

Estimating the age of oil palm trees using remote sensing technique

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Abstract. One of renewable energy that can be converted into electricity is biomass. Biomass energy or bio energy is the largest source of domestic renewable energy in Indonesia. Since palm oil development is rapidly increasing, Empty Fruit Bunch (EFB) and Mesocarp Fiber (MF) are becoming the highest contributor of oil palm waste. Understanding biomass waste potential is very important for further utilization. Remote sensing technique can be used to detect oil palm trees age based on the canopy density and to estimate the amount of EFB in further analysis. In this research, the percentage of canopy density of oil palm trees/stands depends on their ages and the age is divided into four classes; seeds (<3 years old; <10%), young (3-8 years old; 10-40 %), teenage (9-14 years old; 41-80 %), and mature (15-25 years old; >80 %).

1. Introduction

Currently, most countries depend on fossil fuels such as petroleum, natural gas and coal as the main source to generate electricity. Depletion of fossil fuels has been causing the increasing price of crude petroleum and demanding an alternative energy resource which is renewable and environment-friendly. Renewable energy such as biodiesel has the potential to replace petroleum-derived transportation fuel in the future. Biodiesel is defined as the mono-alkyl esters of long-chain fatty acids derived from vegetable oils such palm oil, rapeseed and soybean [1]. The energy output of oil palm is almost three times higher compared to soybean and rapeseed oil [2]. Moreover, other products are also produced from oil palm such as empty fruit bunch (EFB) fibers, shells, fronds, and trunk.

Palm oil is the largest agricultural industry in Indonesia. The total of harvested oil palm area grew from 4.1 million ha in 2006 to an estimated 8.9 million ha in 2015 [3]. According to [4], Indonesia is estimated to have produced 570 million tons of oil palm biomass, among which 299 million tones is OPF (oil palm fronds), 134 million tones is OPT (oil palm trunk), and 28 million tones is EFB (empty fruit bunches). It means that the potential source for renewable energy especially from oil palm was abundant. In addition, one of the important factors influencing fruit bunches production is the age of oil palm trees. According to [5] the data of oil palm trees age can be used in precision farming. Information about oil palm trees age and their spatial distribution is very useful in organization or management of oil palm plantation and one of important variables affecting profit.

On the other hand, lack of information about the age of oil palm trees and changes; also their spatial distribution is mainly problem for energy planning. According to [5], collecting age data of oil palm trees especially on a large area or regional scale is time consuming and costly. Remote sensing provides an effective and efficient approach for oil palm monitoring including the age of oil palm trees. Remote sensing has been widely proven to be essential in monitoring and mapping land use and land cover (LULC), including forest and plantation area [6]. Geospatial data derived from remote sensing can be easily integrated in geographic information system (GIS) for further analysis.



Our study, which is aimed at utilizing optical remote sensing data for oil palm plantation management including mapping, estimation of fruit bunch production and energy potential for electricity, has just been started and is in the preliminary study. In this paper, we focus on investigating the age of oil palms based on Landsat 8 OLI. The study area is the oil palm plantations areas in Cimulang, Bogor Indonesia.

2. Material and Methodology

The methodology consist of collecting Landsat 8 OLI and inventory data on the study area; digital processing of Landsat 8 OLI including of advance vegetation index (AVI), bare soil index (BSI), shadow index (SI), and thermal index (TI); principle component analysis; and performing relationships analysis between canopy density (FCD) and age of oil palm trees. Generally, the methodology on this study can be seen on figure 1.

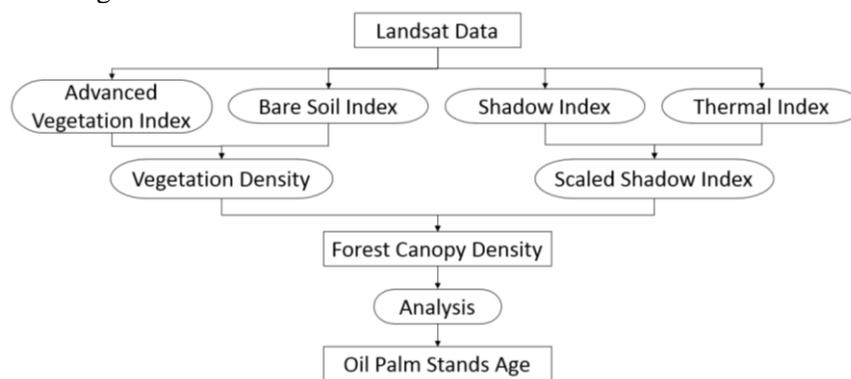


Figure 1. Methodology of estimation of oil palm trees age.

