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Assessment of the Diverse Roles of Home Gardens and Their Sustainable Management for Livelihood Improvement in West Java, Indonesia

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Abstract: Home garden is a traditional agroforestry system, which is an ecologically and socio-economically sustainable land use system in West Java, Indonesia. It plays a fundamental role in providing subsistence food and income to local people through a multi-strata structure. Despite the importance of the home garden, which is strongly linked with quality of living, there is still a lack of quantitative data and information. Therefore, we quantified the economic and ecological characteristics of home gardens in the present study to evaluate their diverse roles. In addition, general strategies that are applicable to home gardens in West Java were developed for sustainable management. The results of this study indicated that: (1) large landholding size showed a significantly higher Net Present Value (NPV) than small landholding size when the home gardens were dominated by fruit tree species, (2) species richness, species diversity, and carbon stock did not differ significantly among the different types and sizes of home gardens in West Java, and (3) multi-layered and diverse species composition is considerable for sustainable management of home gardens in terms of income generation and against urbanization and commercialization in West Java, Indonesia. Further studies should be considered for developing a standardized and generalized model that is able to evaluate and quantify the various ecosystem values that are generally acceptable and applicable in rural areas.

Keywords: home garden; margalef index; ahannon-wiener index; sustainable management; West Java; Indonesia

1. Introduction

Pezer [1] reported that 767 million people are estimated to be suffering from hunger and approximately one billion people live in extreme poverty. At the same time, 80% of poor people are living in rural areas and 64% of them are engaged in agricultural activities including crop cultivation, animal husbandry, forestry, fisheries, and aquaculture as their main income source and for food. In order to achieve poverty eradication and sustainable social, economic, and environmental development, the international community adopted Sustainable Development Goals (SDGs), which are a set of 17 objectives with 169 targets to be achieved from 2015 to 2030. Most of the poorest people who are heavily dependent on natural resources for their living are concentrated in the Southeast Asian region. In this region, more than 47.3% of the people are living in rural areas and most of them are likely to rely on agricultural activities, which provide local people with daily food and income sources. Moreover, they are particularly vulnerable to livelihood risks caused by climate change and other anthropogenic impacts, such as shifting cultivation mainly related to agricultural activities [2,3].

Agroforestry is a bridge between agriculture and forestry, and has been considered for several decades as a series of land management approaches combining trees, agricultural crops, livestock production, and other activities [4,5]. It is also considered to be a potential way to improve socio-economic conditions, environmental sustainability, and food security [4,6–10]. Agroforestry as an integrated land use system is widely practiced by more than 1.2 billion people in the world due to its unique characteristics of small land and low labor requirements, less input costs, and a location close to home [4,8]. Home gardens, which are one of the traditional agroforestry systems, are defined by a variety of characteristics in accordance with the local physical environment, ecological and economic situation, and cultural characteristics [11,12], but they are generally defined as multi-species, multi-storied, and multi-purpose gardens located close to a home [12,13]. The multi-layered structure of home gardens, which is created by the combination of various cultivated plants and wild plants, is responsible for several benefits and services of home garden systems [14].

Pekarangan is defined as a traditional home garden in Indonesia and is widely used in scientific research as one of the agroforestry systems related to its interactions with livelihood and the environment [15]. Many researchers have described home gardens as traditional agroforestry systems that are ecologically and socially sustainable land use systems. There have been numerous studies focused on the diverse structure, and socio-cultural and ecological functions of home gardens [14,16–19].

Home gardens play a fundamental role in providing subsistence food and income to indigenous people, and in serving as an important habitat for wild flora and fauna through a multi-strata structure in the area. Despite the importance of home gardens, which are strongly linked with quality of living, not much quantitative data and information on home gardens is available. In order to compare the economic value of the home gardens between the different types and sizes, we investigated the Net Present Value (NPV) and the B/C ratio, which is widely used for calculating a value of cost and benefits of the home gardens. In addition, we compared ecological value of the home gardens between the different types and sizes. We adopted the Margalef index and the Shannon-Wiener index's commonly used indicator for the ecological condition to investigate the species richness and species diversity, respectively.

In addition, there has been an increase in population while industrial structures have been changed mainly from agricultural to non-agricultural activities in areas with a growth of cities in West Java. However, there is still a lack of information on how to develop home gardens in a sustainable manner based on their ecological characteristics. Therefore, the research questions were set up as: (1) Do ecological and economic values vary according to the dominant species and the landholding size of home gardens? (2) Are species composition and land holding size important factors for sustainable management of home gardens?

The objectives of the study were:

(1) To quantify the economic and ecological characteristics using several indices that represent the specific characteristics of home gardens to evaluate their diverse roles, and

(2) To develop generally applicable strategies for the sustainable management of home gardens in West Java, Indonesia.

One study found a home garden with fruit tree species are more profitable than wood tree species regardless of the size of home gardens, but there was no difference in ecological characteristics between different types and sizes of home gardens in the Sukabumi region. However, further studies should be considered for developing a standardized and generalized model by collecting more information such as increased numbers of sample plots and respondents in the Sukabumi region.

