โครงการ
การเรียนการสอนเพื่อเสริมประสบการณ์

ชื่อโครงการ	**Assessing air pollution removal by urban tree species in Chulalongkorn University Centenary Park**
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ภาควิชา	**Environmental Science**
ปีการศึกษา	**2018**

คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project title	**Assessing air pollution removal by urban tree species in Chulalongkorn University Centenary Park**
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Project advisor	Assistant Professor Pantana Tor-ngern, Ph.D.
Department	Environmental Science
Academic year	2018

Faculty of Science, Chulalongkorn University

Assessing air pollution removal by urban tree species in

Chulalongkorn University Centenary Park

Thananchanok Kiewrat

A Senior Project Submitted in Partial Fulfillment of the Requirements for

the bachelor's degree of Science Program in Environmental Science,

Department of Environmental Science,

Faculty of Science, Chulalongkorn University

Academic Year 2018

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Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfilment of the Requirements for the Bachelor's Degree

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ภาควิชา	วิทยาศาสตร์สิ่งแวดล้อม
ปีการศึกษา	2561

บทคัดย่อ

ในปัจจุบันประชากรในเมืองเพิ่มขึ้นอย่างรวดเร็วทำให้เกิดการขยายตัวของเมืองมากยิ่งขึ้น ซึ่งเหตุเหล่านี้ทำให้เกิดการเพิ่มการปล่อยมลพิษทางอากาศเพิ่มมากขึ้น เช่นไนโตรเจนไดออกไซด์ (NO_2) ในงานวิจัยบางงานค้นพบว่าการเพิ่มพื้นที่สีเขียวในเมืองนั้นสามารถกำจัดมลพิษทางอากาศได้ โดยพืชจะกำจัดมลพิษทางอากาศได้ 2 ทางคือ จับที่ผิวใบ หรือ ดูดซับผ่านทางปากใบ การศึกษานี้ได้ทำการศึกษามลพิษทางอากาศที่ดูดซับทางปากใบนั่นก็คือ ไนโตรเจนไดออกไซด์(NO_2) ในพืช 4 ชนิดที่อยู่ในอุทยาน 100 ปีจุฬาลงกรณ์มหาวิทยาลัย คือต้นมะค่าโมง (*Afzelia xylocarpa*) ต้นตะแบกนา (*Lagerstroemia floribunda*) ต้นขานาง (*Homalium tomentosum*) และต้นชงโค (*Bauhinia purpurea*) ในอัตราการกำจัดไนโตรเจนไดออกไซด์ (NO_2) ของต้นไม้ในแต่ละชนิดจะวัดค่าการเปิดปิดของปากใบ และวัดปัจจัยทางสิ่งแวดล้อมเพื่อมาคำนวณหาค่าอัตราการกำจัดไนโตรเจนไดออกไซด์ (NO_2) ในต้นไม้ที่ศึกษาในแต่ละฤดูกาลและหาความสัมพันธ์กับปัจจัยสิ่งแวดล้อม จากการศึกษาพบว่าอัตราการดูดซับไนโตรเจนไดออกไซด์(NO_2) ของพืชทั้ง 4 ชนิด มีค่าไม่แตกต่างกันในสองฤดูกาล ซึ่งพบว่ามีค่าอัตราการกำจัดมากที่สุดในต้นมะค่าโมง โดยมีความสัมพันธ์กับความเร็วลมอย่างมีนัยสำคัญ พบว่า ในฤดูแล้งเมื่อความเร็วลมเพิ่มขึ้น อัตราการกำจัดไนโตรเจนไดออกไซด์(NO_2) ของต้นมะค่าโมงและต้นตะแบกนาจะเพิ่มขึ้นตามไปด้วย ส่วนในฤดูฝนความเร็วลมไม่ส่งผลต่ออัตราการกำจัด ไนโตรเจนไดออกไซด์ (NO_2) ซึ่งจะเห็นได้ว่าจากผลการศึกษานี้ พันธุ์ไม้แต่ละชนิด มีอัตราการกำจัดไนโตรเจนไดออกไซด์ (NO_2) และมีการตอบสนองต่อความเร็วลมที่แตกต่างกัน จากข้อมูลนี้สามารถช่วยในการคัดเลือกพันธุ์ไม้ที่เหมาะสมในการขยายพื้นที่สีเขียวในเมืองเพื่อช่วยปรับปรุงคุณภาพอากาศได้ดีมากยิ่งขึ้น

คำสำคัญ: การกำจัดมลพิษทางอากาศ, พื้นที่เขียวในเขตเมือง,การขยายตัวของเมือง, อุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัย

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ABSTRACT

Nowadays, urban populations are growing rapidly leading to urbanization that can increase air pollution emission such as Nitrogen dioxide (NO_2). Some studies have suggested that urban greening could contribute to air pollution reduction in two ways; through leaf stomata uptake of gaseous pollutants and leaf interception of particulate matter. This study has studied air pollution absorbed through leaf stomata uptake, nitrogen dioxide (NO_2), in 4 species of urban trees that planted in Chulalongkorn University Centenary Park (CU 100 Park) includes: *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum (Vent.) Benth* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree). The objective of this study is to estimate the air pollution removal and to compare the air pollution removal between wet and dry season of the four species. We estimated air pollution removal rate by measure stomatal conductance (g_s) and environmental factors to calculated NO_2 flux in wet and dry season and to find relationships with environmental factors. We found that NO_2 flux of all species had no difference between wet and dry season (p-value equals 0.08-0.16). The highest NO_2 flux is occurred in *Afzelia xylocarpa* (Black rosewood). In dry season, linear relationships between wind speed affect to NO_2 flux of *Afzelia xylocarpa* and *Lagerstroemia floribunda* while, in wet season wind speed were not affected. Therefore, the information from this study can be used to help planners better design and manage urban trees to improve air quality in parks.

Keywords: Air pollution removal, Urban greening, Urbanization, Chulalongkorn University Centenary Park

ACKNOWLEDGEMENTS

This research become reality with the kind support and guidance of many individuals. Here, I take this opportunity to acknowledge those people who contributed to this work.

First of all, I would like to say a thank you to my advisor, Assistant Professor Pantana Tor-ngern, Ph.D., for her always kind support, suggestion, patience, motivation and inspiration that always helping me in my research and report. Without her guidance, this research would not have been achievable

Besides my advisor, I would like to thank my research chairman, Assistant Professor Pasicha Chaikaew, Ph.D. and my project committee, Chidsanuphong Chart-asa, Ph.D. for their insightful comments and suggestions.

Additionally, I would like to thank Department of Environmental Science for supports from all staffs and Faculty of Science, Chulalongkorn University for research equipment and their kindness

I would also like to thank my colleagues, Miss Keerati Srisathong and Miss Saowapa Namab, for their helped and team work.

Finally, I would like to express my special gratitude toward my parents and my family for stay beside me as always and strong encouragement.

Thananchanok Kiewrat

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CHAPTER 1

INTRODUCTIONS

1.1 Overviews

Nowadays, urban populations are growing rapidly leading to urbanization. Urbanization is associated air pollution emission with subsequent adverse health effects such as cardiovascular disease. In highly populated city such as Bangkok, increases in air pollution such as nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), PM_{10} and $PM_{2.5}$ are expected. Some studies have suggested that urban greening could contribute to air pollution reduction (Escobedo et al., 2011; Currie and Bass, 2008; Nowak et al., 2006). Urban greening refers to all forms of vegetation such as street trees, open parks, gardens, trees, shrubs, green walls, green roofs that create mutually beneficial relationships between city dwellers and their environments. Vegetation remove pollution in two ways; through leaf stomata uptake of gaseous pollutants and leaf interception of particulate matter (Nowak et al., 2006). A case study in USA showed that total annual air pollution removal by US urban trees estimated at 711,000 metric tons (Nowak et al., 2006). It appears that urban trees have important impact to improve air quality.

