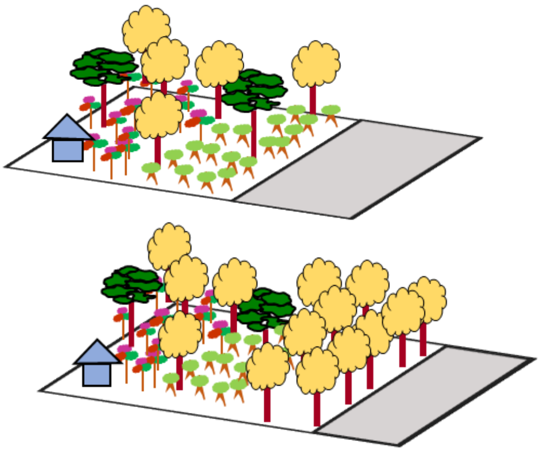
Village name	Number of Households	Sample Households	Large (ha)*	Medium (ha)*	Small (ha)*
Wapoeyae	69	9	1.09 – 1.73	0.50 – 0.81	0.08 – 0.21
Hsatchan	116	9	0.94 – 1.60	0.44 – 0.66	0.22 – 0.35
Myaechar	95	9	0.90 – 1.84	0.43 – 0.53	0.17 – 0.25
Average			**1.35 ± 0.12**	**0.58 ± 0.05**	**0.20 ± 0.03**

"*" describes values including residential areas. ± indicates Standard errors.



(a) Spatial arrangement of tea zone, seasonal crop zone and natural forest zone

(b) Spatial arrangement of coffee zone and seasonal crop zone with trees



(c) Spatial arrangement of tea zone, coffee zone and seasonal crop zone

(d) Spatial arrangement of tea zone, coffee zone, seasonal crop zone and fruit tree zone

Figure 4. Examples of Spatial Arrangements of Zones of Homegardens

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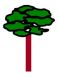
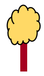
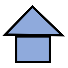
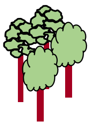
 = Timber tree

 = Fruit tree

 = Coffee plants

 = Tea plants

 = Residential area

 = Natural forest

 = Homestead area

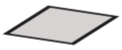
 = Seasonal crop area

Table 3. Number of Sample Plots of Homegardens by Size Classes and Study Villages

Village name	**Size**	**Range value in number of sample plots of each homegarden**	**Total sample plots in each zone /line transects in each fencing**					
			Tea[a]	**Cof**[a]	**NF**[b]	**FT**[c]	**CT**[c]	**Fen**[d]
Wapo	Larg	6	9	-	9	-	-	1

eyae	e							2
	Medium	2-3	6	-	2	-	-	12
	Small	1-2	3	-	1	-	-	12
Hsatchan	Large	3-4	1	6	-	-	3	12
	Medium	3	-	6	-	-	3	12
	Small	1-3	1	3	-	-	2	12
Myaechar	Large	3-4	5	3	1	1	-	12
	Medium	2-3	4	4	-	-	-	12
	Small	1-2	2	3	-	-	-	12
Total			**31**	**25**	**13**	**1**	**8**	**108**

Note: "[a]" describes sample plot size is 10m × 10m (100 m^2): "[b]" sample plot size is 10m × 5m (50 m^2); "[c]" sample plot size is the whole area or half of the area of a zone; and "[d]" 10 m line transect. "Tea" tea zone; "Cof" coffee zone; "NT" natural forest zone; "FT" fruit tree zone; "CT" seasonal crop zone with trees.

2.5 Formulae for Biomass Estimates

Although species and site specific allometric equations can perform accurate estimates of aboveground biomass, there is limited knowledge on such allometric equations in this studied region. The following equations, which include similar species characterization, forest types and climate with study areas, were used to calculate aboveground biomass of each plant measured:

$$\textbf{Tree: } Y = \exp\{-2.134 + 2.530 \times \ln(DBH)\}$$

where Y = biomass in kg, exp = exponential function, DBH = diameter at breast height in cm (R^2 = 0.97; moist forest trees with diameter up to 80 cm and 1500-4000 mm rainfall) (Brown 1997)

