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Article

Determining Oil Palm Stands Age Using Multi Temporal Images Analysis

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Abstract: In the oil palm industry, stands age is an important parameter to monitor the sustainability of cultivation, to develop the growth yield model, to identify the disease or stressed area, and to estimate the carbon storage capacity. This research is focused to estimate and distinguish oil palm stands age based on crown/ canopy density obtained using Forest Canopy Density (FCD) model derived from four indices as follows; Advanced Vegetation Index, Bare Soil Index, Shadow Index, and Thermal Index. FCD model employs multi temporal image analysis resulting four classes of oil palm stands age categorized as seed with FCD value of 29 - 56% (0 years), young with FCD value of 56 - 63% (1 - 9 years), teen with FCD value of 63 - 80% (10 - 15 years), and mature with FCD value of > 80% (> 15 years). Minimum canopy density value is 29% even in the zero years old indicates incomplete land clearance or the type of seed planted in the land.

Keywords: remote sensing, multi-temporal, landsat, age, canopy, FCD.

1. Introduction

Demand and research for renewable energy development have been intensified since the escalating price of crude petroleum in the recent years. Renewable energy such as biodiesel has the potential to replace fossil 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]. Palm oil is the second most traded vegetable oil crop in the world after soy, and over 90% of the world's palm oil exports are produced by Malaysia and Indonesia [2]. This biomass has high potential of turning into renewable energy. Empty Fruit Bunch (EFB) and Mesocarp Fiber (MF) is the highest contributor of oil palm biomass. Oil palm biomasses can be transformed into three types of biomass energy: i.e. bio-products, bio-fuels, and bio-power. The energy output of oil palm is almost three times higher comparatively to soybean and rapeseed oil [3].

Palm oil is the largest agricultural industry in Indonesia with the total harvested oil palm area grew from 4.1 million ha in 2006 to an estimated 8.9 million ha in 2015 [4]. Solid waste in crude palm oil industry can be predicted by the assumption of about 20% of Fresh Fruit Bunch (FFB) of oil palm [5]. It means the potential source for energy especially EFB is abundant. On the other hand, utilization of oil palm by product is not in a significant way. EFB, shells, and fibers as a solid waste in crude palm oil industry does not utilized as an alternative energy resources to generate electricity. Mostly, EFB will be treated as manure but this is not effectively reducing the number of solid waste in palm oil industry due to high cost and low density.

Oil palm stands age is an important parameter to be considered in palm oil industry which are commonly have an economical lifespan up to 25 years and the production starts about 2 years old and reach optimum production at the age between 6–10 years after planting [6]. Age also one of

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important factors to influence fruit bunch production. Therefore, it is essential to determine the age of oil palms because of the several reasons such as i) to monitor the sustainability of oil palm cultivation, ii) to develop the growth yield model, iii) to identify the disease or stressed area of oil palm plantation, and iv) to estimate the carbon storage capacity of the oil palm plantation [7].

Likewise, accurate and reliable information of oil palm production is very important and needed for oil palm management in making decision especially regarding information about plant quality, phenology, health, and yield prediction. Currently, all of oil palm information depend on traditional method of sample surveys in the field [5]. The lack information in oil palm management caused by the dependence of data collection on traditional method of sample surveys in the field that was not effective, cost and time consuming. One technique that can be used for monitoring and predicting EFB production in large scale area is remote sensing.

Several remote sensing studies have been conducted to estimate oil palm stands age. The researchers adopted some methodologies such as linear regression, object-based image analysis (OBIA) including by using various remote sensing data such as Landsat Thematic Mapper and Worldview-2. Phenology characteristics unique to a particular species (e.g., rubber, oil palm) and allow to differentiate from similar cover types such as natural forest, can be used as one approach to map plantations using optical data [8].

McMorrow [9],[10] adopted Landsat Thematic Mapper and linear regression method to estimate the age of oil palm plantations and found a better result at 1 -10 years old oil palm as compared to other age groups [7]. Single age classes also cannot be accurately estimated at the pixel level in this method. The use of generalized age classes (<5, 6-10, 11-15, >15 years) and post prediction averaging to stand age classes made the accuracy was improved, but errors remain unacceptably high, especially for old classes [10]. Srestasathiern and Rakwatin [11] proposed the use of vegetation index that much powerful in distinguish oil palm and non-oil palm objects.