2. Materials and Methods

2.1. Study Sites

This study was conducted in the Hegarmanah and Cicantayan villages, which administratively belong to the Cicantayan sub-district, Sukabumi Regency, in West Java, Indonesia. These villages lie

between 6°57′ and 7°25′ north latitudes, and between 106°49′ and 107°00′ east longitudes (Figure 1). Both the Hegarmanah and Cicantayan villages have an altitude between 100 m and 1000 m (average of 500 m in the Cicantayan village and 600 m in the Hegarmanah village), and also have an average of approximately 3000 mm/year of precipitation and an average temperature of 32 °C [20]. The population density in the Cicantayan village is bigger than that of the Hegarmanah village due to the small area and large population in the Cicantayan village. Home gardens, as one of the typical farming systems commonly used in those villages, are strongly related to the livelihood of local people since it generates the main income source as rice, horticulture products, crops, and fruits for those villages.

Figure 1. Location of the villages of Hegarmanah and Cicantayan as study sites in the Cicantayan District, Sukabumi Regency, in West Java, Indonesia. (source: https://www.mapsland.com/asia/indonesia).

The climatic conditions of average precipitation and temperature of both of the villages are similar to each other. General information for the Hegarmanah and Cicantayan villages is summarized in Table 1.

Table 1. General information of the Hegarmanah village and the Cicantayan village.

	Hegarmanah Village	Cicantayan Village
Area (ha)	1573	600
Population	6006	8483
Population density (people/ha)	3.86	14.14
No. of household	1826	1698
Average precipitation (mm/year)	3000	3000
Average temperature (°C)	32	32

The land use types of these villages can be distinguished into the following three categories: rice paddy, dry land, which includes agriculture and forest areas, and buildings/gardens, which includes residential areas and home gardens. Hegarmanah village only has 81 ha of rice paddy. Most of the

land in Hegarmanah is classified into buildings/gardens with 844 ha, which comprises 53.6% of the total land area. On the other hand, the Cicantayan village has 298.5 ha of rice paddy, which is 49.7% of the total land area, and 221.5 ha of buildings/gardens (Table 2).

Table 2. Land use type and size of the Hegarmanah village and Cicantayan village.

Village	Land Use Type (ha)			Total (ha)
	Rice Paddy	Dry Land	Building/Garden	
Hegarmanah	81	648	844	1573
Cicantayan	299	80	222	600

2.2. Data Collection

The diverse roles of home gardens have been reviewed. It is important to quantify the tangible and intangible benefits for a better understanding of their different roles. In this study, economic and ecological characteristics were identified and quantified in order to evaluate the diverse roles of home gardens using different indices. Primary data was collected through a household survey and in-depth interviews in the villages of Hegarmanah and Cicantayan in Sukabumi Regency, Indonesia. The household surveys were conducted using a structured questionnaire.

In order to conduct financial analysis, 27 households (total of 139 house members, which is approximately 1% of the total population in both villages) were selected and surveyed using a structured questionnaire for the type and size of home gardens. The questionnaire included information on "general information of households and home gardens", "household land ownership and land use systems", "household's main income source and planation activities", and "general cost for plantation activities and expected benefits". During the analysis process, not all of the data was used due to some missing data and the analysis was based on cost and revenue of farm-based activities [21].

For the analysis of ecological characteristics, a total of 29 home gardens (some of the households had two home gardens) were selected to implement the plant inventory survey. The results of the preliminary discussions with local people at the study sites showed that there were two different main income sources: fruit and wood materials. There were two different types of home gardens in this study: wood-dominated home gardens (WDH) and fruit-dominated home gardens (FDH). WDH were dominated by wood tree species, such as mahoni (*Swietenia mahagoni* (L.) Jacq.), gmelina (*Gmelina arborea* Roxb.), suren (*Toona sureni* (Blume) Merr.), jabon (*Anthocephalus cadamba* (Roxb.) Miq.), and teak (*Tectona grandis* L.f.). FDH were dominated by fruit tree species, such as manggis (*Garcinia mangostana* L.), rambutan (*Nephelium lappaceum* L.), and avocado (*Persea americana* Mill.). Among the 29 home gardens, 14 were classified as WDH and 15 were classified as FDH. There were also herbaceous plants, such as vegetables, ornamental plants, and crops, in both the WDH and FDH, which were primarily consumed by family members and not for sale.

Selected home gardens were further categorized into two different landholding size classes: small and large, based on the median value of land size in each type of home garden. Both WDH and FDH were additionally categorized as "WDHS" and "FDHS," which means landholding size smaller than 0.08 ha, and "WDHL" and "FDHL," which means landholding size bigger than or the same as 0.08 ha.

Vegetation characteristics of each home garden were determined within 400 m^2 plots (20 m × 20 m) for trees that were more than 10 cm in diameter at breast height (DBH), 100 m^2 subplots (10 m × 10m) for trees that had DBH values of 5 cm–10 cm and shrubs, and 1 m^2 sub-subplots (1 m × 1 m) for herbaceous plants, such as vegetables, ornamentals, weeds, and spices. The total sample area for this study was 1.16 ha for trees, and 0.29 ha for small trees and shrubs. The DBH (unit: cm) and height (unit: m) were measured for individual tree species with DBH values ≥1.5 cm. The information on the uses and local names were collected from households through questionnaires and interviews. All of the collected species were recorded with local names and scientific names.