$$\textbf{Tea: } Y = 0.047 \times (D)^{1.878}$$

where Y= biomass in kg, D = diameter at 5 cm above the ground in cm (R^2 = 0.97; sub-tropical, warm, and humid climate with the southwest monsoon season) (Kalita et al. 2015)

$$\textbf{Coffee: } \log_{10} Y = -1.181 + 1.991 \times \log_{10} D$$

where Y = biomass in kg, D = diameter at 15 cm above the ground in cm (R^2 = 0.93; subtropical humid forest with 600-2000 mm rainfall) (Segura et al. 2006)

$$\textbf{Bamboo: } Y = 0.179 \times (DBH)^{2.221}$$

where Y = biomass in kg, DBH = diameter at breast height in cm (R^2 = 0.97; tropical monsoon climate with 1487-1640 mm rainfall) (Xayalath et al. 2019)

$$\textbf{Banana: } Y = 0.030 \times (DBH)^{2.135}$$

where Y= biomass in kg, D = diameter at 1.35 m above the ground in cm (R^2 = 0.99; diameter range 7-27 cm) (Arifin 2001 cited in Hairiah et al. 2001)

When calculating aboveground biomass of tea, coffee, bamboo and banana, first average biomass of measured sample plants was calculated and then multiplied by number of plants recorded in sample plots. Aboveground carbon was calculated assuming 50% of aboveground biomass as carbon (IPCC 2008). As stressed earlier, homegarden is composed of different zones and fencing. The aboveground carbon stock of each homegarden was calculated by aggregating carbon estimates of zones and fencing, where carbon values from seasonal crop zones were assumed as “zero”.

2.6 Data Analysis

Analysis of Variance with Games Howell test was used to characterize the variability of aboveground carbon stock by homegarden size classes (large, medium, and small). Path analysis was performed to explore the effect of homegarden size on aboveground carbon stock indirectly through zone area ratio (the proportions of zones) and fencing length ratio. In the path analysis, the dependent variable was aboveground carbon stock per hectare while independent variables were homegarden size, zone area ratio and fencing length ratio (m ha^{-1}). Comparison of aboveground carbon stock between homegardens and logged mixed deciduous forests in Myanmar was observed to characterize the role of homegardens in aboveground carbon storage. All calculations and statistical analyses were taken by Microsoft Office Excel 2010 and R software version 3.6.3, and mean differences were considered as significance when p value is <0.05.

3. Results

3.1 Species Composition

Homegarden owners grow permanent and seasonal crops, timber trees and fruit trees for their subsistence and commercial needs, and conserve natural forests for soil conservation and water sources. So, in 27 homegardens of study areas, 157 timber tree species and 7 fruit tree species of total 164 species were recorded based on sample plots and line transects. Moreover, 3 perennial crops (tea, coffee, and banana) and 4 bamboo species were noted. Most of timber tree species were found in natural forest zones and fencing. Fencing was particularly important for demarcation and fuelwood sources of households, where 92 tree species were found with 269 trees in the total sample length of 1080 m. Fruit tree species were observed in tea zone, coffee zone, fruit tree zone and seasonal crop zone with trees while some timber tree species were found in these zones. Table 8 shows common species planted by local people in study villages.

Table 4. Crop and Tree Species Commonly Planted in Study Villages

Local /common name	Family name	Scientific name
Crops		
Tea	Theaceae	*Camellia sinensis* (L.) O. Kuntze
Coffee	Rubiaceae	*Coffee arabica* L.
Banana	Musaceae	*Musa* sp.
Fruit trees		
Avocado	Lauraceae	*Persea Americana* Mill.
Jackfruit	Moraceae	*Artocarpus heterophyllus* Lam.
Djengkol	Fabaceae	*Archidendro pauciflorum* (Benth.) I.C.Nielsen
Mango	Anacardiaceae	*Mangifera indica* L.
Timber trees		
Cherry	Rosaceae	*Prunus avium* L.
Ohnton	Lauracea	*Litsea glutinosa* (Lour.) C.B.Rob.
Ohntonlaukyar	Lauraceae	*Litsea monopetala* (Roxb.) Pers.
Phetsut	Rosaceae	*Eriobotrya bengalensis* (Roxb.) Hook.f.
Pinsein	Rosacea	*Docynia indica* (Wall.) Decne
Taungtama	Meliaceae	*Cedrela microcarpa* C. DC.
Thanatphet	Boraginaceae	*Cordia dichotoma* G.Forst.
Thinwinpho	Fabaceae	*Millettia pubinervis* Kurz
Willow	Salicaceae	*Salix tetrasperma* Roxb.
Yaemane	Verbenaceae	*Gmelina arborea* Roxb.