2.1. Data Collection

In this research, we used Landsat 8 OLI path/row 122/065 (Figure 2) that was acquired on August 17, 2016. Landsat 8 OLI consist of 11 bands with four visible bands, four infrared bands, one panchromatic, and two thermal bands. The authors also collected field data about age, canopy density, and yield of fruit fresh bunches (FFB) in the study area, which was based on correlation between canopy density class and age class. Composite band 543 of Landsat 8 was employed to delineate oil palm plantation area. This band utilizes near infrared band (NIR) to detect vegetation especially for oil palm trees.

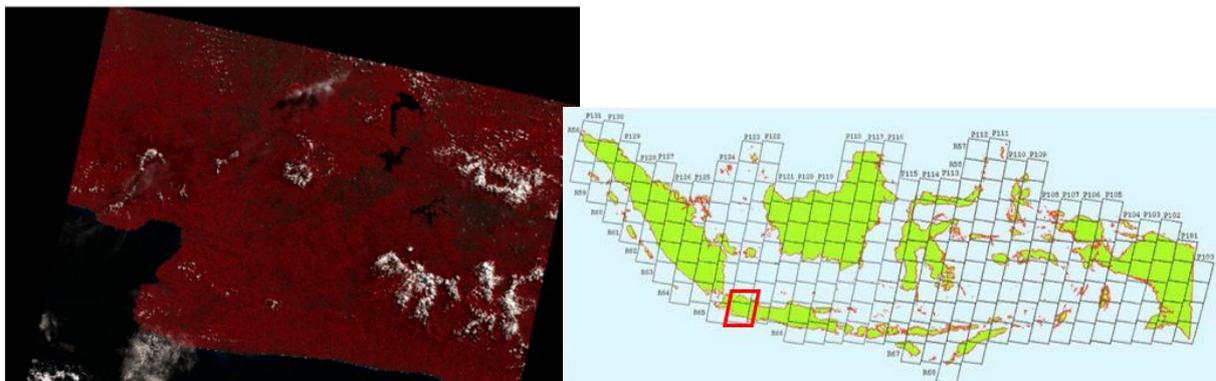


Figure 2. Landsat 8 OLI path/row 122/065.

2.2. Image Processing

The age of oil palm trees was predicted using remote sensing technique based on canopy density of oil palm trees. Forest canopy density (FCD) was utilized as essential method to estimate stand age. This model involved bio-spectral phenomenon modelling and analysis utilizing data derived from four indices as follows:

- Advanced Vegetation Index (AVI)
- Bare Soil Index (BSI)
- Shadow Index (SI)
- Thermal Index (TI)

The result of four indices integration in this modelling is percentage of canopy density in each pixel. Zero percent is no vegetation and 100 percent is very high density.

2.2.1. Advanced Vegetation Index (AVI). This indices was used to measure green vegetation. In remote sensing field, healthy vegetation is characterized by high absorption and low reflectance in visible region. On the other hand, they will have low absorption and high reflectance in near infrared wavelength. AVI has been calculated using Equation 1.

$$AVI = (B5 * (1 - B4) * (B5 - B4))^{1/3} \quad (1)$$

The value of AVI ranged from minus one (-1) to plus one (+1) for each pixel which is no vegetation at zero, highest possibility of green leaves if close to +1, and non-vegetation surface or water for negative value.

2.2.2. Bare Soil Index (BI). Similar to AVI, BI is normalized indices that used to separate vegetation and their background. This indices have opposite result with AVI because this is used to detect soil, it means near infrared wavelength have low reflectance due to absorption by soil moisture. BSI has been calculated using Equation 2.

$$BSI = \frac{(B6 + B4) - (B5 + B2)}{(B6 + B4) + (B5 + B2)} \quad (2)$$

The value of BSI will have ranged from zero to 200 for each pixel which is highest possibility of green leaves or canopy density if close to zero and non-vegetation surface or bare soil if the value close to 200.