2.3. Financial Analysis

Different criteria can be used to evaluate and quantify the economic value of home gardens, and the most widely used methods are the net present value (NPV), the benefit-cost ratio (B/C ratio), and an internal rate of return [22]. The net present value is an absolute measure that estimates the net worth of trees planted in the home gardens by calculating the value of costs and benefits of the home garden system as a whole [23–25]. The benefit-cost ratio is a relative measure and is calculated by dividing the sum of discounted revenues by the sum of discounted cost [24,25]. Normally, when the B/C ratio is bigger than 1 and the NPV is a positive value, then a home garden is considered profitable or feasible [26]. The economic values presented below were compared with the dominant type of home garden, such as WDH and FDH, and the size of the home gardens, which was divided based on the median value of 0.8 ha.

2.3.1. Net Present Value (NPV)

The net present value was calculated using Equation (1) [24,26].

$$\sum_{n=1}^{n} (Bn - Cn) / (1 + i)^n \tag{1}$$

where Bn is the benefit each year, n is the number of years, Cn is the cost each year, and i is the interest rate, which was assumed to be 12% following the interest rate of loan from the bank in Indonesia. Detailed input and output data were collected using the questionnaire.

2.3.2. Benefit-Cost Ratio (B/C Ratio)

Input for home gardens included costs for fertilizer, pesticides, tools, and materials, as well as labor costs for land clearing, planting, and harvesting. On the other hand, output from home gardens included benefits from selling fruits and timber products. Intangible benefits, such as aesthetics, ornamentation, and shading effects, were not considered in this study. The benefit-cost ratio was determined using the following equation [24,26].

$$\sum_{n=1}^{n} \frac{Bn}{(1 + i)^n} / \frac{Cn}{(1 + i)^n} \tag{2}$$

where Bn is the benefit each year, n is the number of years, Cn is the cost each year, and i is the interest rate, which was assumed to be 12%.

2.3.3. Sensitivity Analysis

The sensitivity analysis was conducted by adding a 10% increment to the price of fertilizer, pesticide, and labor, and a reduction of 10% in the market price of timber and fruit. Moreover, the interest rates were controlled by four types and were assumed to be: 10%, 12%, 14%, and 16%.

2.4. Stand Structure and Ecological Characteristics Analysis

Standard ecological references use many different indices to estimate the diversity of a site, and the Shannon-Weiner index is the most commonly used diversity indicator [27]. Furthermore, Nagendra [28] noted that the most commonly used indices are a combination of richness and evenness. Richness refers to the number of different land cover types within a site and evenness refers to the relative percentage of land distributed among these different cover types. In this study, complete inventories were included to calculate species diversity (Shannon-Wiener index), species richness (Margalef index), and species evenness (Simpson index). However, herbaceous plant species, such as ornamental plants, vegetables, weeds, and spices, were not included when assessing the stand structure characteristics (relative density, frequency, and relative frequency) and the aboveground biomass calculation.

2.4.1. Quantitative Structure

The quantitative characteristics of the stand structure were analyzed using relative density (RD), frequency (F), and relative frequency (RF). These were calculated using the following Formulas (3)–(5).

$$\text{RD} = (\text{Total number of individuals of a species})/(\text{Total number of individuals of all of the species}) \times 100\ (\%), \quad (3)$$

$$\text{F} = (\text{Total number of samples in which the species occur})/(\text{Total number of samples enumerated}) \times 100\ (\%), \quad (4)$$

$$\text{RF} = (\text{Frequency of the species in the stand})/(\text{Sum of the frequencies of all of the species in the stand}) \times 100\ (\%). \quad (5)$$

2.4.2. Species Richness (Margalef Index)

The Margalef index is a species diversity index divided into two types of species richness: how many types exist in the area and an assessment of species evenness or dominance, which means how individual species are distributed among the community [15]. The Margalef index can be used to provide an understanding of the species richness of the WDH and FDH. This index adjusts the number of species sampled in an area by the log of the total number of individuals sampled and summed over the species as follows [27].

$$\text{Margalef index} = \frac{(S-1)}{\ln(N)} \quad (6)$$

where S is the total number of species and N is the total number of individuals in the sample plots.

2.4.3. Species diversity (Shannon-Wiener Index)

The Shannon-Wiener index is the most commonly used diversity indicator in plant communities. It has a value of zero when there is only one species in a community and a maximum value when all of the species are present in equal abundance [27]. The index is calculated using Equation (7).

$$\text{Shannon-Wiener index} = -\sum_{i=1}^{S}(pi(\ln pi)) \quad (7)$$

where S is the total number of species and pi is the frequency of the ith species.

2.4.4. Species Evenness (Simpson Index)

The Simpson index is used to emphasize the evenness of the species [28]. Producing values from 0 to 1, the Simpson index defines the probability that two equal sized and randomly selected home gardens belong to the different home garden areas. Thus, the index is calculated using Equation (8) below.

$$\text{Simpson index} = 1 - \frac{\sum n(n-1)}{N(N-1)} \quad (8)$$

where n is number of individuals of each species and N is total number of individuals of all species.

