UNIVERSITI PUTRA MALAYSIA

SOIL CARBON STORAGE POTENTIAL OF AWAT-AWAT MANGROVE FOREST RESERVE AT LAWAS, SARAWAK, MALAYSIA

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By

AHMAD MUSTAPHA BIN MOHAMAD PAZI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

January 2017

Dedicate to my families and friends.

Thank you for everything

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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January 2017

Chairman : Associate Professor Seca Gandaseca, PhD
Faculty : Forestry

Mangrove forest is one of the most important ecosystems to act as carbon pools. The assessment of soil carbon storage has been done in many places, but there is still a lack of data about the estimation of soil carbon storage in Awat-Awat Mangrove Forest Reverse Lawas, Sarawak. The general objective of this study was to assess the soil carbon storage potential in Awat-Awat Mangrove Forest Reserve Lawas, Sarawak and the specific objectives were to determine the soil physiochemical properties under six dominant mangrove tree species by soil depth; to compare the soil physiochemical properties between the seasons, mangrove zones, and soil depths and to estimate the total of soil carbon pools potential in the mangrove soil. In this study, six dominant mangrove tree species were found in three different zones and there are *Sonneratia alba*, *Sonneratia caseolaris*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Lumnitzera littorea* and *Xylorcarpus granatum*. Six study plots (50 m × 50 m) were established randomly based on dominant mangrove tree species in the study area. A total of 300 soil samples were collected in November and December 2014 (wet season) and March and April 2015 (dry season). The soil physiochemical properties under six dominant mangrove tree species by soil depth were determined. In term of the soil physiochemical properties between the seasons, mangrove zones, and soil depths, data were calculated to compare between the factors. The total of the mass of soil carbon pools in 4372 ha of Awat-Awat Mangrove Forest Reserve was also estimated in this study. As a result, the soil physiochemical properties under six dominant mangrove tree species by soil depth showed the soil texture at *Sonneratia alba* soil was sandy clay loam at all depths. While, *Sonneratia caseolaris* soil was sandy clay loam in the soil depth (0-30 cm) and sandy loam in the soil depth (30->100 cm). *Rhizophora apiculata* and *Rhizophora mucronata* soils were sandy clay loam in the soil depth (0-15 cm) and sandy loam in the soil depth (15->100 cm). The soil texture in *Lumnitzera littorea* and *Xylorcarpus granatum* were sandy loam. The soil bulk density, showed the *Sonneratia alba* soil was highest among the other species and the deepest soil were found significantly different among the other soil depth with mean of $1.273^{a}(\pm0.005)$ g cm^{-3}. The soil pH of this area was acidic and deepest soil pH showed the lowest pH. The soil organic matter (SOM) and total organic carbon (TOC) were significantly highest under

the *Rhizophora apiculata* species in the deepest soil depth 30.88[a](±1.56)% and 17.91[a](±0.91)%. Meanwhile, the total mass of soil carbon (C_T) was significantly highest under *Rhizophora mucronata* in the deepest soil depth 235.66[a](±5.37). In term of the seasons, soil texture of mangrove soil was sandy loam and the sand content was significantly higher during the wet season than the dry season, the silt and clay contents were significantly highest during the dry season than the wet season. For the soil bulk density, showed no significant different between the seasons. The mean comparison of the soil pH between the seasons showed significantly different and dry season showed higher values than the wet season. The soil organic matter (SOM) and total organic carbon (TOC) were obtained the higher result during the wet season with 18.30[a](±0.67) and 10.60[a](±0.39). The mean comparison of (SOM) and (TOC) showed significantly different between the seasons. In term of mangrove zone, the soil texture at the seaward was sandy loam, middleward was sandy clay loam and landward was sandy loam. For the soil fractions between the zones, the sand content was significantly highest in the landward zone, silt content was highest at the landward but there is no significantly among the other zones and the clay content was significantly highest at the middleward zone. For the value of the soil bulk density, the seaward zone has recorded the highest value with 1.145[a](±0.009) g cm^{-3} and the mean comparison was showed significantly different among the zones. The soil pH in the mangrove zone was acidic and showed the seaward zone was obtained the highest value. The mean comparison of soil pH showed significantly different among the zones. The middleward zone obtained the highest percentage of SOM and TOC with 25.93[a](±0.403)% and 15.04[a](±0.23)%. The mean comparison of the SOM and TOC showed significantly different among the zones. In term of soil depth, the soil texture was sandy loam. The soil fractions showed the sand and silt contents were significantly highest in the soil depth D4 (50-100 cm) and clay content was significantly highest in the soil depth D1 (0-15 cm). The soil bulk density, soil depth D5 (>100 cm) obtained the highest value and give a significantly different among the soil depths. For the soil pH in soil depth was acidic and the soil depth 1 (0-15 cm) obtained the highest value of soil pH. The mean comparison of soil pH between the soil depth was showed significant different. The percentage of soil organic matter (SOM) and total organic carbon (TOC) in soil depth, soil depth D5 (>100 cm) was obtained the highest percentage with a mean 18.88[a](±1.01)% and 10.95[a](±0.59)%. The mean comparison was showed significantly different among the soil depths. The estimated of soil carbon pools potential of the Awat-Awat Mangrove Forest Reserve Lawas, Sarawak has been done and the total of soil carbon mass in 4372 ha of mangrove forest was 1666431.52 t C. As a conclusion, Awat-Awat Mangrove Forest Reserve has a potential as soil carbon pools regarding on the result of SOM, TOC and C_T were give a significantly result in estimated of soil carbon pools. As a recommendation, this forest should be conserved to maintain this potential areas as carbon pools in the future and need a further study to monitor the soil carbon changes in this mangrove from time to time.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