In this study, we estimated air pollution removal by diffuse-porous trees, which tending to be more drought tolerant than ring-porous trees (Sperry et al., 1992), planted in the Chulalongkorn University Centenary Park (CU 100 Park) in Bangkok, the capital city of Thailand, due to this park is located in center of Bangkok that have pollution from vehicles. This study focuses on pollutants that can be removed via leaf stomata uptake includes nitrogen dioxide (NO_2) and trees which diffuse-porous xylem includes *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum (Vent.) Benth* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree). Trees data are collected 3 times per season which wet season were collected in August - October 2018 and dry season were collected in November 2018 – January 2019 and compare the air pollution removal rate between wet and dry season. From this study, the result can link the air pollution removal with improvement of human health effect and economic values.

1.2 Objectives

1.2.1 To estimate the air pollution removal by *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum (Vent.) Benth* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree).

1.2.2 To compare the air pollution removal by *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum (Vent.) Benth* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree) between wet and dry season

CHAPTER 2

LITERATURE REVIEWS

2.1 Urbanization

The global population is currently estimated at 7.7 billion people with more than half of them living in urban areas (Bettencourt et al. 2007). The trend of global urbanization will continue; it is expected that future population growth will occur in cities with estimates of urban population growth ranging from 1.75 to 4.9 billion people by 2030 (Mcdonald et al. 2008; Patel and Burke 2009). With half of the world's population living in a combined area. However, today's cities are far from sustainable, requiring vast inputs in the form of water, food, and fuel, and producing enormous quantities of heat, waste, and pollution (Crane and Kinzig 2005; Decker et al. 2000).

2.2 Urban greening: Definition

The urban greening is referred to all trees within and associated with an urban area, including the planted landscape, remnants of original forest, and new introductions of invasive or otherwise opportunistic tree species (Gerhold 2007; McPherson 2006; Nowak et al. 2005). Components of the urban forest include parks street trees, open parks, gardens, trees, shrubs, green walls, green roofs. With over half of the world's population living in cities and Urban greening increase rapidly, urban greening may be the primary means by which people experience nature. The benefits attributed to urban greening are wide ranging and include climate moderation, reductions in energy use (and associated CO_2 production), improved air quality, reduced water runoff and flooding (and associated discharge of untreated wastewater), noise reduction, increased wildlife habitat, improvements in human health and general sense of well being, reductions in crime, and increased property values (Nowak and Dwyer 2007).

2.3 Air pollution removal by the urban greening

It is accepted widely that the urban greening can have a significant impact on urban air quality (Manning 2008). A number of complex models have been employed to estimate the magnitude of this impact (McPherson and Simpson 2002; Shan et al. 2007). The most notable of these models is the Urban Forest Effects (UFORE) model created by the U.S. Forest Service (Nowak and Crane 2000). The UFORE model has been applied to a number of cities with great success, suggesting that trees in these cities remove significant quantities of air pollutants (Escobedo and Chacalo 2008; Nowak et al. 2002b). Results from such studies have led the U.S. EPA to grant State Implementation Plan credits for tree planting as pollution reduction strategy for attainment of National Ambient Air Quality Standards under the Clean Air Act (Nowak 2005).

2.4 Nitrogen Dioxide: definition, effect and plant uptake

Nitrogen Dioxide (NO_2) is one of a group of gases called nitrogen oxides. While all of these gases are harmful to human health and the environment, NO_2 is of greater concern. (EPA, 2018) NO_2 primarily gets in the air from the burning of fuel. The principal sources of NO_2 are energy production, industry and road traffic (EEA, 2016), but in cities nitrogen oxides (NOx = NO + NO_2) are mostly emitted from traffic-related combustion as NO, which is quickly oxidized by O_3 to NO_2 or directly as NO_2. NO_2 forms from emissions from cars, trucks and buses, power plants, and off-road equipment. Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2. NO_2 and other NO_x interact with water, oxygen and other chemicals in the atmosphere to form acid rain. Acid rain harms sensitive ecosystems such as lakes and forests.

Dry deposition of NO_2 to plants occurs by adsorption to leaf surfaces, absorption by root surfaces via the air-soil-root pathway, and stomatal uptake to the apoplast, the latter being the primary means of deposition (Wellburn 1990). As the interface between the leaf interior and the atmospheric environment (Parkhurst 1994), the apoplast is of great importance in plant metabolism (Sattelmacher 2001), and thus uptake via the stomata is not only the primary means of NO_2 deposition but also the most physiologically important exposure route. Although some authors have noted large deposition rates to leaf surfaces (GeBler et al. 2002; Theone et al. 1991), which has been attributed to the presence of chemolithoautotrophic bacteria on leaf surfaces (Papen et al. 2002), the focus remains on stomatal uptake as the uptake route of primary importance. A great variety of factors have been shown to affect stomatal uptake of NO_2 , particularly those that affect stomatal aperture and conductance such as quality and intensity of light, temperature, relative humidity, soil water-status, transpiration rate, canopy height and vertical position within the canopy, whole-plant N-status, and pollutant concentrations (GeBler et al. 2002; Theone et al. 1991; Wellburn 1990). In addition to stomatal aperture, basic leaf morphological considerations such as stomatal frequency and distribution, and total leaf surface area also will affect uptake (Wellburn 1990)

2.5 Stomatal conductance

Stomatal conductance is the measure of the rate of passage of gas entering, or water vapor exiting through the stomata of a leaf. Stomata are small pores on the top and or bottom of a leaf that are responsible for taking in CO_2 and expelling water vapor. The rate of stomatal conductance, or its inverse, stomatal resistance, is directly related to the boundary layer resistance of the leaf and the absolute concentration gradient of water vapor from the leaf to the atmosphere. It is under direct biological control of the leaf through the use of guard cells, which surround the stomatal pore (Taiz Zeiger 1991). The measuring stomatal conductance is use leaf porometer. The leaf porometer measures the stomatal conductance of leaves by putting the conductance of the leaf in series with two known conductance elements. By measuring the humidity difference across one of the known conductance elements, the water vapour flux is known. The conductance of the leaf can be calculated from these variables. We know the humidity at three places: inside the leaf, and at both of the humidity sensors. The leaf porometer effectively calculates the resistance between the inside and outside of the leaf: the stomatal conductance. It measures resistance between the leaf and the first humidity sensor and the first and second sensors.

CHAPTER 3

MATERIALS AND METHODS

3.1. Study area

The study area is Chulalongkorn University Centenary Park in Bangkok (13.739274°N 100.524914°E), the capital city of Thailand. The elevation is 0.5-1 meters above sea level (Royal Thai Survey Department, 2018). Bangkok has a tropical climate with the annual maximum temperature of 32-34 ºC and minimum temperature of 24-26 ºC (Meteological department, B.E. 1981-2010). The mean annual precipitation is 1275 mm year^{-1} (Meteological department, 2018). There are 706 trees consist of 48 species in this park base on a survey in February 2017.

3.2. Sampling design

The sampling design and data collection were carried out in two steps: (i) Select 4 species of trees; *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum (Vent.) Benth* (Moulmein lancewood) and *Bauhinia purpurea* Orchid Tree. (ii) Select 5 trees for each species by randomize from trees that have similar height and diameter at breast height (DBH). (Figure 3.1).

Figure 3.1 Location of trees in the Chulalongkorn University Centenary Park.

