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Mapping of smallholder oil palm plantation and development of a growth model

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Abstract. Smallholder plantation accounts for 39% of total oil palm plantation in Indonesia, which is currently estimated at 12 million ha. Limited information on spatial distribution of smallholder oil palm and the growth of plantation pose a great challenge for providing information in scientific based. Therefore, information on smallholder oil palm plantation are necessary and they will give valuable input for policy maker and related stakeholders. This study is aimed to generate smallholder oil palm distribution map using optical satellite data of SPOT 7 and investigate the backscatter values of ALOS PALSAR-2 with height and age of oil palm in mineral soil and peatland. We mapped 46,756 ha of smallholder plantation or about 18% of total oil palm plantation in district of Kotawaringin Barat, Central Kalimantan province and 14% of which is located on peatland area. From the result, height to age mineral soil has a strong relationship with R^2 value 0.80 but weak in peatland with R^2 value 0.31. Relationship between height and backscatter in mineral soil has R^2 value 0.43 for HH and 0.30 for HV and in peatland 0.28 for HH and 0.15. Relationship between age and backscatter in mineral soil has moderately strong correlation with R^2 value 0.55 for HH and 0.37 for HV and in peatland 0.36 for HH and 0.28. In all relationship, independent variables are statistically significant with *Significance-F* value lower than 0.05. In general, height, age, and backscatter relationship in peatland is lower than in mineral soil. Backscatter value can be useful for studying height and age of smallholder oil palm. Further studies are suggested to involve more potential variables and utilize multi temporal datasets in determining height and age of oil palm trees using backscatter values.

1. Introduction

Indonesia is now the world's largest producer of palm oil. It contributed to about 53% of total palm oil traded globally [1]. Revenues from palm oil contribute significantly to the country's national and sub-national income, making palm oil an important and strategic commodity for Indonesia [2,3]. In addition, oil palm contribute significantly to regional economic development, providing employment and increase human well-being [4,5]. Of the total palm oil plantation in Indonesia, currently estimated at 12 million ha, smallholder plantations account for 39% or 4.7 million ha of plantations involving about 2.2 million farmers [6], showing a significant role this actor play in the country's production of palm oil.

One of the challenges facing smallholder in the sector is the low productivity of the crop, caused by low quality of seedling, limited capacity and knowledge among farmers to adopt best management practices, and improper application of fertilizer [7–11]. Improving smallholder's oil palm productivity in order to reach optimal yield and financial assistance to adopt good practices are believed to



discourage smallholders to expand their plantation into forests [12] causing environmental destruction. Efforts to upgrade smallholders and help them adopt better agriculture practices are challenged by limited information regarding the spatial distribution of smallholder oil palm plantation, crop age and condition. The relatively low number of smallholders receiving CPO funds for replanting program and the only certified Indonesian Sustainable Palm Oil (ISPO) are also due to the lack of information on who they are and where they are, and the fact that significant area of smallholders are illegally located on state forestlands. Thus, various efforts have been done by different parties including the Ministry of Agriculture to map smallholders, and characterize smallholder profile, and to estimate smallholder oil palm age.

Remote sensing technology has been improved with more options available on remotely sensed images. In active microwave remote sensing, one of recent technology is Synthetic Aperture Radar (SAR) images. SAR is an active sensor that operates weather and daylight independent delivering information all year round at the time that it is needed. Clouds, haze and smoke do not prevent the sensor from providing images [13]. With sensor ability to penetrate haze and cloud, SAR images could overcome optical sensor limitation in tropical zone where high cloud cover frequently appears.

SAR images has been widely used for land cover mapping and monitoring including oil palm. Several research on utilization of SAR images were proven can distinguish oil palm [14–18]. Second generation of Advanced Land Observing Satellite (ALOS) was launched by Japan Aerospace Exploration Agency (JAXA) with Phased Arrayed L-band SAR (PALSAR) on it. It has higher performance than any previous L-band SAR sensor with higher spatial resolution and shorter satellite revisit time [19]. Compared to other SAR's band, L-band can reach the surface and partially penetrating through vegetation to obtain information of vegetation and ground surface. Several studies investigate correlation of passive and active remote sensing images with age of oil palm and found correlation. A study in large-scale plantation has investigate and found correlation of ALOS PALSAR 2 backscatter with age on large-scale oil palm plantation area in Malaysia [20]. Another study found near-infrared band of UK-DMC 2, fraction of shadow, and mean filter from the Grey-Level Co-occurrence Matrix (GLCM) demonstrated strong correlation of determination with the age of oil palm trees [21].

