Determining the best agroforestry system using multicriteria analysis in Banyumas Forest Management Unit

R Sadono¹, D Soeprijadi¹, S F Nikmah² and P Y A P Wirabuana³
¹Department of Forest Management, Faculty of Forestry, Universitas Gadjah Mada
²Student of Forest Management, Faculty of Forestry, Universitas Gadjah Mada
³Independent researcher, Yogyakarta 55281, Indonesia

Abstract. Social welfare and food security become essential issues of forest management in Java. Agroforestry development have a potential to tackle these both issues without sacrificing the forest sustainability. The best agroforestry system should integrate the following three aspects: production, ecological, and social sustainabilities. This study aimed to identify the best agroforestry system that are established in plantation forest area, in Banyumas Forest Management Unit. Four different agroforestry systems were evaluated i.e. Teak, Pine, Cajuput, and Clonal Teak patterns. Each agroforestry system has different intercropping area based on their initial spacing of woody plant. The analytical hierarchy process method and followed by multi criteria analysis were used to determine the best agroforestry system. The proposed indicators of production aspect were timber forest product and non timber forest product. Meanwhile, the defined parameters of ecological aspect were plant biodiversity, microclimate, as well as soil and water conservation. The indicators of social aspect were market network, adoptability, and manageability. The result indicated that the weight for production, ecological, and social sustainabilities aspects were 0.43; 0.14; 0.43, respectively. This study revealed the best agroforestry system that can integrate the balance of production, ecological, and social sustainabilities aspects was Clonal Teak pattern (2.39). The next position was occupied by Teak pattern (2.08) and then followed by Pine pattern (2.06). The Cajuput pattern, however, was the last position (1.15), and therefore it was not recommended for agroforestry system in this area.

1. Introduction
Agroforestry systems have been developing extensively to support plantation forest management in Java. It provides several benefits from production, ecological, and social aspects. The implementation of agroforestry systems potentially reduces the cost of planting through community involvement in the planting activity [1]. Moreover, the growth performance of stand resulted by agroforestry systems is better than monoculture systems as the effect of intensive maintenance such as fertilization, soil tillage, and weed control [2]. Agroforestry systems are also very helpful to maintain soil fertility, minimize erosion, and enhance plant biodiversity [3]. Furthermore, agroforestry systems development may offer an occasion for the community to participate in plantation forest management [4].

The success of agroforestry systems is depending on the effectiveness of planting design [5]. It relates to resource sharing among trees and crops for light, water, nutrients, and space requirements [6]. This focus is very essential because it has direct impacts to plant productivity. The best agroforestry system is not only determined from the high plants productivity, but also the balance of production, ecological,
and social aspects [7]. Determining the best agroforestry system become an important issue in plantation forest management currently.

This study aimed to evaluate the development of agroforestry systems in commercial plantation forest. The main focus was directed to assess the stability of three important aspects in agroforestry systems including production, ecological, and social. Multi-criteria analysis was used to develop the evaluation instrument. This approach was selected because the evaluation of agroforestry systems should involve many indicators that was capable to explain each its components. The results would determine the best agroforestry system that could be recommended in plantation forest management.

2. Materials and Method

2.1. Study site
This study is located in a plantation forest which has been managing by Banyumas Forest Management Unit. It was situated in Cilacap District around 300 km from southwest of Semarang. The altitude ranged 28-90 m above sea level. Topography was mostly gradient with dominated by hill area. The majority of soil type was latosol that had soil acidity ranging 5-6. Annual rainfall varied between 1,553.35 – 3,500 mm year$^{-1}$. This site had total forest area approximately 55,562.99 ha with 4 different forest commodities, namely Teak, Pine, Clonal Teak, and Cajuput.

2.2. Data collection
There were three steps of data collection: questionnaire, observation, and interview methods. The goals of questionnaire method were (1) to formulate a set of criteria and indicator for evaluation of agroforestry systems; and (2) to obtain the weight of each criteria and indicator. This phase was undertaken by the involvement of several experts in forest science such as silviculture, ecology, economy, and social. The objective of observation method is to seek the pattern of agroforestry systems that were developed in the study site using purposive sampling. In this context, three different variables were considered to select the sample of agroforestry systems including type of forest commodity, initial spacing, and kind of crop. While the purpose of interview method was to explore the community’s knowledge related to agroforestry systems in plantation forest.

