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ESTIMATING CARBON STORAGE OF FOREST FLOOR COMPONENTS AT VARYING ALTITUDES IN TROPICAL FOREST OF PAHANG, MALAYSIA

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By

V. JEYANNY VIJAYANATHAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

Specially dedicated to all my pillars of strength,

my beloved family, Mr. Gerard Felix, Ms. Juliyana and Michael Andrew

For their constant encouragement and inspiration.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Increasing atmospheric carbon dioxide (CO_2) concentrations at alarming rates has triggered the need to conserve and monitor carbon (C) stocks for climate change mitigation. Tropical forests are important carbon sinks which are dynamic due to topographic variations, biomass components, forest floor quality, decomposition processes and spatial variation. Precise and reliable estimation of C stocks and its confounding processes that release/store C are still absent in tropical montane and lowland forests in Malaysia. The objectives of this study were i) to quantify above and belowground biomass C stocks in a lowland forest and montane forest with varying topography; ii) to determine the potential indicators (i.e. litter and duff decomposition rate, forest floor component and properties, soil CO_2 fluxes and C:N ratios) of soil C storage and iii) to determine the spatial variability of litter, soil C, C:N, and forest floor component depths of a tropical lowland forest and tropical montane forest with varying topography. A systematic design of 10 m x 10 m plots was established for soil (0- 15 cm depth), litter and aboveground biomass sampling along three slope positions at the montane forest and one plot in the lowland forest. Basic soil characteristics and botanical distribution were determined. A litter bag study and soil CO_2 flux measurements were conducted for 480 days in the montane and lowland forest.

Forest floor materials were carbon dated and segregated for precise bulk density and carbon fraction measurements. Soil C, C:N, litter depth and various decomposing layers were explored using geostatistics to determine spatial variability. Litter and soil carbon stocks were significantly higher (3 and 5-fold) in the montane forest compared to the lowlands. The aboveground biomass ranged from 100 to 120 Mg C ha^{-1} and was the most dominant pool (> 40%) for all sites. The decomposition decay rate constant, k ranged from -0.002 to – 0.004 day^{-1} for the tropical montane and lowland forest. Lowlands showed increased mass loss and significant linear regression relationships between mass loss and litter quality except for C, lignin and cellulose. Soil CO_2 fluxes were higher in the lowlands and positively correlated with decomposition and water filled pore space (WFPS). Duff (hemic + sapric) segregation resulted higher bulk density values (0.2) compared to litter (0.04) and revealed a more precise carbon fraction for litter (0.43) and duff (0.55) to be used for forest floor C stocks predictions utilizing significant linear regressions. Duff may reside up to 60 years. Duff decomposition is impeded even at higher temperatures in Forest Research Institute Malaysia campus and retained most of its carbon, nitrogen and lignin. Relationship between soil C:N and C were strong for all plots. Soil total C, C:N, and litter depth exhibited spatial variability at both forest types. Similarly, the litter, hemic and the total forest floor depth fractions confirmed spatial variations. Most variables exhibited a strong spatial dependence with the exception of C:N at the sideslope, litter depth at Jengka VJR and hemic depth at the summit (moderate). Surface maps for total C, C:N, litter depths, hemic and total forest floor depth showed distinct spatial clustering and displayed acceptable accuracy of interpolated values. Forest floor in the montane forest acts as an important C stock in the tropical forest which needs to accounted precisely for national C accounting. Research and developments in monitoring C stocks in montane forests within national and regional areas must be explored to avoid undestimation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANGGARAN STOK KARBON DALAM KOMPONEN LAPISAN ORGANIK PADA KEDUDUKAN CERUN BERLAINAN DI HUTAN TROPIKA PAHANG, MALAYSIA

Oleh

V. JEYANNY VIJAYANATHAN

Disember 2014

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Peningkatan drastik dalam kepekatan gas karbon dioksida di atmosfera telah mencetuskan keperluan untuk memelihara dan memantau stok karbon (C) untuk mitigasi perubahan iklim. Hutan tropika merupakan stok karbon yang penting dan dinamik kerana variasi topografi, komponen biomas, kualiti lapisan organik, proses penguraian, dan variasi ruang. Penganggaran stok karbon yang tepat dan persis serta proses-proses yang berkaitan dengan pembebasan dan penyimpanan karbon masih tidak wujud di hutan tanah gunung dan hutan tanah pamah di Malaysia. Objektif kajian projek ini adalah i) untuk menentukan stok biomas karbon diatas dan dibawah tanah di hutan tanah pamah dan hutan gunung dengan kecerunanan berlainan; ii) menentukan indikator-indikator yang berpotensi (kadar penguraian daun luruhan organik dan '*duff*'; ciri-ciri lapisan organik, fluks CO_2 tanah, nisbah C:N) dalam penyimpanan stok karbon dan iii) menentukan variasi ruang ketebalan daun luruhan organik, nilai C tanah, nisbah C:N dan ketebalan lapisan organik hutan gunung dengan kecerunan berlainan dan hutan tanah pamah. Kuadrat bersaiz 10 x 10 m persegi telah ditubuhkan secara sistematik untuk persampelan tanah (kedalaman 0 hingga 15 cm), daun luruhan organik dan biomas di atas tanah di tiga kedudukan cerun di hutan gunung dan satu plot di hutan tanah pamah.

