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SENIOR PROJECT

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Carbon dioxide absorption rate by urban trees in Chulalongkorn University Centenary Park

Keerati Srisathong

A Senior Project Submitted in Partial Fulfillment of the Requirements for

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Project Title	**Carbon dioxide absorption rate by urban trees in Chulalongkorn University Centenary Park**
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Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for The Bachelor's Degree.

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หัวข้อ **การศึกษาอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์ของพันธุ์ไม้ในอุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัย**

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ปีการศึกษา 2561

บทคัดย่อ

ในปัจจุบันหลายประเทศให้ความสำคัญกับการเพิ่มพื้นที่สีเขียวในเขตเมืองมากยิ่งขึ้น เนื่องจากพื้นที่สีเขียวหรือต้นไม้สามารถให้บริการเชิงนิเวศได้ ซึ่งหนึ่งในนั้น คือ การดูดซับก๊าซคาร์บอนไดออกไซด์ในบรรยากาศผ่านกระบวนการสังเคราะห์ด้วยแสง ซึ่งในงานวิจัยนี้ได้ทำการศึกษาอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์ของพันธุ์ไม้ในอุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัย โดยพันธุ์ไม้ที่ศึกษา ได้แก่ ตะแบกนา (*Lagerstroemia floribunda*), มะค่าโมง (*Afzelia xylocarpa*), ชงโค (*Bauhinia purpurea*) และขานาง (*Homalium tomentosum*) โดยใช้วิธีการวัดค่าชักนำการเปิดปิดปากใบ (Stomatal conductance, g_s) วัดอัตราส่วนระหว่างค่าความเข้มข้นของก๊าซคาร์บอนไดออกไซด์ภายในเซลล์ใบพืชและในบรรยากาศ $\left(\frac{C_i}{C_a}\right)$ และนำไปคำนวณอัตราการดูดซับอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์ (A) โดยศึกษาทั้งในฤดูฝนและฤดูแล้ง จากการศึกษาพบว่า ค่า A ของทั้งสองฤดูกาลไม่มีความแตกต่างอย่างมีนัยสำคัญ ($P > 0.05$) และจากการศึกษาความสัมพันธ์ระหว่างอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์กับปัจจัยทางสภาพแวดล้อม ซึ่งได้แก่ ค่าความต่างของความดันไอของน้ำ (Vapor pressure deficit: VPD) พบว่า A เพิ่มขึ้นเมื่อ VPD สูงขึ้น จนถึงค่าประมาณ 2 ถึง 30 kPa และลดลงเมื่อ VPD มีค่าสูงขึ้น และเนื่องจากความชื้นสัมพัทธ์และอุณหภูมิในบรรยากาศเป็นสองตัวแปรที่ส่งผลต่อ VPD จึงได้ทำการศึกษาความสัมพันธ์ระหว่าง A กับ สองตัวแปรนี้ พบว่า A ของ ตะแบกนา, มะค่าโมง และชงโค เปลี่ยนแปลงตามความชื้นสัมพัทธ์ในอากาศมากกว่าอุณหภูมิ ในขณะที่ A ของขานางเปลี่ยนแปลงตามอุณหภูมิมากกว่าความชื้นสัมพัทธ์ในบรรยากาศ จากผลการวิจัยนี้สรุปได้ว่า พันธุ์ไม้ที่มีอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์มากที่สุดของทั้งสองฤดูกาล คือ ตะแบกนา รองลงมา คือ ชงโค, ขานาง และมะค่าโมง ตามลำดับ และไม่มีความแตกต่างระหว่างฤดูกาล นอกจากนี้สามารถใช้ผลจากการวิจัย ในการจัดการดูแลพันธุ์ไม้ในอุทยานแห่งนี้ เช่น ในการเพิ่มจำนวนพันธุ์ไม้ที่จะนำมาปลูก ควรเลือกจากพันธุ์ไม้ที่มีอัตราการดูดซับก๊าซคาร์บอนไดออกไซด์ได้มากที่สุด เพื่อให้พื้นที่สีเขียวแห่งนี้ให้บริการเชิงนิเวศได้ดียิ่งขึ้น

คำสำคัญ: อัตราการดูดซับก๊าซคาร์บอนไดออกไซด์, ค่าชักนำการเปิดปิดปากใบ, ตะแบกนา, มะค่าโมง, ขานาง, ชงโค

Project Title	**Carbon dioxide absorption rate by urban trees in Chulalongkorn University Centenary Park**		
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Department	Environment Science		
Academic year	2018		

ABSTRACT

Nowadays many city governments have adopted policies promoting urban greening because of urban greening provide ecosystem services. One of services is to mitigate the increasing carbon dioxide in atmosphere through photosynthesis. In this study, we studied carbon dioxide absorption rate (A) by urban trees in Chulalongkorn University (CU) Centenary Park in wet and dry season and selected urban trees species which are *Lagerstroemia floribunda (*Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree). We measured stomatal conductance (g_s), the ratio of leaf intercellular CO_2 concentration and atmospheric CO_2 concentration $\left(\frac{C_i}{C_a}\right)$ and then calculated carbon dioxide absorption rate. The results showed that A in all species showed no seasonal difference ($p > 0.05$). Overall, A increased with vapor pressure deficit (VPD) until it reached approximately 2 to 30 kPa and then decreased with VPD. Because VPD is calculated from relative humidity (RH) and temperature, we examined the relationships between these two variables and A to see which one contributed more to the VPD responses. Results showed that RH seemed to affect the VPD in *A. xylocarpa, L. floribunda* and *B. purpurea* while temperature contributed more to the response in dry season of *H. tomentosum.* We conclude that A was the highest in *L. floribunda, B. purpurea, H. tomentosum, and A. xylocarpa,* respectively and all species were no statistically significant differences of A between wet and dry season. The results from this study will be important to increase planting trees that can choose maximize carbon dioxide absorption rate by selecting appropriate species for improve CO_2 mitigation of this park.

Keywords: Carbon dioxide absorption rate, Stomatal conductance, *Lagerstroemia floribunda, Afzelia xylocarpa, Homalium tomentosum, Bauhinia purpurea*

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Keerati Srisathong

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CHAPTER 1

INTRODUCTION

1.1 Overviews

Population in the world is currently growing in every year that known as one of the driving forces behind environmental problems, because the growing population causes the expansion of urbanization. Urbanization affects the physical environment through the impacts of the number of people, their activities and the increased demands on resources including increasing greenhouse gas emissions. With the development of the world economy, the demand for fossil energy is increasing. This is the main reason for the increasing concentration of carbon dioxide (CO_2) in the world and the generation of the earth's greenhouse. (Du & Xia, 2018). Consequently, many city governments have adopted policies promoting tree-planting, the preservation of urban green spaces, and more recently green architecture. The potential benefits and services provided by greenery to the urban ecosystem from a physical point of view include reduction of greenhouse gas emissions (Velasco, Roth, Norford, & Molina, 2016) especially CO_2 removal and therefore climate change mitigation.

