MODELLING ABOVEGROUND BIOMASS OF OIL PALM USING DESTRUCTIVE METHOD AND REMOTE SENSING DATA

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Specially dedicated to:

My beloved mom and dad: NAPISAH SAMAD and ABD.SAMAD DINA

My beloved sister Dr. SRI MULIATHY SAMAD, M.Kes

My beloved kids:

PUTRI GITHA SHANAA TENRI ANGKE

ALFITRAH SURYA PRATAMA TENRI SAU

ALFARAH CHANDRA PUTRI TENRI SANNA

94:5
فَإِنَّ مَعَ الْعُسْرِ يُسْرًا
For indeed, with hardship [will be] ease.

94:6
إِنَّ مَعَ الْعُسْرِ يُسْرًا
Indeed, with hardship [will be] ease.

Surat Ash-Sharĥ 94: 5-6

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ABSTRACT

Biomass serves as an important indicator to assess the role of oil palm in the global carbon cycle, particularly its contribution towards carbon sequestration. Indonesia is a country that has the largest palm oil plantation, and is the second largest country to export CPO (Crude Palm Oil) after Malaysia. As the world market demand for palm oil increases, Indonesia is developing large oil palm plantations. However, information about biomass or carbon stocks contained in oil palm trees is still limited. The study quantified the aboveground biomass (AGB) of oil palm trees in South Sulawesi, Indonesia using harvesting method, allometric equations and remote sensing techniques. Nine oil palm trees ranging from three trees of young (1-3 years), three trees of intermediate (4-10 years) and three trees of matured (11-20 years) trees were harvested, their wet and dry biomass for different components from the stems, fronds, leaflets, fruit bunches as well as flowers were obtained. In addition, 96 trees were also sampled to get Diameters of Breast Height (DBH), height and age information. All the information were used to develop specific allometric equations to estimate dry aboveground biomass of young, intermediate and matured oil palm trees. The use of allometric models resulted in high accuracy when AGB estimated from the equations was compared with DBH and height. Since harvesting method and allometric equations can only be used to get AGB at local (plot) scale, remote sensing data of Advanced Land Observing Satellite Phase Array type L-band Synthetic Aperture Radar/ALOS PALSAR were used to up-scale AGB to the entire study area. Dry AGB obtained from the harvesting method was 0.75 t ha^{-1}, 22.17 t ha^{-1} and 105.41 t ha^{-1} for young, intermediate and matured trees respectively. The allometric equations with dbh parameter produced 0.71 t ha^{-1}, 20.15 t ha^{-1}, 107.41 t ha^{-1}, and dbh with height parameters have produced 1.40 t ha^{-1}, 27.20 t ha^{-1}, 248.52 t ha^{-1} for young, intermediate and matured trees respectively. Manipulation of HH polarization, $(HH + HV)/2$ and $\sqrt{(HHxHV)}$ produced better correlation with AGB (R^2 between 0.53 to 0.61). Empirical models developed with these manipulation polarizations were used to estimate the AGB in South Sulawesi. Total AGBs of the area for intermediate trees ranged between 29.94 t ha^{-1} to 31.51 t ha^{-1} whereas it was between 68.32 t ha^{-1} to 71.29 t ha^{-1} for matured oil palm trees. AGB estimate from ALOS PALSAR showed a 24.5 to 28 percent difference in comparison to AGB obtained via allometric equations for intermediate and matured palms. The results (AGB) obtained in this study have a potential to inform decision makers to impose better land management in oil palm plantation so to alleviate climate change.