Ciri-ciri tanah dan taburan am vegetasi telah ditentukan. Kajian '*litterbag*' dan penentuan fluks CO_2 tanah telah dijalankan untuk 480 hari di hutan gunung dan hutan tanah pamah. Bahan lapisan organik telah ditentukan usia karbon dan dipisahkan untuk mendapatkan ketumpatan pukal dan pecahan karbon. Nilai karbon tanah, C:N dan ketebalan daun luruhan serta lapisan organik pada tahap penguraian yang berbeza telah dianalisis menggunakan kaedah geostatistik untuk penentuan variasi ruang. Hasil kajian mendapati stok karbon daun luruhan organik dan tanah adalah 3 dan 5 kali lebih tinggi secara signifikan di hutan gunung berbanding hutan tanah pamah. Kandungan stok karbon biomas pokok adalah dalam lingkungan 100 – 120 Mg C ha^{-1} di hutan gunung dan merupakan komponen paling dominan (> 40 %) berbanding plot lain. Pemboleh ubah malar kadar penguraian bahan organik, *k*, adalah dalam lingkungan -0.002 – 0.004 day^{-1} untuk hutan gunung dan hutan tanah pamah. Hutan tanah pamah menunjukkan kehilangan berat yang tinggi dan hubungan regresi linear yang signifikan di antara kehilangan berat dan kualiti daun luruhan organik kecuali C, kandungan lignin dan sellulosa daun. Fluks CO_2 tanah adalah lebih tinggi di hutan tanah pamah dan mempunyai korelasi yang positif dengan penguraian daun luruhan organik dan '*water filled pore space'* (WFPS). Pengasingan *duff* (*hemic* + *sapric*) menunjukkan ketumpatan pukal yang lebih tinggi (0.2) berbanding daun luruhan organik (0.04) serta menunjukkan pecahan karbon yang lebih persis iaitu 0.43 untuk daun luruhan organik dan 0.55 untuk *duff* bagi penentuan ramalan stok C dalam lapisan organik permukaan tanah menggunakan hubungan regresi linear yang signifikan. *Duff* dapat bertahan selama 60 tahun. Penguraian *duff* adalah lambat walaupun dengan suhu tinggi di kampus Institut Penyelidikan Perhutanan Malaysia (FRIM) dan menyimpan kebanyakan unsur karbon, nitrogen dan lignin. Hubungan regresi yang signifikan didapati antara nisbah C:N tanah dan C untuk semua plot kajian. Analisis geostatistik menunjukkan variasi struktur ruang (*spatial*) untuk pemboleh ubah nilai C tanah, nisbah C:N dan ketebalan daun luruhan di kedua-dua jenis hutan. Pengasingan pecahan daun luruhan, *hemic* dan keseluruhan lapisan organik juga mengesahkan variasi ruang yang signifikan. Kebanyakan pemboleh ubah menunjukkan ianya bergantung secara kuat kepada variasi ruang, kecuali nisbah C:N di permukaan landai bukit, ketebalan daun luruhan di Jengka VJR dan ketebalan *hemic* di puncak bukit yang bergantung secara sederhana sahaja. Peta permukaan menunjukkan kelompok ruang yang berbeza dan memaparkan nilai interpolasi yang tepat untuk C, C:N, ketebalan daun luruhan, *hemic* dan ketebalan keseluruhan lapisan organik. Lapisan organik di hutan gunung merupakan komponen stok C yang penting di hutan tropika yang perlu dikaji secara tepat untuk penentuan stok karbon negara. Usaha penyelidikan dan pembangunan dalam pemantauan stok karbon hutan gunung di negara dan rantau Asia perlu diterokai untuk mengelakkan kesalahan dalam pengganggaran.