For these reasons, we studied carbon dioxide absorption rate by urban trees in Chulalongkorn University (CU) Centenary Park and its responses to environmental factors because this park is located in the middle of city and may have an important role to reduce CO_2 emission. In this study, we selected urban trees species which are *Lagerstroemia floribunda (*Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum* (Moulmein lancewood) and *Bauhinia purpurea* (Orchid Tree) to measure carbon dioxide absorption rate. These species have diffuse-porous xylem which maybe drought-tolerant comparing to those with ring-porous xylem (Berdanier *et al*., 2016).

Results from this study maybe used to selectively plant trees that efficiently absorb carbon dioxide in the atmosphere, leading to sustainable urban greening management.

1.2 Objectives

1. To estimate carbon dioxide absorption rate by *Lagerstroemia floribunda* (CrepeMyrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum* (Moulmein lancewood), and *Bauhinia purpurea* (Orchid Tree) in CU Centenary Park.
2. To investigate seasonal variation (wet and dry season) of the carbon dioxide absorption rate by *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum* (Moulmein lancewood), and *Bauhinia purpurea* (Orchid Tree) in CU Centenary Park.

CHAPTER 2

LITERATURE REVIEWS

2.1 Theory of carbon dioxide absorption rate

2.1.1 Photosynthesis

Approximately 40% of a plant's dry mass consists of carbon, fixed in photosynthesis. This process is vital for growth and survival of virtually all plants during the major part of their growth cycle. In most plants, CO_2 uptake occurs through leaf pores, the stomata, which can rapidly change their aperture. Photosynthesis and leaf respiration refer to the CO_2 exchange between the leaf and the atmosphere (Lambers et al., 2008). Leaf-level gas exchange between the plant and the atmosphere can be measured by enclosing a leaf in a cuvette connected to a portable infrared gas-exchange system (Weissert, Salmond, & Schwendenmann, 2014).

2.2 Modelling carbon dioxide assimilation and intercellular CO_2 from measured conductance

According to Katul, Ellsworth, & Lai (2000), the relationship between CO_2 assimilation or carbon dioxide absorption rate (A) and conductance to CO_2 (g_c) is given by a system of equations based on Fick's law

$$A = -g_c\left(C_i - C_a\right)$$

$$g_c = \frac{D_{CO_2}}{D_q}\frac{E}{q^* - q} \qquad (1)$$

Where D_{CO_2} and D_q are the molecular diffusivities of CO_2 and water vapor, respectively , E is the evaporation rate (in molar units), q^* and q are the saturation and

actual water vapor mole fractions within the leaf corresponding to surface. The variables g_c and g_w (conductance to water vapor) can be equated by the ratio of the diffusivities of CO_2 and water vapor in air (= 1.6) if the diffusion pathways are assumed identical. With estimates of g_c from transpiration measurements, and with measured atmospheric CO_2 concentration (C_a), equation (1) cannot predict A because leaf intercellular CO_2 concentration (C_i) is unknown. After that Wong *et al*. (1979) and Norman (1982) were among the first to conjecture that $\frac{C_i}{C_a}$ in plant leaves may be nearly constant for a wide range of environmental conditions, but this constant varies from species. In a series of experiments Wong *et al*. (1979) found that perturbations in A resulted in parallel changes in g_c such that a nearly constant $\frac{C_i}{C_a}$ was maintained for a wide range of environmental conditions. With a constant R_c and measured g_c (1) reduces to

$$A = -g_c C_a \left(\frac{C_i}{C_a} - 1 \right) \qquad (2)$$

Hence, with a known $\frac{C_i}{C_a}$ then A can be readily computed.

2.3 C_i and C_a measuring method

According to TARGAS-1 operation's manual, the CO_2/H_2O gas analyzer is a major part of any portable photosynthesis system that can be used as part of a powerful leaf gas exchange system (with leaf cuvette) or as a self-contained instrument for continuous measurement of CO_2 and H_2O in air. Its open-path design allows for continuous, unattended air sampling, as the pump introduces fresh sample gas to the essential component, the IRGA (infrared gas analyzer). The IRGAs form the core of the TARGAS-1 Portable Photosynthesis System for measurement of both CO_2 and H_2O. Non-dispersive infra-red (NDIR) refers to the transmission of a broad-band infra-red wavelength from the IRGA source lamps. A single IRGA consists of four basic components (Figure 2.1):

1) Infra-red source
2) Sample cell of known path length and volume
3) Optical interference filter
4) Infra-red detector

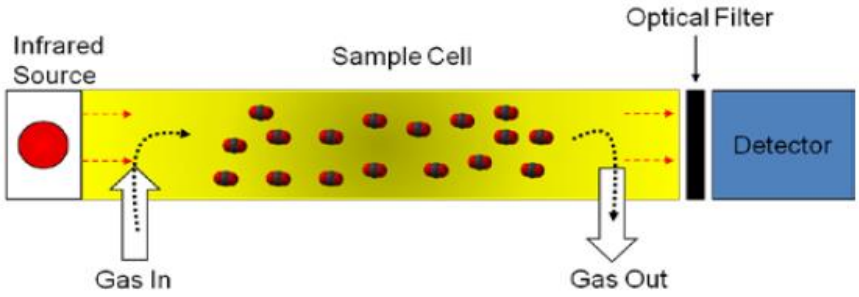

Figure 2.1 Components of single IRGA (infrared gas analyzer)

Light from mid-infra-red wavelengths is produced by the source and pulsed through a gold-plated cell. The interference filter narrows the bandwidth of the IR source received by the detector to the signature wavelength absorbed by the target gas molecule, e.g. CO_2. The CO_2 and H_2O cells each employ a unique optical filter. As the sample gas fills the cell, it absorbs IR, and the reduction in IR source strength is measured instantaneously by the detector. The higher the target gas concentration, the lower the infra-red signal received at the detector, as defined by the Lambert-Beer Law of Attenuation. Both H_2O and CO_2 molecules have diverse absorption spectra, so we use two prominent absorption peaks, seen below at 2.60 and 4.26 micrometer, respectively. The TARGAS-1 electronics could be considered the fifth component, which processes raw analog-to-digital (A/D) information from the IRGAs detectors, accurately translating this information into gas concentrations.