Expanding knowledge from previous research on remote sensing application into smallholder plantation area will enrich information on oil palm age distribution of smallholder oil palm. Information on smallholder area and age distribution are therefore necessary, giving valuable input for the policy makers and relevant stakeholders. Remote sensing can assist in providing such information at regional scale. This study is aimed to generate smallholder oil palm distribution map using optical satellite data of SPOT 7 and investigate the backscatter values of ALOS PALSAR-2 with height and age of oil palm in mineral soil and peatland.

2. Methodology

Methodology consists of mapping smallholder area using high resolution images, SAR images pre-processing, and field surveys for collecting data on height and age of oil palm plantation. Results from smallholder mapping were used for selecting sampling plot, where field surveys were conducted to collect age and height information. In understanding the relationship, we used a linear regression model between backscatter value of HH and HV with height and age.

2.1. Study site

This study covers a district area of Kotawaringin Barat, Central Kalimantan province. According to statistics data, total smallholder plantation in Kotawaringin Barat is about 31 percent from total smallholder oil palm plantation in Central Kalimantan, making it the largest district with smallholder oil palm in the province. In Central Kalimantan, oil palm smallholders account for 12 percent of the total oil palm plantation, which is lower than its proportion at national level accounting for 39 percent of total oil palm plantation [6].

2.2. Mapping smallholder

In mapping smallholder plantations, we used a visual method to interpret high-resolution satellite images of SPOT 7 acquired in March 14 and July 10, 2016. Smallholders oil palm can be identified from their size that relatively small with irregular pattern of plantation boundaries. Some smallholder plantations create compact plantation in medium size but with different canopy size indicating various planting age. Another characteristic is that they are usually located close to or around settlement area. Areas not classified as industrial oil palm nor smallholder oil palm are classified into unclassified oil palm. Unclassified oil palm usually has a grid-like pattern like industrial oil palm but with smaller size or has medium size of plantation and located relatively far from settlement area. Based on ground truthing, such areas were later corrected and reclassified into smallholder or industrial oil palm.

2.3. Pre-processing

In investigating age and height to backscatter responses, we used ALOS PALSAR 2 Fine Beam Double Polarization (FBD) product level 1.5 that was acquired on May 16, 2016. FBD product level 1.5 has spatial resolution of 10 meters and swath of 70 km which multi-look data on slant range from map projection amplitude data with range and azimuth compressed [20]. The FBD product provides double polarizations (i.e. horizontal transmitting and horizontal receiving (HH) and horizontal transmitting and vertical receiving (HV)) [21]. Processing of ALOS PALSAR 2 including of converting digital numbers to normalize radar cross sections (NRCS) in decibel (dB), reducing multiplicative speckle noise using frost enhancement filtering, and orthorectification.

2.4. Data collection and relationship analysis

Based on height and age information from field survey, we create regions of interest for sampling area and making of relationships analysis between backscatter value of HH and HV with height and age. L-band sensor has ability to penetrate to surface and get information of soil conditions. We separate the sampling for mineral and peat soil to see difference based on type of soil. In distinguishing mineral and peat soils, we used peat soil maps from the Ministry of Agriculture [22]. For analyzing relationships between age, height, and backscatter value, we used a linear regression.

3. Results and Discussion

Oil palm plantation cover about 24% of Kotawaringin Barat or about 260,603 ha where 18% of it, is smallholder plantation. From total 46,756 ha of smallholder oil palm, 6,523 ha, or 14% of it, is located on peatland area, mostly in shallow peatland (Figure 1).

