Suitability criteria of land characteristics related to Eucalyptus pellita production

D Nadalia1*, A Sutandi1 and B Nugroho1

1 Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Indonesia

*Email: desitnh@apps.ipb.ac.id

Abstract. Existing land suitability criteria are generally based on empirical data relative to land characteristics estimates and have not been related to production estimates. This study aimed to arrange land characteristics suitability related to Eucalyptus pellita production by the boundary line method approach. Soil samples, soil characteristics, and actual production of the tree were taken from districts at PT. Arara Abadi, Riau. A relationship between land characteristics and plant production was plotted in the scatter diagram. The data scatter confined by boundary lines consists of one or two lines of simple linear regression equations. The intersection between boundary lines equations with the bulkhead production on the x-axis (soil characteristics) derived land characteristics suitability criteria. The results showed that the optimum land characteristics to support maximum productivity of E. pellita were sandy clay loam, sandy clay, or loamy sand soil texture, pH 4.0 - 4.7, base saturation > 7.51%, organic C > 1.10%, Al saturation < 37%, total N > 0.08%, available P > 4.7 ppm, exchangeable K > 0.03 cmol (+) kg−1, and slope < 18%. The criteria were then validated on the field and suggested that the land characteristics suitability criteria were about 70% valid.

1. Introduction

Industrial Timber Plantation (ITP) is overgrowing in tropical countries. This phenomenon causes the supply of wood from natural forests are decreasing, thus encouraging the development of ITP for the wood processing industry program, mainly pulp and paper. The initial objective of plantation forest development was to rehabilitate critical forest areas. Plantation forests were then directed as raw materials for the forestry industry to replace natural forests. The types of plants widely developed by ITP are fast-growing species to accelerate forest productivity and provide sufficient wood for production, one of which is Eucalyptus pellita [1]. Eucalyptus pellita (E. pellita), including the Myrtaceae family, which one of the priority species for ITP because fast-growing species with a straight stem and a high dense canopy, highly tolerant to a variety range of climates, soil types, and the wood can be used as raw material for pulp and paper [2][3][4]. E. pellita can be used for reforestation efforts in places with infertile soil conditions [5].

Although these types of plants can grow in various soil types and do not require growing conditions or fertile soil, the production of E. pellita was correlated with soil properties. [6] stated that regular fertilization applications could increase the volume and biomass in the eucalyptus stand. The results showed that adequate fertilization could increase the productivity of E. pellita, about 38% in Spain and 15% in Brazil [7][8]. The use of fertilizers by soil characteristics has a role in sustainable wood production. Many companies apply the same fertilizer amount for the second fertilizer and subsequent
so that fertilization is inefficient. This way causes fertilization is not done using a specific location approach [9]. The use of land that is not suitable for its capabilities can cause land damage and its environment, and it can also cause poverty and other economic problems [10].

The boundary line method is a method for determining the productivity of a commodity. A dataset describing the relationship between production and nutrient content or land characteristics are plotted into a scatter diagram [11]. The higher the production, the narrower the distribution of nutrient content. The higher the nutrient content, the higher the output to a certain level, then the production decreases again with the higher the nutrient content. Such descriptions are beneficial in diagnosing the possible maximum output consistent with any value of the growth factor that can be determined. [12] used boundary line analysis to examine the limiting effects of soil organic carbon, pH, K, and Fe on sorghum yield. [13] used the boundary line model to assess how the water-filled pore space fraction of soils affect nitrous oxide emission's potential rate. In the research [14], boundary line models correlate wheat yield with P, K, and Mg concentrations in the soil.

Proper land management for E. pellita can provide high productivity and create sustainable forests by attention to land suitability criteria. In general, existing land suitability criteria are still based on estimates of relative land properties and have not been linked to the estimated production. The land suitability criteria must be developed using the E. pellita plant production approach through the Boundary Line Method to achieve the production potential. Based on this description, the purpose of this study is to arrange the criteria for the suitability of land characteristics associated with the production of E. pellita.

2. Materials and method

The research includes secondary data collection from 5 districts, namely Rasau Kuning, Sorek, Malako, Nilo, and Duri I at PT. Arara Abadi, Riau, and primary data collection in 4 districts, namely Gelombang, Rasau Kuning, Tapung, and Duri II at PT. Arara Abadi, Riau. The research method used is the exploratory survey method. The secondary data collected was land characteristics data (texture, cation exchange capacity/ CEC, Al saturation, total N, available P, organic C content, soil pH, base saturation, and slope), plant growth, and productivity parameters (wood volume). The secondary data comes from collaborative survey research between the Department of Soil and Land Resources, IPB, and PT. Arara Abadi, Riau, in 2011. This data is used to compile criteria for the suitability of land characteristics.