TARGAS-1 calculates and displays the CO_2 difference ($C_{out} - C_{in}$). As related to the calculated values in the TARGAS-1 is

$$C_{out} = CO_2 a$$
$$C_{out} - C_{in} = CO_2 d \quad (3)$$

Calculate CO_2 concentration in the sub-stomatal cavity (intercellular CO_2 Concentration, C_i) using the equation derived by von Caemmerer & Farquhar, 1981. The sub-stomatal CO_2 concentration, C_i, is given by:

$$C_i\left(\mu mol\ mol^{-1}\right) = \frac{\left\lfloor\left(g_c - \frac{E}{2}\right) \times C_{out}\right\rfloor - A}{\left(g_c + \frac{E}{2}\right)} \quad (4)$$

Where g_c is the total conductance to CO_2 transfer:

$$g_c\left(mmol\ m^{-2}s^{-1}\right) = \left\lfloor \frac{1}{\left(1.585 \times r_s\right) + \left(1.37 \times r_b\right)} \right\rfloor \times 10^3 \quad (5)$$

(1.585 is the diffusion ratio of CO_2 and water in air, and 1.37 is the diffusion ratio of CO_2 and water in the boundary layer).

In this study, we used the equation (2) to compute carbon dioxide absorption rate (A) of urban trees species by using TARGAS-1 (Portable Photosynthesis System) to measure $\frac{C_i}{C_a}$ of each trees species and using leaf porometer (SC-1, Meter services) to measure g_w or g_s and convert to g_c.

2.4 Variation of A with environments

Temperature and humidity are important environmental factors in influencing g_s and leaf photosynthetic rate and the effect of g_s on photosynthesis is mainly through CO_2 diffusion from the atmosphere to the substomatal cavities.

Increasing air temperatures and atmospheric CO_2 concentrations lead to changes in stomatal conductance (g_s) over short and long timescales (Way, Oren, & Kroner, 2015). In the short-term (instantaneous responses), increasing air temperatures typically lead to a reduction in g_s due to stomatal closure with increasing vapor pressure deficit (VPD), which prevents excessive water loss under high evaporative demand. At very high temperatures, g_s may actually increase in order to avoid reaching dangerously high leaf temperatures. (Fauset *et al*., 2019)

According to (Mathur, Agrawal, & Jajoo, 2014) , they find under high temperature conditions, plants exhibit short-term avoidance or acclimation mechanisms such as changing leaf orientation, transpirational cooling, or alteration of membrane lipid compositions. Closure of stomata and reduced water loss increased stomatal and trichomatous densities, and larger xylem vessels are common heat induced features in plant. Plants with small leaves are also more likely to avoid heat stress. They evacuate heat to ambient more quickly due to smaller resistance of the air boundary layer in comparison with large leaves.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study site, sampling design and environmental factors

The study area was conducted in Chulalongkorn University Centenary Park (CU100 Park) in Bangkok (13.739274°N 100.524914°E), the capital city of Thailand. The elevation is 0.5-1 meters above sea level. Bangkok has a tropical climate with the annual maximum temperature of 32-34 ºC and the minimum temperature of 24-26 ºC. The mean annual rainfall was 1275 mm $year^{-1}$ (Thai Meteorological Department, 2018). As of February 2018, there were 706 trees consisting of 48 species in this park.

In this study, carbon dioxide absorption rate was estimated in 4 selected species that are *Lagerstroemia floribunda* (Crepe Myrtle), *Afzelia xylocarpa* (Black rosewood), *Homalium tomentosum* (Moulmein lancewood), and *Bauhinia purpurea* (Orchid Tree). These species were similar diffuse porous of xylem. We selected 5 trees from each species by stratified randomization from the trees that had similar height and diameter at breast height (DBH). The locations of selected trees in the CU Centenary park are shown in Figure 3.1.

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

The environmental factors that influence carbon dioxide absorption rate are air temperature, relative humidity and soil moisture.The temperature and relative humidity of the air (The data from www.bangkokairquality.com which selected Pathumwan station, about 800 meters form CU100 Park) are 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 (kPa), could be calculated by the following equation:

$$VPD = \left(1 - \frac{RH}{100}\right) \times SVP \qquad (6)$$

where RH is relative humidity (%); SVP is saturation vapor pressure (kPa) that was calculated from the following equation:

$$SVP = 610.7 \times 10^{\frac{7.5T}{237.5+T}} \qquad (7)$$

where T is atmospheric temperature (ºC). The study area was a park with high maintenance of management such as pruning, mowing, fertilizing, debris removing and watering, therefore we anticipate enough water for the trees throughout the study period. To evaluate if trees will not suffer from soil drought, we will measure volumetric soil moisture and compare it against the field capacity, which is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. The field capacity of soil can be determined based on laboratory measurements of water content by collect soil samples at depth 5 cm then put soil samples in straining cloth and soak them for one night. Drain water out of soil by using gravitation and weight soil samples before and after drying in oven 24 hours at 105 ºC (Robock *et al*., 2000). The volumetric soil moisture at field capacity is

$$\theta_{FC} = \theta_m \times \rho \times 10^{-3} \quad (8)$$

Where θ_{FC} is volumetric soil moisture in $m^3\ m^{-3}$

Then, first measured soil moisture by gravimetric method with collecting soil samples at depth 5 cm near the study trees and collect 5 samples once a week to measure soil moisture and bulk density. Soil moisture ($\theta_m, kg\ \ kg^{-1}$) could be calculated by the following equation

$$\theta_m = \left(\frac{m_{soil,wet} - m_{soil,dry}}{m_{soil,dry}}\right) \quad (9)$$

where $m_{soil,\ wet}$ is wet mass of soil (kg); $m_{soil,\ dry}$ is the dry mass of soil (kg). Then measure bulk density of soil.

To assure that there is enough water in the soil for plant growth, θ_v were compared with the soil moisture at 70% of field capacity base on soil characteristics (Kätterer *et al*., 2006) .

3.2 Calculations of variables

3.2.1 Stomatal conductance $\left(g_s,\ mmol\ m^{-2}s^{-1}\right)$

Stomatal conductance means the value that explains stomatal regulation when plants transpire through stomata. Stomatal conductance measured by using a leaf porometer (SC-1, Meter services) as shown in Figure 3.2 and measured on leaves. From each tree species (5 trees per 1 species), we selected 3 fully sunlit leaves per 1 tree and measurement from 7.00 to 17.00 (5 times). The measurement divided into two seasons including wet and dry season with three replicates in each season. The wet season we collected data in August to October and dry season in November to January.