2.5. Statistical Analysis

Data were analyzed using SPSS Statistics 25 (SPSS Inc., Chicago, IL, USA). The various statistical procedures utilized in this study included analysis of variance (ANOVA) to compare the characteristics of different types and size categories of home gardens.

3. Results and Discussions

The 27 households and 29 home gardens were randomly selected to analyze the economic and ecological characteristics of each household in both the Hegarmanah village and the Cicantayan village. A total of 13 households were classified as WDH and 14 households were classified as FDH. Selected home gardens were further categorized into two different landholding size classes indicated as: “WDHS”, “WDHL”, “FDHS”, and “FDHL”.

Each household had three to seven total family members (4.5 members on average). A total of one to six members from each household were dependent on the living and income sources from the home gardens. WDH had mean areas of 0.03 ha and 1.17 ha in small landholding size and in large landholding size, respectively. FDH had mean areas of 0.04 ha and 0.57 ha in small landholding size and in large landholding size, respectively. In general, the large landholding size in FDH had the furthest distance of 416.7 m from the household followed by distances for WDH with large landholding size and small landholding size of 271.4 m and 90 m, respectively (Table 3).

Table 3. Characteristics of selected home gardens in woody-dominated home gardens (WDH) and fruit-dominated home gardens (FDH) with its landholding size.

Types	*N*	Area (ha)	Distance (m)
WDHS	7	0.03 ± 0.02	90.0 ± 80.4
WDHL	7	1.17 ± 1.29	271.4 ± 205.9
FDHS	6	0.04 ± 0.02	49.5 ± 75.9
FDHL	9	0.57 ± 0.93	416.7 ± 433.7

Values are means ± SD.

In the study sites, there were 28 species of woody and fruit tree species with 306 individuals, which had DBH values of more than 1.5 cm, and 12 species of herbaceous species including vegetables, ornamental plants, and weeds (Table 4). There were 13 woody tree species that are primarily considered to be long-term income sources and are used as raw materials for building houses or fences. These species include sengon (*Paraserianthes falcataria* (L.) I.C.Nielsen), suren (*T. sureni*), jabon (*A. cadamba*), and mahoni (*S. macrophylla*). There are also 15 fruit tree species that are used for annual income generation of households, but are also sometimes consumed by local people for nutritional support, such as durian (*Durio zibethinus* L.), manggis (*G. mangostana*), rambutan (*N. lappaceum*), and bacang (*Mangifera foetida* Lour.) found in the study sites. Among these species, suren (*T. sureni*) and sengon (*P. falcataria*) were the most favorable woody tree species for the households, which occupied 45% of the total tree species. In addition, manggis (*G. mangostana*) and durian (*D. zibethinus*) were the most favorable fruit tree species.

Table 4. List of tree species mainly distributed in woody-dominated home gardens (WDH) and fruit-dominated home gardens (FDH).

WDH	FDH
Scientific Name	**Scientific Name**
Paraserianthe falcataria	*Durio zibethinus*
Toona sureni	*Garcinia mangostana*
Anthocephalus cadamba	*Nephelium lappaceum*
Agathis alba	*Mangifera foetida*
Swietenia macrophylla	*Archidendron pauciflorum*
Manglietia glauca	*Artocarpus heterophyllus*
Vitex pinnata	*Myristica fragrans*
Maesopsos eminii	*Lansium domesticum var. Aqueum*
Tectona grandis	*Parkia speciosa*
Peronema canescens	*Ceiba pentandra*
Gmelina arborea	*Citrus* sp.
Schima wallichii	*Aleurites moluccanus*
Neofelis nebulosa	*Persea americana*
	Lansium domesticum
	Syzygium aqueum

3.1. Economic Values of the Home Gardens

A summary of the quantified economic values of the home gardens is presented in Table 5. This table shows the B/C ratio and NPV according to the types and sizes of home gardens. The B/C ratio

of all of the different types and sizes was bigger than 1, and a positive NPV meant that they were profitable at a 12% interest rate.

Table 5. Quantified economic value of different types and sizes of the home gardens.

Types	B/C Ratio	NPV (year^{-1})	NPV (ha^{-1} year^{-1})
WDHS	3.7 ± 2.4 ^{a}	300.7 ± 228.8 ^{ab}	10,622.3 ± 9538.1 ^{a}
WDHL	4.2 ± 2.0 ^{a}	1105.8 ± 643.9 ^{ab}	4177.7 ± 6870.5 ^{a}
FDHS	2.5 ± 1.8 ^{a}	274.1 ± 310.1 ^{b}	3618.0 ± 3146.0 ^{a}
FDHL	5.2 ± 2.8 ^{a}	1311.5 ± 932.4 ^{a}	4080.6 ± 3980.6 ^{a}

Values are means ± SD. Superscript lower-case letters indicate significant differences among the types and sizes according to Scheffe's test at $p < 0.05$. NPV is in USD.

There was only a significant difference in NPV between FDHS with $274.10 USD per year and FDHL with $1311.50 USD per year. In the case of WDH, NPV was $300.70 USD per year and $1105.80 USD per year for WDHS and WDHL, respectively, but there was no significant difference.