Primary data were obtained by taking soil samples by dividing one district into several smallest management units (SMU) depending on the land's homogeneity. There are several blocks or compartments in one district and at least one block, then the block that best represents the SMU or the most central block with an area of 25 or 50 ha was selected. In the block, a 1000 m$^2$ area was chosen that best represented the observation and sampling location. Each location observed plant diversity and soil properties, the number of plant samples observed at each site was ten trees from 1000 m$^2$.

Observations were conducted on plant height and stem diameter, soil morphological properties, number of dead plants in 1000 m$^2$, and plant age. The following equation calculated the volume of wood.

\[
E. \text{pellita wood volume (EP 05)} = 1667 \times \frac{(DBH^2 \times H)}{23163.87 + 149.03 \times DBH} \times \frac{(% \text{SR})}{100} \tag{1}
\]

\[
E. \text{pellita wood volume (EP 077)} = 1667 \times \frac{(DBH^2 \times H)}{24256.55 + 296.15 \times DBH} \times \frac{(% \text{SR})}{100} \tag{2}
\]

Note: DBH: stem diameter at breast height (cm), H: plant height (m),

\[
\% \text{SR: survival rate (100-% dead plants)} \tag{3}
\]

After being observed, soil samples were taken for soil analysis. The number of soil samples taken to validate the criteria from the whole district is ten samples. For each unit of observation land, soil samples
were taken at a layer depth of 0-30 cm. The physical and chemical properties analysis consisted of texture, Cation Exchange Capacity (CEC), pH in H₂O and KCl, organic C, total N, available P, total P, Base Saturation (BS), and exchangeable Aluminium (Al). The texture using the pipets method. The CEC and quantification of the bases exchanged (Ca, Mg, K, and Na) were extracted with 1 N NH₄OAc pH 7.0, K, and Na by flame photometry, and Ca and Mg by Atomic Absorption Spectrophotometer. The pH in H₂O and KCl (1:1 weight) was determined by the glass electrode method. Walkley and Black method determined the organic C content. The total N content was determined by the Kjeldahl method. The available P content was determined by the Bray-I method. The total P content was extracted with HCl 25%, and exchangeable Al was determined by the titration method.

The calibration of production was conducted because the plant samples were not of the same age. The production (wood volume) of the plants was first calibrated by age so that the production data of each sample can be compared with one another [15]. Production in the formulation of land suitability criteria for E. pellita plants are relative production.

\[
\text{Relative production} = \frac{Y_{\text{calibrate}}}{Y_{\text{calibration maximum}}} \times 100\% \quad (4)
\]

Note: \( Y = E. \text{pellita production} \)

The land suitability ranges of S1, S2, S3, and N were defined by the boundary line method. The distribution diagram of the relationship between relative production and land characteristics wrapped the outer boundary. The line is in the form of one or two simple linear regression equation lines (simple regression) built from the farthest points of the data distribution of the relationship between land characteristics and relative production. The selected outer boundary pattern is logical and has the highest determinant coefficient (R²) [16]. The projection of the intersection between the boundary lines and the production bulkhead on the x-axis (land characteristics) is a criterion for land suitability. The production bulkhead used for S1 and S2 classes refer to [17], namely S1 land suitability class (very suitable) with an outstanding production level is > 80% of the maximum production and the S2 land suitability class (moderate suitable) has a production level good (60-80% of the maximum production). In this study, class S3 (appropriate to marginal) with medium production levels used the production interval from BEP (break-even point) of E. pellita, namely 29.5-60% of the maximum production, while for class N (unsuitable) with low production levels, namely lower than BEP (<29.5% of the maximum production).

If the land suitability for E. pellita is under BEP, then it is not profitable. The validation test was conducted on the land suitability criteria generated through the applied analysis (ground check) on plant productivity data and land characteristics. The used test was carried out on ten samples by collecting primary data for both production and soil properties. After that, land suitability assessments were conducted on several land characteristics data using the principle of limiting factors [18].

3. Results and discussion

3.1. Soil characteristics in the study area
Secondary data of soil characteristics had been assessed qualitatively based on the [19] can be seen in [20] research. General description of soil characteristics as a whole in the research location (Rasau Kuning, Sorek, Malako, Nilo, Duri I, Tapung, Gelombang, and Duri II districts), namely the texture of sandy loam to sandy clay loam. The sand content in all districts was above 50%, with a clay content of around 20%. Soil reactions (pH) generally very acid with a general pH below 4.5, except the soils in Gelombang, Tapung, and Duri II districts had an acid reaction. The average Al saturation value was classified as a very high category. The soil organic C levels, total N, and available P in the study location varied from very low to very high. The average was low (Sorek, Tapung, Gelombang, and Duri II districts) to high (district Rasau Kuning and Nilo). Ca, K, and Na levels were very low to low, while the average Mg content was very low. The CEC of the study location was, on average, classified as very
low to low, and the value of BS was generally classified into the very low category except in the Rasau Kuning district, which was low.