3.2 Zones and Fencing of Homegardens

3.2.1 Area Allocation of Zones

Homegarden is complex with a spatial arrangement of zones. Number of zones occupied by each homegarden were different with a mode value of 2 zones ranging from 1 to 4 zones and their proportions were different. In large homegardens, 3 different zones per homegarden were commonly found ranging from 2-4 zones, and in medium and small homegardens, 2 zones per homegarden were common with range values of 2-3 zones and 1-3 zones, respectively. High area allocation was found in coffee zone, tea zone, and seasonal crop zone with trees in all size classes accounting for mean values of 43.93% (ranging 11.70-87.10%), 45.81% (ranging 11.36-86.57%), and 46.43% (ranging 19.54-85.24%) respectively. Méndez et al. (2001) and Alam (2012) mentioned that presence or absence of zones and their size varied among homegardens depending on the available homegarden area and homegardeners' wealth and management strategies.

Figure 8 shows the proportion of zones to total area of each homegarden, where the rest proportions are residential areas.

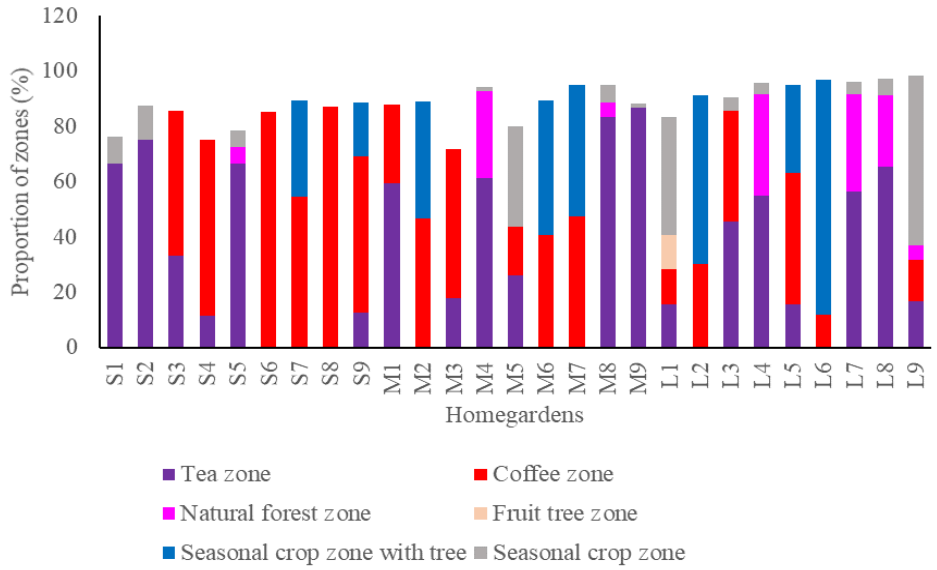


Figure 5. Area Allocation of Zones to Total Area of Each Homegarden

Note: "L" means large homegarden; "M" medium homegaden; "S" small homegarden.

3.2.2 Tree Density and Aboveground Carbon Stock Contribution of Zones and Fencing

Although number of trees, bamboo, banana, tea, and coffee were collected in zones and fencing, only tree density was described. Figure 9 shows the tree density of homegardens through zones and fencing. From this figure, it was found more keeping trees in fencing, coffee zones and natural forest zones amounting for 41.97% (ranging 8.04-100%), 45.47% (ranging 0-81.06%), and 53.07% (ranging 20.45-79.83%) respectively. Moreover, natural forest zone, fencing, and coffee zone highly contributed aboveground carbon of homegardens with 42.25% (ranging 6.29-81.93%), 42.58% (ranging 1.23-99.57%), and 50.03% (ranging 2.43-90.23%) respectively. Table 10 shows the aboveground carbon stock of homegardens through zones and fencing. Local people grew trees on the fencing for homestead demarcation and fuelwood sources, and in coffee zones for shading coffee plants while natural regeneration of trees was encouraged in natural forest zones for soil and water sources. Weston et al. (2015) mentioned that shade promotes slower and more balanced filling and uniform ripening of coffee berries which performed product quality. However, some homegardeners have introduced and planted new coffee varieties according to the market demand. These varieties need less shade, which may seem to have less tree density leading to reducing aboveground carbon storage.