In general, the B/C ratio and NPV per year showed a similar trend that large landholding size had higher values than small landholding size in both WDH and FDH. However, there were no significant differences due to the large standard deviation value. The results of the presented economic value indicated that home gardens have various income sources derived from their unique structure and different species composition of each home garden within the study sites. NPV per year per ha in WDHS was $10,622.30 USD, but there was not a significant difference from other types and sizes of home gardens due to the large standard deviation value. Mohan et al. [29] quantified the financial values of home gardens based on size (small, medium, and large) in Kerala, India. The results showed that the large size of home gardens had the largest mean financial values. However, small size home gardens had the largest mean profit generated per unit area (m^2). In addition, Alam [30] and Rahman et al. [25] studied the financial benefits of home gardens in Bangladesh and showed that financial benefits increased along with increased farm size.

The variable range of the B/C ratio and NPV may have been caused by different levels of productivity and species composition in the home gardens. Rohadi et al. [21] summarized different smallholder timber plantations including teak plantation home gardens, rubber plantations, and palm oil plantations in Indonesia. Commercial plantations, such as palm oil plantations and rubber plantations showed relatively higher values for their B/C ratio and NPV value. The tegalan system, mostly planted with food crops and teak, showed a B/C ratio range of 1.59–6.21 and palm oil plantations had a B/C ratio value of 10.22. In addition, Current and Scherr [23] summarized the financial analysis of different agroforestry systems and agricultural intercrops showed an average B/C ratio of 1.79, which is comparable with that of alley cropping (2.10), perennial intercrops (1.75), taungya (2.50), and woodlots (0.97).

3.2. Sensitivity Analysis

Financial sensitivity analysis was conducted to determine whether or not the land-use is vulnerable to changes in the cost and benefit components as well as the interest rate. The effects of four interest rates (10%, 12%, 14%, and 16%), and two percentage changes with a 10% increase in cost and 10% decrease in benefits to BCR and NPV were examined. The results are presented in Tables 6–8.

Table 6. Sensitivity of the B/C ratio and NPV on different home garden types and sizes to changes in cost and benefit components.

Types	Normal		10% Increase of Cost		10% Decrease of Benefits	
	B/C Ratio	NPV	B/C Ratio	NPV	B/C Ratio	NPV
WDHS	3.7 ± 2.4 [a]	300.7 ± 228.8 [a]	3.4 ± 2.2 [a]	287.8 ± 230.2 [a]	3.3 ± 2.2 [a]	259.0 ± 208.6 [a]
WDHL	4.2 ± 2.0 [a]	1105.8 ± 643.9 [a]	3.8 ± 1.8 [a]	1086.3 ± 604.3 [a]	3.8 ± 1.8 [a]	956.8 ± 568.3 [a]
FDHS	2.5 ± 1.8 [a]	274.1 ± 310.1 [a]	2.3 ± 1.7 [a]	251.8 ± 302.2 [a]	2.2 ± 1.6 [a]	230.2 ± 273.4 [a]
FDHL	5.2 ± 2.8 [a]	1311.5 ± 932.4 [a]	4.7 ± 2.6 [a]	1280.6 ± 1913.7 [a]	4.7 ± 2.5 [a]	1143.9 ± 827.3 [a]

Values are means ± SD. Superscript lower-case letters indicate significant differences among the values on normal, 10% increase of cost, and 10% decrease of benefits, according to Duncan's test at $p < 0.05$. NPV is in USD.

Table 7. Sensitivity of the B/C ratio on different home garden types and sizes to changes in different interest rates on 10%, 12%, 14%, and 16%.

Types	Interest Rate (%)			
	10	12	14	16
WDHS	3.8 ± 2.4 [a]	3.7 ± 2.4 [a]	3.6 ± 2.4 [a]	3.5 ± 2.3 [a]
WDHL	4.2 ± 2.0 [a]	4.2 ± 2.0 [a]	4.1 ± 2.0 [a]	4.1 ± 2.0 [a]
FDHS	2.5 ± 1.8 [a]	2.5 ± 1.8 [a]	2.5 ± 1.8 [a]	2.4 ± 1.8 [a]
FDHL	5.3 ± 2.9 [a]	5.2 ± 2.8 [a]	5.1 ± 2.7 [a]	5.0 ± 2.6 [a]

Values are means ± Standard Deviation. Superscript lower-case letters indicate significant differences among the interest rates, according to Duncan's test at $p < 0.05$.

Table 8. Sensitivity of NPV on different home garden types and sizes to changes in different interest rates on 10%, 12%, 14%, and 16%.

Types	Interest Rate (%)			
	10	12	14	16
WDHS	4.5 ± 3.4 [a]	300.7 ± 228.8 [a]	280.6 ± 215.8 [a]	266.2 ± 208.6 [a]
WDHL	16.2 ± 9.4 [a]	1105.8 ± 643.9 [a]	1050.4 ± 611.5 [a]	1000.0 ± 582.7 [a]
FDHS	4.0 ± 4.5 [a]	274.1 ± 310.1 [a]	259.0 ± 295.0 [a]	244.6 ± 280.6 [a]
FDHL	19.2 ± 13.6 [a]	1311.5 ± 932.4 [a]	1244.6 ± 892.1 [a]	1187.1 ± 848.9 [a]

Values are means ± SD. Superscript lower-case letters indicate significant differences among the interest rate according to Duncan's test at $p < 0.05$. NPV values are in USD.