3.3 Environmental measurement

The environmental factors that can influence air pollution removal by trees are air temperature, relative humidity, wind speed and soil moisture. The temperature, relative humidity and wind speed of the air were collected from Bangkok air quality at Pathumwan district station (800 meters from the park. The temperature & relative humidity is used to calculate vapor pressure deficit (VPD, kPa) which is the difference between the actual amount of moisture in the air and how much moisture the air can hold when it is saturated. The VPD was calculate using the following equation

$$VPD = (1-\frac{RH}{100}) \text{ x } SVP \quad (1)$$

where RH is relative humidity (%); SVP is Saturation Vapor Pressure (kPa) that was calculate using the following equation

$$SVP = 610.7\text{x}10^{\frac{7.5T}{237.5+T}} \quad (2)$$

where T is air temperature (°C). This study assume that trees have enough water in soil throughout the study period due to frequent irrigation. To confirm such hypothesis, soil samples in this area will be collected to determine volumetric soil moisture and compare against the wilting point which is the minimum soil water that plant can survive. Collect soil samples about 5 cm depth and collect 5 samples once a week near the selected trees to measure soil moisture and bulk density. Soil moisture (θ_m, kg kg^{-1}) was calculate using the following equation:

$$\theta_m=(\frac{m_{soil,wet}-m_{soil,dry}}{m_{soil,dry}}) \quad (3)$$

where $m_{soil,wet}$ is wet mass of soil (kg) ; $m_{soil,dry}$ is dry mass of soil (kg). Then, we compare soil moisture with 70% Field capacity to confirm that there is enough water in the soil for plant growth (Kätterer et al., 2006). Field capacity is the amount of water that held in the soil after excess water has been drained. To define field capacity, we measure the following: 1) Collected soil samples by using core soil at 5-15 cm depth. 2) Put soil samples in straining cloth and soak them for 24 hours.

3) Drained water out from soil by gravitation method. 4) Weighed soil sample before and after drying in oven approximately 24 hours at 105 ºC (Robock et al., 2000).

3.4 Studied variables

To perform air pollution removal quantification, the study requires several variables including (i) stomatal conductance (ii) leaf area index (LAI)

Stomatal conductance (g_s, mmol m^{-2} s^{-1}) means value that explain stomatal regulation when plants transpire through stomata. It's based on its link to leaf photosynthesis. Stomatal conductance measure by using a leaf porometer (SC-1, Meter services) and measured in 4 dominant tree species. Each tree should measure 3 fully sunlit leaves and collected every two hours from 7.00 am to 17.00 pm. The measurement divided into two seasons were rainy and dry season with three replicates in each season. Rainy season was collected in August to October and dry season in November to January.

We used Leaf area index (LAI) to scale up leaf tree. Leaf area index (LAI) means leaf area per unit ground area and measured by using LAI-2200C Plant Canopy Analyzer. LAI measured the canopy structure by measurement radiation being detected by Fisheye (at an angle 148 °) and calculated by the model of radiation transfer canopy. The studied trees were measured in form Isolated trees and placed monitor at the bottom of the canopy at an angle 180°.

3.5 Calculation of the air pollution removal by trees

Pollution removal or flux (F; in g m^{-2} s^{-1}) is calculated as the product of deposition velocity (V_d; in m s^{-1}) and pollutant concentration (C; in g m^{-3}).

$$F = V_d \times C \qquad (4)$$

Pollution concentration for NO_2 data were obtained from Pollution Control Department, Bangkok, Thailand. Deposition velocities will be calculated using the following equation:

$$V_d = \frac{1}{(R_a + R_b + R_c)} \qquad (5)$$

where Ra is aerodynamic resistance is independent of the air pollutant type, R_b is quasi-laminar boundary layer resistance and R_c is canopy resistance. Hourly estimates of R_a and R_b will be calculated using standard resistance formulas (Killus et al., 1984; Pederson et al., 1995; Nowak et al., 1998). R_a and R_b effects relatively small compared to R_c effects (Nowak et al., 1998). Hourly canopy resistance will be calculated using the following equation

$$\frac{1}{Rc} = \frac{1}{(rs+rm)} + \frac{1}{rt} \tag{6}$$

where r_m is mesophyll resistance, r_t is cuticular resistance and r_s is stomatal resistance. The stomatal resistance is calculated as the inverse of stomatal conductance (g_s) that will be measured from selected trees. The mesophyll resistance and cuticular resistance for NO_2 was set by from literature: r_m = 100 s m^{-1}, r_t=20,000 s m^{-1} (Hosker and Linberg, 1982). The aerodynamic resistance (R_a) is calculated as (Killus et al. 1984):

$$R_a = \frac{u(z)}{u_*^2} \tag{7}$$

where u(z) is mean wind speed at height z (ms^{-1}), u_* is Friction velocity (ms^{-1})

$$u_* = \frac{(k \times u(z\text{-}d))}{\ln(\frac{z-d}{z_0})} \tag{8}$$

where k is von Karman constant (0.41), u(z) is mean wind speed at height z (ms^{-1}), z is height of the weather station (m), d is displacement height (m), z_0 is roughness length. Quasi-laminar boundary layer resistance (R_b) is calculated as (Pederson et at,1995)

$$R_b = 2(Sc)^{2/3}(Pr)^{-2/3}(ku_*)^{-1} \tag{9}$$

Where Sc is Scmidt number (0.98 for NO_2) and Pr is Prandtl number (0.72)

3.6 Data analysis

Results reported using descriptive statistics including mean along with the measure of standard deviation. Compare air pollution removal rate between wet and dry season by function independent t-test and to find the relationship between NO_2 flux and weather factor by function regression using SPSS program.

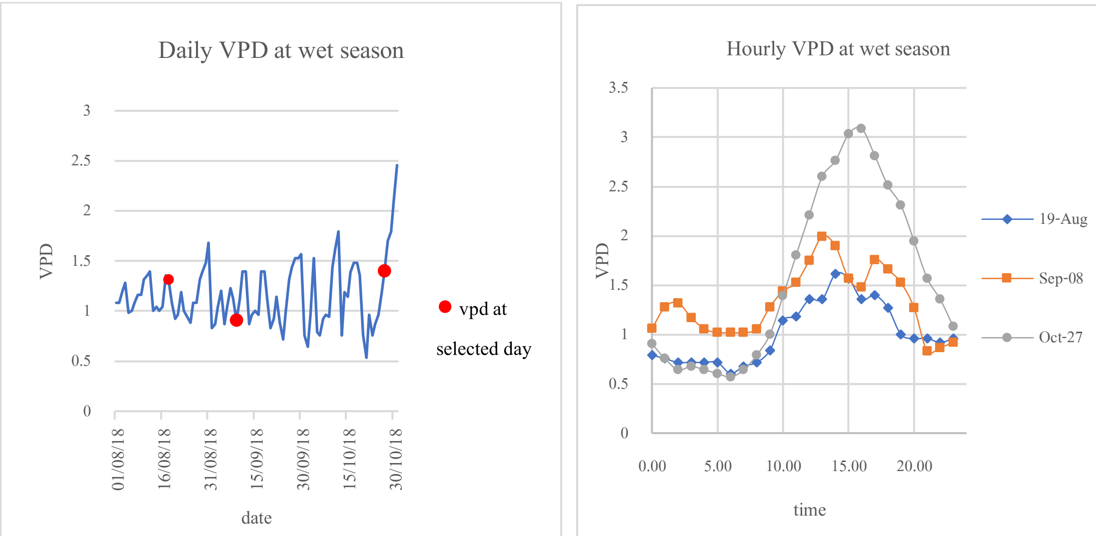
CHAPTER 4

RESULTS AND DISCUSSION

4.1 Environmental conditions

4.1.1 VPD

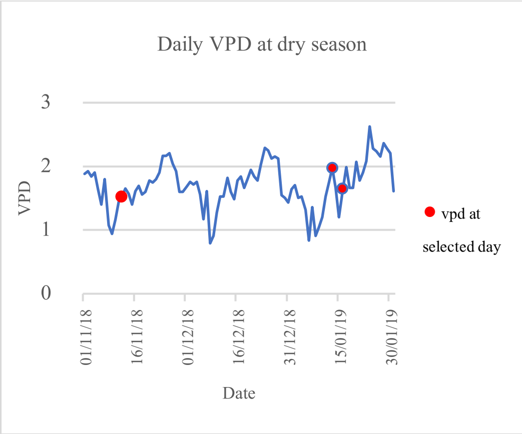
Figure 4.1 showed VPD at study site at wet season (August 2018 – October 2018) and 2 hourly VPD from 19 August, 8 September and 27 October 2018 are similar pattern therefore can be used as an average for the wet season.