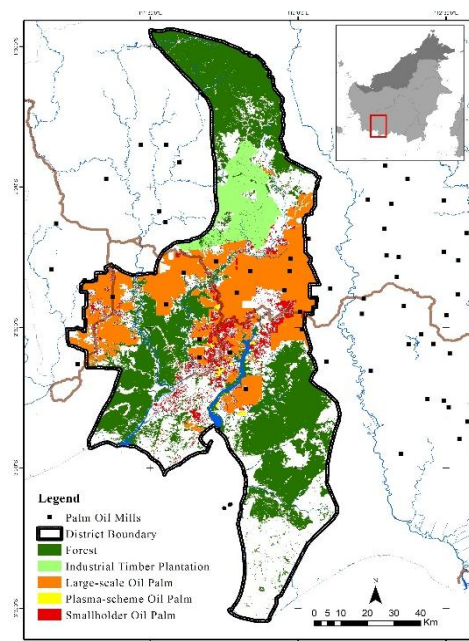


Figure 1. Smallholder oil palm distribution

Age and height of oil palm plantation have a strong and positive correlation in mineral soil with R^2 value of linear regression 0.80. In comparison, another research with study site in private plantation found relationship is higher with R^2 value 0.90 [21]. We assume lower correlation between age and height is related with productivity problem where smallholder has limited access to good quality seedling, lack of knowledge to adopt good agricultural practices and to use fertilizer properly. This limitations make smallholder plantation unable to grow palm crops at the same productivity rate of company plantation.

While oil palm on peatlands, we found R^2 value from linear regression between age and height is 0.31 (Figure 2). This number is much lower than those on mineral soil. Oil palms on peatlands have more varied height distribution in each age class. This condition shows that growth of oil palm on peatland area is more diverse. However, height has a significant correlation to age with *Significance-F* value 0.003.

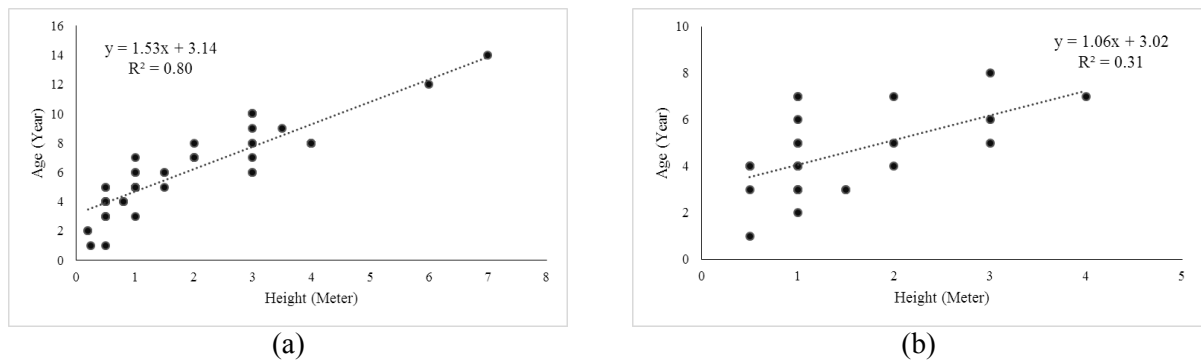


Figure 2. Relationship between age and height in mineral soil (a) and peatland (b)