Table 6 indicates the changes in the B/C ratio and NPV indicates the home gardens when the cost components were increased by 10% and the benefit components were decreased by 10%. When the cost components were increased by 10%, the B/C ratio decreased by almost 10% in all of the different types and landholding sizes. However, the NPV decreased from USD 15.4 to USD 13.3 (approximately 11.9% reduction) in WDHL and from USD 3.8 to USD 3.2 (approximately 7.0% reduction) in FDHS. When the benefit decreases by 10%, the B/C ratio decreased similarly by about 10% in all of the different types and land holding sizes, but the NPV decreased from USD 18.2 to USD 15.9 (approximately 12.5% reduction) in FDHL and from USD 3.8 to USD 3.2 (approximately 17.0% reduction) in FDHS (Table 6). In a previous study, Mohan et al. [29] resulted in a relatively smaller level of change in the annual profit range (0.24%–2.46%) compared to our study, since we consider price fluctuation of all input cost since Mohan et al. [29] consider only labor cost. Although we were not able to find any significant differences between the increase in cost and decrease in benefits in all of the sites, home gardens are more sensitive to a decrease in benefits, which is caused by fluctuations in market prices, than an increase in cost, since home gardens have less input costs, so the B/C ratio and NPV are more dependent on the benefits.

Tables 7 and 8 show the changes in the B/C ratio and NPV of the different types and sizes based on various interest rates of 10%, 12%, 14%, and 16%. The B/C ratio was 3.8, 3.7, 3.6, and 3.5 with interest rates of 10%, 12%, 14%, and 16%, respectively, in WDHS, but there were no significant differences among the interest rates in all of the different types and sizes of home gardens (Table 8). Changes in

NPV are shown in Table 9 based on the different interest rates and the NPV decreased constantly while the interest rate increased in all of the different types and sizes of home gardens, but there were no significant differences. FDHL is still preferable for households with the highest NPV, which is followed by WDHL.

Table 9. List of tree species planted in home gardens in the study sites and characteristics of a quantitative stand structure.

No.	Scientific Name	Usage	RD (%)	F	RF (%)
1	*Maesopsis eminii*	Wood	0.96	6.90	1.59
2	*Agathis alba*	Wood	1.93	10.34	2.38
3	*Persea americana*	Fruit	0.96	10.34	2.38
4	*Mangifera foetida*	Fruit	1.29	13.79	3.17
5	*Lansium domesticum*	Fruit	2.25	13.79	3.17
6	*Durio zibethinus*	Fruit	4.50	27.59	6.35
7	*Gmelina arborea*	Wood	0.32	3.45	0.79
8	*Anthocephalus cadamba*	Wood	4.50	13.79	3.17
9	*Syzygium aqueum*	Fruit	0.32	3.45	0.79
10	*Tectona grandis*	Wood	0.96	10.34	2.38
11	*Archidendron pauciflorum*	Fruit	1.93	17.24	3.97
12	*Citrus* sp.	Fruit	0.64	3.45	0.79
13	*Ceiba pentandra*	Fruit	0.32	3.45	0.79
14	*Aleurites moluccanus*	Fruit	0.64	6.90	1.59
15	*Lansium domesticum* var. aqueum	Fruit	1.93	13.79	3.17
16	*Vitex pinnata*	Wood	0.32	3.45	0.79
17	*Swietenia macrophylla*	Wood	0.64	6.90	1.59
18	*Swietenia mahagoni*	Wood	1.29	6.90	1.59
19	*Garcinia mangostana*	Fruit	15.11	58.62	13.49
20	*Manglietia glauca*	Wood	0.32	3.45	0.79
21	*Artocarpus heterophyllus*	Fruit	2.57	17.24	3.97
22	*Myristica fragrans*	Fruit	3.22	6.90	1.59
23	*Parkia speciosa*	Fruit	1.93	13.79	3.17
24	*Schima wallichii*	Wood	0.64	6.90	1.59
25	*Nephelium lappaceum*	Fruit	2.57	20.69	4.76
26	*Euodia roxburghiana*	Wood	0.64	6.90	1.59
27	*Paraserianthes falcataria*	Wood	20.26	44.83	10.32
28	*Peronema canescens*	Wood	0.64	6.90	1.59
29	*Toona sureni*	Wood	24.76	62.07	14.29
30	*Camellia sinensis*	Fruit	1.61	10.34	2.38

3.3. Ecological Values of Home Gardens

The results of our study showed a smaller number for plant diversity than those of a previous study on plant diversity of traditional home gardens in Indonesia due to the characteristics of the home gardens. Arifin et al. [31] analyzed vegetation structure dynamics of traditional home gardens in Indonesia, and summarized six major factors that influence the vegetation structure of home gardens as follows: (1) small open space area, (2) land fragmentation, (3) different owner, (4) changes in function of some part of the home gardens, (5) plant popularity trend, and (6) economic condition changes. Kehlenbeck et al. [14] also found that commercialization, fragmentation, and urbanization threatened the plant diversity of home gardens in Indonesia. Farmers living within the study sites have their own job for their major income source and it is not possible for them to spend all of their time cultivating diverse plant species in their home gardens. In addition, the number of family members tends to decrease, because the younger generation wants to stay in urban areas to generate their own income. As a result, farmers tried to plant wood trees and fruit trees, which needed less effort to manage and achieved longer term benefits than those of tangible crops, including vegetables and herbal plants.