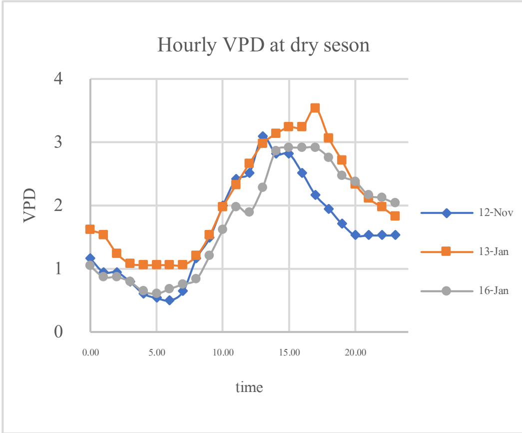
(a) **(b)**

Figure 4.1 (a)Daily VPD at wet season (August 2018 – October 2018) (b) Hourly VPD at selected day 19 August, 8 September and 27 October 2018

Figure 4.2 showed VPD at study site at dry season (November 2018 – January 2019). From figure 4.4 hourly VPD of 12 November 2018, 13 January 2019 and 16 January 2019 are similar pattern therefore can be used as an average for the dry season



(a)



(b)

Figure 4.2 (a) Daily VPD at dry season. (November 2018 – January 2019) (b) Hourly VPD at collection day 12 November 2018, 13 January 2019 and 16 January 2019

4.1.2 Soil moisture

The soil moisture content is greater than 70% field capacity (70% of the amount of water that soil can be stored) (Figure 4.5) so it can be concluded that soil moisture is sufficient for the growth of plants throughout the study period. Therefore, can remove this factors and study only the weather factors.

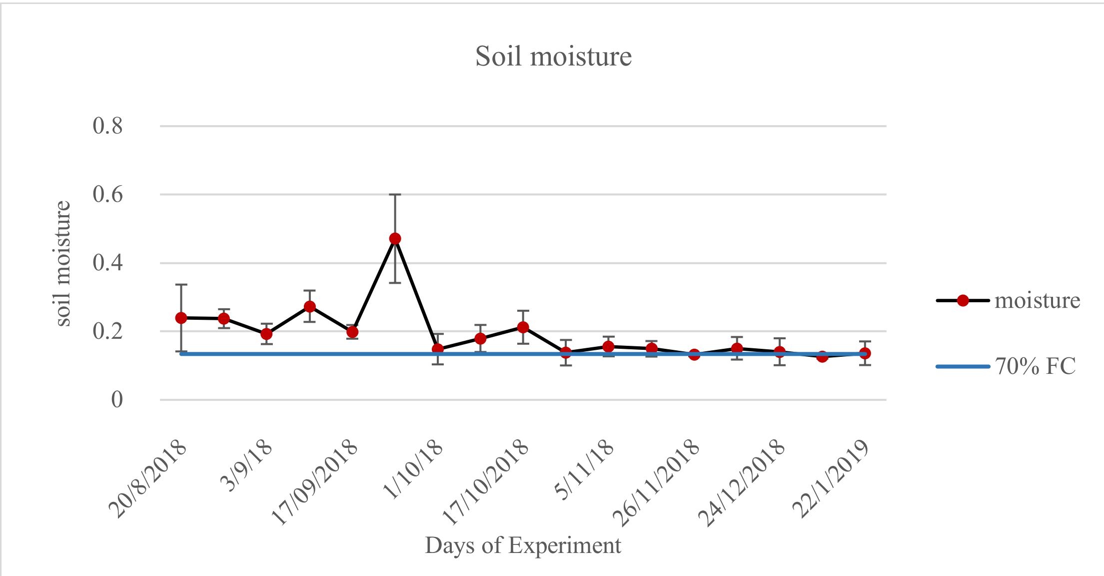
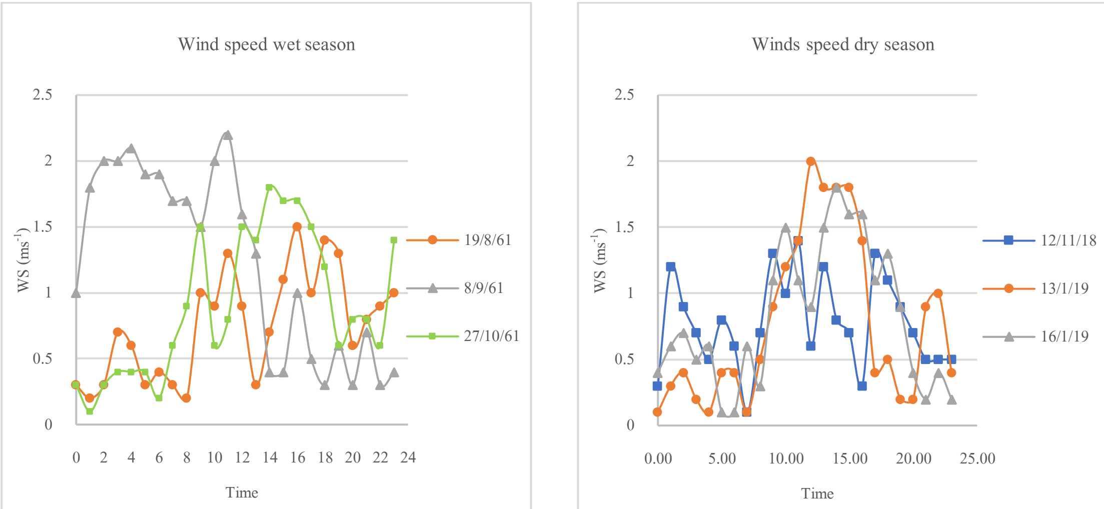


Figure 4.3 The relationship between soil moisture and 70% of field capacity throughout the study period

4.1.3 Winds speed

From wind speed variation over time in wet and dry season show that the trend of wind speed is uncertain depending on the weather in that day but mostly wind speeds are highest between 10.00 am to 4.00 pm both in wet and dry season. (Figure 4.4)



(a) (b)

Figure 4.4 Hourly winds speed at (a) wet season (b) dry season

4.3 Characteristics of urban trees species

Table 4.1 Mean and one standard deviation of height (m), diameter at breast (cm) and LAI of 4 selected species within CU centenary park.

Species	DBH (cm)	Height (m)	n	LAI (wet season)	LAI (dry season)
Lagerstroemia floribunda	11.71 ± 1.11	5.99 ± 0.37	5	0.748	0.614
Afzelia xylocarpa	14.16 ± 2.75	6.20 ± 0.45	5	0.65	0.808
Homalium tomentosum	10.58 ± 2.29	7.66 ± 0.42	5	0.432	0.548
Bauhinia purpurea	9.65 ± 2.83	6.82 ± 3.08	5	1.15	0.934

DBH= diameter at breast in meter at 1.3 m from ground, n= number of individuals, the mean ± one standard definition (SD) of 5 individuals of each species, LAI = leaf area index

4.2 Stomatal conductance

In wet season, the stomatal conductance of *Lagerstroemia floribunda* has highest g_s value (385.79 mmol m^{-2} s^{-1}) and *Afzelia xylocarpa* has lowest g_s value (155.16 mmol m^{-2} s^{-1}). In dry season, the stomatal conductance of *Lagerstroemia floribunda* has highest g_s value (301.23 mmol m^{-2} s^{-1}) and *Afzelia xylocarpa* has lowest g_s value. (115.60 mmol m^{-2} s^{-1}). A Comparison of daily stomatal conductance showed that all of studied species have g_s value in wet season higher than dry season (figure 4.5). The analyzing of different g_s value in wet and dry season by using independent t-test statistical showed that all species have p-value greater than 0.05 that can be concluded that there are no differences in 4 species between the wet season and dry season. (Table 4.2)

Table 4.2 Mean with one standard deviation and p-value of daily stomatal conductance (g_s) in wet and dry season.