2.3. Data analysis
Analytical hierarchy process and followed by multi criteria analysis were applied to determine the best agroforestry systems in the study site. It consisted of several stages, i.e. [8]:

1. Identifying problem and specific objective
   The fundamental problem of this study was how to determine the best agroforestry system that were established in a plantation forest. It involved many aspects of forest management including production, ecological, and social. The best agroforestry system should integrate the balance of those aspects based on the priority level.
2. Determining a set of criteria and indicator for problem assessment
Several requirements should be considered to select the criteria and indicator. These parameters were simple, responsible, measurable, representative, and high quality. Many kinds of literature about agroforestry systems were very required to retrieve a good set of criteria and indicator (Table 1).

Table 1. Formatting a set of criteria and indicator

| Goal | Criteria | Sub Criteria | Indicator | Description |
|------|----------|--------------|-----------|-------------|
|      | 1        | 1.1          |           | xxx         |
|      |          | 1.1.1        |           | xxx         |
|      |          | 1.1.2        |           | xxx         |
|      | 1.2      | 1.2.1        |           | xxx         |
|      |          | 1.2.2        |           | xxx         |
|      |          | 1.2.3        |           | xxx         |
|      | 2        | 2.1.1        |           | xxx         |
|      |          | 2.1.2        |           | xxx         |
|      | 2.2      | 2.2.1        |           | xxx         |
|      |          | 2.2.2        |           | xxx         |
|      |          |              |           |             |

etc.
3. Validating the selected criteria and indicator
   The validation process was conducted using two different methods. First, it was consulted with
   some experts to obtain suggestion and recommendation for further enhancement. Second, it was
   directly examined in the field as preliminary stage to assess its capability for field measurement.

4. Comparative judgment of each criteria and indicator
   This process aimed to identify the priority level of each criteria and indicator. In this context, we
   asked several experts to assess the importance of parameters using pairwise comparison method
   (Table 2). It was started from criteria comparison and followed with indicators of each criteria
   (Table 3). For explanation, if an element was compared to its self, the value would be given 1.
   Meanwhile, if \( i \) element was compared to \( j \) element and obtained a specific value, the \( j \) element
   would received the opposite value of \( i \) element (Table 4).

| Scale | Definition |
|-------|------------|
| 1     | Equal important |
| 3     | Moderately more important |
| 5     | Strongly important |
| 7     | Very strongly important |
| 9     | Extremely more important |
| 2, 4, 6, 8 | Between two adjacent value considerations |

| Indicator A | Criteria 1 | Indicator B |
|-------------|------------|-------------|
| 1.2.1       | 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 | 1.2.2 |
| 1.2.1       | 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 | 1.2.3 |
| 1.2.2       | 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 | 1.2.3 |

| Table 4. Pairwise comparison matrix |
|-----------------------------------|
| \( 1.2.1 \) | \( 1.2.2 \) | \( 1.2.3 \) |
|\( 1.2.1 \) | \( 1 \) | \( 1/6 \) | \( 1 \) |
|\( 1.2.2 \) | \( 6 \) | \( 1 \) | \( 8 \) |
|\( 1.2.3 \) | \( 1 \) | \( 1/8 \) | \( 1 \) |
5. Verifying the priority of criteria and indicator
   The priority of criteria and indicator were verified using matrix calculation through mathematic equation. Detail of theses phases were as follow:
   a. Calculate the sum of each column

   |     | I 1.2.1 | I 1.2.2 | I 1.2.3 |
   |-----|---------|---------|---------|
   | I 1.2.1 | 1       | 1/6     | 1       |
   | I 1.2.2 | 6       | 1       | 8       |
   | I 1.2.3 | 1       | 1/8     | 1       |
   | Total   | 8       | 1.29    | 10      |

   b. Normalize the elements in each column by dividing with the number of column

   |     | I 1.2.1 | I 1.2.2 | I 1.2.3 | Total |
   |-----|---------|---------|---------|-------|
   | I 1.2.1 | 1/8 (0.13) | 1/6/1.29 (0.13) | 1/10 (0.1) | 0.35  |
   | I 1.2.2 | 6/8 (0.75) | 1/1.29 (0.78) | 8/10 (0.8) | 2.33  |
   | I 1.2.3 | 1/8 (0.75) | 1/6/1.29 (0.10) | 1/10 (0.1) | 0.32  |

   c. Estimate the average of each row as the relative weight

   | Indicator | Total | Relative Weight | Priority |
   |-----------|-------|-----------------|----------|
   | I 1.2.1   | 0.35  | 0.35/3 = 0.12   | 2        |
   | I 1.2.2   | 2.33  | 2.33/3 = 0.77   | 1        |
   | I 1.2.3   | 0.32  | 0.32/3 = 0.11   | 3        |