Ibrahim et.al [5] also employed Landsat TM to estimate oil palm age and developed a regression model to distinguish age class using different variable such as vegetation indices and the leaf area index. The results indicated a high correlation of using Landsat TM and the relationship between Landsat TM bands and the age classes of the oil palm plantation. In addition, other factors such as canopy, chlorophyll, and ground reflectance can be used to distinguish oil palm stands age class. [7].

Different from two previous researchers, Chemura [12] adopted high resolution satellite imagery (Worldview-2) to investigate oil palm age. Object based image analysis (OBIA) method was conducted to identify the crown area resulting an empirical function. Estimating oil palm age from OBIA delineated crown area was showed that estimating oil palm age from this approach for the age of younger oil palm (less than 8 years) will overestimated and underestimated older stands.

Several studies were conducted using remote sensing technique especially Forest Canopy Density (FCD) model but most of them used for forest management and monitoring. Rikimaru, et.al [13] used this model to map tropical forest cover density. In 2006, [14] conducted research to estimate forest canopy density in a forest corridor linking the Himalayan middle mountains to the Royal Chitwan National Park in Chitwan district Nepal, and tried to compare FCD model with three other methods that are artificial neural network, multiple linear regression, and maximum likelihood classification. Akike and Samantha [15] studied Forest Canopy Density (FCD) model to estimate forest canopy density of the proposed deforestation site in Wafi-Golpu Project site, Papua New Guinea. Himayah, et.al [16] also conducted forest reclamation priority of natural disaster areas at Kelud Mountain, East Java using FCD Model.

The focus of this research is to estimate and distinguish oil palm stands age based on crown/ canopy density obtained from FCD model. Many factors can be used to explain the spectral response of vegetation including interaction of radiation with canopy. Corley (1973) [5] explained that light intensity below the canopy is important caused by oil palm canopy closure starts at 4 years-old stand. By 20 years-old, the change of leaflets horizontal angle becomes less and more vertical. This condition makes the canopy gap fraction is greater and the ground cover will have more contribution to light intensity below the canopy. Multi-temporal satellite image analysis of oil palm plantation area also has been performed in this research. This step is very useful for monitoring and detailing information of oil palm stands age, and to investigate their correlation with canopy density.

2. Materials and Methods

2.1. Study Area

Study area of this research is located at PT. Perkebunan Nasional (PTPN) VIII as national plantation company of Indonesia. PTPN VIII is one of national plantation companies of Indonesia that was established under Government Regulation no. 13 of 1996. Cikasungka farm is one of PTPN VIII farms located in Bogor District with total area around 3,500 ha. This farm has six division that are Cimulang, Cindali, Cikasungka, Toge, Bolang, and Cigelung. In this research, only three division that are Cimulang, Cindali, and part of Cikasungka with large area around 1,700 ha was chosen.

2.2. Datasets

In this research, we used Landsat satellite image time series path/ row 122/ 065 from 2003 until 2018 except 2011 caused by massive cloud coverage on the image data on the research area. The satellite images data consist of Landsat 7 ETM that was acquired on May 2nd, 2003; Landsat 5 that was acquired on April 29th, 2005; July 24th, 2007; and July 29th, 2009; also Landsat 8 OLI that was acquired on July 8th, 2013; August 17th, 2016; June 17th, 2017; and April 1st, 2018.

2.3. Forest Canopy density (FCD) Model

The age of oil palm stands was predicted using remote sensing technique based on canopy density. Forest canopy density (FCD) model 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), and Thermal Index (TI) [17]. 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.