ABSTRAK

Biojisim merupakan penunjuk penting untuk menilai peranan kelapa sawit kitaran karbon global, terutama sumbangan kepada pengasingan karbon. Indonesia ialah sebuah negara yang mempunyai ladang kelapa sawit terbesar dan negara pengeksport CPO (minyak sawit mentah) kedua terbesar selepas Malaysia. Memandangkan permintaan minyak sawit dalam pasaran dunia semakin meningkat, Indonesia telah meneroka ladang kelapa sawit yang luas. Namun, maklumat tentang biojisim atau stok karbon yang terkandung didalam pokok kelapa sawit masih terhad. Kajian ini mengukur biojisim atas tanah (AGB) pokok kelapa sawit di wilayah Sulawesi Selatan, Indonesia dengan menggunakan kaedah penuaian, persamaan alometrik dan teknik penderiaan jauh. Sembilan batang pokok kelapa sawit yang terdiri daripada tiga anak pokok (1-3 tahun), tiga pokok sederhana besar (4-10 tahun) dan tiga pokok matang (11-20 tahun) telah dituai. Biojisim basah dan kering pokok-pokok tersebut telah diperoleh daripada komponen yang berbeza, iaitu batang, pelepah, anak daun, tandan buah dan bunga. Di samping itu, 96 batang pokok telah dijadikan sampel untuk mendapatkan diameter paras dada (DBH), ketinggian dan maklumat umur. Semua maklumat tersebut digunakan untuk membina persamaan alometrik tertentu bagi menganggarkan biojisim atas tanah kering bagi anak pokok kelapa sawit, pokok sederhana besar dan pokok kelapa sawit matang. Penggunaan model alometrik menghasilkan ketepatan yang tinggi apabila AGB yang dianggarkan daripada persamaan tersebut dibandingkan dengan DBH dan ketinggian. Memandangkan kaedah penuaian dan persamaan alometrik hanya boleh digunakan untuk mendapatkan AGB pada skala tempatan (plot), data penderiaan jauh *Advanced Land Observing Satellite Phase Array type L-band Synthetic Aperture Radar*/ALOS PALSAR digunakan untuk menambah skala AGB ke seluruh kawasan kajian. AGB kering yang diperoleh daripada kaedah penuaian adalah 0.75 t ha^{-1}, 22.17 t ha^{-1} dan 105.41 t ha^{-1} yang masing-masing untuk anak pokok, pokok sederhana besar dan pokok matang. Persamaan alometrik dengan parameter DBH menghasilkan 0.71 t ha^{-1}, 20.15 t ha^{-1}, 107.41 t ha^{-1} manakala DBH dengan parameter ketinggian memperoleh 1.40 t ha^{-1}, 27.20 t ha^{-1}, 248.52 t ha^{-1} masing-masing untuk anak pokok, pokok sederhana besar dan pokok matang. Manipulasi polarisasi HH, (HH+HV)/2 dan $\sqrt{(HHxHV)}$ menghasilkan korelasi yang lebih baik dengan AGB (R^2 antara 0.53 dan 0.61). Model empirikal yang dibina dengan manipulasi polarisasi tersebut digunakan untuk menganggarkan AGB di Sulawesi Selatan. Jumlah AGB pokok sederhana besar merangkumi kawasan di antara 29.94 t ha^{-1} dengan 31.51 t ha^{-1} manakala pokok kelapa sawit matang adalah di antara 68.32 t ha^{-1} dengan 71.29 t ha^{-1}. AGB yang dianggarkan daripada ALOS PALSAR menunjukkan perbezaan 24.5 hingga 28 peratus berbanding dengan AGB yang diperoleh melalui persamaan alometrik bagi pokok-pokok kelapa sawit sederhana besar dan matang. Hasil (AGB) yang diperoleh dalam kajian ini mempunyai potensi untuk membantu pihak pembuat keputusan agar mengurus tanah kelapa sawit dengan lebih baik bagi menangani perubahan iklim.