Figure 3.2 Leaf porometer (SC-1, Meter services)

(Source: https://www.metergroup.com)

3.2.2 Leaf Area Index (LAI)

Leaf Area Index (LAI) means leaf area per unit ground area and measured by using LAI-2200C Plant Canopy Analyzer as shown in Figure 3.3. LAI was measured the canopy structure at the low sunlight and will calculate by the canopy model.

Figure 3.3 Leaf Area Index (LAI-2200C Plant Canopy Analyzer)

(Source: https://www.licor.com)

3.2.3 Atmospheric CO_2 concentration (C_a) and leaf intercellular CO_2 concentration (C_i)

Inside leaves, mesophyll cells consume CO_2 during photosynthesis and consequently the CO_2 concentration in the intercellular (C_i) is lower than in atmosphere outside the leaf (C_a), which, in this study, we measured by using TARGAS-1 (Portable Photosynthesis System) as shown in Figure 3.4. For measurement of leaf gas exchange should set up the system before starting are flow rate is 250 cc min^{-1} and the light unit is 1200 μmol m^{-2} s^{-1}. The analysis CO_2 concentration (CO_2 a) was less than the reference CO_2 concentration (CO_2 r) as the plant was taking up CO_2.

Figure 3.4 TARGAS-1 (Portable Photosynthesis System)
(Source: http://www.hansatech-instruments.com)

3.2.4 Calculation of carbon dioxide absorption rate (A)

The mechanism for carbon dioxide absorption rate in the tree is photosynthesis, the conversion of atmospheric carbon dioxide into plant material and the rate of carbon dioxide absorption rate was determined by measuring the rate at which the leaf assimilate CO_2 calculate using equation (10)

$$A_{leaf} = g_c C_a \left(1 - \frac{C_i}{C_a}\right) \quad (10)$$

$$A_{tree-level} = g_c C_a \left(1 - \frac{C_i}{C_a}\right) \times LAI \quad (11)$$

Where A_{leaf} is carbon dioxide absorption rate (μmol $m^{-2}s^{-1}$) per leaf; $A_{tree-level}$ is carbon dioxide absorption rate (μmol $m^{-2}s^{-1}$) per tree; C_a is atmospheric CO_2 concentration (μmol mol^{-1}) and C_i is leaf intercellular CO_2 concentration (μmol mol^{-1}). LAI is leaf area index (m^2 m^{-2}) and g_c is leaf conductance to CO_2 (mmol $m^{-2}s^{-1}$) that calculated as

$$g_c = \frac{g_s}{1.6} \quad (12)$$

where g_s is stomatal conductance to water (mmol $m^{-2}s^{-1}$)

3.3 Data analysis and Interpretation

Data analyses were conducted using t-test to compare carbon dioxide absorption rate between dry season and wet season and using 2-way ANOVA to compare the differences diurnal pattern of carbon dioxide absorption rate of each species between time and season. Regression analysis to study the relations between carbon dioxide absorption rate and environmental factors that are vapor pressure deficit (VPD), relative humidity (RH) and temperature. The analyses were performed using Microsoft Excel and SPSS 22 (IBM, Inc., New York, USA).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characteristics of the studied trees and environmental conditions

Table 4.1 summarizes characteristics of the samples used in this study within CU centenary park that had the height (H) of trees and diameter at breast height (DBH).

Table 4.1 characteristics of trees used in this study

Species	DBH (cm)	H (m)	n	LAI (wet)	LAI (dry)
Lagerstroemia floribunda	11.17 ± 1.11	5.99 ± 0.37	5	0.648	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

H = tree height measured from the bottom to the top; DBH = diameter at breast height i.e. 1.3 m from the ground; n = number of individuals used in this study and all values are the mean ± error bar represents one standard deviation (SD) of 5 individuals of each species. LAI = leaf area index of wet and dry season

Environmental conditions obtained at the study site during the study period (19 August 2018 – 16 January 2019) are shown in Figure 4.1 and Figure 4.2. The total of days in the study period was 151 days which we divided into 2 periods, wet season and dry season. Wet season mostly occurred between August to October in 2018 while dry season occurred between November 2018 to January 2019.