3.2. Formulation of land characteristics suitability criteria
The suitability criteria of land characteristics were developed from the correlation between land characteristics and plant production. The plant production used is a production that has been calibrated based on the plant's age [20].

3.3. Relationship of the *E. pellita* production with root media
The relationship between the relative production of *E. pellita* and root media, which includes the percentage of sand and clay, is presented in Figure 1. It illustrates that the higher of sand and clay content, the higher the production, but then decreases again with the higher the sand and clay content. After that, the pattern was made a boundary line model that wraps the relationship data. The chosen equation model is the one that best fits the outer data distribution by selecting the highest coefficient of determination.

![Figure 1. Relationship of relative production with sand and clay fractions](image)

The first outer boundary line (1) determines the value of the lowest class boundary, while the second of the line equation (2) defines the value of the highest class boundary. The boundary line results indicate that *E. pellita* can produce a sand content of 40.97-81.74% optimally in the soil texture. High sand content > 81.74%, the soil's ability to absorb and exchange cations were low, which causes low nutrient availability. In these conditions, the plant production will decline because *E. pellita* is a plant that requires relatively large amounts of nutrients. The same thing happens if the higher the clay content, the lower the production. The clay content is too high (> 35%), causing the penetration of plant roots to be inhibited so that the plants will generally be disturbed in their growth.

3.4. Relationship of the *E. pellita* production with nutrient retention
Some of the soil characteristics related to the soil properties' nutrient retention include soil pH, organic C, and BS. The outer boundaries of the relationship between relative production and soil characteristics are shown in Figure 2.

This equation shows that an increase in pH will be followed by an increase until optimum production, after which the production level will decrease along with the subsequent increase in pH. The outer boundary equation line for organic C has a polynomial pattern, with a trend for production to increase with increasing organic C levels up to a certain point. Based on the outer boundary line equation, the higher the BS, the higher the production. The results showed that *E. pellita* could produce optimally at pH <5.0. The increased soil acidity level causes BS to be low, but production can increase with higher BS to a certain point. *E. pellita* can produce very well at levels of organic C > 1.10%. Low of organic C at the study area because the litter's mass under the *E. pellita* stands has a low decomposition process.
3.5. **Relationship of the E. pellita production with toxicity**

The toxicity that affects the increase in production is Aluminum saturation (Al). The outer boundary line of the data on the relationship between relative production and Al saturation is shown in Figure 3.

![Figure 3. Relative production relationship with Al saturation](image)

This line shows the trend of decreasing production with increasing Al saturation. High Al saturation can inhibit primary root growth and inhibit the formation of lateral roots. Thus, if root growth is stunted, the root system is disrupted, which results in inefficient roots absorbing nutrients, which can reduce plant productivity.

3.6. **Relationship of the E. pellita production with available nutrients**

The boundary line equation from the distribution of data on the relationship between relative production with total N, available P, and exchangeable K presented in Figure 4.
The line equation for the relative production relationship data's outer boundary with the total N content has a logarithmic pattern. A trend for production increases with increasing total N levels. The levels of total N, available P, and exchangeable K at the study sites were generally low, so the land suitability class S1 with outstanding production levels were >0.08%, >4.71 ppm, and >0.03 cmol(+)kg⁻¹, respectively. Therefore, it is necessary to improve nutrient management so that E. pellita can produce optimally. N, P, and K nutrients are essential nutrients that are needed by plants. According to [21], sufficient N needs will support plants' vegetative growth, such as leaves, stems and roots, while sufficient P nutrients can play a role in accelerating and strengthening plant growth. The availability of potassium nutrients in the soil influences protein and carbohydrates' formation, thereby determining plant stem diameter [22].

3.7. Relationship of the E. pellita production with terrain conditions
The relationship of relative production with terrain conditions (slopes) is shown in Figure 5.

Figure 4. Relative production relationship with total N, available P, and Exchangeable K

Figure 5. Relative production relationship with slope
The slope is an important factor because it determines soil nutrients' movement in dissolved nutrients by surface runoff. Steep slopes are easily eroded, so the nutrient and water content is low and can reduce plant productivity.