POTENSI PENYIMPANAN KARBON TANAH DI HUTAN SIMPAN PAYA BAKAU AWAT-AWAT LAWAS, SARAWAK, MALAYSIA

Oleh

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Januari 2017

Pengerusi : Profesor Madya Seca Gandaseca, PhD
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Hutan Paya Bakau adalah salah satu ekosistem yang paling penting untuk bertindak sebagai penyimpanan karbon. Penilaian penyimpanan karbon tanah telah dilakukan di banyak tempat, tetapi masih terdapat kekurangan data tentang anggaran penyimpanan karbon tanah di Hutan Simpan Paya Bakau, Awat-Awat Lawas, Sarawak. Objektif umum kajian ini adalah untuk menilai penyimpanan karbon tanah berpotensi di Hutan Simpan Paya Bakau Awat-Awat Lawas, Sarawak dan objektif khusus adalah untuk menentukan sifat-sifat fisikokimia tanah di bawah enam spesies pokok bakau yang dominan dengan kedalaman tanah; untuk membandingkan sifat-sifat fisikokimia tanah antara musim, zon-zon bakau dan kedalaman tanah dan untuk menganggarkan jumlah penyimpanan karbon tanah berpotensi dalam tanah bakau. Dalam kajian ini, enam dominan spesies pokok bakau telah ditemui di tiga zon yang berbeza dan ia adalah *Sonneratia alba, Sonneratia caseolaris, Rhizophora apiculata, Rhizophora mucronata, Lumnitzera littorea* dan *Xylorcarpus granatum*. Enam plot kajian (50 m × 50 m) telah ditubuhkan secara rawak berdasarkan spesies pokok bakau yang dominan di kawasan kajian. Sebanyak 300 sampel tanah telah dikumpulkan pada bulan November dan Disember 2014 (musim tengkujuh) dan Mac dan April 2015 (musim kering). Sifat fisikokimia tanah di bawah enam spesies dominan pokok bakau dengan mengikut kedalaman tanah telah ditentukan. Dari segi sifat fisikokimia tanah antara musim, zon bakau dan kedalaman tanah, data telah dikira dan dibandingkan antara faktor-faktor tersebut. Jumlah keseluruhan jisim tanah penyimpanan karbon dalam 4372 ha Hutan Simpan Paya Bakau Awat-Awat juga telah dianggarkan dalam kajian ini. Hasilnya, sifat-sifat fisikokimia tanah di bawah enam dominan spesies pokok bakau mengikut kedalaman tanah menunjukkan tekstur tanah di tanah *Sonneratia alba* adalah lom liat berpasir di semua kedalaman. Manakala, tanah *Sonneratia caseolaris* adalah lom liat berpasir di kedalaman tanah (0-30 cm) dan lom berpasir di kedalaman tanah (30->100 cm). Tanah *Rhizophora apiculata* dan *Rhizophora mucronata* adalah lom liat berpasir di kedalaman tanah (0-15 cm) dan lom berpasir di kedalaman tanah (15->100 cm). Tekstur tanah di *Lumnitzera littorea* dan *Xylorcarpus granatum* adalah loam berpasir. Kepadatan pukal tanah, menunjukkan tanah *Sonneratia alba* adalah tertinggi antara spesies yang lain dan tanah bawah didapati berbeza antara kedalaman tanah yang lain