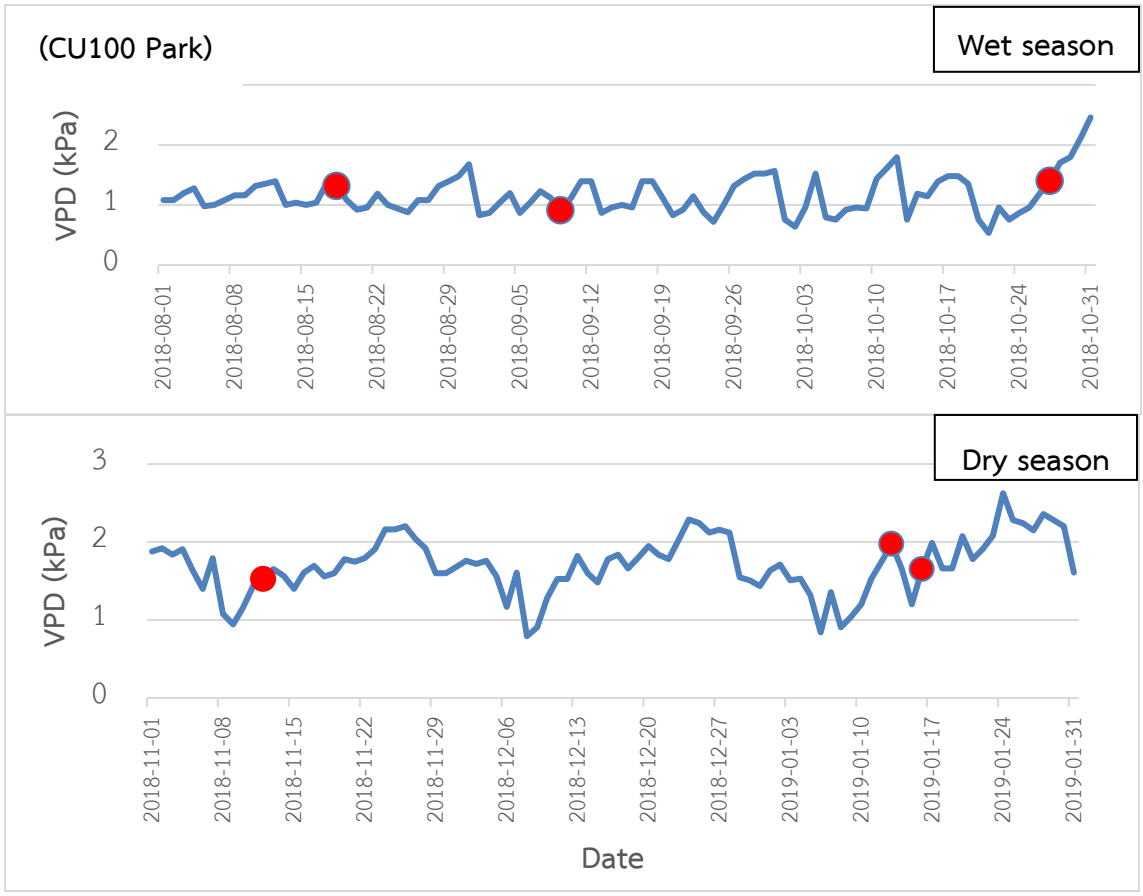

Figure 4.1 Daily average of vapor pressure deficit (VPD) at the study site in wet season (1 August 2018 – 31 October 2018) and dry season (1 November 2018 – 31 January 2018) and red point is collected data days

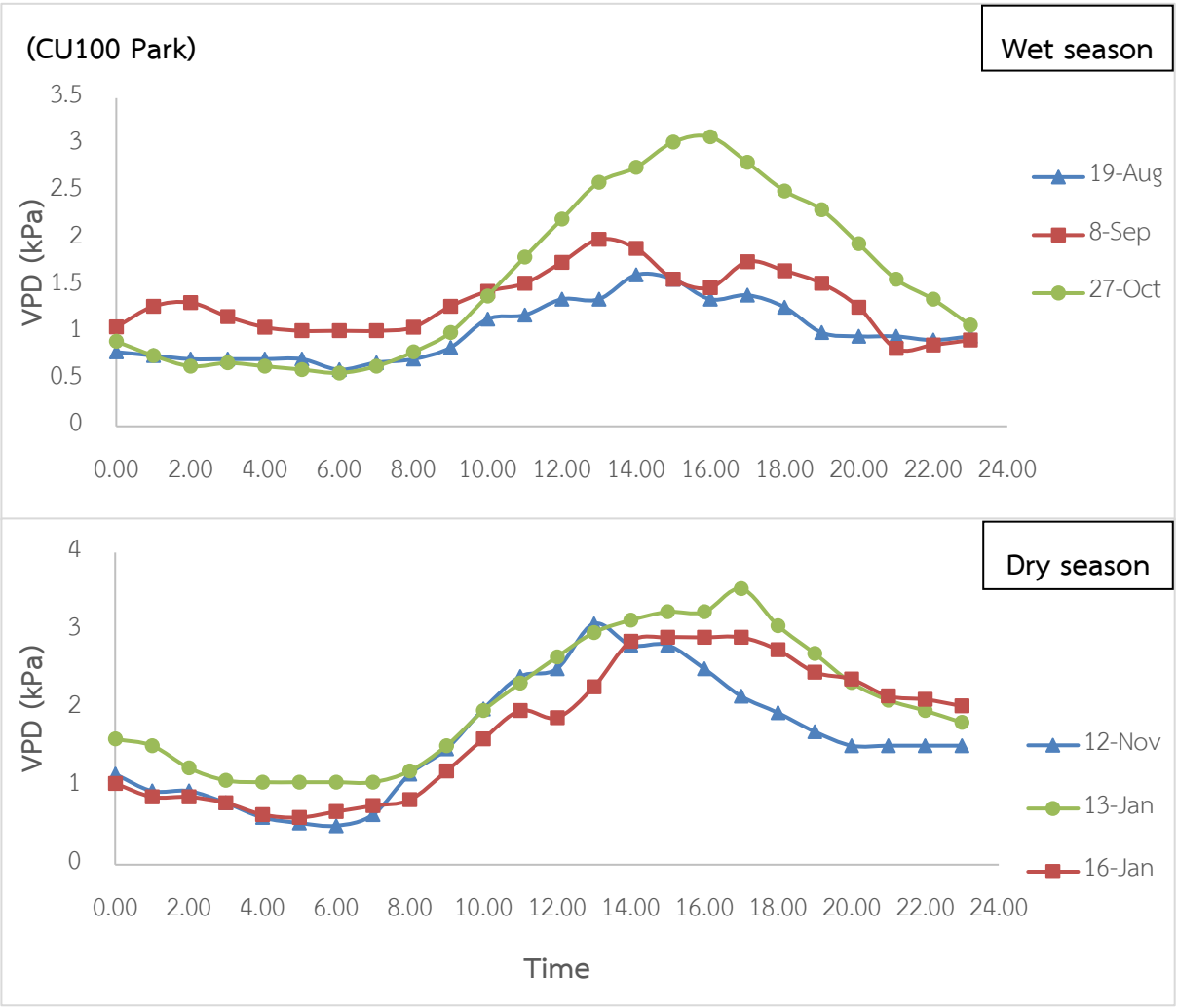

Figure 4.2 Diurnal of vapor pressure deficit (VPD) at the study site in wet season (19 August, 8 September and 27 October 2018) and dry season (12 November 2018, 13 January and 16 January 2019)

In this study, we measured soil moisture by gravimetric method (θ_m) to ensure that soil moisture remain around 70% of field capacity (θ_{FC}) in the study period. The result shown that volumetric soil moisture (θ_m) mostly remained above 70% of field capacity (0.134 m^3 m^{-3}, blue line) because of frequent irrigation from gardeners during study period, however in 24 September 2018 had the highest soil moisture content because we collected soil sample after rainy that affect soil moisture different other days and had the lowest soil moisture in 7 January 2019 maybe due to lacking of watering.