2.2.3. Shadow Index (SI). Canopy density can also be detected by shadow characteristics derived from spectral information and thermal information of the forest shadow. In remote sensing, shadow characteristics are defined by shadow index (SI) as spectral information because crown arrangement of oil palm trees will have shadow pattern which affects spectral responses. The young age will have low value of SI compare to the old oil palm trees. The shadow index is derived from the low radiance of visible bands of Landsat 8 OLI image [7]. SI has been calculated using Equation 3.

$$SI = ((1 - B2) * (1 - B3) * (1 - B4))^{1/3} \quad (3)$$

2.2.4. *Thermal Index (TI)*. This index was used to check if the black or shadow is real shadow not black soil. Land surface that is close to shadow will have low temperature because leaf surface blocks and absorbs energy from the sun. The source for this index comes from thermal information infrared band of Landsat 8 OLI data (band 10 and band 11). TI has been calculated using Equation 4 and Equation 5.

$$L_I = M_I * Q_{cal} + A_I \quad (4)$$

where:

- LI = Top of Atmosphere (TOA) radiance in (Watts/m²*srad*um)
MI = Band specific multiplicative rescaling factor from the metadata (RADIANCE_MULTI_BAND_x, where x is the band number)
Qcal = Quantized and calibrated standard product pixel values (DN)
AI = Band specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

$$T = K_2 / \ln\left(\frac{K_1}{L_I} + 1\right) \quad (5)$$

where:

- T = at-satellite brightness temperature (OK)
K2 = band specific thermal conversion constant from metadata (K2_CONSTANT_BAND_x; where x is band number 10 or 11)
K1 = band specific thermal conversion constant from metadata (K1_CONSTANT_BAND_x; where x is band number 10 or 11)
LI = product of the radiance formula

2.2.5. *Forest Canopy Density (FCD)*. FCD value was shown as percentage of canopy density. Integration of four indices was used to calculate this model. AVI and BSI were integrated to produce vegetation density (VD). Processing method employed principal component analysis. This method showed that AVI and BSI have high negative correlation. Higher AVI value has low value in BSI because canopy density or vegetation cover is high and no bare soil or open surface at there. After that, VD will be set in the percentage scaling from zero percent to a hundred percent point.

Another calculation is scaled shadow index (SSI) that was derived from integration of SI and TI. In areas where the SSI value is zero (low), this corresponds to oil palm plantation that have lowest shadow value or minimum canopy density, opposite with areas where the SSI value is 100 meaning have the high canopy density. VD and SSI were integrated to achieve FCD value with Equation 6.

$$FCD = (VD * SSI + 1)^{1/2} - 1 \quad (6)$$

For accuracy assessment and collected ground truth, the distance between classes were changed to the form below (Table 1):

Table 1. Distance between classes for accuracy assessment.

Class	Category	Density (%)
1	Water and Cloud (W&C)	-
2	No Forest (NF)	0-5
3	Low Forest (LF)	5-40
4	Middle Forest (MF)	41-70
5	Dense Forest (DF)	71-100

2.3. The Age of Oil Palm Tree

Forest canopy density (FCD) was used to estimate oil palm trees age with the assumption that older trees will have higher percentage of canopy density. The class number of stands age divided into 4 classes, according to oil palm classification from Plantation Education Agency of Indonesia. Correlation between oil palm trees age and canopy density was shown in Table 2.

Table 2. Correlation between oil palm tree age and canopy density.

Nr.	Class	Stands Age	% Canopy Density
1	Seed	0 - 3	< 10
2	Young	3 - 8	10 - 40
3	Teen	9-14	41 - 80
4	Mature	15 - 25	> 80

In this research, we have assumption if some variable was equal for all area such as soil type, planting pattern, type of fertilizer, and another plantation management, because this entire variable has big correlation with canopy. Other plantation management have big correlation with canopy density is pruning tree branches. Many plantations have this policy to keep the amount of sunlight in that plantation and it will make the dense of oil palm trees canopy will different compare with natural oil palm trees. In the future, field survey will be conducted to verify the model result.

3. Result and Discussion

3.1. Forest Canopy Density Model

Advanced Vegetation Index (AVI), Bare Soil Index (BSI), Shadow Index (SI) and Thermal Index (TI) were calculated using GIS software (QGIS 2.8.2 and Arc GIS 10.2) to obtain a canopy density percentage (%). This indicator was adopted to analyze remote sensing measurements to observe contains live green vegetation that was used to find canopy cover density. Oil palm canopy cover, also known as canopy coverage or crown cover, is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns [9] that was useful for distinguishing seed, young, teen, and mature old oil palm stands.