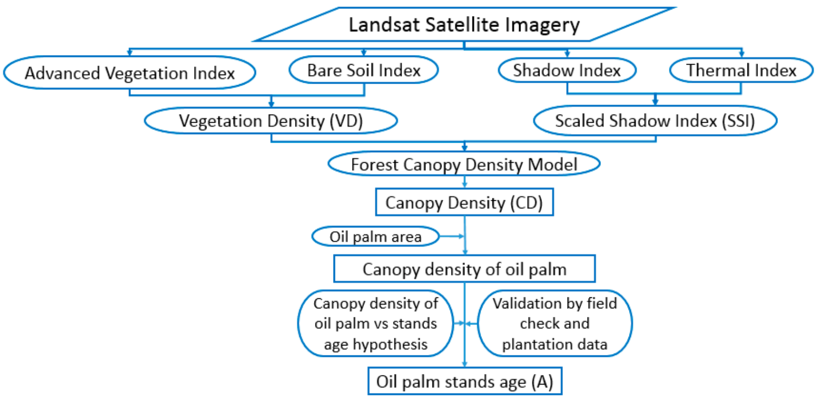

Figure 1. Forest canopy density model

Advanced Vegetation Index (AVI) 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 for Landsat 5 and 7ETM or Equation 2 for Landsat 8 OLI.

$$AVI = \left((B4 + 1) * (256 - B3) * (B4 - B3)\right)^{1/3} \quad (1)$$

$$AVI = \left((B5 + 1) * (65536 - B4) * (B5 - B4)\right)^{1/3} \quad (2)$$

Similar to AVI, Bare Soil Index (BI) is normalized indices that used to separate vegetation and their background. This index 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. BI has been calculated using Equation 3 for Landsat 5 and 7ETM or Equation 4 for Landsat 8 OLI.

$$\frac{(B5+B3)-(B4+B1)}{(B5+B3)+(B4+B1)}X100+100 \quad (3)$$

$$\frac{(B6+B4)-(B5+B2)}{(B6+B4)+(B5+B2)}X100+100 \quad (4)$$

The value of BI will have range of value 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.

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 5 for Landsat 5 and 7ETM or Equation 6 for Landsat 8 OLI.

$$SI = \left((256-B1)*(256-B2)*(256-B3)\right)^{1/3} \quad (5)$$

$$SI = \left((65536-B2)*(65536-B3)*(65536-B4)\right)^{1/3} \quad (6)$$

Thermal Index (TI) 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 band of Landsat 5 or 7 (band 6) and Landsat 8 OLI data (band 10 and band 11). TI has been calculated using Equation 7 and 8.

$$L_I = M_I * Q_{cal} + A_I \quad (7)$$

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)

$$T = K_2/\ln(\frac{K_1}{L_I}+1) \quad (8)$$

where:

T = at-satellite brightness temperature (0K)

K2 = band specific thermal conversion constant from metadata (K2_CONSTANT_BAND_x; where x is band number)

K2 = band specific thermal conversion constant from metadata (K1_CONSTANT_BAND_x; where x is band number)

LI = product of the radiance formula

Forest Canopy Density (FCD) value was shown as percentage of canopy density. Integration of four indices was used in the model to calculate canopy density. AVI and BSI was integrated to produce vegetation density (VD). The processing method employed principal component analysis. This result showed that AVI and BSI have high negative correlation. Higher AVI value have 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 to a hundred percent point.

Another calculation is scaled shadow index (SSI) derived from linear transformation of SI. In areas where the SSI value is zero (low) corresponds to oil palm plantation that have lowest shadow value or minimum canopy density, opposites with areas where the SSI value is 100, which means has high canopy density. VD and SSI were integrated to achieve FCD value using Equation 9. FCD was used to estimate oil palm stands age with the assumption that older stands will have higher percentage of canopy density.

$$FCD = (VD * SSI + 1)^{1/2} - 1 \quad (9)$$

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. It means only oil palm stands age have significantly contribute to canopy density differentiation. Oil palm 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.

Another assumption used in this research was non linier assumption [18][19] caused by the characteristic of oil palm stands after 20 years old is different, the diameter of the canopy or stem leaves increases is equal with growing phases, but the direction is different which stem leaves will grow with smaller angle and tend to lead downwards [20].