3.8. Land suitability criteria for *Eucalyptus pellita*

Based on the projection of the relative production bulkhead's intersection to the outer boundary lines of several land characteristics, the land suitability criteria for *E. pellita* were obtained, which are presented in Table 1.

| Land characteristics | S1       | S2       | S3       | N       |
|----------------------|----------|----------|----------|---------|
| Root Media           |          |          |          |         |
| - Sand (%)           | 40.97-81.74 | 17.67-40.97 | <17.67   | >17.67  |
| - Clay (%)           | 10-31.73  | 2.08-10  | <2.08    | >2.08   |
| Texture              | Sandy clay loam, sandy loam, loamy sand | Loam, sandy clay, silty loam | Clay, sand, silt |
| Nutrients Retention  |          |          |          |         |
| - pH                 | 4.0-4.7  | 3.7-4.0  | <3.7     | >3.7    |
| - Base Saturation (%)| >7.51    | 4.2-7.51 | <4.2     | >4.2    |
| - Organic C (%)      | >1.10    | 0.85-1.10 | <0.85    | >0.85   |
| Toxicity             |          |          |          |         |
| - Al Saturation (%)  | <37      | 37.90    | >90      |         |
| Available Nutrients  |          |          |          |         |
| - Total N (%)        | >0.08    | 0.02-0.08 | <0.02   | >0.02  |
| - Available P (ppm)  | >4.71    | 2.94-4.71 | <2.94   | >2.94  |
| - Exchangeable K (cmol(+)/kg) | >0.03 | 0.01-0.03 | <0.01 | >0.01 |
| Terrain Conditions   |          |          |          |         |
| - Slope (%)          | <18      | 18.25    | 25-31    | >31     |

The land suitability criteria resulted from this study were built based on empirical data in the field. In contrast, the existing land suitability criteria [23] for *Eucalyptus grandis* were only based on plant requirements. The land suitability criteria resulting from this study are expected to be appropriate with the types of plants and local climatic conditions. The land suitability criteria can provide an overview of the expected production potential compared to the existing land suitability criteria, which are generally based on estimates of relative land characteristics. However, this study's land suitability criteria cannot be applied to a broader scale of location or are still site-specific. Besides, it is necessary to make periodic observations of land characteristics because some land characteristics are dynamic to change.

3.9. Validation test results

The validation test was conducted to assess the suitability of the resulting land characteristics with relative production criteria. Samples were used for validation, are excluded from generating criteria model. The land suitability criteria model is valid if the assessment results using the land characteristics criteria are the same as the evaluation results based on the production criteria.

Based on the validation test (Table 2), the resulting land characteristics suitability criteria have a validation value of 70%. It means that as much as 70% of the data tested is valid or following the resulting criteria. It is attempted to take soil samples for validation to spread from outstanding production to low production. However, the research results showed that production covers from good to medium production. The relative production of *E. pellita* in ITP is, on average good production level or land suitability class S2 (relative production 60-80%) and medium production level or S3 land suitability class (relative production 60-29.5%).
### Table 2. Results of the validation test for land suitability criteria of E. pellita

| Districts                  | Relative Production (%) | Land Suitability Class Based on Relative Production | Based on Land Characteristics Respectively | Based on Land Characteristics Overall | Validation Test |
|----------------------------|-------------------------|------------------------------------------------------|-------------------------------------------|-------------------------------------|-----------------|
| Gelombang/1 01             | 30.81                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S2 S1 S2           | 0               |
| Rasau Kuning/80A           | 43.29                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S3 S1     | 1               |
| Rasau Kuning/175           | 58.03                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S3 S1 | 1               |
| Rasau Kuning/583A          | 51.66                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S3 | 1               |
| Tapung/52 A01              | 47.07                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S2 | 0               |
| Tapung/52 B                | 51.41                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S3 S1 | 1               |
| Tapung/206                 | 71.39                   | S2                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S1 | 1               |
| Duri II/341 A02            | 76.78                   | S2                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S1 | 1               |
| Duri II/256 B01            | 45.47                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S1 | 1               |
| Duri II/362                | 51.03                   | S3                                                   | S1                                        | S1 S2 S1 S3 S1 S1 S1 S2 S1 S1 S1 S1 | 2               |

Note: 1 = valid; 0 = not valid

Some soil samples are invalid because there are several factors, namely:

- Many land characteristics affect plant productivity (wood volume). Only a few land characteristics are used, so several other land characteristics affect crop production, but these criteria are not accommodated. It allows for bias between production and land characteristics that have been determined in the built criteria.

- The possibility of different crop management with other treatments causes different production, in which the level of crop management was not included in this study.

### 4. Conclusion

The optimum land characteristics to support maximum productivity of E. pellita were sandy clay loam, sandy clay, or loamy sand soil texture, pH 4.0 - 4.7, base saturation > 7.51%, organic C > 1.10%, Al saturation < 37%, total N > 0.08%, available P > 4.7 ppm, exchangeable K > 0.03 cmol (+) kg\(^{-1}\), and slope < 18%. The criteria were then validated on the field and suggested that the land characteristics suitability criteria were about 70% valid.

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