Analysis of agroforestry tree species composition and coffee cultivation production tropical highlands, Aceh Tengah - Indonesia

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Abstract. Agroforestry system is a mixed plantation between cultivation planting and tree species in a forest land area. Coffee with a shade tree is commonly found out as an agroforestry system in Aceh Tengah highlands. Many farmers choose tree species suit for coffee to support coffee productivity. This research aimed to identify the planting of shade trees and coffee; what kinds of species mainly be grown by farmers. The research found that most farmers prefer to plant Leucaena leucocephala than other species causes the benefit of Leucaena leucocephala species. Coffee farmers should use trees as a protective crop to increase the total coffee production. Use Leucaena leucocephala as a protective tree because Leucaena leucocephala root contains rhizobium, helping coffee production.

1. Introduction
Coffee is a tropical plant that can grow well in almost all places, except in places with a too high elevation and lower degree temperatures. Indonesia, as a country with a tropical climate, provides a suitable land for growing coffee. Many farmers around Indonesia planted coffee and harvested coffee fruit as the primary commodity of their land. It has a high economic value among other plantation crops, including annual crops that can reach productive life for 20 years. Coffee is also an important export commodity from Indonesia, which plays an important role as a foreign exchange source.

Coffee is included as an important commodity in Indonesia. As a coffee-producing country, Indonesia occupies the top four in the world. Indonesia’s coffee production reaches 600 thousand tons per year, and more than 80% comes from smallholder plantations [1]. The level of domestic coffee consumption was 500 grams/capita/year. Nowadays, coffee entrepreneurs estimate that Indonesia’s level of coffee consumption has reached 800 grams/capita/year. Thus, within 20 years, the increase in coffee consumption has reached 300 grams/capita/year. However, the increase in coffee consumption that occurs is not in line with the development of production and productivity of several types of coffee, one of which is Arabica coffee’s productivity. It happens because of several obstacles that occur. One of them is the acquisition
of lower coffee yields. It causes very many residents who are less focused on coffee farming [2].

The coffee plant itself originates from Africa, which is a mountainous region in Europe. Coffee plants are included in the family Rubiaceae, which has many types, but the coffee types are commonly known to include Coffea arabica, Coffea robusta, and Coffea liberica. Shade plants play an important role in sustainable coffee production systems. Shade in coffee cultivation acts as a micro-climate controller so that coffee growth is optimal. The presence of shade plants will affect the intensity of light received by plants. Besides loose soil and rich in organic matter, coffee also requires somewhat acidic soils. If the soil pH is less than that number, the coffee plant is still growing, but it is less able to absorb some nutrients, so it needs to be given lime. On the other hand, coffee plants do not want slightly alkaline soils (pH over 6.5), so lime should not be overused [3].

The coffee shade tree is distinguished from temporary shade tree types and permanent shade tree types based on its function. Temporary shade plants are needed if the shade trees still do not function because they are still small or the shade's intensity is still lacking. The planting of these two shade trees should be done 2-3 years before planting coffee. The shade tree is usually twice the height of the coffee plant. After the shade tree continues to function correctly, the temporary shade is gradually removed [4]. The provinces of Aceh and North Sumatra accounted for more than 50% of the national Arabica coffee production. Lately, the specialty coffee market has developed rapidly, especially in major consumer countries. For Bebesen villages, Central Aceh Regency, coffee is identical with life because most of the population in the highlands region depends on coffee commodities. Bebesen villages have a coffee plantation with a planting area of 39,533 ha and productivity of around 0.68 tons/ha/year. In comparison, Central Aceh district has a coffee plantation with a planting area of 48,001 ha and coffee production of 0.78 tons /ha/year.

Arabica coffee has low production power, requires complex maintenance, and a longer growth cycle [5]. This coffee is planted in the highlands, which have a dry and rainy season and altitudes around 1000-1750 meters above sea level [6]. Many coffee plantations experience very harmful disorders, and weeds cause these disorders. Coffee belongs to the genus Coffee of the family Rubiaceae. The coffee genus consists of four sections, 66 species that are Eucoffeae 24 species, Mascaroffeae 18 species, Paracofeae 13 species, and Agrocoffeae 13 species. Of the four sections that are commercially Eucoffeae. Arabica and Robusta coffee plants have different heights and temperature levels. Arabica coffee can be cultivated at an optimum height of 800-1500 masl with a temperature of 17-21°C. It is located in the optimum height of 400-800 masl with an average temperature of 21-24°C. Both coffee species require an optimum rainfall of 2000-3000 mm/yr with approximately three dry months, but with sufficient shipment rain. The existence of a dry season with high temperatures is essential for the preparation of flowering and fruit formation, but on blossoming, the flower requires adequate rainfall [7].