First step of image analysis was to obtain the value of AVI ranging from minus one (-1) to plus one (+1) for each pixel which was no vegetation at zero. The result of AVI in Cimulang area showed index range from 0.21 – 0.55 for each pixel with mean value at 0.44. This result showed that all of the research area was covered by vegetation.

The next step was BSI that it has opposite result with AVI because this indices was used to detect soil. The value of BSI ranged from zero to 200 for each pixel which had the highest possibility of green leaves or canopy density if close to zero and non-vegetation surface or bare soil if the value close to 200. The result of BI in Cimulang area showed index 58.79 – 97.86 for each pixel with mean value at 66.25. This result had same implication to AVI meaning that all of the research area was covered by vegetation or no bare soil.

The next step is vegetation density (VD) which is the procedure to synthesize AVI and BSI, because essentially, AVI and BSI have high negative correlation. Processing method employed principal component analysis and set the scaling of zero percent point and a hundred percent point. The result of VD in Cimulang area showed index 58.786 – 97.856 for each pixel with mean value at 66.25. Comparison of AVI and BSI, and VD was shown in figure 3. High value of AVI will have low value of BSI. The high value of AVI had high percentage in VD and this results show that AVI and BSI have negative correlation.

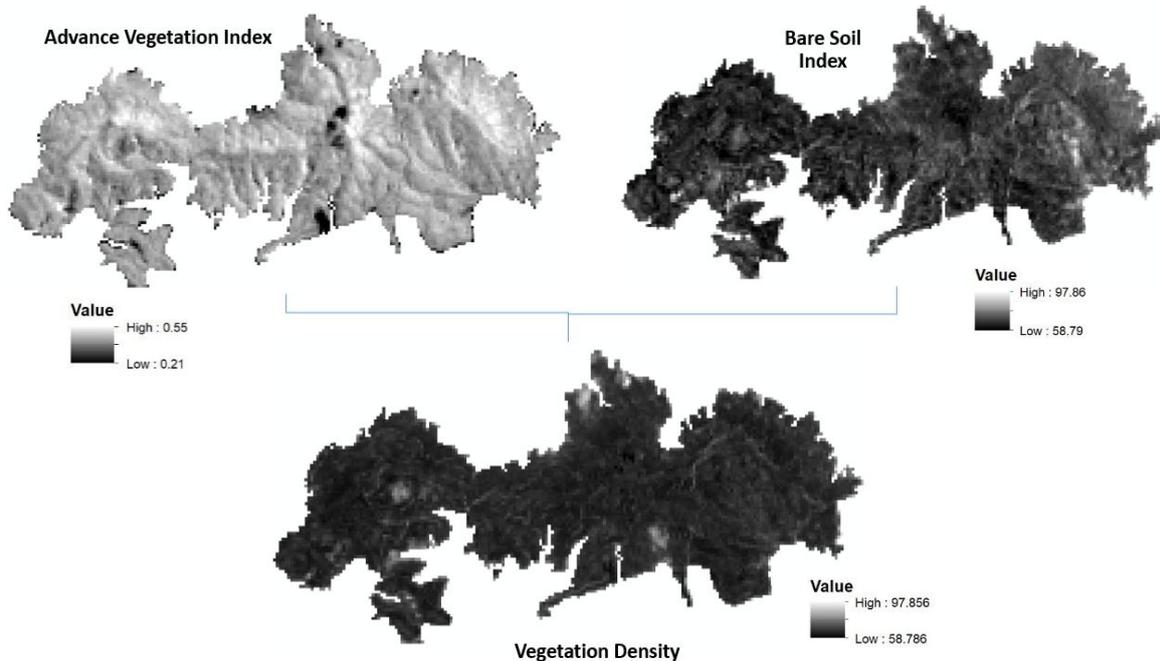


Figure 3. Procedure of VD mapping.

Canopy density can also be detected by shadow characteristics that were derived from spectral information and thermal information of the forest shadow. The result of shadow index (SI) shows the young stands have low value of canopy shadow index compared to the old stands age shadow. The result of SI in Cimulang area shows index 0.79 – 0.97 for each pixel with mean value at 0.96. This result shows that the research area was covered by vegetation and this result will be compared to thermal index.