Quantitative stand structure characteristics are shown in Table 10. The results showed that suren (*T. sureni*) constituted the highest percentage (RD 24.76%) of the relative density followed by sengon (*P. falcataria*, RD 20.26%), manggis (*G. mangostana*, RD 15.11%), durian (*D. zibethinus*, RD 4.50%), and jabon (*A. cadamba*, RD 4.50%). Those five species occupied almost 70% of the home garden vegetation. Woody species (58.20%) occupied more than fruit species (41.80%). It was also revealed that suren is the most frequently occurring species with RF of 14.29%, followed by manggis, sengon, and durian with RF values of 13.49%, 10.32%, and 6.35%, respectively. In this study, we also showed that the RF of five frequently occurring woody species (suren, sengon, jabon, jati, and agathis) and five frequently occurring fruit species (manggis, durian, rambutan, nangka, and jengkol) were the same at 32.54%. In the case of woody species, suren and sengon occupied more than 55.37% of the total woody species (Table 9).

Table 10. Ecological values of different home garden types and sizes.

Types	*N*	Margalef Index	Shannon-Wiener Index	Simpson Index
WDHS	7	1.8 ± 0.4 [a]	1.4 ± 0.4 [a]	0.6 ± 0.1 [a]
WDHL	7	1.8 ± 0.5 [a]	1.3 ±0.4 [a]	0.6 ± 0.2 [a]
FDHS	6	2.0 ± 0.5 [a]	1.6 ± 0.2 [a]	0.8 ± 0.1 [a]
FDHL	9	1.9 ± 0.5 [a]	1.5 ± 0.4 [a]	0.7 ±0.1 [a]

Values are means ± SD. Superscript lower-case letters indicate significant differences among the types and sizes, according to Scheffe's test at $p < 0.05$.

Table 10 shows the ecological features of the 29 households surveyed in this study, according to the dominant species and the landholding size classes. Species richness values were determined to be 2.0 and 1.9 in FDHS and FDHL, respectively. As for WDHS and WDHL, the species' richness value was determined to be 1.8. The species' richness values were not significantly different among the different types and sizes of home gardens (Table 10). Saha et al. [32] also found that smaller home gardens had higher richness values in Kerala, India. Mohan et al. [27] assessed the ecological diversity in home gardens and compared the species' richness, according to the landholding size as small, medium, large, and commercial purpose home gardens. The commercial purpose of home gardens showed the lowest species' richness value (Margalef index: 5.43) and the small home gardens showed the highest species' richness value (Margalef index: 6.42). Rahman et al. [25] tried to explore the species composition with ecological features in homestead agroforestry systems in Northern Bangladesh and found that the Margalef index values ranged from 4.93 to 5.76.

Considering the species' diversity values through the Shannon-Wiener index and Simpson index, the values were determined to be 1.4 and 0.6 in WDHS and 1.3 and 0.6 in WDHL, respectively (Table 10). It was also determined that the values were 1.6 and 0.8 in FDHS and 1.5 and 0.7 in FDHL, respectively. However, we could not find a significant difference in ecological values among the different types and sizes of home gardens (Table 10).

In previous research, it has been determined that mean Shannon indices vary widely in tropical home gardens and those have been reported to range from 3.0 in West Java, Indonesia [33], 2.03 in West Java, Indonesia [34], 3.02–3.28 in Ethiopia [35], and 1.9–2.7 in Thailand [36]. In addition, mean Shannon indices were determined to be 2.0 in the dry zone in Sri Lanka [37], 1.71 in Cuba [38], 1.15–1.42 in the state of Kerala in India [27], and 3.36 in Bangladesh [25]. The Shannon-Wiener index values ranged from 1.5–3.5 and were seldom more than 4.5 [37]. The Shannon-Wiener index characterizes the proportion of species abundance in the population, being at a maximum when all of the species are equally abundant and being at the lowest when the sample only contains one species [37]. Mohan et al. [27] assumed that home gardens that were more than 1 ha in size were more likely to look like agricultural fields or plantations. Thus, this could cause lower species richness and diversity. Commercial home gardens have larger areas, a smaller number of species, a higher number of species, and a lower Shannon-Wiener diversity index value than non-commercial home gardens [34].

3.4. Sustainable Management of Home Gardens in West Java, Indonesia

Due to the rapid sprawl of the cities in West Java, starting with Jakarta, the population has increased, and industrial structures have changed mainly from agricultural to nonagricultural activities. Home gardens in the area of West Java have been faced with population pressure on the land and fragmentation, an increase in land cost, a growing market economy, and large-scale land conversion to non-agricultural activities that are primarily related to urbanization and commercialization in the area. In most of the changes presently observed, home gardens have lost their original characteristics in terms of rich biodiversity and multiple dimensions of the household economy [39]. Gangopadhyay and Balooni [40] noted that the sizes of the home gardens were negatively affected by urbanization, and Arifin et al. [41] found that home gardens were in critical trouble due to ecological and financial aspects when the size of home gardens fell to below 100 m^2.