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LIST OF ABBREVIATIONS

AGB	-	Aboveground Biomass
ALOS	-	Advanced Land Observing Satellite
ASTER	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CPO	-	Crude Palm Oil
DN	-	Digital Number
DOM	-	Dead Organic Matter
FBD	-	Fine Beam Dual polarization
GDEM	-	Global Digital Elevation Model
GHGs	-	Green House Gasses
HH	-	Horizontal transmitting and Horizontal receiving
HV	-	Horizontal transmitting and Vertical receiving
ICESat	-	Ice, Cloud and land Elevation Satellite
IPCC	-	Intergovernmental Panel on Climate Change
JAXA	-	Japan Aerospace Exploration Agency
JERS-1	-	Japanese Earth Resources Satellite 1
LANDSAT TM	-	Land Satellite Thematic Mapper
LiDAR	-	Light Detection And Ranging
MODIS	-	Moderate Resolution Imaging Spectrometer
NRCS	-	Normalized Radar Cross Section
PALSAR	-	Phase Array type L-band Synthetic Aperture Radar
PIR	-	Perkebunan Inti Rakyat (Nucleus Plantation Company)
PKO	-	Palm Kernel Oil
PTPN XIV-Persero	-	PT Perkebunan Nusantara XIV Persero
REDD	-	Reducing Emission from Deforestration and Forest Degradation
RMSE	-	Root Mean Square Error

SAR	-	Synthetic Aperture Radar
SOM	-	Soil Organic Matter
UTM	-	Universal Transverse Mercator
VH	-	Vertical transmitting and Horizontal receiving
VV	-	Vertical transmitting and Vertical receiving
WGS	-	World Geodetic System

LIST OF SYMBOLS

AGB	-	Aboveground biomass
B	-	Bottom slab area (m^3)
C	-	Carbon
cf	-	Correction factor (0.7)
CO_2	-	Carbon dioxide
d1	-	Diameter of bottom slab (m)
d2	-	Diameter of middle slab (m)
d3	-	Diameter of upper slab (m)
dbh	-	Diameter at breast height
h	-	Height
ha	-	Hectare
M	-	Middle slab area (m^3)
R^2	-	Coefficient determination
t	-	Tonne
U	-	Upper slab area (m^3)
$\sigma°$	-	Sigma Naught or Backscatter Coefficient
π	-	22/7 or 3.14

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Accurate information on the biomass and carbon stored in oil palm (*Elaeis guineensis*) trees can describe the condition of the ecosystems to support oil palm management and conservation of oil palm resources. It is also critical to understand the dynamics of carbon in oil palm ecosystems and the estimated impact on the ecosystem as a consequence of deforestation, changes in land use, and climate change (Eamus *et al.*, 2000; Comley and McGuiness, 2005; Soares and Vovelli, 2005). Such information is also important to act as a basic component in national carbon accounting and monitoring which is a major input in developing a strategy for reduction emission of greenhouse gas (GHG), particularly carbon dioxide (CO_2) from the land sector (Keith *et al.*, 2009).

Global climate change is strongly influenced by human activities (fossil fuel consumption, deforestation, forest fires, logging, the conversion of forest to plantation, and etc.) that emit greenhouse gases (GHGs) into the atmosphere. One of the GHGs that give a substantial contribution to global warming is carbon dioxide (CO_2) (IPCC, 2007). The concentration of CO_2 has increased from 390.33ppm in

July 2010 to 394.28ppm in December 2012 (CO_2 Now, 2013). In 2050, the concentration of CO_2 would rise to 450-550ppm and the global temperature would increase too if no actions are taken to reduce CO_2 emission (Salim, 2010). One natural way of removing the excessive CO_2 in the atmosphere is through CO_2 uptake by vegetation especially by woody plants. The capacity of oil palm plantations in absorbing CO_2 (net) has been found to be greater than that of the tropical forests (Henson, 1999). Thus, it is critical to study the potential of oil palm trees in removing CO_2 from the atmosphere. Biomass serves as an important indicator to assess the role oil palm in the global carbon cycle, particularly its contribution towards carbon sequestration. Data estimates of biomass and carbon stocks are an indispensable prerequisite for implementing the Kyoto Protocol which is the result of joint implementation; Clean Development Mechanism (CDM); and Emission Trading. Due to the uncertainty of current global carbon levels would require an accurate technique for estimating biomass and carbon stocks to help improve our understanding of the global the carbon cycle and to monitor the effectiveness of the global initiatives for dealing climate change (IPCC, 2007). Techniques remote sensing using satellite data can help estimate the AGB and carbon stocks for a large area even if the area is difficult to reach directly.

