UNIVERSITI PUTRA MALAYSIA

SAP FLOW DENSITY AND HYDRAULIC CONDUCTIVITY OF THREE MATURE EXOTIC FOREST SPECIES UNDER SIMILAR PLANTING CONDITION

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By

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Chairman : Professor Hazandy bin Abdul Hamid, PhD
Institute : Tropical Forestry and Forest Products

Water is the most vital element for any living organism especially for trees. It plays a major role in regulating the daily biochemical process that responds physiologically towards soil and atmospheric factors. Water requirement of species is an essential measure for the tree's survival and adaptation in a particular environment especially for exotic species. The aim of this study is to determine sap flow and hydraulic conductivity of three mature exotic species belonging to the same site. Relationship of sap flow and hydraulic conductivity with climate factors were also assessed. Data was collected for duration of eight months in Randomized Incomplete Block Design (RIBD) using three different mature exotic species; *Gmelina arborea* (Yemane), *Swietenia macrophylla* (Mahogany) and *Pinus caribaea* (Pine). Judgement and simple random sampling were used to select the samples from the site at Universiti Putra Malaysia (UPM) with the support of random number generator. Thermal Dissipation Probe (TDP) was used as the main equipment and supported by pressure chamber together with other tools while climatic data were obtained from Faculty of Environmental Studies, UPM and Sultan Idris Shah Forestry Education Center (SISFEC) weather station. Research findings indicated that Pine species had the highest sap flow density and hydraulic conductivity by mean value of 950.052 (±45.096) g/day and 9.086 (±0.413) kg/m²/day/MPa respectively. Meanwhile, Mahogany showed the lowest sap flow density and hydraulic conductivity which are 232.074(±9.150) g/day and 0.330 (±0.022) kg/m²/day/MPa respectively. Closest positive association at 96.8% is between Pine's sap flow and hydraulic conductivity which is significantly different as indicated from p-value of less than 0.0001. Temperature and relative humidity have slightly contributed to the water system of Pine. Current results revealed that water potential, sapwood and leaf area were identified to have significant role in regulating the sap flow density and hydraulic conductivity. Tree height, structure, type of leaf and different structure of tracheid and vessels have

contribute to the water system of trees and been the crucial factor for the whole phenomena of sap flux and biochemical process of the tree. Thus, sap flow study is an important process in evaluating water consumption of tree species and should be carried out on potential native species which can be helpful in species selection, planning and establishment of forest plantation.

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

KETUMPATAN ALIRAN SAP DAN KEBERALIRAN HIDRAULIK OLEH TIGA SPESIES EKSOTIK MATANG DI BAWAH KEADAAN PENANAMAN YANG SAMA

Oleh

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Air merupakan salah satu keperluan yang amat penting kepada semua benda hidup terutamanya pokok. Air memainkan peranan utama dalam proses biokimia harian yang bertindak balas secara fisiologi terhadap faktor tanah dan atmosfera. Keperluan air oleh spesies adalah kriteria penting untuk mengambil kira daya tahan pokok dan langkah penyesuaiannya di sesuatu tempat terutamanya spesies eksotik. Objektif kajian ini adalah menentukan ketumpatan aliran air dan keberaliran hidraulik oleh tiga spesies eksotik yang matang di kawasan kajian yang sama. Perkaitan antara aliran air dan keberaliran hidraulik dengan faktor iklim telah dinilai. Data telah direkodkan selama lapan bulan dalam reka bentuk '*Randomized Incomplete Block Design (RIBD)*' dengan menggunakan tiga spesies eksotik yang matang iaitu *Gmelina arborea* (Yemane), *Swietenia macrophylla* (Mahogani) and *Pinus caribaea* (*Pine*). Persampelan bertujuan dan persampelan rawak mudah telah digunakan untuk memilih sampel dari lokasi kajian di Universiti Putra Malaysia (UPM) dengan penggunaan sistem penjana nombor rawak. '*Thermal Dissipation Probe*' (TDP) digunakan sebagai peralatan utama, '*pressure chamber*' dan peralatan yang lain. Data meteorologi telah diperolehi dari Fakulti Pengajian Alam Sekitar, UPM dan stesen kaji cuaca Hutan Simpan Ayer Hitam (SISFEC). Hasil penyelidikan menunjukkan spesies *Pine* telah mencatat ketumpatan aliran air dan keberaliran hidraulik yang tertinggi iaitu 950.052(± 45.096) g / hari dan 9.086(± 0.413) kg / m² /hari /MPa. Spesies Mahogani menunjukkan ketumpatan aliran air dan keberaliran hidraulik yang paling rendah iaitu 232.074 (± 9.150) g/hari dan 0.330(± 0.022) kg/m²/hari / MPa. Ketumpatan aliran air oleh Pine menunjukkan korelasi positif yang tinggi terhadap keberaliran hidraulik ($R = 0.968$, $p < 0.0001$). Suhu and kelembapan relatif menunjukkan sedikit pengaruh terhadap ketumpatan aliran air dan keberalairan hidraulik melalui kolerasi. Output mendedahkan potensi air dalam daun, keluaasan lapisan kayu gubal and keluasan daun memainkan peranan penting dalam mengawal ketumpatan aliran

air dan keberaliran hidraulik. Struktur dan ketinggian pokok,jenis daun and jenis struktur xilem merupakan faktor utama dalam segala proses ketumpatan aliran air dan proses biokimia dalam pokok.Kajian ketumpatan aliran air adalah satu usaha penting dalam menilai penggunaan air oleh pokok dan harus dilaksanakan atas pokok spesies asli yang berpotensi tinggi dalam memilih spesies, perancangan dan penubuhan ladang hutan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