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I certify that a Thesis Examination Committee has met on 15 December 2014 to conduct the final examination of V.Jeyanny Vijayanathan on her thesis entitled "Estimating Carbon Storage of Forest Floor Components at Varying Altitudes in Tropical Forest of Pahang, 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 Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ABD	Above Ground Biomass
AFPC	Air Filled Pore Space
AGB	Above Ground Biomass
AMF	Arbuscular Mycorrhizal Fungi
AMS	Accelerated Mass Spectrometry
ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
BD	Bulk Density
C	Carbon
C:N	Carbon: Nitrogen
C:P	Carbon: Phosphorus
Ca	Calcium
CDM	Clean Development Mechanism
CF	Carbon Fraction
CNS	Carbon: Nitrogen: Sulfur
CS	Carbon Sequestration
CTFS	Centre for Tropical Forest Science
CV	Coefficient of Variation
CWD	Coarse Woody Debris
DBH	Diameter at Breast Height
DNA	Deoxyribonucleic acid
DWD	Downed Woody Debris
EDA	Exploratory Data Analysis

ENSO	El Nino Southern Oscillation
ER	Effective Range
ESD	Extreme Studentized Deviated
FAO	Food Aid Organization
FFC	Forest Floor Carbon
FR	Forest Reserve
FRIM	Forest Research Institute Malaysia
GCM	Global Circulation Model
GHG	Greenhouse Gases
GIS	Geographic Information System
GPG	Good Practice Guidance
GPS	Global Positioning System
Gt	Giga tonnes
HCL	Hydrochloric Acid
IDW	Inverse Distance Weighting
IPCC	Intergovernmental Panel on Climate Change
K	Kalium/Potassium
LULUCF	Land Use and Land Use Chang and Forestry
ME	Mean Error
Mg	Mega gram (10^6)
Mn	Manganese
MOA	Ministry of Agriculture
MRT	Mean Residence Time

MSE	Mean Square Error
N	Nitrogen
NaOH	Sodium Hydroxide
NH_4OAc	Ammonium Acetate
NPP	Net Primary Production
NSCCC	National Steering Committee on Climate Change
NW	North West
Oa	Sapric (organic)
Oe	Hemic (organic)
Oi	Fibric (organic)
OM	Organic Matter
P	Phosphorus
PA	Precision Agriculture
Pg C	Pentagram (10^{15})
PMC	Percent Modern Carbon
PRECIS	Providing Regional Climates for Impacts Studies
PVC	Poly Vinyl Chloride
REDD	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
RNA	Ribonucleic acid
SE	South East
SIC	Soil Inorganic Carbon
SOC	Soil Organic Carbon
SMSE	Standardized Mean Squared Error

SOM	Soil Organic Matter
SOS	Soil Organic Carbon
SW	South West
TFF	Total Forest Floor
UNFCCC	United National Framework Convention On Climate Change
UPM	Universiti Putra Malaysia
VJR	Virgin Jungle Reserve
WFPS	Water Filled Pore Space

CHAPTER I

INTRODUCTION

The progressive global industrial and agricultural development has caused increased carbon dioxide (CO_2) emissions. The concentration of CO_2 in the atmosphere has been reported to soar up to 391 ppm in 2011 (IPCC, 2013) compared to 280 ppm in the 1800 (Pitelka & Rojas 2001). According to the Intergovernmental Panel on Climate Change (IPCC), this will simultaneously increases Earth's temperature between 0.6 to 1.1° C over the period of 1880 to 2012. In order to reduce the Greenhouse Gases (GHG) in the atmosphere, two key activities are relevant: decrease the anthropogenic emissions of CO_2 and create or promote carbon (C) sinks in the biosphere.

Tropical forests clearly dominate the role of forests both on C flux, and the volume of C stored. Tropical soils constitute 26% of the soil organic carbon (SOC) in the world (Batjes, 1996). Worldwide, SOC in the top one meter of soil comprises about 3/4 of the earth's terrestrial carbon and has tremendous potential to sequester additional carbon in soil (Soil Science Society of America, 2009). Malaysia had voluntarily agreed to CO_2 emission reductions, increased carbon sinks and promoting research on carbon cycling in the Kyoto Protocol (Soderstrom, 2002). During the Bali Convention on Climate Change (2007), Malaysia being part of the 80% of the world's tropical rainforest has further reaffirmed its stand by showing interest in obtaining funds to reduce emissions from deforestation. At present, the total forest cover of Malaysia stands at 60% (excluding rubber) [FAO, 2010].

However, the amount of C which can be sequestered in native ecosystem types are limited. Regional estimation which is currently used may not reflect the actual values for Malaysia in the Land Use and Land Use Change and Forestry (LULUCF). Moreover, definitive quantification of various carbon stocks, especially in aboveground and belowground biomass has not be delineated successfully due to dynamic ecological systems, budget constraints, and lack of collaboration in the research and development of climate change related issues.