dengan min 1.273[a](±0.005) g cm^{-3}. pH tanah bagi kawasan ini adalah berasid dan pH tanah paling bawah menunjukkan pH yang terendah. Tanah organik (SOM) dan jumlah karbon organik (TOC) adalah signifikan tertinggi di bawah *Rhizophora apiculata* spesies di kedalaman tanah paling bawah 30.88[a](±1.56)% dan 17.91[a](±0.91)%. Sementara itu, jumlah jisim tanah karbon (C_T) adalah signifikan tertinggi di bawah *Rhizophora mucronata* di kedalaman tanah paling bawah 235.66[a](±5.37). Dari segi musim, tekstur tanah bakau adalah lom berpasir dan kandungan pasir adalah signifikan tertinggi ketika musim tengkujuh daripada musim kering, kandungan kelodak dan tanah liat adalah tertinggi semasa musim kering berbanding musim tengkujuh. Bagi kepadatan pukal tanah, menunjukkan tiada perbezaan signifikan antara musim. Perbandingan min pH tanah antara musim, musim kering menunjukkan perbezaan signifikan tertinggi daripada musim tengkujuh. Bagi tanah organik (SOM) dan jumlah karbon organik (TOC) memperolehi hasil yang tertinggi ketika musim tengkujuh dengan min 18.30[a](±0.67) dan 10.60[a](±0.39). Perbezaan min bagi (SOM) dan (TOC) menunjukkan perbezaan yang signifikan antara musim. Dari segi zon bakau, tekstur tanah di zon darat adalah lom berpasir, zon pertengahan adalah lom liat berpasir dan zon laut adalah lom berpasir. Bagi pecahan tanah antara zon, kandungan pasir adalah signifikan tertinggi di zon darat, kandungan kelodak adalah tertinggi di zon darat tetapi tidak ketara antara zon yang lain dan kandungan tanah liat adalah signifikan tertinggi di zon pertengahan. Untuk nilai ketumpatan pukal tanah, zon laut telah mencatat nilai yang tertinggi dengan 1.145[a](±0.009) g cm^{-3} dan perbandingan min adalah menunjukkan perbezaan yang signifikan antara zon. pH tanah di zon bakau adalah berasid dan menunjukkan zon laut telah memperolehi nilai tertinggi. Perbandingan min bagi pH tanah menunjukkan perbezaan yang signifikan antara zon. Zon pertengahan mendapat peratusan tertinggi SOM dan TOC dengan 25.93[a](±0.403)% dan 15.04[a](±0.23)%. Perbandingan min SOM dan TOC menunjukkan perbezaan yang signifikan a antara zon. Dari segi kedalaman tanah, tekstur tanah adalah lom berpasir. Pecahan tanah menunjukkan kandungan pasir dan kelodak adalah signifikan tertinggi di kedalaman tanah D4 (50-100 cm) dan kandungan tanah liat yang signifikan tertinggi di kedalaman tanah D1 (0-15 cm). Kepadatan pukal tanah, kedalaman tanah D5 (>100 cm) memperolehi nilai tertinggi dan memberikan perbezaan yang signifikan antara kedalaman tanah. Untuk pH tanah di kedalaman tanag adalah berasid dan kedalaman tanah D1 (0-15 cm) telah mendapat nilai tertinggi bagi pH tanah. Perbandingan min pH tanah diantara kedalaman tanah adalah menunjukkan perbezaan yang signifikan. Peratusan tanah organik (SOM) dan jumlah karbon organik (TOC) dalam tanah, kedalaman tanah D5 (>100 cm) telah memperolehi peratusan yang tertinggi dengan min 18.88[a](±1.01)% dan 10.95[a](±0.59)%. Perbandingan min menunjukkan perbezaan yang signifikan antara kedalaman tanah. Anggaran keupayaan penyimpanan karbon tanah di Hutan Simpan Paya Bakau Awat-Awat Lawas, Sarawak telah dilakukan dan jumlah jisim karbon tanah di 4372 ha hutan paya bakau adalah 1666431.52 t C. Kesimpulannya, Hutan Simpan Paya Bakau Awat-Awat mempunyai potensi sebagai penyimpanan karbon tanah daripada hasil SOM, TOC dan C_T telah memberi hasil yang signifikan dalam menganggarkan penyimpanan karbon tanah. Sebagai cadangan, hutan ini perlu dikekalkan dan dipelihara untuk memastikan kawasan yang berpotensi ini sebagai penyimpanan karbon pada masa akan datang dan memerlukan kajian lanjut untuk memantau perubahan karbon tanah di bakau ini dari masa ke semasa.