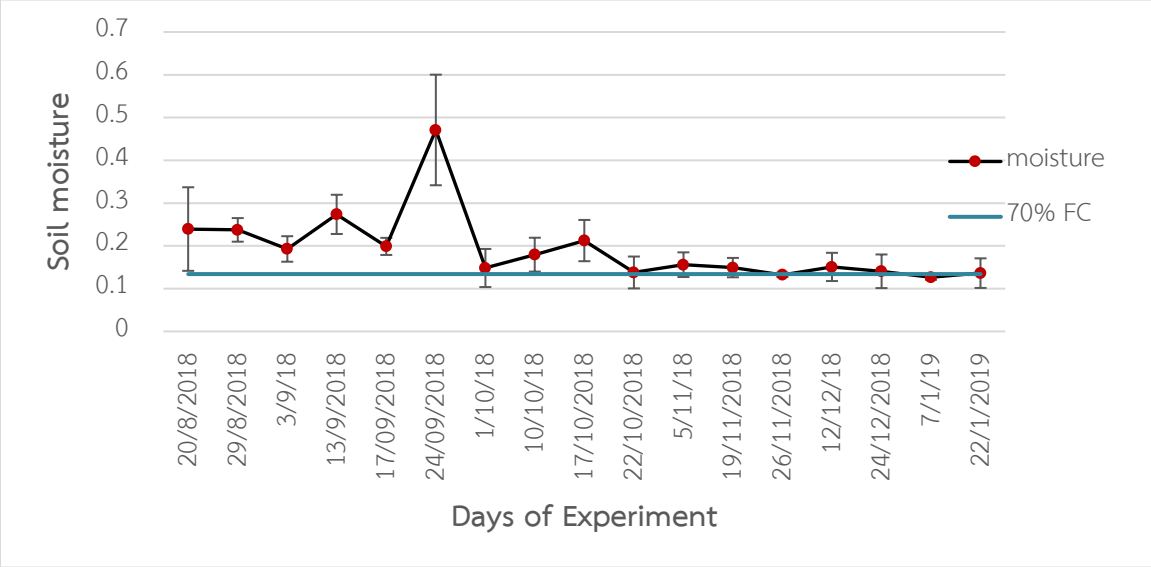

Figure 4.3 Weekly volumetric soil moisture data (dots) as measured at the site during 20 August 2018 – 22 January 2019

4.2 Daily stomatal conductance (g_s) and pattern of trees species

To compare the daily average (7.00 - 17.00) stomatal conductance (g_s) of trees species between wet and dry season we found that there were no significant differences at 0.05 significant level as shown in Table 4.2 and all species had stomatal conductance (g_s) higher in wet season than dry season as shown in Figure 4.4.

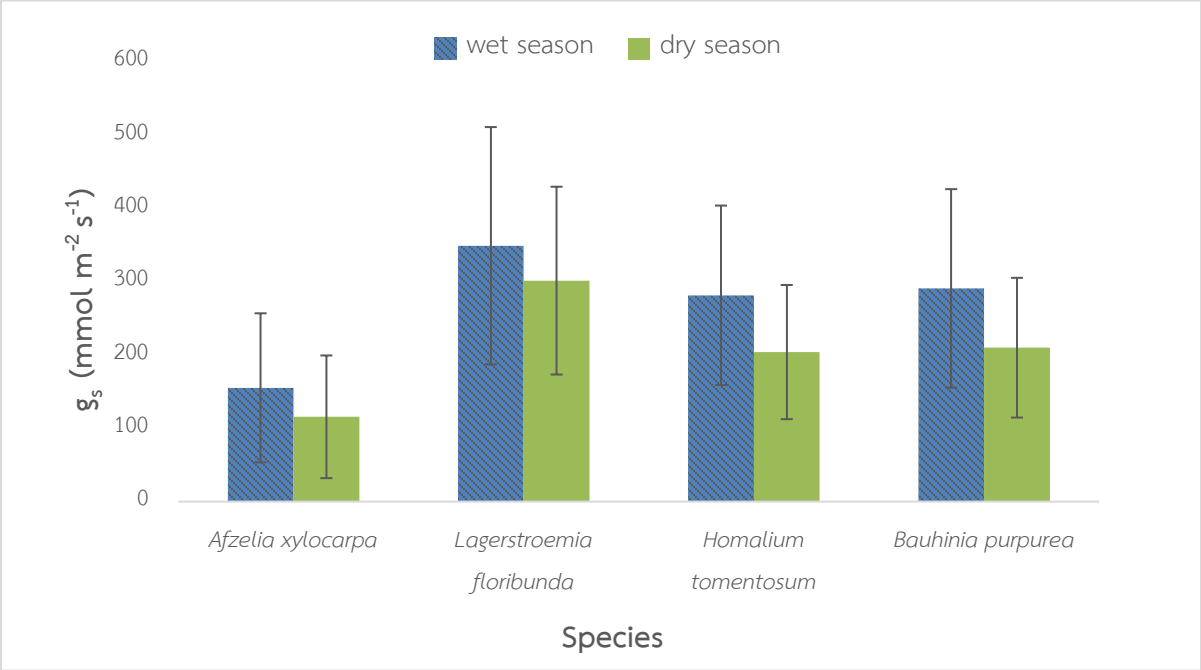

Figure 4.4 Comparison of stomatal conductance (g_s) of tree species between wet and dry season.

Table 4.2 Comparison of the differences stomatal conductance (g_s) of each species between wet and dry season by using independent t-test (n=15)

Species	g_s in wet season (mmol m^{-2}s^{-1})	g_s in dry season (mmol m^{-2}s^{-1})	P-value
Afzelia xylocarpa	155.1 ± 101.57	115.6 ± 83.61	0.440
Lagerstroemia floribunda	348.8 ± 161.74	301.23 ± 128	0.129
Homalium tomentosum	281.2 ± 122.32	203.82 ± 91.45	0.625
Bauhinia purpurea	290.6 ± 135.33	209.81 ± 95.23	0.854

g_s values are the mean and error bar represent one standard deviation (SD) of each species. Significant level is 0.05.

The diurnal pattern of stomatal conductance (g_s) of trees species in wet season as shown in Figure 4.5 (a) found that the highest value is *Lagerstroemia floribunda* that grew steadily in the morning and become declined around midday then slightly increased in 13.00 to 15.00 and went down moderately in 15.00 to 17.00 and *Afzelia xylocarpa* is the lowest value that grew steadily in the morning until around midday and slowly decreased in 13.00 to 15.00 and slightly increased in the evening. Stomatal conductance (g_s) of *Bauhinia purpurea* and *Homalium tomentosum* were relatively similar but with different patterns from *Lagerstroemia floribunda* and *Afzelia xylocarpa* that grew steadily in the morning until noon and slowly decreased in 13.00 to 15.00.

In dry season as shown in Figure 4.5 (b) found that the highest value is *Lagerstroemia floribunda* and *Afzelia xylocarpa* is the lowest value consistence with the wet season. Stomatal conductance (g_s) pattern of *Lagerstroemia floribunda* slowly increased in the morning and peaked at around midday then slowly decreased in the evening. *Homalium tomentosum* and *Bauhinia purpurea* were nearly constant and *Afzelia xylocarpa* show decreasing trend.