Species	g_s wet season (mmol m^{-2} s^{-1})	g_s dry season (mmol m^{-2} s^{-1})	p-value
Afzelia xylocarpa	155.1 ± 101.57	115.6 ± 86.61	0.440
Lagerstroemia floribunda	348.8 ± 161.74	301.2 ± 128	0.129
Homalium tomentosum	281.2 ± 122.32	203.8 ± 91.45	0.625
Bauhinia purpurea	290.6 ± 135.33	209.8 ± 95.23	0.854

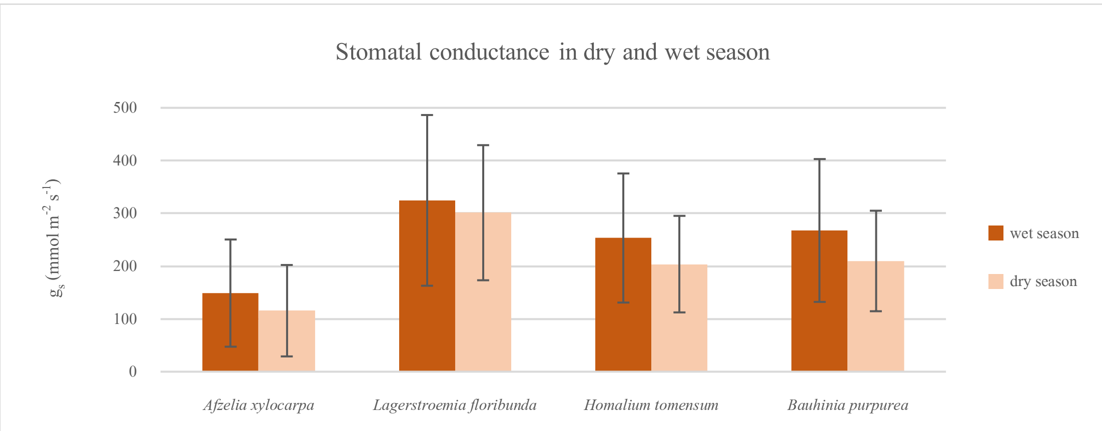


Figure 4.5 Mean with one standard deviation of stomatal conductance between wet and dry season.

In wet season the highest stomatal conductance occurs in *Lagerstroemia floribunda* and the lowest stomatal conductance occurs in *Afzelia xylocarpa*. Stomatal conductance of *Lagerstroemia floribunda, Homalium tomensum* and *Bauhinia purpurea* was increases steadily in the morning, peak during 11:00 am to 1:00 pm. And then decreases during 1:00 pm to 3:00 pm and increases again during the 3:00 pm to 5:00 pm. Stomatal conductance *Afzelia xylocarpa* was increases steadily in the morning, peak during 9:00 to 11:00 am. And then decreases during 11:00 am to 3:00 pm and increases again during the 3:00 pm to 5:00 pm. (Figure 4.6)

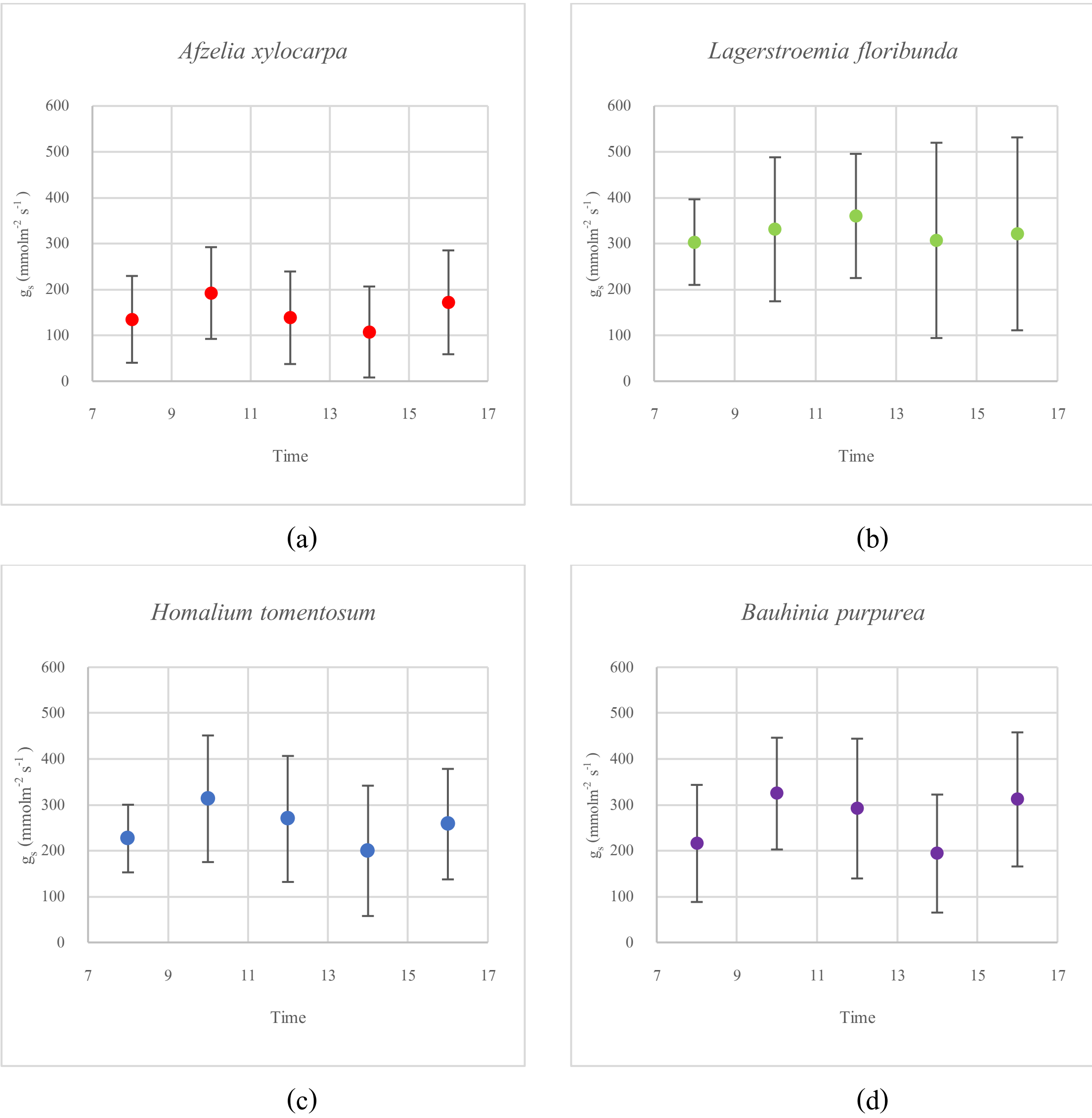
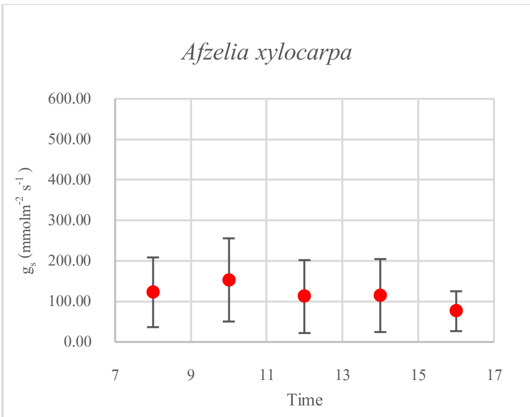
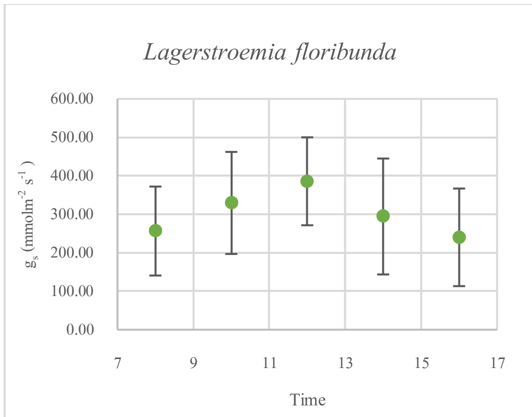