In its development to date, the community's coffee product often faces several problems that interfere in implementing aquaculture activities. One of the farm problems is the limited knowledge and skills in the technology of coffee cultivation. Coffee plants are usually planted in shade trees (shade), but some are planted without shade. The study aims to find out the types of shade trees and agroforestry crop patterns of Arabica coffee in Bebesen villages, Aceh Tengah district, Indonesia.

2. Methods
This research was carried out in February 2019. Analysis of the shade tree density on Arabica coffee production was completed in Forest Inventory Laboratory, Universitas Sumatera Utara. The tools used for data collection are a tally sheet, roll meter, tape meter, camera, stationery. The material used is shade tree stands and coffee plants in Bebesen villages, Aceh Tengah highlands, Indonesia (Figure 1).
2.1. Data collecting methods

Data collecting consists of primary and secondary data. Secondary data collected is a map of the research location, data from relevant agencies, reports of previous research results, and various libraries related to the research location. Primary data covers coffee production, the area size of land farmers, owner status, and direct measuring of vegetation. Farmers’ data is collected from community respondents’ results such as questionnaires, field coordinates, photo documentation, and coffee production.

The research measure and identify composition and structure of shade tree in the coffee plantation. Some plots sized 50 m x 50 m layout in the coffee lands. The researcher designed the sample plot base on the distribution of area size of farmer coffee land (less than 1 ha, 1 – 3 ha, and more than 3 ha). The plots distribute using systematics sampling (Figure 2). The coffee plant and shadow tree data are taken species, several trees, and agroforestry patterns. By each village sample, 15 plots were taken with some criteria. Its criteria cover the land area of less than 1 Ha, 1-3 Ha, and more than 3 Ha with low, medium, and high coffee production.

Figure 1. Research location
2.2. Data analysis method

2.2.1. Vegetation structure and composition. The study analyzes field data to get vegetation structure and composition. The analysis uses the formula below:

Density per ha (D) = \frac{\text{total number of number species} \times 10000 \text{ m}^2}{\text{total number of quadrat studied} \times \text{area of quadrat}} \quad (1)

Relative density (RD) = \frac{\text{density per ha of a species}}{\text{total number of density all species}} \times 100 \% \quad (2)

Frequency of species (F) = \frac{\text{total number of quadrat in which species found}}{\text{total number of quadrat studied}} \quad (3)

Relative frequency (RF) = \frac{\text{frequency of a species}}{\text{total number of frequency all species}} \times 100 \% \quad (4)

Basal area (m^2) = \frac{2}{4} \times 3.1416 \times (\text{diameter})^2 \quad (5)

Dominance (Dm) = \frac{\text{basal area of a species}}{\text{total number of quadrat studied}} \quad (6)

Relative dominance (RDm) = \frac{\text{dominance of a species}}{\text{total dominance of all species}} \times 100 \% \quad (7)

Important Value Index (IVI)_tree = RD + RF + RDm \quad (8)

Important Value Index (IVI)_{seedling, sapling} = RD + RF \quad (9)

2.2.2. Coffee production analysis. Coffee production data from questionnaires were analyzed to get the average production per year. The average coffee production is calculated using the formula below.

\[ X = \frac{\sum_{i=1}^{n} x_i}{\text{coffee harvesting cycle}} \quad (10) \]

\( X \) = average coffee production per year

\( x_i \) = the coffee production of respondents - i (i=1, 2, 3,...etc), on the coffee plant with or without shade tree
3. Result and discussion

3.1. Coffee plant distribution

Based on the interview with the respondent, it has been known coffee plant location. By using google-earth and location coordinate, the distribution highlands coffee plantation of Bebesan village is mapped. The distribution map of all coffee plants is illustrated in Figure 3. The pattern of shade trees for coffee plants consisted of irregular coffee planting patterns and shade trees, regular coffee planting patterns and shade trees, and irregular coffee patterns without shade trees. Coffee distribution for each village is listed in Table 2.