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I certify that a Thesis Examination Committee has met on 5 January 2017 to conduct the final examination of Ahmad Mustapha bin Mohamad Pazi on his thesis entitled "Soil Carbon Storage Potential of Awat-Awat Mangrove Forest Reserve at Lawas, Sarawak, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
C	Carbon
CO_2	Carbon Dioxide
Cm	Centimeter
E	East
FAO	Food Agriculture Organization
g	Gram
g cm^{-3}	Gram Meter Cubic
GPS	Global Positioning System
ha	Hectare
K	Karbon
KCl	Potassium Chloride
km	Kilometer
L	Litre
M	Mole
Mg ha^{-1}	Megagram Per Hectare
m	Meter
Mg	Milligram
mL	Millilitre
N	North
No.	Number
OM	Organic Matter
ORP	Redox Potetential
ppm	Parts Per Million
rpm	Revolution Per Minute

SAS	Statistical Analysis System
Spp.	Species
TOC	Total Organic Carbon

CHAPTER 1

INTRODUCTION

1.1 General Background

The total worldwide of mangrove forest was around 15.6 and 19.8 million hectares and it is just around 0.40% of world forest and forest respectively. The world mangrove can be found in Asia (39%), followed by Africa (21%) and North and Central America (15%). Malaysia is one of the top nations in the biggest region of mangrove on the earth (FAO, 2007). In Sarawak, mangrove covering approximately 173,792 ha, or less than 1.4% of the total area. Although, 15,983 hectares have been gazetted as Totally Protected Area (TPA) and around 28,000 ha remain as a forest reserve and protected forest. Mangrove real living space arranged in Kuching (52 318 ha), Sarikei in Rejang Delta (87 544 ha) and Limbang (8359 ha) (Rambok *et al.*, 2010; Chai, 1975).

The world's forests store more than 650 billion t C, 44% of C was found in the aboveground biomass, 11% from the root, litter, dead wood and other debris and 45% present in soil (FAO, 2010). Mangrove forests are very effective in storing carbon from years to years and it can help to store the CO_2 in the plant and soil (Kauffman and Donato, 2012). Most of the mangrove forest assumes a critical part in the worldwide carbon cycling since they hold a larger pool of carbon and also the potential carbon sinks and sources to the air (Arianto *et al.*, 2015). Worldwide, mangrove ecosystem deforestation accounts for 10% of the carbon released from deforestation each year and yet mangroves amount to just 0.7% of the tropical forest areas (Donato *et al.*, 2011).

Mangrove forest has several important functions in the tropical coastline area and provides a broad array of ecosystem services including the protection from tsunamis and support of coastal water quality. Mangrove also provides important habitats for mammals, reptiles, birds, fish, crustaceans and feeding nursery areas for commercial and artisanal fishery species (Pazi *et al.*, 2016; Kuenzer and Gebhardt, 2011).

Mangrove forest is among the most productive ecosystems on the earth and plays an important role in the global cycle (Alogi, 2012). The decreases of mangrove forests are caused by conversion to agriculture, aquaculture, house development, overharvesting and overexploitation (Alongi, 2002). The loss and degradation of mangrove forest could have a negative impact on mangrove ecosystem and influenced the climate change (Giri *et al.*, 2011).

1.2 Problem Statement

Soil carbon pools are important for describing the current state of mangrove forests in the soil carbon changes. The mangrove environments influencing the soil carbon pools changes directly by the nature disaster and human activities. Thus, it will affect to estimate soil carbon pools in the mangrove forest.

Awat-Awat Mangrove Forest Reserve Lawas, Sarawak is possible to have the highest potential for soil carbon pools, but there is little information on its method and quantification on estimate the soil carbon pools. This mangrove forest is experiencing in a legal and illegal rate of deforestation, conversion the area of large scale development and overexploitation of mangrove forest resources by local communities.

Moreover, the assessment of soil carbon storage in mangrove forest has been done in tropical countries, including Malaysia. But there are no many data about the estimation of soil carbon pools in Awat-Awat Mangrove Forest Reverse Lawas, Sarawak. So, it is envisaged that the information obtains from this study will be useful and provide a better understanding in assessing soil carbon pools of the mangrove forest and in designing proper management plans for the mangrove forest. This will ensure the sustained potential of this mangrove forest contribution to soil carbon pools and climate change mitigation.

1.3 Objectives

The general objective of this study was to assess the soil carbon pools potential in Awat-Awat Mangrove Forest Reserve Lawas, Sarawak.

The specific objectives were:

1. To determine the soil physiochemical properties under six dominant mangrove tree species by soil depth at Awat-Awat Mangrove Forest Reserve Lawas, Sarawak.

2. To compare the soil physiochemical properties between the seasons, mangrove zones, and soil depths at Awat-Awat Mangrove Forest Reserve Lawas, Sarawak.

3. To estimate the total of soil carbon pools potential of the mangrove soil at Awat-Awat Mangrove Forest Lawas, Sarawak.

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