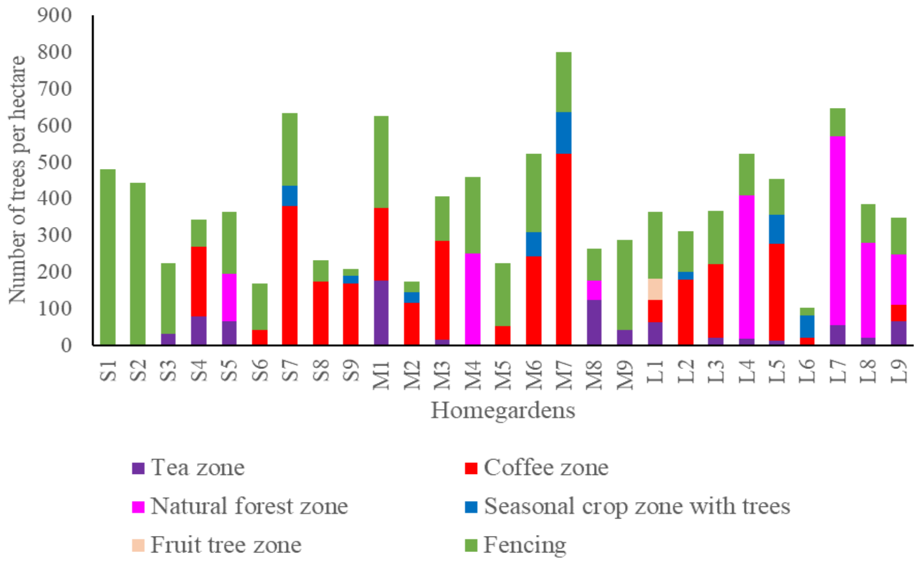


Figure 6. Tree Density of Zones of Individual Homegardens

Note: "L" describes large homegarden; "M" medium homegarden; "S" small homegarden.

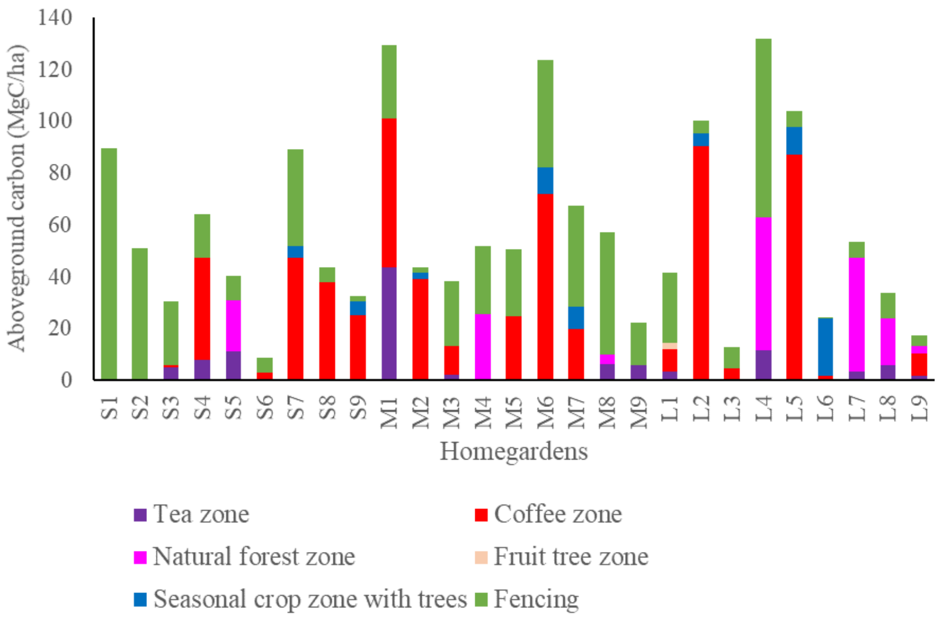


Figure 7. Aboveground Carbon Stock of Zones of Individual Homegardens

Note: "L" describes large homegarden; "M" medium homegarden; "S" small homegarden.