6. Measuring logical consistency
   Logical consistency was evaluated by two parameters: consistency index (CI) and consistency ratio (CR). Detail procedure of each parameter was as follow:
   a. Multiply the column total (Nc) for each indicator with the calculated of relative weight (Rw) for each indicator (λ max)

   \[
   \lambda_{max} = (Nc \ I \ 1.2.1 + Rw \ I \ 1.2.1) + (Nc \ I \ 1.2.2 \times Rw \ I \ 1.2.2) + (Nc \ n + Rw \ n)
   \]  

   b. Calculate the consistency index (CI)

   \[
   CI = \frac{(\lambda_{max} - N \ criteria)}{(N \ criteria - 1)}
   \]

   c. Estimate the consistency ratio (CR)

   \[
   CR = \frac{CI}{RI}
   \]
Random index (RI) was determined by the size of matrix (Table 8). The tolerance level of CI and CR permitted for both parameters were approximately 10%.

| Size of Matrix | RI |
|----------------|----|
| 1 or 2         | 0.00 |
| 3              | 0.58 |
| 4              | 0.90 |
| 5              | 1.12 |
| 6              | 1.24 |
| 7              | 1.32 |
| 8              | 1.41 |
| 9              | 1.45 |
| 10             | 1.49 |
| 11             | 1.51 |
| 12             | 1.48 |
| 13             | 1.56 |
| 14             | 1.57 |
| 15             | 1.59 |

7. Scoring each criteria and indicator

Three different scales were used to value each criteria and indicator: 1 (low), 2 (medium), and 3 (high). Alternative value of each indicator ($V_i$) was the result of multiplication between its relative weight and sum of internal scoring.

$$V_i = \sum_{i=1}^{n} (S_i \times R_{wi})$$

Where $S_i$ stated sum of internal scoring, and $R_{wi}$ was the relative weight of each indicator. Meanwhile, the alternative value of each criteria ($C_i$) was calculated by equation:

$$C_i = \left(\sum_{i=1}^{n} (S_i \times R_{wi})\right) \times R_{wc}$$

Where $C_i$ represented alternative value of each criteria and $R_{wc}$ was the relative weight of each criteria. Total value of goal ($G$) was estimated following equation:

$$G = \sum_{i}^{n} C_i$$

$G$ value demonstrated the balance of production, ecological, and social aspects in agroforestry systems that were developed in plantation forest. The highest $G$ indicated the best agroforestry system that was capable to integrate the aspects of forest management.
3. Results and Discussion

3.1. Type of agroforestry systems in Banyumas Forest Management Unit

Four different patterns of agroforestry systems were observed in the study site including Cajuput, Teak, Pine, and Clonal Teak. Each pattern had specific attributes that were reviewed from spacing and species composition (Table 9). The most narrow spacing was recorded in Teak plantation, meanwhile the widest spacing was demonstrated by Clonal Teak plantation. In agroforestry systems, the difference spacing determined the size of intercropping area that was potentially used for crop cultivation. Several studies reported the use of wide spacing for agroforestry systems in plantation forest was commonly adopted in the compartments that was directly adjacent to settlement with high dependence on land [9–12].