Figure 3. Distribution map of coffee plantation plot

3.2. Area distribution of coffee plantation

The land area of coffee farmers is different between respondents. The respondents were taken from five villages which are Atu Tulu, Burbiah, Blang Gele, Dating, and Lelabu. Data interviews show that the number of farmers having land area is almost similar on three categories of size area. It is about 25 farmers with less than 1 ha, 26 farmers with 1-3 ha, and 24 farmers with more than 3 ha coffee lands-the comparison diagram of the area is illustrated in Figure 4.

Figure 4. Area distribution of land owner for coffee plantation
3.3. Shade tree composition
Vegetation analysis results from shade tree composition. The research found three species of shade trees. The *Leucaena leucocephala* species is dominant in the coffee lands. It has important index value (IVI) 67.92%. Other shade trees are *Citrus maxima Merr* and *Mangifera indica*. *Mangifera indica* is the lowest IVI of a shade tree in farmers’ lands area less than 1 hectare and more than 3 hectares. Meanwhile, *Citrus maxima Merr* has the lowest IVI in farmers’ land area of 1 – 2 hectares. The detailed composition of shade tree vegetation is shown in Table 1.

### Table 1. Shade tree composition on farmer land with coffee plantation

| No | Local name                  | Number (ind) | Density (ind/ha) | RD (%) | Frequency | RF (%) | Dm (m²/ha) | RDm (%) | IVI |
|----|-----------------------------|--------------|------------------|--------|-----------|--------|------------|---------|-----|
| A  | Farmer land area less than 1 hectare |              |                  |        |           |        |            |         |     |
| 1  | *Leucaena leucocephala*     | 537          | 85.92            | 7.79   | 0.75      | 37.50  | 0.0022     | 22.62   | 67.92|
| 2  | *Citrus maxima Merr*        | 70           | 11.20            | 1.02   | 0.13      | 6.25   | 0.0029     | 30.12   | 37.39|
| 3  | *Mangifera indica*          | 69           | 11.04            | 1      | 0.13      | 6.25   | 0.0038     | 38.69   | 45.94|
|    | Total                       | 252          | 1102.56          | 100    | 2.00      | 100    | 0.0097     | 100     | 300 |
| B  | Farmer land area between 1 - 3 hectare |              |                  |        |           |        |            |         |     |
| 1  | *Leucaena leucocephala*     | 535          | 85.60            | 7.64   | 0.76      | 35.85  | 0.002      | 43.96   | 87.45|
| 2  | *Citrus maxima Merr*        | 200          | 32.00            | 2.86   | 0.36      | 16.98  | 0.002      | 37.90   | 57.74|
|    | Total                       | 288          | 1800             | 100    | 5         | 100    | 0.005      | 100     | 300 |
| C  | Farmer land area more than 3 hectare |              |                  |        |           |        |            |         |     |
| 1  | *Leucaena leucocephala*     | 729          | 116.64           | 10.41  | 1         | 41.67  | 0.0021     | 28.07   | 72.00|
| 2  | *Citrus maxima Merr*        | 180          | 28.8             | 2.57   | 0.32      | 13.33  | 0.0018     | 23.92   | 37.84|
| 3  | *Mangifera indica*          | 46           | 7.36             | 0.65   | 0.08      | 3.33   | 0.0028     | 37.37   | 128.70|
|    | Total                       | 288          | 1800             | 100    | 5         | 100    | 0.005      | 100     | 300 |

From Tables 2, it can be known that the highest density of shade trees is in the ownership of coffee land with an area of more than 3 hectares, which is 116.64 individuals/ha with a relative density of 10.41%. The highest number of shade trees is 729 trees of *Leucaena leucocephala*. The highest shade tree density of an area less than 1 ha is 85.92 trees/ha, with a relative density of 7.79%. The shade trees found were 537 trees of the *Leucaena leucocephala* type. The smallest density of shade trees on coffee land ownership with an area of more than 3 hectares is 7.36 trees/ha and a relative density of 0.65%.

In Bebesen villages, Aceh Tengah highland, the farmer’s plant *Leucaena leucocephala*, *Citrus maxima Merr*, and *Mangifera indica* as shade trees of coffee. Its were planted on irregular or disordered planting spacing with a 3 x 3 m², but some use a size of 2.5 x 2.5 m. The shade trees can support the growth of coffee plants to be more optimal. Rukmana (2005) explains that spacing is made to utilize light effectively and distribute nutrients evenly [8].

Coffee shade is a strategy to cope with the variability of available water and an adaptation to global climate changes. Shade trees protect the coffee from the high temperature on coffee understory [9–12]. It also increases water availability for plants use by reduction of soil erosion and runoff [13,14].