3.3 Tree Density and Aboveground Carbon Stock of Homegardens by Size Classes

The mean value of aboveground carbon of homegardens was 39.35 ± 7.55 MgC varying from 1.95 MgC to 143.96 MgC with the mean tree density of 277.79 ± 48.72 trees. The mean values of aboveground carbon and tree density of large homegardens (72.04 ± 16.04 MgC and 525.74 ± 87.50 trees) were higher than those of medium and small homegardens (36.66 ± 6.93 MgC and 242.19 ± 43.36 trees) and (9.34 ± 1.76 MgC and 65.43 ± 11.18 trees) respectively. Per unit area, the mean value of aboveground carbon per hectare of homegardens was 57.53 ± 6.85 MgC ha^{-1} varying from 8.91 MgC ha^{-1} to 131.75 MgC ha^{-1} with the mean tree density of 384.53 ± 32.26 trees/ha. Medium homegardens (64.91 ± 12.38 MgC ha^{-1} and 418.75 ± 68.45 trees/ha) had high mean aboveground carbon and tree density per hectare followed by large and small homegardens amounting for 57.71 ± 14.45 MgC ha^{-1} and 389.65 ± 49.97 trees/ha and 49.97 ± 8.99 MgC ha^{-1} and 345.19 ± 51.22 trees/ha. According to the Analysis of Variance with Games Howell test, there were no statistically significant differences in aboveground carbon stocks of homegardens by size classes. Table 9 shows statistical differences of aboveground carbon stocks of homegardens by size classes. Figure 11 and Figure 12 show tree density and aboveground carbon stock distribution of homegardens by size classes, respectively.

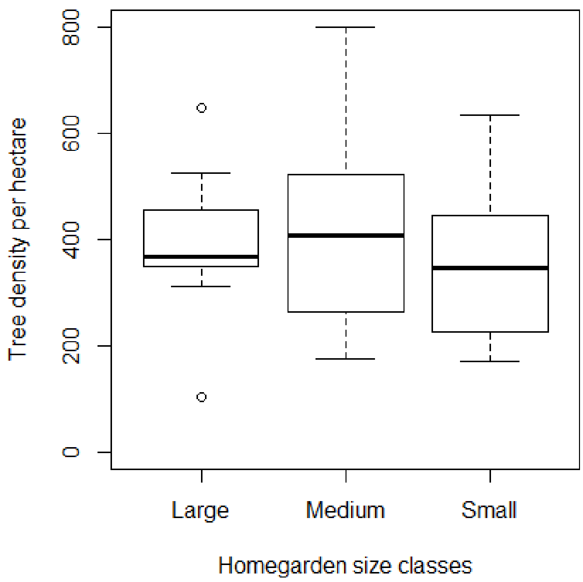


Figure 8. Boxplot of Tree Density of Homegardens by Size Classes

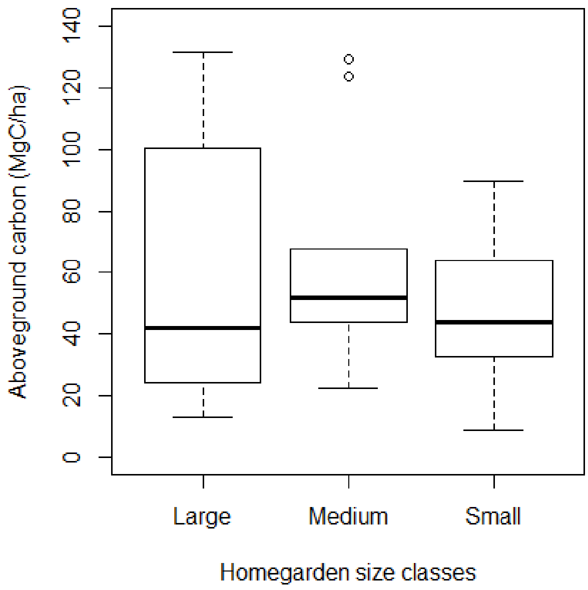


Figure 9. Boxplot of Aboveground Carbon Stock of Homegardens by Size Classes

Table 4. Statistical Differences of Aboveground Carbon Stocks of Homegardens by Size Classes

Size classes	**Difference**	**Confidence interval (lower limit)**	**Confidence interval (upper limit)**	**t value**	**Degree of freedom**	**p value**
Medium - Large	7.2	-42	56	0.38	16	0.92
Small - Large	-7.7	-53	37	0.46	13	0.89
Small - Medium	-14.9	-55	25	0.98	15	0.60

p value <0.05 means significant difference.