Figure 4.6 Mean with one standard deviation of stomatal conductance in every two hours from 7:00 am to 5:00 p m at wet season of (a) *Afzelia xylocarpa* (b) *Lagerstroemia floribunda* (c) *Homalium tomentosum* (d) *Bauhinia purpurea*

In dry season the highest stomatal conductance occurs in *Lagerstroemia floribunda* and the lowest stomatal conductance occurs in *Afzelia xylocarpa*. Stomatal conductance *Afzelia xylocarpa* was increases steadily in the morning, peak during 9:00 am. to 11:00 am. And then decreases during 11:00 am to 3:00 pm and increases again during the 3:00 pm to 5:00 pm. Stomatal conductance of *Lagerstroemia floribunda* increased steadily in the morning, peak during 11:00 am to 1:00 pm. And then decreases during 1:00 pm to 5:00 pm. Stomatal conductance of *Homalium tomensum* was increases steadily in the morning, peak during 9:00 to 11:00 am. And then decreases during 11:00 am to 3:00 pm and increases again during the 3:00 pm to 5:00 pm. Stomatal conductance of *Bauhinia purpurea* was increases steadily in the morning, peak during 11:00 am to 1:00 pm. And then decreases during 1:00 pm to 5:00 pm. (Figure 4.7)



(a)



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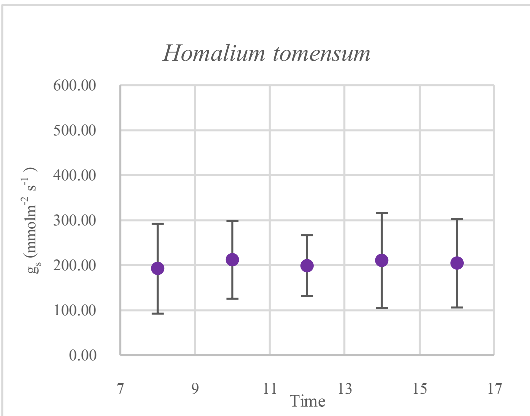

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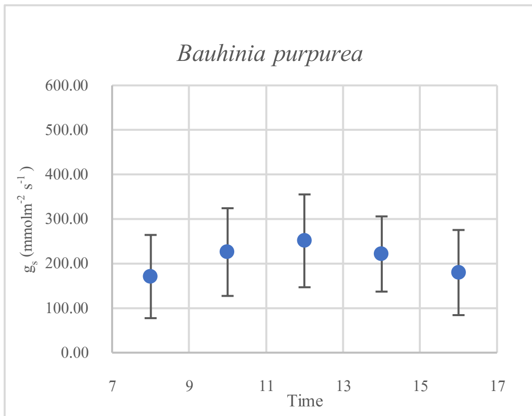


(d)

Figure 4.7 Mean with one standard deviation of stomatal conductance in every two hours from 7:00 am to 5:00 pm at dry season of (a) *Afzelia xylocarpa* (b) *Lagerstroemia floribunda* (c) *Homalium tomentosum* (d) *Bauhinia purpurea*

4.3 NO_2 removal by trees

In wet season, the NO_2 flux of *Afzelia xylocarpa* has highest NO_2 flux 0.182 µg $m^{-2}s^{-1}$ and *Bauhinia purpurea* has lowest NO_2 flux (0.128 µg $m^{-2}s^{-1}$). In dry season, the NO_2 flux of *Afzelia xylocarpa* has highest NO_2 flux (0.186 µg $m^{-2}s^{-1}$) and *Lagerstroemia floribunda* has lowest NO_2 flux (0.163 µg $m^{-2}s^{-1}$). A comparison NO_2 flux showed that all of studied species have NO_2 flux in wet season higher than dry season (Figure 4.8). The analysis of different NO_2 flux value in wet and dry season by using t-test statistical showed that all species have p-value greater than 0.05 that can be concluded that there are no different in 4 species between the wet season and dry season. (Table 4.3)

Table 4.3 Mean with one standard deviation and p-value of NO_2 flux between wet season and dry season

Species	NO_2 flux wet season (µg $m^{-2}s^{-1}$)	NO_2 flux dry season (µg $m^{-2}s^{-1}$)	p-value
Afzelia xylocarpa	0.182 ± 0.031	0.186 ± 0.041	0.878
Lagerstroemia floribunda	0.151 ± 0.041	0.163 ± 0.034	0.693
Homalium tomentosum	0.143 ± 0.024	0.172 ± 0.030	0.166
Bauhinia purpurea	0.128 ± 0.039	0.175 ± 0.032	0.088

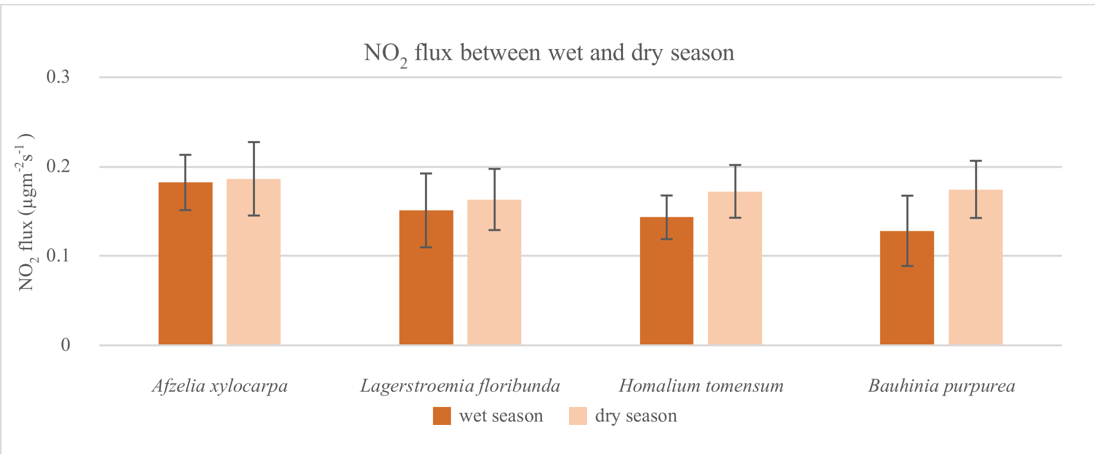
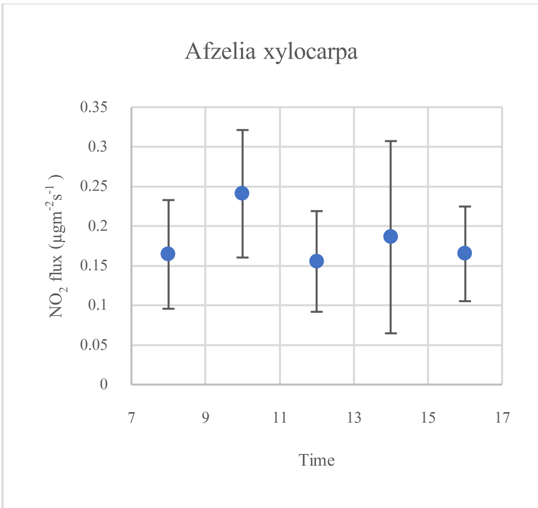
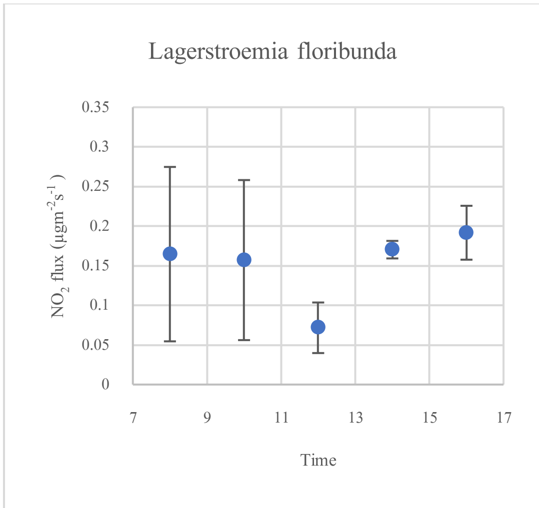