Recently, scientists and environmentalists have been giving strong attention to carbon studies of oil palm (*Elaeis guineensis*) because the plantations have expanded rapidly in tropical regions during the last few decades (Henson, 2008). The area of oil palm plantations has occupied over 16 Mha globally (FAO, 2013) therefore the sequestration of carbon by oil palms is a significant component of the global carbon cycle.

In Indonesia, the largest agricultural plantation sector is oil palm (i.e. 86.78% of total agricultural land) (BPS, 2013), Indonesia has a total of 6908.8 Mha of oil palm plantations in 2012 (BPS, 2013). Sumatera Island covers 6145.80 Mha of oil palm plantations while Kalimantan Island and Sulawesi Island covers 3311.52 Mha and 330.5 Mha respectively of oil palm plantations (BPS, 2013).

1.2 Problem statement

High yield and low production costs of palm oil are the reasons driving commercial plantation companies to cultivate oil palm trees on a large scale in areas where the climate is suitable, especially in Indonesia, Malaysia, Nigeria and many more countries. Indonesia is a country that has the largest palm oil plantation, and is also the second largest country to export CPO (Crude Palm Oil) after Malaysia. Along with the increase in world market demand for palm oil, Indonesia is developing large oil palm plantations. This phenomenon can be seen by the conversion of considerable areas of forests (non productive) into oil palm plantations. Moreover, sustainable management practices have discovered the potential of oil palm waste to useful products such as fibre board, plywood (Ng, 1977) and promising raw material for power generation (Yusoff and Hansen, 2007). Therefore, estimating the biomass of oil palm trees has high potential to provide relevant information not only for carbon cycle and climate change studies but also for energy and furniture sector in Indonesia.

Nevertheless, information about biomass or carbon stocks contained in a landscape with oil palm trees is still limited. There are several methods that can be applied to estimate biomass of oil palm plantations namely direct measurement including destructive sampling/harvesting (Hairiah *et al.*, 2001; Yulianti, 2009) and non-destructive sampling using allometric equations (Sharma, 2009; Roy *et al.*, 2013; Asari *et al.*, 2013). Traditionally, the AGB was estimated by felling down trees and separating tree components such as stem, branches, leaves etc and dry them in a oven at certain temperatures i.e. 100°C to get their dry weight or biomass (Khalid *et al.*, 1999; Henson, 2003 and Syahrinudin, 2005). This method can result in high accuracy however, it is not a sustainable method. Alternatively, researchers estimate the biomass based on field surveys. Oil palm tree parameters such as the tree height (h), diameter at breast height (*dbh*) and age profile of trees are used to estimate biomass using existing allometric equations that was developed using the harvesting method. In principle allometric equation is a mathematical function or equation showing a relationship between specific part of a living being with other parts or functions of the living beings. The equation used to estimate certain parameters using the other parameters are more easily measured such as height, *dbh* and age (Sutaryo 2009). Then the aboveground biomass of the plantation can be easily estimated with some accuracy from allometric relationships of trunk height and diameter (Corley *et al.*, 1971).

The harvesting and the use of existing allometric equations to estimate biomass require very intensive work, time consuming and costly to acquire information on individual trees. The limitation of allometric equations is that they are very site specific and have specific weight and growth patterns (Ketterings *et al.*, 2001) thus, cannot be applied to other locations. If they are applied in locations with different geographic, soil and climatic conditions they may result in a significant error in estimating the biomass (Heiskanen, 2006). A review of literature shows that there are only four allometric equations available to estimate oil palm biomass and most of them were developed for Malaysia. Therefore, in this study specific allometric equations are developed to estimate aboveground biomass of oil palm trees in south Sulawesi, Indonesia. Climatic regions in South Sulawesi has a different character than other areas in Indonesia. This is certainly influenced by the geographic location near the beach. Nevertheless, the same season as the season Indonesian region in general, the dry season and the rainy season. In topography, the east coast of South Sulawesi has a swampy land and brackish water due to the influence of tidal. South Sulawesi has many hills and high mountains. Land in South Sulawesi has two categories, namely, lowland covering almost all the districts/cities, the highlands include Luwu district, Tana Toraja, Luwu Utara, Enrekang, Sinjai, Gowa, Bone, and parts of Sidrap, Wajo, Pinrang, Maros, Pangkep and Pare-Pare and includes coastal waters and district/city that stretches on the coast of the East and West coast and the sea in covering the Makassar Strait, Gulf of Bone and Selayar sea (BPS, 2013).