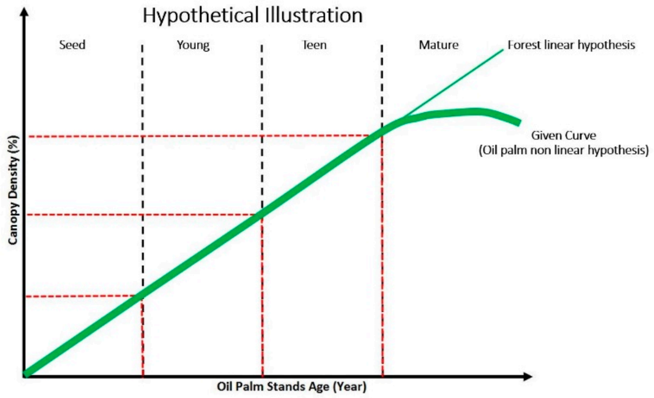

Figure 2. Correlation of canopy density with the age of oil palm trees

Multi-temporal satellite image analysis of oil palm plantation area also has been conducted in this research. This step is very useful for monitoring and detailing information of oil palm trees age and to know their correlation with canopy density.

3. Results

3.1. Single date image analysis

This research was conducted from April 2017 until May 2018 and divided into two research areas. Cimulang and Candali area was used as first area for field check. Based on image satellite analysis from Landsat 8 OLI acquisition date on August 17th 2016, FCD model showed value range from 49.4 – 74.6 % in this area. To evaluate the accuracy of FCD model, we conducted field check and divided into 5 class that are 0-20%, 20-40%, 40-60%, 60-80%, and more than 80% to make it easier to located sample point.

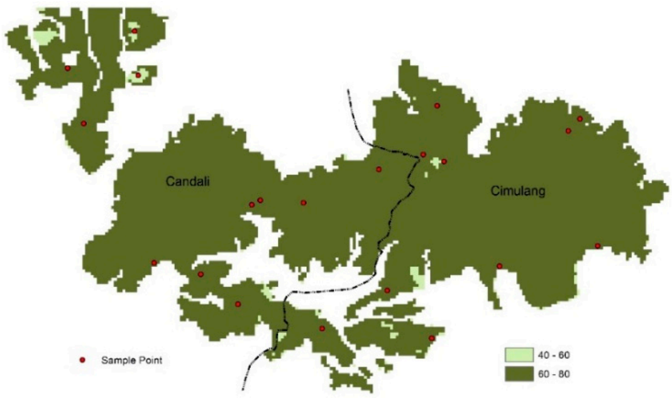

Figure 3. Canopy density of oil palm trees based on Landsat 8 OLI 2016 analysis

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Field surveys in Cimulang and Candali area was conducted on October 2017 with 21 sample points that was spread into two class that are 40-60% and 60-80%. In every sample point, we used drone to take pictures from the air with coverage area of area 30m x 30m, this was chosen to make sample area has similar size to Landsat 8 OLI pixel size. Based on the field check result, almost all Candali and Cimulang area was covered by class 60-80% of canopy density and only one area in the class more than 80% of canopy density. Two sample points with 40-60% of canopy density caused by the influence from cloud shadow and built up area. The result of accuracy test based on field check data in this area is accuracy 85.7% and shown in table 1.

Table 1. Accuracy test FCD model in Candali and Cimulang area

Classification data	Field Data						Total Row	Commission	User Accuracy
	0 - 20	20-40	40-60	60-80	>80				
0 - 20%	**0**						0	0	0
20-40%		**0**					0	0	0
40-60%			**0**	2	1		3	100	0
60-80%				**18**			18	0	100
>80%					**0**		0	0	0
						18			
Total Column	0	0	0	20	1		**21**		
Omission (%)	0	0	0	10	100				
Producer Accuracy	0	0	0	90	0				**85.71**

Cikasungka area was used as second area for field check. Based on image satellite analysis from Landsat 8 OLI with acquisition date on June 17th, 2017, FCD model shows in this area have value from 57.7 – 79.5 %, but only one pixel show value less than 60% of canopy dense.

Figure 4. Canopy density of oil palm trees based on Landsat 8 OLI 2016 analysis

Field surveys in Cikasungka area was conducted on March 2018 with 16 sample point that was only one class that is 60-80%. In every sample point, we used drone to took picture from the air with large area 30m x 30m, this was choose to made sample area have same size with Landsat 8 OLI pixel.

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Based on the result of field check, almost all of Cikasungka area covered by class 60-80% of canopy dense. One pixel in image analysis that was shown 40-60% of canopy dense caused by the influence from built up area.. The result of accuracy test based on field check data in this area had accuracy 100% and it was shown in table 2.