Table 9. Pattern of agroforestry systems in Banyumas Forest Management Unit

| Agroforestry Systems | Spacing (m) | Primary Species | Border Species | Edge Species | Filler Species | Crop Species |
|----------------------|-------------|-----------------|----------------|--------------|---------------|--------------|
| Pine                 | 3 x 2       | Pinus merkusii  | -              | Swietenia macrophylla | -              | Pennisetum purpureum |
| Teak                 | 3 x 1       | Tectona grandis | Caesalpinia sappam | Swietenia macrophylla | -              | Zea mays |
| Cajuput              | 6 x 1       | Melaleuca leucadendron | - | - | - | Oryza sativa |
| Clonal teak          | 3 x 3       | Clonal teak | Caesalpinia sappam | Calophyllum leucocephala | Leucaena | Zea sativa mays |

Species distribution in each pattern also performed different composition. Agroforestry systems using Clonal Teak pattern had the highest species composition than other patterns. It consisted of five species compositions that had diverse functions. Primary species was directed to result the commercial forest product, meanwhile the objective of border was to prevent the wild animal for disturbing the growth of primary species. The existence of edge plant aimed to enhance biodiversity in plantation forest. Then, Filler species was established to improve soil fertility. Our study verified the lowest number of species composition was found in Cajuput agroforestry.

3.2. Criteria and indicator for agroforestry evaluation

The list of criteria and indicator for agroforestry evaluation was developed from study literature, field survey, and communication with several experts in forest science (Table 10). The main objective of this instrument was to assess the best agroforestry systems for sustainable plantation forest management. Three kinds of criteria were selected to evaluate each agroforestry pattern, i.e. production, ecological, and social aspects. Every criteria had several indicators to help the assessment process. Six indicators were selected to represent the production aspect, while the ecological aspect had five indicators. Total indicators of social aspect reached eight elements.

Results of pairwise comparison demonstrated that the relative weight of production and social aspects were similar by approximately 0.43. Ecological aspect had the lowest relative weight ranging 0.14. It indicated that the priority of agroforestry development in Banyumas Forest Management Unit focused on solving production and social aspects. Nevertheless, the involvement of ecological aspect should be considered in evaluation process because it played an essential role in agroforestry systems. This study also documented there were some indicators that became the most priority in each criteria according to their relative weight such as site suitability, risk of erosion, and market availability. The higher priority meant those indicators had more influence on the sustainable of agroforestry systems.
Table 10. List of criteria and indicator for agroforestry evaluation

**Goal: The best agroforestry system for sustainable plantation forest management**

| Criteria | Indicator | Description | Relative Weight |
|----------|-----------|-------------|-----------------|
| 1        | Production aspects | 0.43 |
| 1.1.1    | Site suitability | 0.49 |
| 1.1.2    | MAI | 0.22 |
| 1.1.3    | Gum or leaves | 0.07 |
| 1.1.4    | Feed | 0.07 |
| 1.1.5    | Crops | 0.07 |
| 1.1.6    | Firewood | 0.07 |
| 2        | Ecological aspects | 0.14 |
| 2.1.1    | Plant diversity | 0.15 |
| 2.1.2    | Temperature and air humidity | 0.15 |
| 2.1.3    | Canopy closure | 0.25 |
| 2.1.4    | Run off | 0.08 |
| 2.1.5    | Risk of erosion | 0.37 |
| 3        | Social aspects | 0.43 |
| 3.1.1    | Market availability | 0.50 |
| 3.1.2    | Market demand | 0.14 |
| 3.1.3    | Price | 0.05 |
| 3.1.4    | Cultivation | 0.06 |
| 3.1.5    | Post harvesting | 0.03 |
| 3.1.6    | Production facilities | 0.08 |
| 3.1.7    | Human resource capacity | 0.05 |
| 3.1.8    | Finance | 0.08 |

3.3. The best priority of agroforestry systems in Banyumas Forest Management Unit
Assessment of production aspects obviously documented that each agroforestry pattern was developed in different site quality. Moreover, there was not an agroforestry pattern that completed all indicators (Table 11). For example, the production of leaves was only obtained from Cajuput agroforestry. While the production of gum was only recorded in pine agroforestry. Compared to other patterns, the Cajuput pattern had the greatest economic value of food crops. But, the highest commercial value of firewood was owned by Teak pattern.
Table 11. Overview of production aspects in each agroforestry pattern

| Agroforestry Systems | Site index | MAI (m$^3$ ha$^{-1}$) | Feed yield (IDR ha$^{-1}$) | Food crops (IDR ha$^{-1}$) | Firewood (IDR ha$^{-1}$) | Gum (IDR ha$^{-1}$) | Leaves (IDR ha$^{-1}$) |
|----------------------|------------|------------------------|-----------------------------|-----------------------------|--------------------------|---------------------|-----------------------|
| Pine                 | low        | 0.63                   | 262,500                     | 10,600,000                  | 187,500                  | 5,500,000           | -                     |
| Teak                 | medium     | 0.48                   | 218,750                     | 8,850,000                   | 312,000                  | -                   | -                     |
| Cajuput              | -          | -                      | -                           | -                           | -                        | 57,900,000          | - 880,000             |
| Clonal teak          | high       | 0.89                   | 131,250                     | 30,400,000                  | 62,500                   | -                   | -                     |