The harvesting technique and allometric equations are also limited in terms of getting biomass information at a large spatial scale. Thus, for a fast, cost effective and wide coverage of biomass estimation remote sensing technology has been found to be the best choice. Plantations of oil palms constitute an important example of land use that has only recently become a topic of remote sensing research. In recent decades there has been a vast amount of activity devoted to the remote sensing of various types of agricultural production. But until recently this did not extend to oil palms and the industry has been successfully established and monitored using more conventional data sources. There are two reasons for the current interest in remote sensing of oil palms and they are both concerned with carbon sequestration. The first is in connection with studies of climate change where there is a need for more accurate information on the carbon cycle and the second is the interest in the possible introduction of carbon trading among nations in an attempt to restrain global warming. Several studies have attempted at determining the biomass, and therefore the rate of carbon sequestration (Thenkabail *et al.*, 2004; Morel *et al.*, 2012, Cracknell *et al.*, 2013(a), 2013(b); Tan *et al.*, 2014; Shasikant *et al.*, 2012) in Malaysia and Africa. Results of these studies indicate the utility of remote sensing data in carbon budget calculations which is important for assigning carbon credits in agro-forestry systems such as oil palm plantations. In this study, Advanced Land Observing Satellite Phase Array type L-band Synthetic Aperture Radar (ALOS PALSAR) radar data is used to estimate oil palm AGB in south Sulawesi, Indonesia adding another literature to the existing database on the use of remote sensing for oil palm biomass estimation.

1.3 Objectives of the study

The aim of this study is to provide biomass data for oil palm trees in South Sulawesi, Indonesia and the aim is achieved using a set of objectives as follows:

1. To quantify the aboveground biomass of oil palm trees with different age groups using an harvesting method.
2. To develop allometric equations to quantify the aboveground biomass of oil palm trees.

3. To scale up aboveground biomass estimated using allometric equation from plot to larger scale (entire oil palm region in south Sulawesi, Indonesia) using ALOS PALSAR satellite data.

1.4 Scope of the study

This study is only concerned with the aboveground biomass (AGB) that includes oil palm trees without the root and other plants that grow in the study area. AGB is the key index in the carbon balance study. Estimating AGB is important to determine the total amount of CO_2 that enters the oil palm ecosystem over a time (Hairiah *et al.*, 2001). This is because approximately 45% of AGB in oil palm trees is carbon stock. Furthermore, determining the belowground biomass (biomass contained in the root of oil palm trees) is rather difficult because there is no clear separation of roots among the trees. Therefore, only AGB is considered as a key carbon balance variable in this study.

A total of only 9 trees were harvested to get their biomass. Statistically these numbers are not significant however, since felling down trees is a not a sustainable method the plantation owner only allowed 9 trees to be cut down. More specifically AGB was calculated/estimated for three age groups of oil palm trees that cover the young (1-3 years), intermediate (4-10 years) and the matured (11-20 years) of trees. In oil palm plantation, the growth of trees and accumulation of biomass and production occurs from the age of 3 years and increases drastically until oil palm trees reach the age 10 years. After 20 years the biomass/productivity will start to decrease. Therefore, trees representing these three stages of development were selected in this study to get their biomass. Specific allometric equations were developed for each of these age classes using the biometric data (tree *dbh* and height) collected in the field. These allometric equations were then used to estimate the aboveground biomass of all oil palm trees in the study area using ALOS PALSAR L-band satellite data. This data was chosen to estimate the aboveground biomass because L-band is capable to penetrate the canopy and trunk of oil palm trees tp provide a more representative aboveground biomass.