Soil organic matter (SOM) accumulation influences the SOC stocks in soil. Other indicators that may also influence the C stock in forests are C:N ratios, moisture, temperature, topography, elevation, vegetation, forest floor components, litter decomposition and spatial variability. Changes in SOM decomposition rates at different altitudes was influenced by temperature (Wang et al., 2009) and soil moisture (Reynolds, 2000). Therefore, it is believed that increase in soil C stocks was significantly associated with elevation and temperature (Leifeld et al., 2005). In subtropical and temperate forests, the stocks of SOC were found to be decreasing with altitude, from 185.6 (1600-1800 m) to 160.8 t C ha^{-1} (2000-2200 m) and from 141.6 (600-800 m) to 124.8 tC ha^{-1} (1000- 1200 m) respectively (Sheikh et al., 2009).

Research in quantifying carbon stocks in the Malaysian region according to topographical variations is scarce. Earlier work by Kitayama and Aiba (2002) on sedimentary substrate interspersed with ultrabasic rock of Mount Kinabalu, Sabah, and presented evidence that SOC concentrations were increased with increasing elevations of 700 – 3100 masl. Lim (2002) whereas estimated the highest amount of SOC in Malaysia were found in the highlands (300-1200 masl), followed by agricultural land between 20-100 masl. His values were derived from different soil profiles of agricultural areas in Peninsular Malaysia. However, both studies did not account the landform segmentation (i.e summit, sideslope and toeslope) variations and the influence of parent material type which were present in the tropical forest of the Peninsular Malaysia region.

Generally, most research agrees that temperature, precipitation, litter chemistry (Adair et al., 2008), soil nutrient content and microbial communities (Attignon et al., 2004) strongly control rates of litter decomposition. However, how these factors independently or interactively influence decomposition across large spatial and temporal scales remains unclear. Wang et al., (2009) reported that mean mass loss of litter was positively correlated with mean annual temperature along elevational gradient in the Wuyi mountains, China. In another study, temperature effects were evident when comparing the decomposition rates of pine needle litter and the forest floor (Prescott et al., 2004). In tropical forests, the decomposition coefficient (k) of leaf litter ranges from 0.1 to 0.5 per month (He et al., 2009).

C:N influences the decomposition rate of organic matter, which partly controls the mineralisation or immobilization of soil nitrogen (N). Carbon : nitrogen ratio were significantly influenced by altitude, parent material, and their interactions (Wagai, 2008).

The thickness of forest floor is usually influenced by climate, vegetation, time and faunal communities (Bens et al., 2006). Although litter decomposition studies in the Malaysian tropical forest is quite common, segregation of various components of the forest floor (i.e duff, litter, and DWD) in providing accurate estimates of carbon densities for tropical forests, especially in a tropical montane forest has not been initiated. Separated data acquired via this exercise would provide accurate duff and litter bulk density values for use in calculating mass and carbon, and the influence of different components in CS in mineral soil. Understanding SOC and its associations (C:N and forest floor) will provide useful insights in forest CS and quantification of C stocks at varying topography will be vital.

Geostatistics, a branch from geographic information system (GIS) is a tool that has been successfully used in tropical soil studies (Couto et al., 1997). Soil organic carbon (SOC) is unevenly distributed in forest and agricultural soils (Grove et al., 2008). Spatial patterns of SOC have been computed using geostatistics (Van Meirvenne et al., 1996; Frogbrook and Oliver, 2001). Besides SOC, it will be vital to quantify spatial variability of C:N and forest floor depth variations to determine the C stocks in soil. These innovative methods will greatly reduce human resource requirements, costs, and allow forest managers to strategize management zoning in order to avoid areas which are significantly potential in sequestering carbon. Based on the current knowledge gaps and scarce information available on the various factors as mentioned above, the dissertation mainly investigates the various components of C stocks in the tropical lowland and montane forest in Chapter II. Chapter III identifies potential indicators that are related to soil C storage whereas Chapter IV determines the spatial variability of forest floor material and its depths, soil C and C:N in a tropical lowland and montane forest with varying topography.

Main objectives

To quantify soil C, C:N, aboveground biomass, forest floor components (depths and layers of decomposing materials) and decomposition at varying topographic positions in a tropical montane forest and in a lowland forest that could assist in quantifying C stocks related to C management.

Sub objectives

Experiment 1: To quantify litter, soil (0-15 cm depth), roots and aboveground biomass C stocks in a tropical lowland forest and tropical montane forest with varying topography.

Experiment 2: To determine the potential indicators (i.e. litter and duff decomposition rate, forest floor component and properties, soil CO_2 fluxes, C:N ratios) of soil C storage.

Experiment 3: To determine the spatial variability of litter and soil C, C:N, and various depths of forest floor component of a tropical lowland forest and tropical montane forest with varying topography.

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