Table 2. Accuracy test FCD model in Cikasungka area

Classification data	Field Data						Total Row	Commission	User Accuracy
	0 - 20	20-40	40-60	60-80	>80				
0 - 20%	**0**						0	0	0
20-40%		**0**					0	0	0
40-60%			**0**				0	0	0
60-80%				**16**			16	0	100
>80%					**0**		0	0	0
						16			
Total Column	0	0	0	16	0		**16**		
Omission (%)	0	0	0	0	0				
Producer Accuracy	0	0	0	100	0				**100**

In the field check, we also tried to get secondary data such as planting years map. Based on the field data and secondary data, all of research area have planting years from 2002 until 2005 with distribution area was shown in Figure 5.

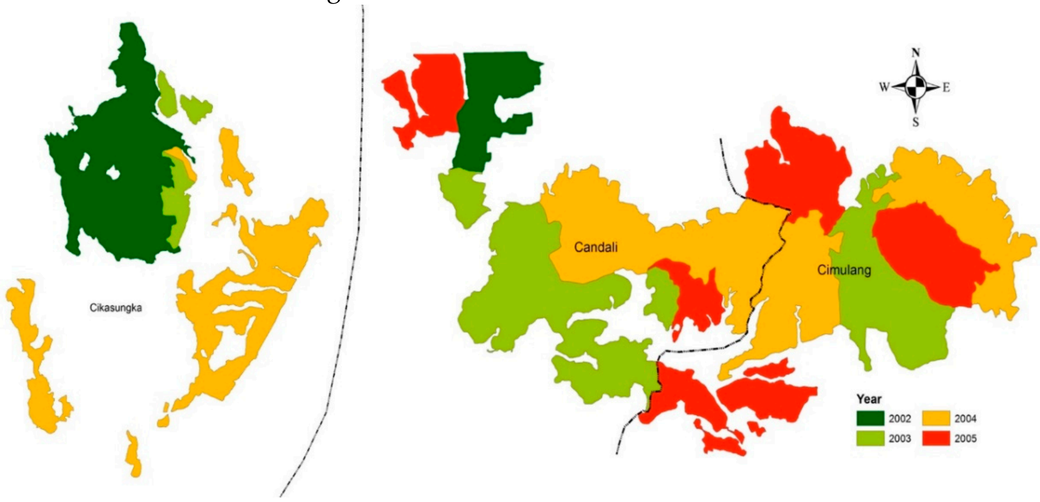

Figure 5. Planting years in research area

Based on planting year map and image satellite analysis, combining with non-linear assumption, we tried to classify oil palm trees age and their correlation with canopy density and the results was shown in table 3.

Table 3. Correlation stands age with canopy density

No	Class	Stands Age	% Canopy Density
1	Seed	0 - 4	0 - 11
2	Young	4 - 9	11 - 41
3	Teen	9-15	41 - 80
4	Mature	15 - 25	> 80

Source: Plantation Education Agency, 2013 with modification

3.2. Multi temporal image analysis

Multi-temporal satellite image analysis of oil palm plantation area also has been conducted as one step to evaluate and detailing information of oil palm trees age and to know their correlation with canopy density compare with single date image analysis.

The secondary data shown that planting years in research area started from 2002 until 2005 and all of area was planted during October until December or in wet season. Based on this information, we tried to analyze time series data which are acquisitioned during May 2003 until April 2018 which are consist of Landsat 7 ETM that was acquired on May 2nd, 2003; Landsat 5 that was acquired on April 29th, 2005; July 24th, 2007; and July 29th, 2009; also Landsat 8 OLI that was acquired on July 8th, 2013; August 17th, 2016; June 17th, 2017; and April 1st, 2018. Combination of time-series image analysis and planting years was shown in table 4.