The farmer uses more *Leucaena leucocephala* trees as shade trees because the *Leucaena leucocephala* trees have cone-like crowns, with a 7-9 m long crown. It can protect coffee plants...
from the sun and can provide nutrients. Moreover, *Leucaena leucocephala* tree was chosen because it has many benefits, and planting this type does not require many costs. Coffee farmers choose *Leucaena leucocephala* as a protective crop because it has a long life with a canopy shape that can protect 2 to 3 rows of coffee plants underneath and can be used as firewood. According to Prastowo (2010), selecting shade tree species is recommended to choose a group of plants that have a long canopy shape with leaves that are thick enough and have a reasonably high stem shape [5]. *Leucaena leucocephala* is a plant that has many uses because almost all parts of the plant can be utilized. *Leucaena leucocephala* wood is used for fuel, while the leaves are used as animal feed. Also, *Leucaena leucocephala* fruit can be used as food.

The coffee shade tree composition consists of just one type of shade tree called a simple shade system and consists of many types of shade trees with various canopy heights, forming several strata agroecosystems. This shade system affects coffee agroecosystems' productivity, income, and sustainability [15]. In the production phase, 30% of coffee plant growth is influenced by genetic traits, while 70% is influenced by environmental factors, mainly light intensity [16]. Besides, coffee production is also affected by an increase in the maximum temperature and minimum temperature, which can cause the flowering process to fail. Flower of shade tree can attract the bee i.e. It is better for support farmers to get honey. The other studies show that the giant Asian honeybee, *Apis dorsata*, which is the main pollinator of C. canephora, also requires large canopy trees for nesting, including *Artocarpus hirsutus*, *Canarium strictum*, *Mangifera indica*, and *Magnolia champaca*, of which nearly all occurred in diverse plantations [17].

Coffee plants can optimally grow if they get direct sunlight intensity. The coffee is not a resistant plant to strong wind shocks. In addition to damaging branching and making trees fall, strong winds also increase water evaporation on the soil's surface and leave that cause plants to experience drought [18]. Plant spacing is very influential on plant growth and yield. Plant spacing is shown to utilize light effectively and distribute nutrients evenly [8]. Abidin et al., (1984) explain that plant spacing can affect the growing environment and crop yields; the denser the plant spacing, the higher the plant population, so that competition between plants to absorb nutrients from the soil will increase [19].

The role of light is significant for the survival of plants. Yusianto and Mulato (2002) stated that light is crucial in plants' survival, especially for young plants [20]. Therefore, recognizing the nature of the need for light for trees at each growth stage is vital information. Coffee plants exposed to pests and diseases must undergo plant care, but this process can not run optimally because of the influence of density on disordered plants. Hot direct sunlight in large quantities will increase the soil's evaporation and leaves to disturb the balance of photosynthesis, especially in the dry season [21].

### 3.4. Coffee production with shade and without shade trees

The research interview results show coffee production with shade trees is more than coffee production without shade trees (Table 2). The coffee production gain length the life of the coffee plant. The cycle of coffee harvested from agroforestry is more long time than without agroforestry. It causes average production per year along cycle coffee planting with shade tree is more than without shade tree.

| Variable                        | Average (kg/year/ha) |
|---------------------------------|----------------------|
| Coffee production without a shade tree | 1,866                |
| Coffee production with a shade tree | 2,479                |

The protective tree benefits the coffee plant by protecting it from excessive sunlight, affecting growth stabilization, flower development, and fertilization. Beer et al., (1997) explain that shade trees' effect on reducing or increasing production depends on soil and environmental conditions, shade tree species, and garden management [22]. It proves that a
protective tree given to coffee can increase coffee production compared to coffee planted without a protective tree. Coffee cultivation agroforestry was a more efficient water user when compared to a non-shaded coffee system since most of the soil water was used for coffee transpiration in comparison to shade trees or loss by evaporation from the soil surface [23].

4. Conclusion
The types of protective trees used are *Leucaena leucocephala*, *Citrus maxima* Merr., and *Mangifera indica*. Coffee farmers should use trees as a protective crop to increase the amount of coffee production. Use *Leucaena leucocephala* as a protective tree because *Leucaena leucocephala* root contains rhizobium, helping coffee production. Furthermore, further research is expected to test the use of tree species that are most suitable for coffee trees.

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