Age-surface temperature estimation model: When will oil palm plantation reach the same surface temperature as natural forest?

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Abstract. Oil palm plantation has often been accused as the cause of global warming. However, along with its growth, it would be able to decrease surface temperature. The question is ‘when will the plantation be able to reach the same surface temperature as natural forest’. This research aimed to estimate the age of oil palm plantation that create similar surface temperature to those in natural forest (land cover before the opening and planting of oil palm). The method used in this research was spatial analysis of land cover and surface temperature distribution. Based on the spatial analysis of surface temperature, five points was randomly taken from each planting age (age 1 15 years). Linear regression was then employed in the analysis. The linear regression formula between surface temperature and age of oil palm plantation was $Y = 26.002 - 0.1237X$. Surface temperature will decrease as much as 0.1237 $^\circ$C with one year age growth oil palm. Surface temperature that was similar to the initial temperature, when the land cover was natural forest ($23.04 ^\circ$C), was estimated to occur when the oil palm plantation reach the age 24 year.

1. Introduction

1.1. Background
The world is currently facing global warming issue. Air temperature of the earth’s surface has increased between $0.3^\circ$–$0.6^\circ$C at the end of 1800 and will keep increasing up to $1^\circ$–$3.5^\circ$C on the upcoming 2100 [1]. The raise of earth’s surface temperature was triggered by the increase of greenhouse gasses effect intensity due to greenhouse gasses [2]. Global emission of greenhouse gasses has increased about 45% since 1990, and about 30% since 2000 [3]. The increase of greenhouse gasses was caused by two factors, i.e.: (1) the increase of CO$_2$ emission from various activities; (2) decrease of CO$_2$ absorbent agents. Oil palm plantation is amongst the activities that cause greenhouse gasses emission, and therefore contribute to the increase of earth’s surface temperature that led to global warming. To cope with the increase of earth’s surface temperature, all parties and sectors, including oil palm plantation sector, have to take part in global warming adaptation and mitigation effort [4, 5].

Oil palm plantations were developed on an area with Other Uses Area (Known as APL) status with various land cover condition, such as shrubs, imperata, and might be remnants of secondary forest. The accusation that oil palm plantation is one of causes of global warming is not always true. Oil palm plantation will provide a temperature decreasing effect through its planting activities and the increasing age (growth) of the plants. Vegetation can decrease temperature through direct shade and...
evapotranspiration [6]. Canopy of vegetation, which provide shading, will reduce the amount of solar radiation that reach earth’s surface and reflects the radiation back into the atmosphere. Surface temperature of vegetation is lower than temperature of open land and other man-made objects due to relatively high albedo [7].

As the oil palm plants grow, the canopy will get denser and the area covered by the plants’ canopy will be wider, and therefore solar radiation reaching the earth’s surface will decrease; thus the surface temperature will decrease. As a reference, the ideal surface temperature is one found in natural forest ecosystem that has crucial role in controlling the climate [8, 9].

Oil palm plantation with single canopy layer and only one plant species is predicted could not generate surface temperature similar to natural forest with various canopy layers and plants composition [10]. However, oil palm plantation could be expected to have surface temperature close to natural forest. Therefore, this research was carried out to examine the extent to which the growth of oil palm trees can reduce the surface temperature so that the surface temperature approaching natural forests.

1.2. Objective
The objective of this research was to identify the age of oil palm plantation that can generate a closer surface temperature to natural forest.

2. Method
The research was carried out at Oil palm Plantation in Kubu Raya District. Land cover and surface temperature analysis for 1989, 1997, and 2014 was carried out. Materials used in the analysis were Landsat 5 TM imageries for 1989 and 1997, and Landsat 8 OLI/TIRS imageries for 2014 (table 1). Erdas software was used for the analysis, while ArcGIS software was used for sample point generation for statistical analysis and map layout.

Focusing on calculating surface temperature for oil palm, the land cover classes was generated based on imagery interpretation and field observation. There were only 5 classes, which included water body (natural water body, such as river, and man-made water body, such as pool), tree vegetation, non-tree vegetation (included oil palm vegetation, and imperata, grasses, and shrubs in 1989), built land, and open land.

There were 20 training areas for 1989 imagery, 39 training areas for 1997 imagery, and 100 training areas for 2014. Ground check was employed to identify oil palm age and land cover, while surface temperature was calculated using formula based on Landsat.