Table 4. Combination of time-series data and planting years

Stands Age	Satellite Image		Planting Year
	Type	Acquisition Date	
0	Landsat 7 ETM	2-May-03	2002
1	Landsat 5 TM	29-Apr-05	2003
		24-Jul-07	2005
2	Landsat 5 TM	29-Apr-05	2002
		24-Jul-07	2004
3	Landsat 5 TM	25-Jul-07	2003
		29-Jul-09	2005
4	Landsat 5 TM	25-Jul-07	2002
		29-Jul-09	2004
5	Landsat 5 TM	29-Jul-09	2003
6	Landsat 5 TM	29-Jul-09	2002
7	Landsat 8 OLI	8-Jul-13	2005
8	Landsat 8 OLI	8-Jul-13	2004
9	Landsat 8 OLI	8-Jul-13	2003
10	Landsat 8 OLI	8-Jul-13	2002
		17-Aug-16	2005
11	Landsat 8 OLI	17-Aug-16	2004
		17-Jun-17	2005
12	Landsat 8 OLI	17-Aug-16	2003
		17-Jun-17	2004
		1-Apr-18	2005
13	Landsat 8 OLI	17-Aug-16	2002
		17-Jun-17	2003
		1-Apr-18	2004
14	Landsat 8 OLI	17-Jun-17	2002
		1-Apr-18	2003
15	Landsat 8 OLI	1-Apr-18	2002

Based on planting year map and multi-temporal image satellite analysis, combining with non-linear assumption, we tried to classify oil palm trees age and their correlation with canopy density and the results was shown in table 5.

Table 5. Correlation stands age with canopy density

No	Class	Stands Age	% Canopy Density
1	Seed	0	29-56
2	Young	1 - 9	56-63
3	Teen	10-15	63 - 80
4	Mature	15 - 25	> 80

Figure 6. Canopy density of oil palm trees 10-15 years old

This figure shows that oil palm trees from 10 until 15 years old will have canopy density around 63 – 80%. The other class in this figure (49-63%) was shown as settlement. This condition also seen in the young class that was from one until nine years old. The value from 44-56% as known as settlement.

Figure 7. Canopy density of oil palm trees 1-9 years old

4. Discussion

All of research area, Candali, Cimulang, and Cikasungka, based on single-date image satellite analysis and field check survey shows that oil palm trees in that area have age around 10 – 14 years old. This also as evidence for their correlation with canopy density. In this class, all of oil palm trees age have 60-80% of canopy dense and area with value less than 60% as known as settlement.

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Based on classification from Plantation Education Agency of Indonesia, we can divide into four class even from this agency they divided into five class. The last class for old age from 20-25 years old was union into mature class caused by non-linear assumption that was characteristic from oil palm trees after 20 years old is different, the length of canopy or steam leaves increases is equal with growing phases, but the direction is different which steam leaves will grow with smaller angle and tend to lead downwards[18][19].

To evaluate and specify the class from single data analysis, we employed multi temporal image analysis. The result shows if the number of class for oil palm trees age are still divided into four class that were seed only for zero old, young for one until nine years old, teen for 10 until 15 years old, and mature for more than 15 years old.

The canopy density value from one until nine years old, even starts from 34 until 65% but mostly have 56-63 % of canopy dense. The value below 56 caused by settlement or near with settlement, and for value more than 63 caused by their location near with other plantation such as rubber. It was very difficult to separate young class due to the absence of oil palm trees with age between one until nine years old in the field.

Limitation from this research area the absence of oil palm trees with age between one until nine years old also more than 15 years old in the field. This made we cannot evaluate the density value for that stands age in the field.

Future research will be better to conduct in oil palm plantation area that they have large range in diversity of stands age. In line with that, this research also can be evaluate for other oil palm plantation with different condition such as soil type, precipitation, contour, and planting management

5. Conclusions

This research was conducted to applied FCD model as one tools to estimate the age of oil palm trees. The result for single date data and multi temporal image analysis was shows if there is no obvious difference in the number of classes, which are only have four class that are seed, young, teen, and mature.

Generally, FCD model can be used as a tool to estimate the age of oil palm trees even though it was difficult to separate the class of one until nine years old and more than 15 until 25 years old. From this research we can see if in the oil palm plantation we cannot found canopy density less than 29% even in the zero years old. This could be indicates that plantation was not optimize in land clearance or this phenomenon happen caused by the type of seed of oil palm trees that was like a young trees.

6. Patents

Author Contributions: Fitrianto and Tokimatsu conceptualized and designed the project; Fitrianto and Yuwono executed image processing and analysis, Darmawan performed statistical analysis, Fitrianto, Yuwono, and Darmawan wrote the paper, Tokimatsu supervised research and edited the manuscript.

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