Thermal index is used to check whether the shadow is real shadow or black soil. Land surface closed to shadow will have low temperature because leaf surface will block and absorb energy from the sun. The result of TI in Cimulang area shows ranges from 293.24 K – 295.56 K for each pixel with mean value at 294.15 K. This result shows the research area was covered by vegetation and showed by low temperature at that area.

Another calculation is scaled shadow index (SSI) that was derived from integration of SI and TI. In areas where the SSI value is zero low, this corresponds with oil palm plantation that have the lowest shadow value or minimum canopy density, opposite with areas where the SSI value is 100 that have high canopy density. The result of SSI in Cimulang area shows ranges from 79.73 – 97.42 for each pixel with mean value at 96.12. Comparison of SI, TI, and SSI will be shown in figure 4.

Figure 4 shows high value of SI and low value of TI. The high value of SI also have high percentage of SSI and this results show that the area with high value of SI was covered by vegetation and have low temperature.

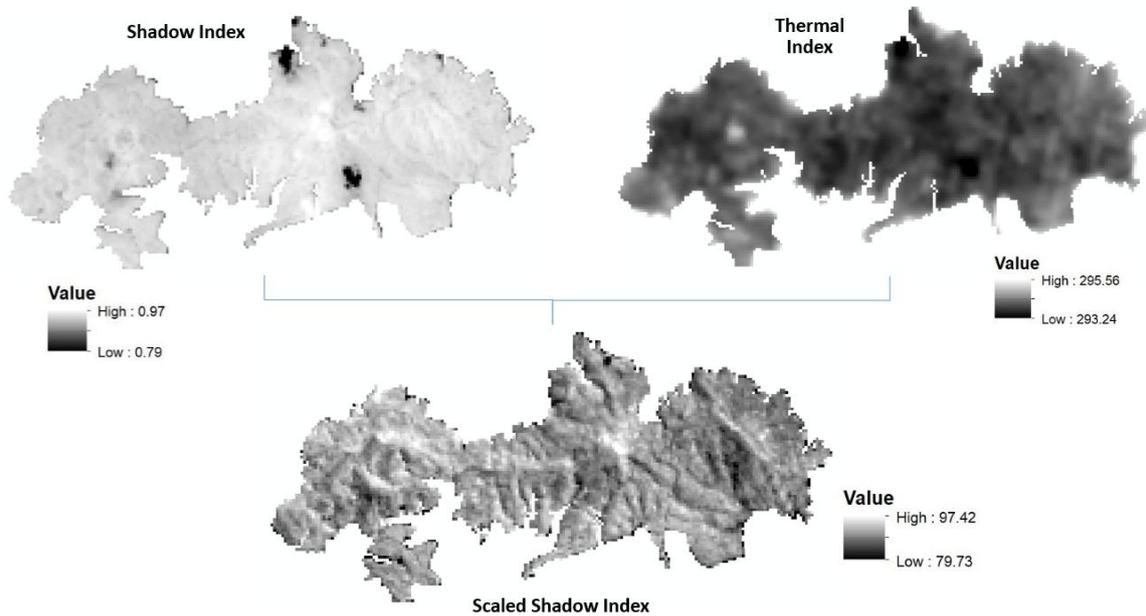


Figure 4. Procedure of SSI mapping.

The last step from this model is FCD that was obtained from the integration of VD and SSI. FCD percentage value have ranges from 0% to 100% meaning that 0% indicates this area is lack of coverage of the canopy and dominated by bare land. On the other hand, the area with greater percentage of the FCD value indicates more covered by canopy.



Figure 5. Forest canopy density.

The result of FCD in Cimulang area shows ranges from 74.66 – 94.79 for each pixel with mean value at 78.77 (Figure 5). Forest canopy density indicates that the area covered by vegetation with class of canopy density was Dense Forest (DF). The result from satellite image analysis shows that there is 100% dense forest cover in Cimulang area (figure 6).