Table 1. Types and source of study materials.

| No. | Types of study materials | Source |
|-----|---------------------------|--------|
| 1.  | Landsat 8 OLI/TIRS path/row 121/60 imagery captured on 09:52:23 acquired date on 21 August 2014 | http://glovis.usgs.gov |
| 2.  | Landsat 5 TM path/row 121/60 imagery captured on 09:20:16 acquired date on 13 June 1989 | http://glovis.usgs.gov |
| 3.  | Landsat 5 TM path/row 121/60 imagery captured on 09:21:52 acquired date on 19 June 1997 | http://glovis.usgs.gov |

Pre-processing of the imageries was carried out before conducting the analysis. Pre-processing include channel composite, image projection change, and image cut. Channel composite used in land cover analysis was channel 1–7, while the channels used in temperature analysis was channel 10 for Landsat 8 and channel 6 for Landsat 5. The projection used was Universal Transverse Mercator (UTM) 49 S zone. Analysis phases is presented in figure 1.
2.1. Land cover analysis
Supervised classification with maximum likelihood classifier method was employed in land cover analysis. Land cover was classified into 5 classes, i.e. water body, tree vegetation, non-tree vegetation, build land, and open land. There were unclassified pixels due to image cutting with administrative boundary and cloud and cloud’s shadow, which thereafter was presented as no data available. Accuracy assessment was conducted after classification. Training area for planting year was determined based on planting year block obtained from map using the tools create random points in ArcGIS application. Training area was determined based on imagery interpretation by user, aided by ground check data.

2.2. Surface temperature analysis
Calculation of surface temperature value was carried out in stages [11-13]. First, calculation was conducted from temperature channel to obtain spectral radian value using equation (1). Spectral radian value was then converted into temperature in Kelvin (K) unit using equation (2). After surface temperature value in K unit was obtained, it was then converted into Celsius (°C) unit using equation (3).

$$L_\lambda = ML \cdot Q_{cal} + AL$$  \hspace{1cm} (1)

Explanation:

- $L_\lambda$ = Spectral radian value (Watt/m²·s·rad·μm)
- $ML$ = Specific multiplier factor of thermal band
- $Q_{cal}$ = Specific digital imagery value of thermal band
- $AL$ = Specific additional factor of thermal band

$$Ts = K_2 / \ln[(K_1/L_\lambda)+1]$$  \hspace{1cm} (2)

Explanation:

- $Ts$ = Surface temperature (K)
- $L_\lambda$ = Spectral radian value (Watt/m²·s·rad·μm)
- $K_1$ = 1 constant conversion (774.89 for Landsat 8 imagery and 607.760 for Landsat 5 imagery)
- $K_2$ = 2 constant conversion (1,321.08 for Landsat 8 imagery and 1,260.56 for Landsat 5 imagery)

$$Ts = Ts (K) - 273$$  \hspace{1cm} (3)

Explanation:

- $Ts$ = Surface temperature (°C)
2.3. Correlation analysis between variables of surface temperature and oil palm age

Correlation analysis between age of oil palm and surface temperature was carried out by determining sample points on oil palm plot from 1–15 year (15 age classes) with 5 replications for each plot that the total points being analyzed was 75 points. The oil palm plot data were obtained from field observation. The map of surface temperature sample points’ distribution is presented in figure 2.

Correlation analysis was used to measure the strength of relation (linear relation) between two variables. After correlation analysis, a test of correlation hypothesis was also carried out based on the following conditions:

1. \( H_0 : \rho = 0 \) (there is not any correlation between \( X \) and \( Y \))
   \( H_1 : \rho \neq 0 \) (there is correlation between \( X \) and \( Y \))

2. Level of significance \( \alpha = 0.05 \)

3. Reject \( H_0 \) if \( t < -t_{n-2, \alpha/2} \) or \( t > t_{n-2, \alpha/2} \)
   and using P-Value, if P-Value < \( \alpha \) then \( H_0 \) is rejected.

4. Statistic test:

\[
t_{0.05} = \frac{r - \rho}{\sqrt{1 + r^2}} t_{tabbed}
\]

When the \( t_{0.05} > t_{tabbed} \), then the \( H_0 \) is rejected, or using the P-Value, when P-Value < 0.05 then \( H_0 \) is rejected. Thus the conclusion would be that there is correlation between \( X \) and \( Y \).

3. Result and Discussion

3.1. Land cover changes

Evaluation of classification result was carried out through accuracy assessment using GPS coordinate data. A good overall accuracy based on the criteria from United States Geological Survey (USGS) is above 85% [14]. The overall accuracy value resulted from land cover analysis as much as 80%, not much different from the USGS’s criteria that the accuracy can be stated as good. This is further
supported by kappa accuracy as much as 0.6827. The closer kappa accuracy value to 1 (the higher kappa accuracy value), means that the classification is better.

Analysis of land cover in 1989, 1997 and 2014 showed a decrease of tree vegetation. In 1989, tree vegetation covered 4,261 ha, which decreased to 1,523 ha in 1997 and 33 ha in 2014. On the contrary, non-tree vegetation (oil palm) had been increasing from year to year. In 1989, it covered an area of 1,998 ha, which increased to 1,131 ha in 1997, and kept increasing to 5,777 ha in 2014. Land cover changes is presented in figure 3 and figure 4.

Figure 3. Map of land cover in 1989, 1997, and 2014.