TDP	Thermal Dissipation Probe
HPV	Heat Pulse Velocity
SISFEC	Sultan Idris Shah Forest Education Center
VPD	Vapor Pressure Deficit
UPM	Universiti Putra Malaysia
USA	United States of America
FAO	Food Agriculture Organization
WWF	World Wildlife Fund
REDD	Reducing Emissions from Deforestation and Forest Degradation
MTC	Malaysian Timber Council
MPIC	Ministry of Plantation Industries and Commodities
IBS	Institute of Bioscience
ANOVA	One–way Analysis of Variance
SAS	Statistical Analysis System
SPSS	Statistical Package for the Social Sciences
HSD	Tukey's Studentized Range Test (Honestly Significant Difference)
Volt	Voltage
Amp	Ampere
ha	Hectare

CHAPTER 1

INTRODUCTION

1.1 General Overview

In a single growing season, a tree absorbs 11,000 gallons of water from the soil and releases it into the air again, as oxygen and water vapor (Georgia Pacific, 1999). The availability of the soil water in the soil-plant-atmosphere system plays a crucial factor in controlling the distribution and growth of the trees.

Forest with uneven aged stand usually have lower water usage compare to even aged stand on account of smaller proportion of the area occupied with full grown trees develops interception on the canopy (Nisbet, 2005). Younger trees require more water from the soil compare to older trees in a competitive environment. Higher usage of water from younger trees are due to its rapid metabolism which enable it to uptake more water as to satiate with its growth. Hence, differences in water uptake among trees are complex because of several factors such as age, species, soil fertility and other factors that influence the amount of resources need which is also associated with phases of survival.

Trees uptake water the most during growth as it involves in various vital processes such as transpiration, photosynthesis, respiration, enzymatic activity and nitrogen metabolism (Kozlowski, 1982). Leaf acts as an important organ for tree because these biochemical process such as transpiration and photosynthesis take place in leaves. Efficiency of transpiration and photosynthesis depends on species where conifers or broadleaves are more specialized for particular processes attributed from its leaf structure. Conifer needles are more efficient at retaining moisture than broadleaf trees because they have stiff, needle waxy leaves needle with small stomata that are recessed in the leaf surface (Nisbet, 2005). Meanwhile broadleaves are more adapted for photosynthesis than a conifer due to wider leaf surface area is exposed to gather more sunlight.

Surface of leaf is the place where water evaporates through pores or stomata after water is taken up by roots in the soil. This process known as transpiration is a physiological process for trees to respond from environments of soil and atmosphere (Nisbet, 2005). Tree water relations are dominated by transpiration because major water loss takes part in this process and is influenced by variety of factors such as climate, forest age, species, structure as well soil condition (Roberts, 1983).

Higher transpiration rate may cause injury to trees; however, it is ultimately unstoppable because of the leaf structure need to compensate for entrance of carbon dioxide while losing moisture in the form of water vapour (Kozlowski *et al.,* 1991). The driving force of water transport or loss in trees are due to the water potential gradient that occurs across the membrane (Taiz & Zeiger, 1998). Usually, water potential of the tissue may affect the growth rates directly because of the role of turgor in cell enlargement while indirectly through perturbation of various essential physiological processes.

Hydraulic conductivity explains the ease of water movement through pore spaces in trees. Tree can vary hydraulic resistance and conductance along its organ pathways in order to maintain water balance on the shoot (Steudle, 2000). Transportation of water along the sap also known as sap flow in the xylem provides stability of hydraulic connection from the roots in the soil to the leaf at the atmosphere (Steppe *et al*, 2015). Water potential gradient in xylem occurs from simultaneous action of water uptake on the root which is transported to the stems, branches, and leaves while excess water is deposited across stomata pores to the atmosphere, where the vapor pressure deficit (VPD) of the air provide the largest contribution to transpiration (Whitehead & Jarvis 1981; Nobel 1983; Nobel & Jordan 1983; Whitehead 1998).