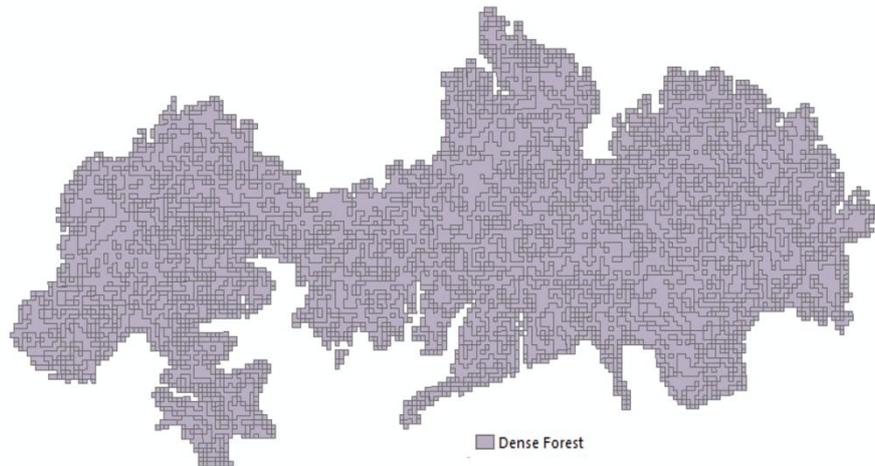


Figure 6. Class of forest canopy density.

3.2. Oil Palm Trees Age

Forest canopy density was used to estimate the age of oil palm trees with assumption older trees will have higher percentage of canopy density. Satellite image analysis shows the results for Cimulang area covers with FCD value ranges from 74.66 – 94.79 for each pixel. These results were used to estimate oil palm trees age (Table 2). This area consist of two classes of oil palm trees age i.e. teen with canopy density 41–80% and mature with canopy density more than 80%.

The result from satellite image analysis shows in Cimulang plantation teen old oil palm trees covers around 81.5% of that area, followed by mature oil palm trees with 18.5% or corresponding to 100 hectares. In this area we cannot find seed or young oil palm trees and it means no new plantation in this area.

The class number of stands age divided into 4 classes i.e. seed, young, teen, and mature. Table 2 shows that almost all of this class has small range of age difference such as seed class from 0 – 3 years old, young class from 4-8 years old, and teen from 9 – 14 years old. But, this condition is different for mature class where it has large range of age class from 15 – 25 years old. This condition was happened because, in this class, it was difficult to distinguish the mature (15-20 years) and old stands age (more than 20 years old). Characteristic from oil palm trees after 20 years old is different, even the length of canopy or steam leaves increases is equal with growing phases, but the direction of steam leaves will grow with smaller angle and tend to lead downwards.

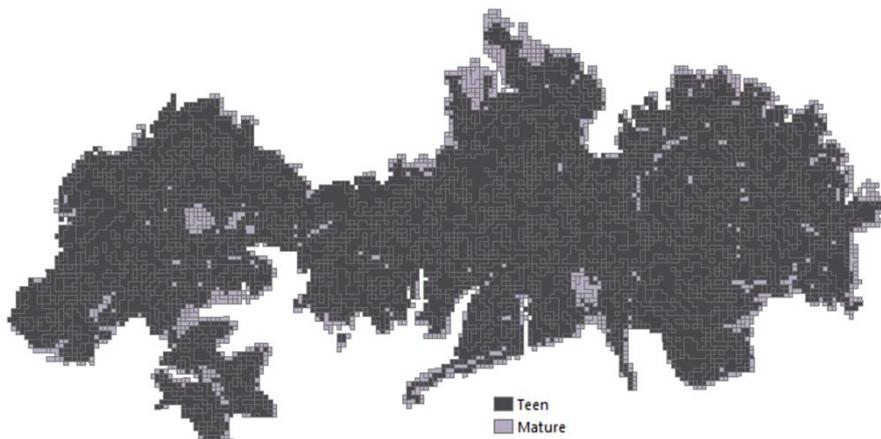


Figure 7. Class of oil palm trees age.

4. Conclusion and Future Work

Forest canopy density can be used to estimate the age of oil palm trees with the assumption that older trees will have higher percentage of canopy density. Result from this research is Cimulang plantation area consists of teen old oil palm trees covering around 81.5% of the area, followed by mature oil palm trees with 18.5% (100 hectares).

Remote sensing technique, especially using Landsat can be used to estimate oil palm trees age even though this method can only divide 4 classes i.e. seed, young, teen, and mature. There is a difficulty to distinguish the mature (15-20 years) and old stands age (more than 20 years old). This problem was happened because oil palm trees have steam leaves growing with smaller angle and tend to lead downwards after 20 years old.

Multi-temporal satellite image analysis of oil palm plantation area will also be conducted in the future. This step is very useful for monitoring and detailing information of oil palm trees age particularly to distinguish the mature (15-20 years) and old stands age (more than 20 years old).

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