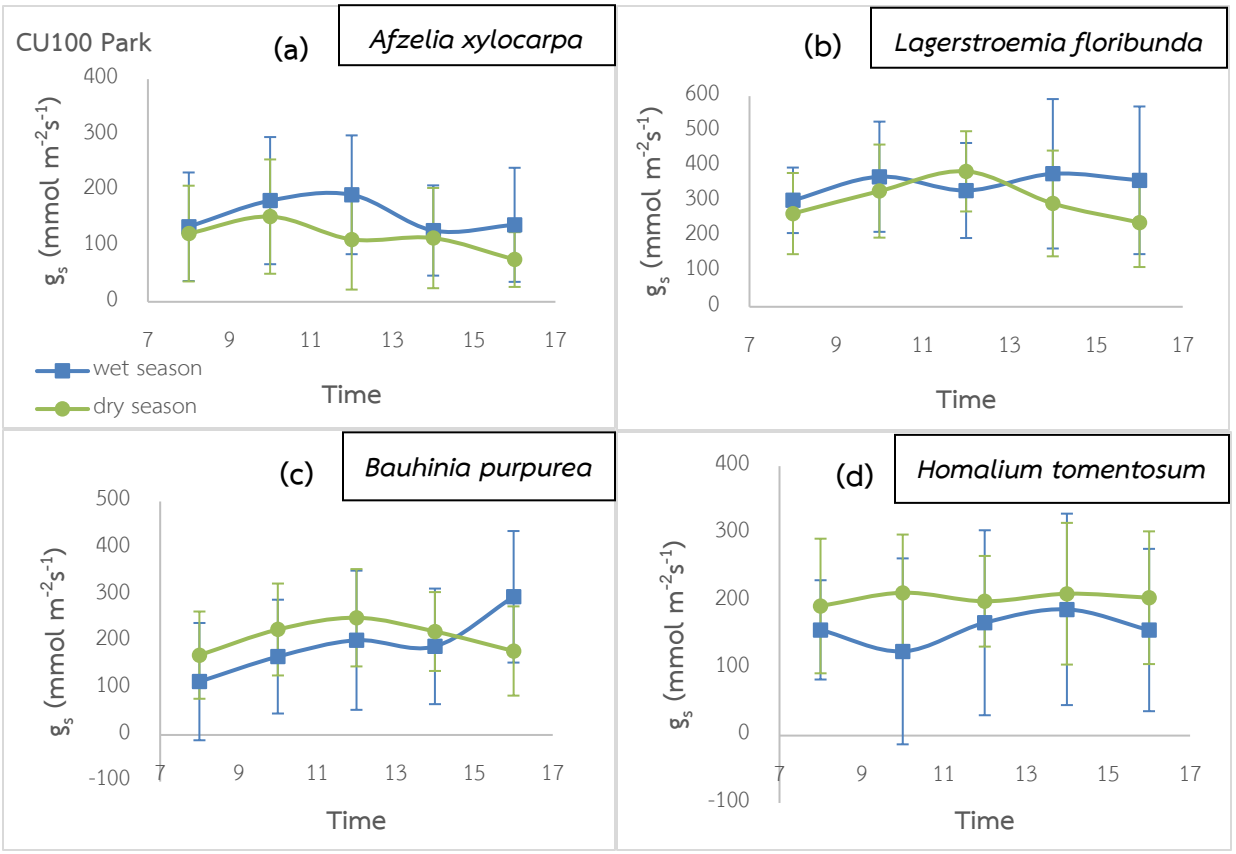

Figure 4.5 Diurnal pattern of stomatal conductance (g_s) of *Afzelia xylocarpa* (a), *Lagerstroemia floribunda* (b), *Bauhinia purpurea* (c) and *Homalium tomentosum* (d) in wet and dry season.

To compare the differences diurnal stomatal conductance (g_s) of each species between time and season by using 2-way ANOVA as shown in the Table 4.3, there were no significant differences at 0.05 level between stomatal conductance (g_s) and time including season (wet and dry).

Table 4.3 Comparison of the differences diurnal stomatal conductance (g_s) of each species between time and season by using 2-way ANOVA (n=45)

Species	P-value
Afzelia xylocarpa	0.530
Lagerstroemia floribunda	0.937
Bauhinia purpurea	0.878
Homalium tomentosum	0.957

4.3 Carbon dioxide absorption rate (A) of trees species

To compare the daily average (7.00 - 17.00) carbon dioxide absorption rate of trees species between wet and dry season we found that all species were no significant differences at 0.05 level ($p > 0.05$) as shown in Table 4.4. *Lagerstroemia floribunda* and *Bauhinia purpurea* had carbon dioxide absorption rate higher in wet season than dry season while *Afzelia xylocarpa and Homalium tomentosum* were quite similar as shown in Figure 4.6.

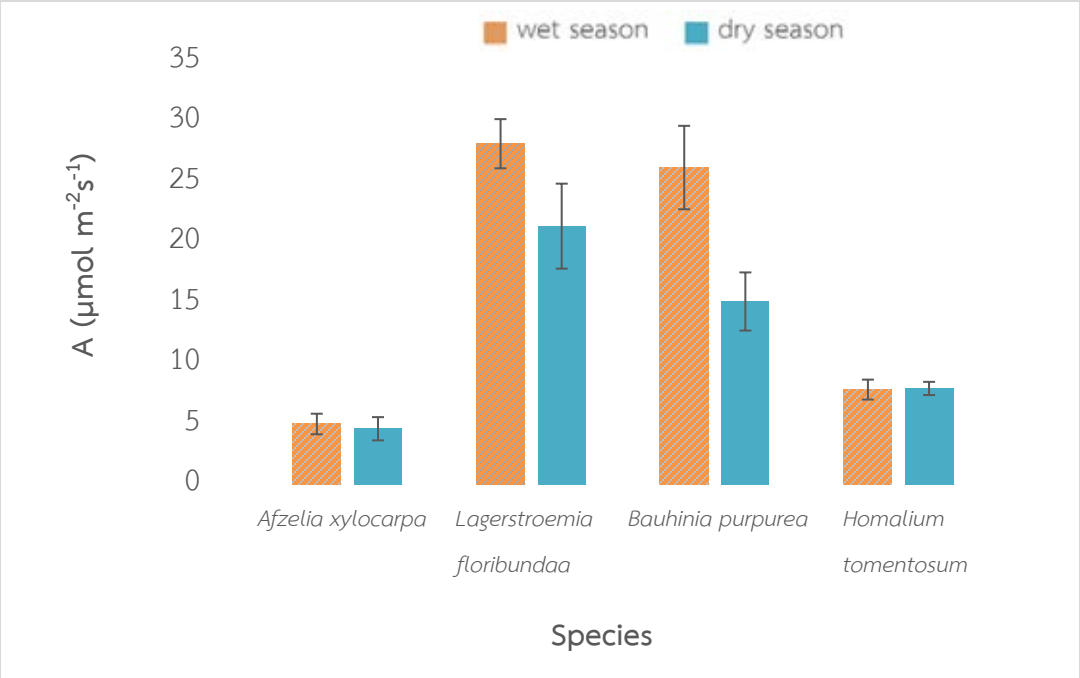

Figure 4.6 Comparison of carbon dioxide absorption rate (A) of trees species between wet and dry season.