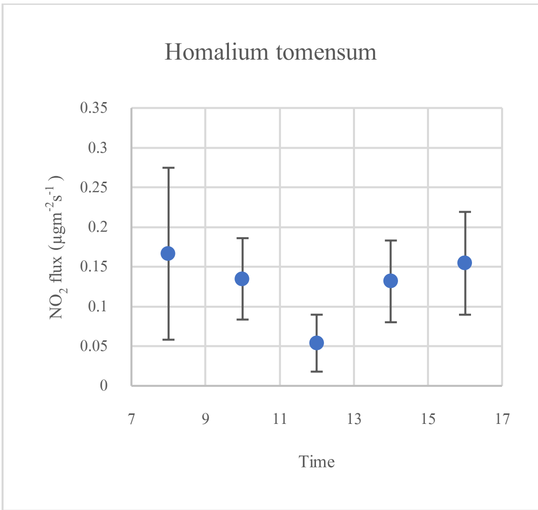
Figure 4.8 Mean with one standard deviation of NO_2 flux between wet season and dry season

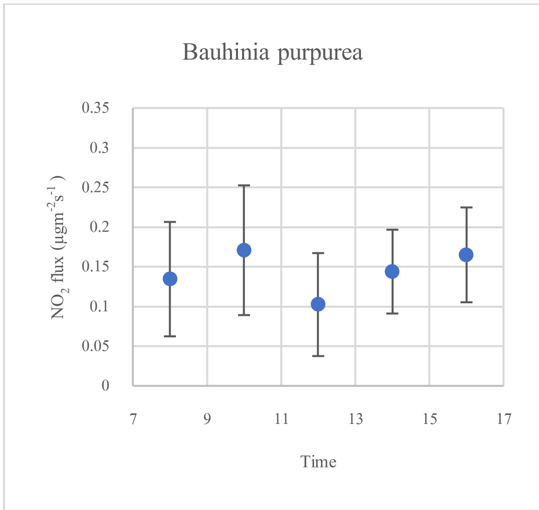
In wet season the highest mean of NO_2 flux occurs in *Afzelia xylocarpa* and the lowest mean of NO_2 occurs in *Homalium tomensum.* The daily NO_2 flux of 4 species has similar pattern which NO_2 flux is gradually increases to the maximum during 9:00 am to 11:00 am and then decrease in 11:00 am to 1:00 pm and increase during 1:00 pm to 3:00 pm and decrease again in 3:00 pm to 5:00 pm. (Figure 4.9)





(a) (b)

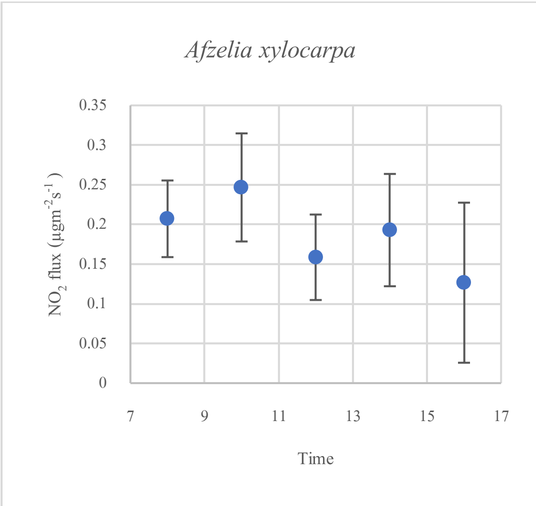




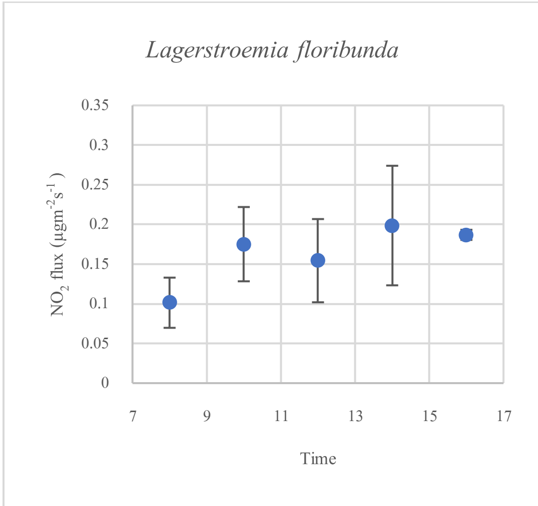
(c) (d)

Figure 4.9 Mean with one standard deviation of NO_2 Flux in every two hours from 7:00 am to 5:00 pm at wet season of (a) *Afzelia xylocarpa* (b) *Lagerstroemia floribunda* (c) *Homalium tomentosum* (d) *Bauhinia purpurea*

In dry season the daily NO_2 flux of 4 species has similar pattern which NO_2 flux is gradually increases 9:00 am to 11:00 am and then decrease in 11:00 am to 1:00 pm and increase during 1:00 pm to 3:00 pm and decrease again in 3:00 pm to 5:00 pm. (Figure 4.10)



(a)



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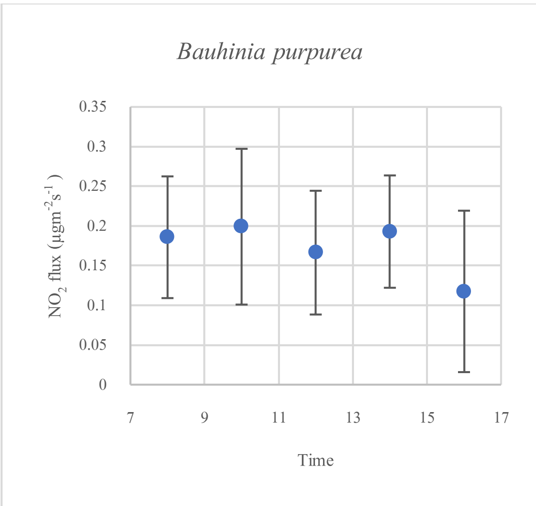

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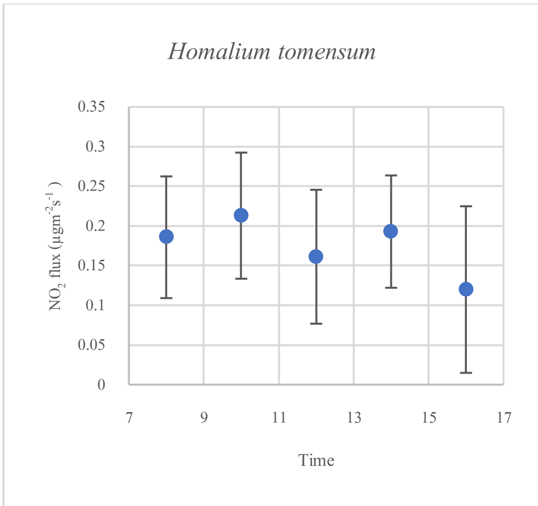

(d)

Figure 4.10 Mean with one standard deviation of NO_2 flux in every two hours from 7:00 am to 5:00 pm at dry season of (a) *Afzelia xylocarpa* (b) *Lagerstroemia floribunda* (c) *Homalium tomentosum* (d) *Bauhinia purpurea*

4.4 Relationship between NO_2 flux and wind speed

To find the relationship between NO_2 flux and weather factor we test NO_2 flux regression with VPD but we found no significant relationship (p-value equals 0.1-0.4). Another factor that may affected the flux is wind speed, so we test the relationship between NO_2 flux and wind speed.