Results of ecological evaluation informed the highest number of species composition was observed in Clonal Teak agroforestry. However, this pattern had a high risk of erosion with low canopy closure. It was identified from the great light intensity on the forest floor. The level of light intensity had strong relationship with shade condition that was caused by canopy closure [13]. Our study revealed that the Teak agroforestry had a better microclimate condition than other patterns. It was indicated by the highest air humidity and the lowest surface temperature.

Table 12. Overview of ecological aspects in each agroforestry pattern

| Agroforestry systems | Number of Species | Temperature (°C) | Humidity (%) | Light Intensity (Lux) | Coef. Run Off | Risk of Erosion |
|----------------------|-------------------|------------------|--------------|----------------------|---------------|----------------|
| Pine                 | 3                 | 32               | 68           | 8380                 | 0.75 Low      | Low            |
| Teak                 | 4                 | 30               | 70           | 16070                | 0.60 Medium   | Medium         |
| Cajuput              | 2                 | 35               | 65           | 19770                | 0.50 High     | High           |
| Clonal teak          | 5                 | 32               | 65           | 18170                | 0.60 High     | High           |

This study identified the high market availability for each agroforestry systems. It was also supported by the great market demand for every products. Despite it had the medium price, Cajuput agroforestry had the higher market demand than other patterns. However, our results informed that most ideal value of social aspects were showed by clonal teak agroforestry which did not have low category in every indicator (Table 13).

Table 13. Overview of social aspect in each agroforestry pattern

| Agroforestry systems | Market Availability | Market Demand | Price | Cultivation | Harvesting | Post | Production Facilities | Human Resource | Finance |
|----------------------|---------------------|---------------|-------|-------------|------------|------|------------------------|----------------|---------|
| Pine                 | High                | Medium        | High  | Low         | Low        | Low  | Low                    | Low            | Medium  |
| Teak                 | High                | Medium        | High  | Medium      | Medium     | Medium| High                   | High           | Medium  |
| Cajuput              | High                | Medium        | Medium| Medium      | Low        | Medium| Low                    | Low            | Medium  |
| Clonal teak          | High                | Medium        | Medium| Medium      | Medium     | Medium| High                   | High           | Medium  |
Table 14. Result of agroforestry evaluation based on production, ecological, and social aspects

| Agroforestry Systems | Production | Ecological | Social | Total Score |
|----------------------|-----------|-----------|--------|-------------|
| Pine                 | 0.67      | 0.40      | 0.99   | 2.06        |
| Clonal teak          | 1.04      | 0.25      | 1.11   | 2.39        |
| teak                 | 0.70      | 0.27      | 1.11   | 2.08        |
| Cajuput              | 0.18      | 0.14      | 0.83   | 1.15        |

Summarize valuation of each agroforestry systems declared the greatest score for production aspect was occupied by Clonal Teak pattern. Meanwhile, the greatest rank for ecological aspect was assigned by Pine pattern. The biggest grade for social aspect was Clonal Teak and Teak pattern. However, the best agroforestry system should integrate the balance of production, ecological, and social aspects. From the accumulation of three aspects (Table 14), the best agroforestry system for supporting sustainable plantation forest management in Banyumas Forest Management Unit was Clonal Teak agroforestry. This pattern was most recommended because it had the greatest total score as the resultant of three essential aspects in agroforestry.

4. Conclusion

Agroforestry systems in Banyumas Forest Management Unit consisted of four patterns: Pine, Teak, Cajuput, and Clonal Teak. The best agroforestry system that was capable to integrate the balance of production, ecological, and social sustainabilities aspects was Clonal Teak pattern (2.39). The next position was occupied by Teak pattern (2.08) and followed by Pine pattern (1.26). The Cajuput pattern was the last position (1.15), and therefore it was not recommended for agroforestry systems in this area.

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