Figure 4. Land cover changes
3.2. Surface temperature changes

In 1989, the highest percentage (89%) was those of surface temperature ranging from 21–22 °C. At the time, land cover was dominated by tree vegetation. Land opening and oil palm planting has been started in 1997. Area with surface temperature ranging from 21–22 °C decreased to 14% in 1997. In that year, 38% of the area has surface temperature on 23–24 °C, and 34% 20–21 °C. In 2014, the coverage of non-tree vegetation increased. The surface temperature on 23–24 °C increased to 43%. From 1989 to 2014, there had been a shift of surface temperature. The highest range of surface temperature in 1989 was 23–24 °C, while in 1997 the highest range increased to a range of 25–26 °C. In 2014, the highest range of surface temperature rose to 28–29 °C. Apparently, the highest surface temperature will increase with the increase of changes from tree vegetation to non-tree vegetation. This condition due to a decrease of percentage of radiation interception by tree canopy.

There is a relation between vegetation density and climate, particularly air temperature [15]. The increase of area stress occurred in forest lands had caused the increase of air temperature. However, though the land opening from tree-vegetated area causes an increase of air temperature, the growth of oil palm plants (non-tree vegetation) can increase carbon absorption, proven in research by [16], which stated that biomass carbon stock (excluding fresh fruit bunches) of oil palm agroecosystem on the age of 1 to 18 year ranged from 0.7–16.43 ton/ha. Based on this research, a prediction can be made that oil palm absorbs CO₂ as much as 2.57–60.30 ton/ha. Oil palm growth can increase carbon stock and decrease greenhouse gasses, particularly CO₂.

A study in Beijing, China using a variety of spatial resolution of the imagery a consistent result that the higher coverage of green open space will decrease land surface temperature [17]. Similar condition applies in oil palm plantation, where we found an increase of surface temperature at the beginning of land opening. However, along with the increasing age of the oil palm (and the increase of vegetated area), carbon stick will also increase and therefore reducing surface temperature. Thus, surface temperature of oil palm plantation is greatly influenced by land opening activities that can increase surface temperature, but also by the growth of oil palm that can reduce surface temperature through radiation interception by oil palm canopy and the increase of greenhouse gasses (CO₂) absorption in its photosynthesis process. The changes of surface temperature due to land cover changes, particularly in oil palm plantation area from 1989 to 1997 and 2014 is presented in figure 5.

3.3. Relation between oil palm age and surface temperature

A comparison of oil palm plantation’s surface temperature and tree vegetation’s surface temperature was also employed in order to estimate the age of oil palm plantation that generates surface temperature close to tree vegetation. Therefore, spatial analysis was also carried out on area surrounding the oil palm plantation, resulted in map of surface temperature distribution (figure 6).

As the age of oil palm plantation increase, the solar radiation interception will also increase, and therefore reducing radiation reaching to land surface. The condition will cause a decrease of surface temperature. Statistical analysis showed that $t_{0.05} > t_{tabled}$, and the P-value $< 0.05$, therefore $H_0$ is rejected. It can be concluded that there is correlation between X (oil palm age) and Y (surface temperature) with an equation of $Y = 26.002 - 0.1237 X$. In other words, an addition of one year of X (oil palm age), the Y (surface temperature) will decrease as much as 0.1237 °C. In 2014, the highest range of surface temperature increased to a range of 25–26 °C.

It can be concluded that there is correlation between X (oil palm age) and Y (surface temperature) with an equation of $Y = 26.002 - 0.1237 X$. With an addition of one year of X (oil palm age), the Y (surface temperature) will decrease as much as 0.1237 °C. In other words, an addition of oil palm age will caused lower surface temperature. The older oil palm age, the lower surface temperature would be, and this condition proved that oil palm also has a role in absorbing CO₂ and decreasing surface temperature. This finding is in line with [18], which stated that one of mitigation options in Agriculture, Forestry, and Other Land Use (AFOLU) is reducing greenhouse gasses by enhancing the uptake of carbon in terrestrial, and thereby removing CO₂ from the atmosphere. Oil palm plantation growth is enhancing the uptake of carbon in terrestrial, which can reduce the concentration of greenhouse gasses and decrease the surface temperature. The relation between surface temperature and oil palm age is presented in figure 7.
Figure 5. Map of surface temperature distribution changes.

Figure 6. Map of surface temperature distribution in 2014.
4. Conclusion
Linear regression analysis between oil palm plantation age and surface temperature enables us to conclude that the surface temperature will decrease as much as 0.1237 °C with one year age growth oil palm. The decrease of surface temperature proved that solar radiation interception and CO₂ absorption occur in the process of oil palm growth, which causes a decrease of surface temperature along with oil palm age increase. Surface temperature that was similar to the initial temperature, when the land cover was natural forest, was estimated to occur when the oil palm plantation reach the age 24 year.

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