3.4 Effect of Homegarden Size on Aboveground Carbon Stock per Hectare through Zones and Fencing Trees

There was no direct relationship between homegarden size and aboveground carbon stock. So, in the path analysis, the effect of homegarden size on proportion of zones (% of total area) and fencing length ratio (m ha^{-1}) was considered and then, the effect of proportion of zones and fencing length ratio on aboveground carbon stock of homegardens was analyzed. The results showed that homegarden size significantly positively affected the proportion of natural forest zone ($p < 0.05$) while significantly negatively affected the proportion of coffee zone and fencing length ratio ($p < 0.05$). However, there were weak positive relationships between homegarden size and the proportion of other zones (tea zone, fruit tree zone, seasonal crop zone with trees and seasonal crop zone) ($p > 0.05$). Table 10 shows the relationship between homegarden size and proportion of zones and fencing length ratio.

Table 5. Relationship between Homegarden Size and Proportion of Zones (% of total area) and Fencing Length Ratio (m ha^{-1})

Variables	Estimate	Standard error	z-value	p (>|z|)
Tea zone	0.030	0.192	0.155	0.877
Coffee zone	-0.390	0.177	-2.200	**0.028**
Natural forest zone	0.422	0.174	2.421	**0.015**
Fruit tree zone	0.070	0.192	0.364	0.716
Seasonal crop zone with trees	0.207	0.188	1.097	0.273
Seasonal crop zone	0.326	0.182	1.790	0.073
Fencing	-0.594	0.155	-3.840	**0.000**

p value <0.05 means significant difference.

The proportion of tea zone, coffee zone, and seasonal crop zone significantly negatively affected aboveground carbon stock per hectare of homegardens ($p < 0.05$) while fencing length ratio significantly positively affected ($p < 0.05$). However, there were weak relationships between the proportion of other zones (natural forest zone, fruit tree zone and seasonal crop zone with trees) and aboveground carbon stock ($p > 0.05$). Table 11 shows the relationship between proportion of zones and fencing length ratio and aboveground carbon stock of homegardens.

Table 6. Relationship between Proportion of Zones (% of total area) and Fencing Length Ratio (m ha^{-1}) and Aboveground Carbon Stock per Hectare of Homegardens

Variables	Estimate	Standard error	z-value	p (>|z|)
Tea zone	-0.518	0.167	-3.095	**0.002**
Coffee zone	-0.538	0.174	-3.091	**0.002**
Natural forest zone	0.246	0.175	1.405	0.160
Fruit tree zone	-0.009	0.168	-0.051	0.959
Seasonal crop zone with	0.033	0.169	0.194	0.846

trees				
Seasonal crop zone	-0.378	0.172	-2.195	**0.028**
Fencing	0.383	0.179	2.135	**0.033**

p value <0.05 means significant difference.

4. Discussion

This study identified the aboveground carbon stock of homegardens, the direct and indirect effects of homegarden size on aboveground carbon stock, and comparison of aboveground carbon estimates among land uses. The aboveground carbon stocks of homegardens ranged from 8.91 MgC ha^{-1} to 131.75 MgC ha^{-1} with the mean value of 57.53 ± 6.85 MgC ha^{-1} which was lower than mean values of studies in India, Sri Lanka, and Indonesia (87.77 MgC ha^{-1}, 87 MgC ha^{-1} and 69.5 MgC ha^{-1} respectively) (Mattsson et al. 2013; Wiryono et al. 2016; Singh and Sahoo 2018) but was higher than mean values of other studies in the same countries (24.32 MgC ha^{-1}, 35 MgC ha^{-1} and 35.3 MgC ha^{-1} respectively) (Roshetko et al. 2002; Kumar 2011; Mattsson et al. 2013). These differences may be because of geographical characteristics, species composition, and management practices (Kumar 2011; Singh and Sahoo 2018). Nevertheless, this result was in the range of results of Southeast Asia (12-228 MgC ha^{-1}) (Albrecht and Kandji 2003).