The productivity of home gardens is related to a number of factors including multi-layered species composition, diversity, climatic parameters, and management intensity [25,30]. Well-developed home gardens provide households with high-nutrient food items through annuals and perennials [42], and multi-strata systems are more sustainable and profitable for the households by promoting income generation throughout the year as well as pest and disease prevention [43]. Species composition used to be decided by farmers' preferences for household consumption and market value for income generation. Fruit-growing is presently considered to be a proper activity related to the production economy throughout the year and it is well adapted to garden conversion, which has a higher productivity margin under the lower availability of land on Java Island [39,44]. Herbaceous plants, such as vegetables, starchy crops, and spice plants, are seasonal plants that are highly affected by climatic parameters, such as rainfall and temperature, and they are easily accessed through the market for subsistence consumption. On the other hand, when considering economic aspects, ornamental species are more attractive for households than vegetables due to the market economy in urbanized areas in particular [14,19,34,45–48].

One of the most important functions of home gardens is providing a sustainable income source over the short-term as well as over the long-term. It has been reported that the growing of fruit trees is a proper agricultural activity related to the production economy [39,44]. Fruit tree species, such as manggis (*G. mangostana*), bacang (*M. foetida*), durian (*D. zibethinus*), and rambutan (*N. lappaceum*), are important sources for generating income by selling to the market a highly marketable product. In the study sites, manggis and durian showed the highest frequency and these are one of the products that had the largest production values in the Sukabumi Regency. However, households are not able to generate income by fruit selling throughout the year, since fruit production is seasonal, and dependent on the climate and healthy tree conditions. In this case, ornamental plants are able to alternatively provide sustainable income for households as well as aesthetic function in response to urbanization [45]. Ornamental plants are used to plant in the space between houses as a fence to emphasize aesthetic function with medicinal plants and clove trees [39]. Arifin et al. [31] listed 103 species of ornamental plants that are planted in the home gardens on Java Island. Coffee (*Coffea canephora* var. robusta) was also cultivated by some households to replace the ornamental plants with higher income-generating plants. Considering further long-term benefits, sengon (*P. falcataria*) is the most preferable tree species for households in the study sites due to its short harvesting rotation of 7–10 years and high market demand [49]. Jati (*T. grandis*) and mahoni (*S. mahagoni*) are high value trees in the domestic market as well as in the international market with 20 to 30 years of harvesting rotation. Therefore, these trees act as saving accounts and safety nets just in case households urgently need money for special cases, such as a wedding ceremony or when building a new house [21].

4. Conclusions

In the present study, we quantified economic and ecological characteristics using several indices that represent the specific characteristics of home gardens to evaluate the diverse roles of home gardens. The results of this study indicated that the financial status of the households and large landholding

sizes had an NPV of 18.23 per year, which was significantly higher than that of small landholding sizes of 3.81 per year when the home gardens were dominated by fruit tree species (FDH). On the other hand, home gardens dominated by woody-tree species (WDH) did not show a difference in NPV values between small landholding sizes and large landholding sizes. In addition, there was no significant difference in the B/C ratio within the study sites. Although we were not able to find any significant differences between an increase in cost and a decrease in benefits at all of the sites, home gardens are more sensitive to a decrease in benefits, which is caused by a fluctuation in the market price rather than an increase in cost. This is due to home gardens having a lower input cost. Therefore, the B/C ratio and NPV are more vulnerable to the benefits.

The diversity status values of the home gardens were very similar to each other even though they had different dominant tree species, types, and land sizes. There were 29 tree species with 311 individuals and 12 species of herbaceous plants including ornamental, vegetables, and tea. Suren (*T. sureni*) and sengon (*A. chinensis*) comprised 45% of the total number of trees, and manggis (*G. mangostana*) and durian (*D. zibethinus*) comprised 20% of the total number of trees within the study sites. Those four species also showed the highest relative density (RD) and relative frequency (RF) among the species. Their species composition was also fairly similar, which indicates that home gardens retain some specific species that are considered to be important for farmers' consumption as well as income generation. Considering the ecological characteristics of the study sites, there was no difference in species richness, species diversity, and evenness among the different types and sizes of home gardens.

Under the limited availability of land area on the entire island of Java especially with regard to the urbanization and commercialization pressure of the study sites, sustainable management of home gardens needs to consider livelihood improvement through multi-layered and diverse species composition. Combination of fruit tree species and ornamental plants are able to generate continuous income throughout a year due to higher market demand. Additional wood tree species act as a savings account in the home gardens.

A further study should be considered for developing a standardized and generalized model that is able to evaluate and quantify the various ecosystem values generally acceptable and applicable in rural areas, particularly for the Sukabumi region in West Java. To this end, we recommend selecting more classified local people based on their income, income source, and labor type in order to make a more exact calculation of the B/C ration and NPV. In addition, it is recommended to survey not only trees but also herbaceous plants including ornamental plants, which are increasing demand from the market. Therefore, the financial status can be analyzed more precisely.

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