For *Afzelia xylocarpa* and *Lagerstroemia floribunda* showed significant linear relationship with wind speed in dry season but not significant in wet season indicating that the wind speed is affect to NO_2 Flux in dry season but not affect in wet season. For *Homalium tomensum* and *Bauhinia purpurea* showed not significant linear relationship with wind speed in both wet and dry season indicating that the wind speed does not affect to NO_2 flux both wet season and dry season. (Figure 4.11)

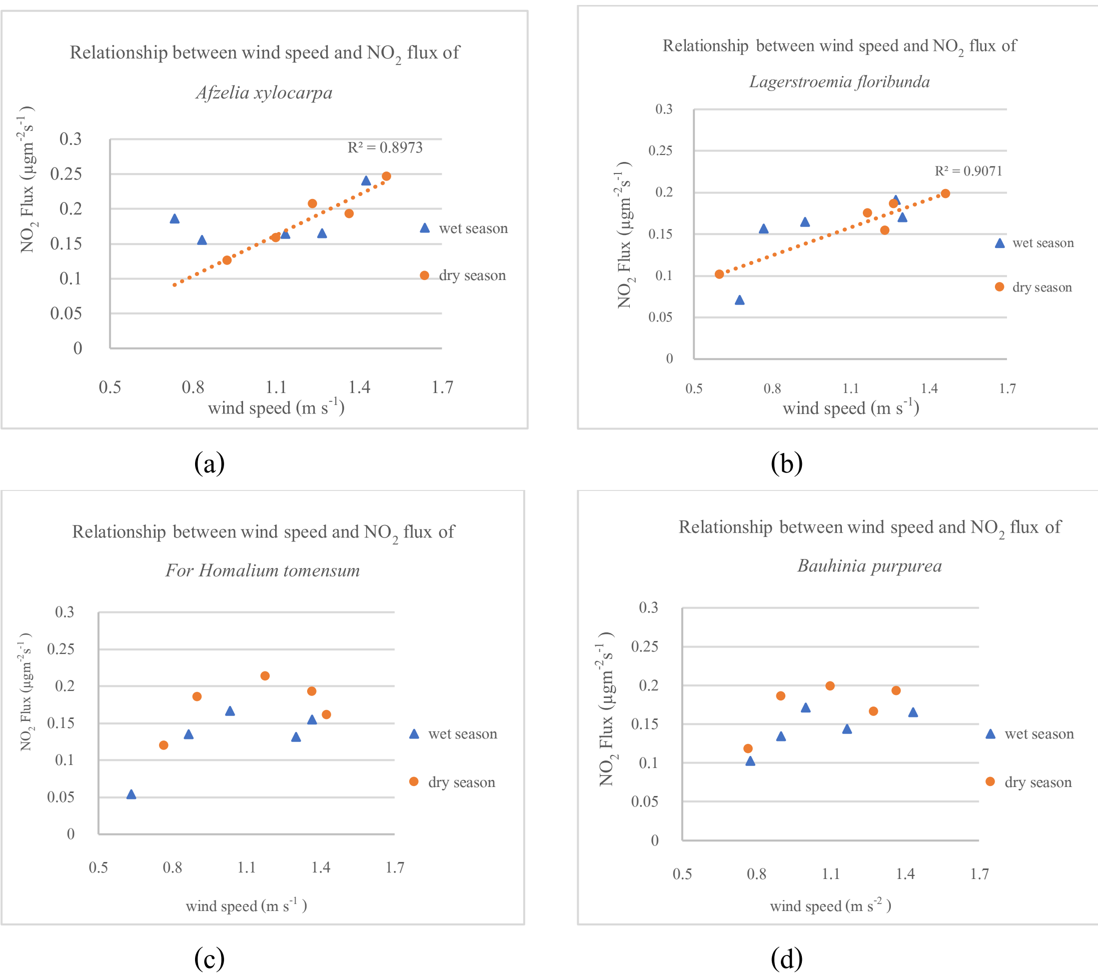

Figure 4.11 Relationship between wind speed and NO_2 flux of (a) *Afzelia xylocarpa* (b) *Lagerstroemia floribunda* (c) *Homalium tomensum* (d) *Bauhinia purpura*

Table 4.4 p-value from linear regression of wind speed and NO_2 flux

Species	p-value wet season	R^2	p-value dry season	R^2
Afzelia xylocarpa	0.375	0.219	0.014	0.897
Lagerstroemia floribunda	0.137	0.575	0.012	0.907
Homalium tomensum	0.174	0.513	0.412	0.224
Bauhinia purpurea	0.186	0.493	0.279	0.366

From table 4.4 *Afzelia xylocarpa* and *Lagerstroemia floribunda* in wet season have p-value >0.05 indicating that wind speed does not affect to NO_2 flux but in dry season p-value < 0.05 showing that wind speed is effect to NO_2 flux. *Homalium tomensum* and *Bauhinia purpurea* both wet season and dry season have p-value > 0.05 show that wind speed does not affect to NO_2

Based on this result, average NO_2 removal rate was higher in dry season from November to January which differed from the results of empirical study in Strasbourg city, France in which highly removal rate in June to October (W. Selmi et al., 2016). The differences could be attributed to vegetation seasonality, local weather and pollutant abstraction throughout the year. In addition, the removal rate in this study was similar from the Guangzhou city, in which highly removal rate in December and January. The estimated removal rate of NO_2 by urban trees in CU 100 (about 0.12-0.18 µg $m^{-2}s^{-1}$) park was higher than Guangzhou city (0.05 to 0.12 µg $m^{-2}s^{-1}$) (C.Y. Jim and W.Y. Chen 2008) due to Traffic is fairly heavy in Bangkok causing high concentration of NO_2 therefore, the NO_2 removal rate by urban trees was high too. In nearly the park, the highest pollutant emissions occurred in dry season also permitted more removal by trees in the period. (figure 4.12)

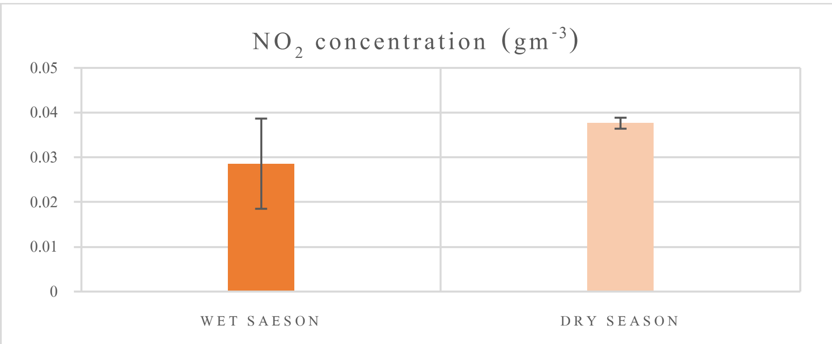

Figure 4.12 NO_2 concentration at collected day in wet and dry season

CHAPTER 5

RESEARCH CONCLUSIONS

5.1 Conclusions

Urban trees could help improve air quality through removing NO_2. In our study we conclude that there were no statistical differences NO_2 flux in wet and dry seasons. But the most removal occurred in dry season due to the higher average prevailing NO_2 concentrations and higher average daily wind speed. The highest removal rate occurred in *Afzelia xylocarpa* showed that the urban trees in this study have different NO_2 removal rates and responses so that in the future the planners can be better designed and managed urban trees using the information from this study to improve air quality.

5.2 Research Recommendations

5.2.1 The limitations of this study were unavailable of more detailed mereological data such as sunlight and rain fall. The results may be more accurate if we include other environmental variables in the analyses.

5.2.2 This study did not include others pollutant due to the lack of data in near station therefore it was not able to evaluate the overall air pollution removal of the CU100 park.

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