Information on the amount of tree water usage is beneficial for agriculture based work because it enables the industry to get an understanding on trees physiological needs. However, it is difficult to quantify the water usage of large trees given that there are factors need to be considered to measure as well managerial constraints that may consider the information as unworthy. In contrast, there are techniques economical and practical enough to measure sap flow via direct estimation of water use by individual tree. The most widely applied techniques are based on the use of heat as the tracer for water movement in the sap by detecting thermal dissipation probe of the constant heat flow in order to measure sap flow density for trees (Granier, 1987). Thus, study on sap flow method is possible to estimate tree water consumption which the information gained able to assist future efforts to devise solutions to hydrological problems encountered by farmers, foresters and conservationists (Smith & Allen, 1996).

1.2 Problem Statement

Malaysia has been listed as one of the top-ranking countries in high rates of deforestation in the world according to article published by Rhett Butler in 2013 referring study conducted by University of Maryland on 2012 using Google Maps data. The study reported that 47,278 square kilometer of Malaysia's forest cover had been lost during the period of 2000 to 2012 while forest loss was partly offset by a 25,978 square kilometer gained in vegetation cover from natural recovery, reforestation, and establishment of industrial timber and plantation of oil palm. Rapid growth in Malaysia's economy relies much from oil palm and rubber plantations which lead to land clearance and deforestation.

Furthermore, Star Online on May 4th, 2015 had published regarding World Wildlife Fund (WWF)'s Saving Forests at Risk report, which describes the issue as "a major deforestation front". The report roughly zoned areas in Borneo with high distribution of forest area is deforested at a rampant rate. Deforestation has been a global concern where much attention on environmental conservation yet most developing countries such as Malaysia still depend on the availability of forest resources as an economic generation. This has been taken as an initiation by the United Nation through a program on Reducing Emissions from Deforestation and Forest Degradation (REDD) as a main strategy in international conventions to foster developing country's industry as well to mitigate consequences of environmental destruction with stress on climate change phenomenon (Miyamoto *et al.,* 2014).

Even still, Malaysian government had plans to encourage ventures in large-scale commercial forest plantations development as a measure to minimize the pressure on native forest as a main source for raw materials and to ensure its continuous availability for the domestic timber industry (Krishnapillay & Varmola, 2002). In accordance, Malaysian Timber Council (MTC) had completed and handed over a study on the establishment of large scale forest plantations in Malaysia as to alleviate the pressure on the country's natural forests to the Ministry of Plantation Industries and Commodities (MPIC) in 2003. The study recommends to MPIC for establishment of forest plantations total at 375,000 ha by 2020 with a rate of 25,000 ha per year for 15 years starting on 2005 (Krishnapillay & Varmola, 2002).

The success of large scale forest plantation establishment in Malaysia is yet to be determined. There are factors need to be considered to develop forest plantation which ultimately requires extensive information that is relatable with managerial prescription. In general, forest plantations essentially focus on reclaiming deforested areas with fast growing species. Selection of fast growing species in Malaysia is divided between native or exotic species which the latter is more favored with the notion of it being more productive than the former.

Nonetheless, there is limited reference to back with proper exotic species plantation management in Malaysia supposing it is in fact favored by the industry. This reach to the need for credible information of exotic species physiology either it is suitable with Malaysian environment which in return provide reference for justifiable resource allocation in a plantation area. Earlier study seeing back in 1990 indicates there were two major programs initiated to establish large-scale plantations in Peninsular Malaysia. To be specific, plantation of exotic species namely *Pinus caribaea* were established during 1970's while *Acacia mangium* in the 1980's. However, establishment of these plantations made without any prior intensive research on species requirement, site and stand management (Appanah & Weinland, 1993).

Consequently, there is an exigency to provide information of physiological characteristics of exotic species given circumstance that exotic species is selected for plantation in Malaysia. This is because different species have different needs and one of the basic requirements for tree survival is sufficient water resources. Predominantly, water is a fundamental need in tree physiological activities especially transpiration, evaporation, respiration and others. Access for water in plantation is impactful to tree survival while ability of tree to absorb and transport water able to shed light on quantity of water needed for a species to sustain growth.

Estimation on quantity of water needed for exotic species need to be clarified which serve as useful information for the industry to allocate such resources as to cater with dry and wet seasons of Malaysia. Advance in technology have secured several technics that can be applied in studying tree water relations. For example, Heat Pulse Velocity (HPV) and Thermal Dissipation Probe (TDP) are used to measure the water flow in the sap of a tree. These technologies are able to analyze the water usage of tree which eventually provide a great outcome on tree water relation study especially in forest plantations of exotic species.

This study was coordinated in a small exotic species planted area located in Universiti Putra Malaysia (UPM). The beauty of this study is to investigate water relation of three different exotic species; *Gmelina arborea*, *Swietenia macrophylla* and *Pinus caribaea*. The water relations study on these species is envisaged to bear several facts on the physiology of exotic species in Malaysia which may potentially be referred for application in forest plantations.

1.3 Objective

This study main purpose of this study is to determine the sap flow density of *Gmelina arborea, Swietenia macrophylla,* and *Pinus caribaea.* Secondly, measurement of hydraulic conductivity of three mature exotic species which were, located at the same site was calculated. Relationship of sap flow density and hydraulic conductivity with climatic factors were also assessed.

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