Per unit area, medium homegardens stored more aboveground carbon followed by large and small homegardens, which differed from the results of Kumar (2011), Mattsson et al. (2015) and Singh and Sahoo (2018) where aboveground carbon decreased with increasing size. Moreover, they found that there were significant differences among homegarden size classes and concluded that homegarden size was a major factor for carbon stock variability. Kumar (2011) and Mattsson et al. (2015) highlighted that small homegardens practiced denser planting and more intensive management compared to other sized homegardens and had high carbon stock. Moreover, Mattsson et al. (2015) discussed the importance of management practices in homegardens where large homegarden owners practiced shifting cultivation within their homegardens for cash crop cultivation, resulting in reducing number of trees for not having excessive tree shading on cash crop, thereby decreasing carbon storage of large homegardens. This study did not show significant differences by size classes. It may be because of fencing practices especially in small and medium sized homegardens.

Although there was no direct relationship between homegarden size and aboveground carbon stock, the results showed that there was an indirect relationship between them. There was a positive relationship between homegarden size and the proportion of natural forest zone. Households with large sized homegardens especially in the steep area, were likely to allocate more area for natural forest zones because of less intensive practice and an important practice for soil and water conservation. The strong negative relationship between homegarden size and fencing ratio and coffee zone showed that homegardeners were likely to allocate less area to highly intensive practices with increasing homegarden size.

The proportion of tea zone, coffee zone and seasonal crop zone significantly negatively related with the aboveground carbon stock of homegardens because these zones may be intensively practiced for crop production, and not for keeping large trees. Some homegarden owners thought that excessive tree shading affects the productivity of tea and seasonal crops and so, they grew less or no trees in such zones. Homegarden owners grew more trees including fruit and timber trees in coffee zones compared to other zones because they were aware of coffee plants needs shade to yield high quality and quantity. However, because of a highly intensive practice, increasing the proportion of coffee zones may seem to encourage homegardeners to plant some coffee varieties which need less shade thereby reducing tree density. Moreover, it may be because of planting systems of small homegardeners with the large proportion of coffee zones: for example, small homegardeners keep many trees on the fencing where the fencing trees shade the coffee plants to some extent, and consequently, they tend to grow less plants inside the coffee zones. Fencing ratio significantly positively related with the aboveground carbon because of increasing keeping large trees on fencing boundary.

5. General Conclusion

Climate change is happening all over the world with increasing GHG emissions, affecting the environment and livelihood of human beings. The trajectory of land use changes becomes important for climate change mitigation and adaptation. As an integrated land use, agroforestry systems including homegardens have been recognized. This study showed that homegardens have the potential in ecological and economic roles. The results showed that homegarden size did not directly affect the aboveground carbon stock and income per hectare of homegardens. However, homegarden size positively affected the proportion of zones with less intensive practices like natural forest zones and negatively influenced the proportion of coffee zones and fencing length with highly intensive practices. Increasing proportion of zones (tea, coffee, and seasonal crop zones) mainly focusing on productivity less contributed the aboveground carbon of homegardens whereas increasing length of fencing keeping large trees for homestead demarcation and fuelwood sources highly contributed. Moreover, the proportion of zones (tea, coffee, natural forest, fruit tree, seasonal crop with trees and seasonal crop zones) significantly negatively affected the income of homegardens. Management practices including zones and fencing trees influenced by homegarden size play a considerable role in aboveground carbon stock and economic benefit of homegardens. However, increasing proportion of single zones may result in reducing carbon and income values. So, keeping multiple zones and fencing trees is important for the role of homegardens. Agroforestry systems implemented in the reforestation and rehabilitation programs by Myanmar Forest Department include tree intercropping with agricultural crops and boundary plantings. Fencing trees practice (planting trees on the homestead boundary) is similar with boundary plantings. So, it might be concluded that boundary plantings currently practiced by Myanmar Forest Department contribute aboveground carbon stock. Moreover, this study suggests that practicing multiple zones plays an important role in the benefit of homegardens. So, the implementation of agroforestry systems with such practices might contribute to the reforestation and rehabilitation programs of Myanmar through carbon storage and local livelihood enhancement.

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