Estimation of biomass in a large area of oil palm plantation is possible by using remote sensing techniques. The study area have 2059 ha in Keera South Sulawesi, Indonesia. Remote sensing techniques can overcome the obstacles that occur in estimating primarily a matter of time and trouble location. Data ALOS PALSAR L-band selected as a primary data in this study because it has a penetration to the soil surface and are not disturbed by the presence of clouds, operate day and night and is not dependent on the sun. Digital Number (DN) values in the image data converted to the backscatter of ALOS PALSAR. All the image processing involved in this study were done using various software namely Erdas Imagine and ENVI.

1.5 Significance of the study

Research on biomass and carbon in oil palm plantations is very interesting as there are many pros and cons regarding the expansion of oil palm plantations with its impact to the environment. With the REDD (Reducing Emissions from Deforestation and Forest Degradation) mechanism, Indonesia conducted negotiations that can lead to policies that focus on the reduction of greenhouse gases. Niles *et al.* (2002)

predicted that Indonesia could earn US $ 14.3 million of the total ability of carbon sinks. But REDD is only focusing on a single forest when oil palm plantations also has the potential to put forward in reducing CO_2 emissions in the decision making for a sustainable environment. Data of biomass and carbon stock of oil palm plantations is not widely available compared to forests. Similarly, in Indonesia, a small number of studies have been conducted in Sumatra and Kalimantan (Khalid *et al.*, 1999; Henson, 2003; Corley and Tinker, 2003; Syahrinudin, 2005; Yulianti, 2009; Sharma, 2009; Morel *et al.*, 2012). South Sulawesi province itself has oil palm plantations covering an area of 32.26 Mha (BPS Prop Sulawesi Selatan, 2013). Biomass/carbon stock data on oil palm is vital to understand the role plays by oil palm plantation in Sulawesi in the global carbon cycle and climate change.

Scaling up the AGB to a regional scale (South Sulawesi) is important to understand the role of oil palm ecosystem in the global carbon cycle and future climate change. Understanding of oil palm AGB in Indonesia is critical for (1) assisting the International Sustainable and Carbon Certification (ISCC) in carbon accounting and thus its capability to manage the carbon cycle of oil palm responsibly, which can alleviate the effects of oil palm plantations on future climate change (2) promoting the sustainability of the oil palm industry (3) assisting policy makers in the Kyoto Protocol, Intergovernmental Panel on Climate Change (IPCC) and the Roundtable on Sustainable Palm Oil (RSPO) to enforce the code of practice/ treaties among the members to impose a better land management.

In terms of the economy, data on Greenhouse Gases (GHG) exchange on an annual basis by the oil palm industry, including the action that the companies are taking to address the risks and opportunities associated with climate change are needed in the Carbon Disclosure Project. Since April 2013, a GHG report is compulsory to be submitted by the companies listed on the London Stock Exchange. The information obtained would be used by investors and policy makers to guide decision making. Besides, if carbon trading among nations becomes a feature of global economics, it would be necessary for countries, such as Indonesia, Malaysia and other tropical producers of palm oil, to be able to have accurate figures for the carbon sequestration by oil palms. This has also been suggested by Lamade and Bouillet (2005).

1.6 Overview of the thesis

The thesis comprises six chapters. Chapter two provides necessary background information to understand the distribution of oil palm plantations in Indonesia and its role in the global carbon cycle. There are four main methods used for estimating biomass namely: i) destructive, ii) non-destructive, iii) remote sensing and iv) modelling. Destructive and non-destructive methods are both in-situ work. Various methods available to calculate/estimate oil palm biomass is also reviewed in this chapter and this is important to select the most appropriate technique and data to obtain biomass of oil palm in this study. In Chapter three more detailed and specific methods adopted to achieve the objectives of the study as outlined in Chapter one is provided. This includes field data collection, development of allometric equations and the use of remote sensing to estimate biomass at a larger scale. The results of the study are presented and discussed in Chapters Four and Five. Chapter four provides biomass calculated using harvesting method and the allometric equations produced from the data collected in the field. The result of validation of the equations are also presented in this chapter. Chapter five shows the results of biomass estimated using ALOS PALSAR satellite data. This chapter also shows the results of the estimated biomass using satellite data that is validated by AGB value obtained by u sing allometric equations. The last Chapter (Chapter six) concludes the thesis and outlines some recommendations for future studies.

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