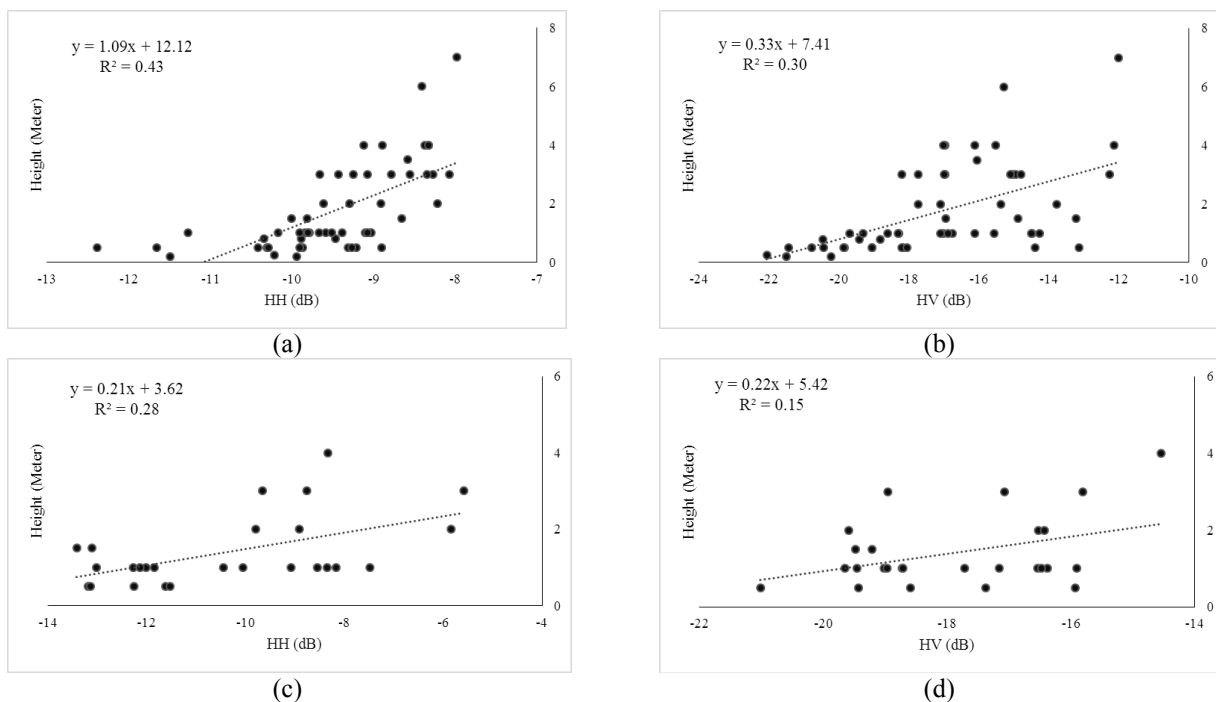


Figure 3. Relationship between height of oil palm in mineral soil with HH (a) and HV (b); and height of oil palm in peatland with HH (c) and HV (d)

Soil and climate are the basic resources for growth of any crop. Peatland are identic with poorly-drained soil and commonly water-logged. Peat soils and other soils with a high content of organic matter, especially those which exhibit a peat layer deeper than 100 cm, lead to weak anchorage of palms in the fibrous peat and tropical peat soils frequently pose problems of plant nutrition [23].

Different types of peat, which related to soil properties, have significant effect on oil palm growth and yield [24]. Oil palm growth well in deep and well-drained soil. Inappropriate soil management in peatland area may lead to condition where growth of oil palm in peatland are more various than oil palm that planted in mineral soil.

Relationship between HH, HV, and height of oil palms in mineral soil is low with R^2 value is 0.43 for HH and 0.30 for HV. In peatland, R^2 value is lower with height relationship to HH 0.28 and to HV 0.15. However, looking from the Figure 3, backscatter response is in positive correlation where increase of HH and HV value indicate increase of biomass, particularly in form of height growth.

In relationship between HH, HV, and age of oil palms in mineral soil, the linear regression analysis show that there are moderate correlation with R^2 value 0.55 for HH and 0.37 for HV (Figure 4). In peatland, R^2 value for age to HH 0.36 and to HV 0.28. Similar to backscatter values relationship to height, increase of HH and HV value has positive correlation with age. For comparison, a similar study in large-scale oil palm plantation found moderate correlation with R^2 value 0.63 [20]. In studying backscatter value to height and age, it is necessary to explore other potential variables as well. Another study on oil palm age that incorporates optical remote sensing data found that texture measurement and fraction of shadow are useful for studying the age of oil palm trees [21].

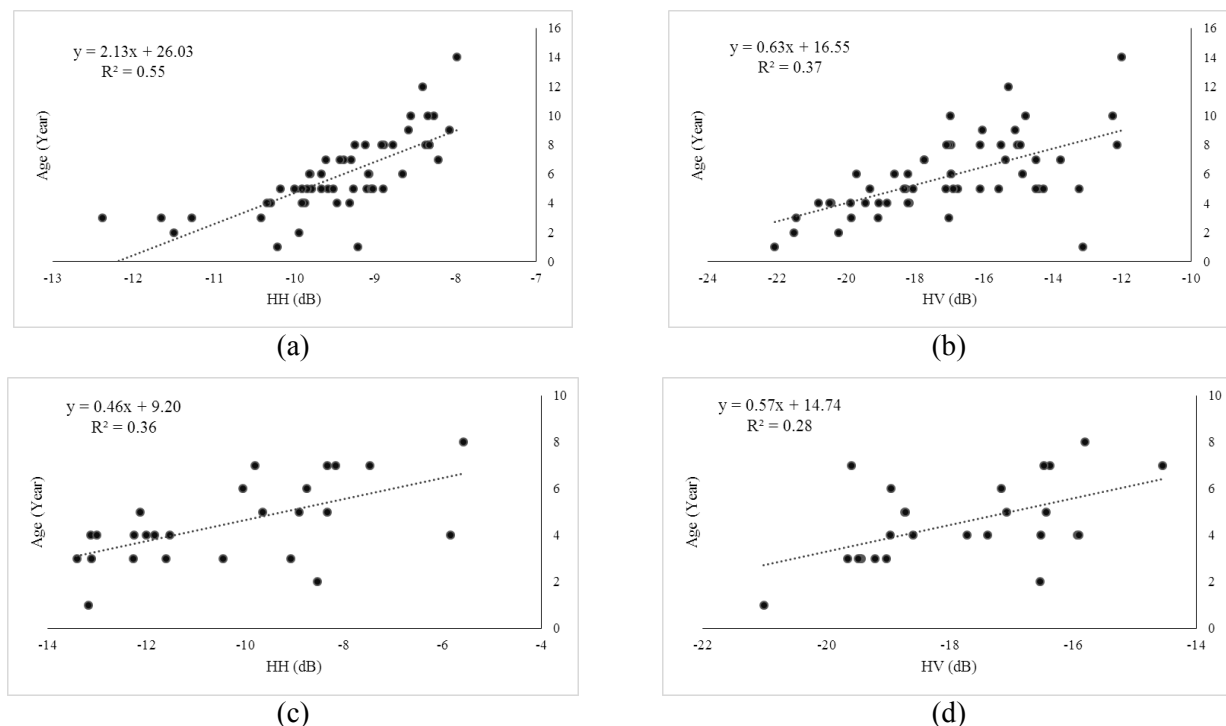


Figure 4. Relationship between age of oil palm in mineral soil with HH (a) and HV (b); and age of oil palm in peatland with HH (c) and HV (d)

Many factors involved in analyzing backscatter values relationship to height and age of smallholder plantation. Backscatter values depend on wavelengths, polarization, incident angle and temporal data, environment (e.g. moisture, landscape) [25,26] and precipitation give significant effect on the backscatter [27]. Backscatter value is also depend on structure of oil palm (e.g. size, geometry and orientation of leaves, trunks, branches, and aerals or stilt roots) [16,28]. Compared to large-scale plantation, smallholder plantation conditions are more diverse. Limitations in smallholder agricultural practices make oil palm not to grow uniformly. This condition possibly contributes to diverse of backscatter intensity in sampling area.

4. Conclusion

Our study has identified around 46,756 ha of smallholder plantation or about 18% of total oil palm plantation in district of Kotawaringin Barat, Central Kalimantan province. 14% of these plantations are found to be located on peatland areas. From linear regression results, we found a strong correlation of height to age in mineral soil but not correlate well in peatland. Relationship analysis of backscatter to height found a positive correlation where increased backscatter value is followed by increases in height. In backscatter to age, we found a moderately strong correlation. Overall, the relationship between backscatter value, height and age is stronger in mineral soil than in peatland. In all linear regression model, independent variables are statistically significant with *Significance-F* value lower than 0.05. Backscatter value can be useful for studying height and age of smallholder oil palm. Further studies are suggested to involve more potential variables and utilize multi temporal datasets in determining height and age of oil palm trees using backscatter values.

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