Table 4.4 Comparison of the differences diurnal carbon dioxide absorption rate (A) of each species between wet and dry season by using independent t-test (n=15)

Species	A in wet season ($\mu mol\ m^{-2}s^{-1}$)	A in dry season ($\mu mol\ m^{-2}s^{-1}$)	P-value
Afzelia xylocarpa	5.03 ± 0.85	4.63 ± 0.96	0.671
Lagerstroemia floribunda	28.20 ± 2.03	21.38 ± 3.51	0.354
Bauhinia purpurea	26.03 ± 3.45	15.16 ± 2.40	0.788
Homalium tomentosum	7.87 ± 0.82	7.97 ± 0.55	0.104

A values are the mean and error bar represent one standard deviation (SD) of each species.

The diurnal pattern of carbon dioxide absorption rate of trees species in wet season as shown in Figure 4.7 (a) found that overall pattern almost no different diurnal values and the magnitude were similar between *Lagerstroemia floribunda* and *Bauhinia purpurea* and between *Homalium tomentosum* and *Afzelia xylocarpa*.

In dry season as shown in Figure 4.7 (b) found that the highest value is *Lagerstroemia floribunda* that rose steadily in the morning and peaked at around midday then slightly decreased in the evening and *Bauhinia purpurea* grew steadily until around midday and went down moderately in the evening. *Bauhinia purpurea* and *Afzelia xylocarpa* were similar but in the evening *Homalium tomentosum* slightly increased while *Afzelia xylocarpa* slightly decreased.

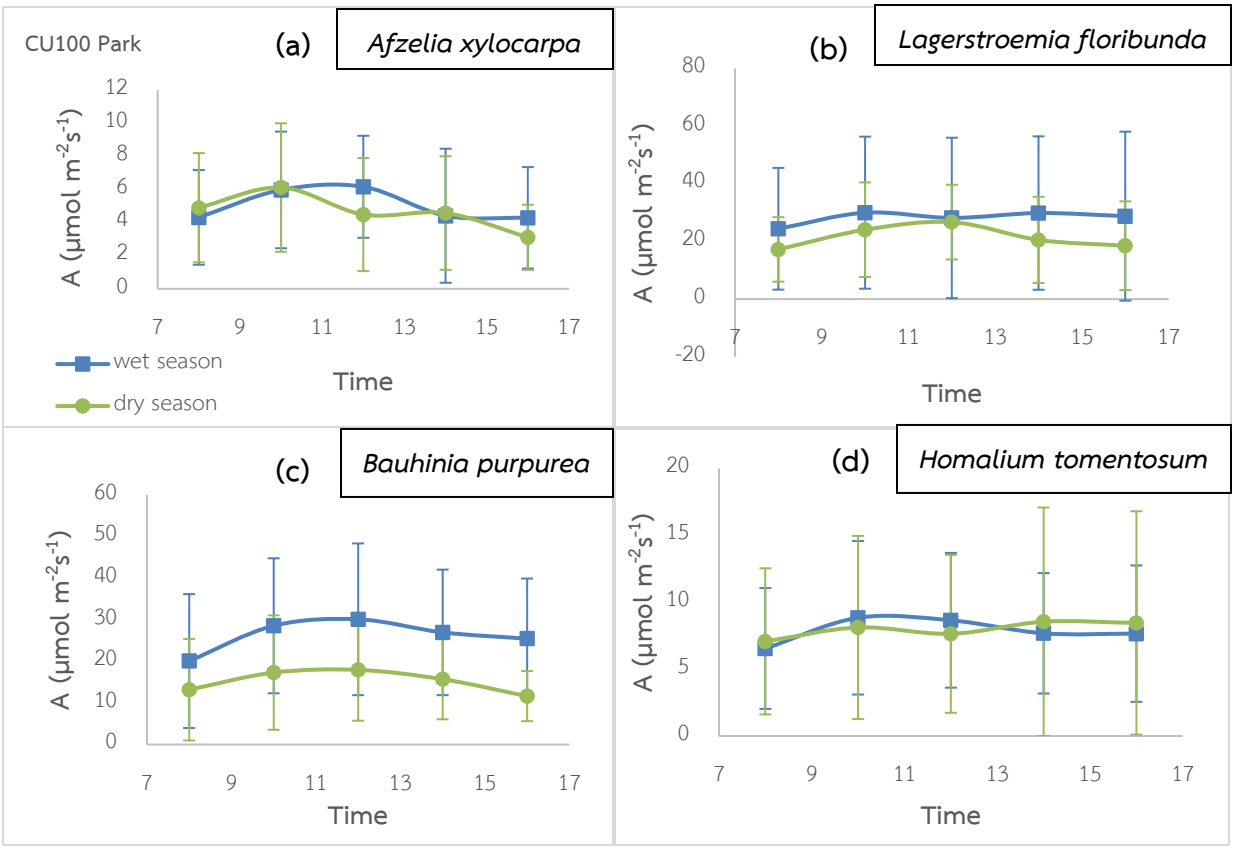

Figure 4.7 Pattern of carbon dioxide absorption rate (A) of *Afzelia xylocarpa* (a), *Lagerstroemia floribunda* (b), *Bauhinia purpurea* (c) and *Homalium tomentosum* (d) in wet and dry season

To compare the differences diurnal carbon dioxide absorption rate (A) of each species between time and season by using ANOVA as shown in the table 4.5, there were no significant differences at 0.05 level between carbon dioxide absorption rate (A) and time including season (wet and dry).

Table 4.5 Comparison of the differences diurnal carbon dioxide absorption rate (A) of each species between time and season by using one-way ANOVA (n=45)

Species	P-value
Afzelia xylocarpa	0.530
Lagerstroemia floribunda	0.937
Homalium tomentosum	0.878
Bauhinia purpurea	0.956

4.4 Relationship between carbon dioxide absorption rate and environmental factors

Relationship between carbon dioxide absorption rate and environmental factors in the studied species that are vapor pressure deficit (VPD, kPa), temperature (°C) and relative humidity (RH, %) are shown in Figure 4.8 – 4.11.

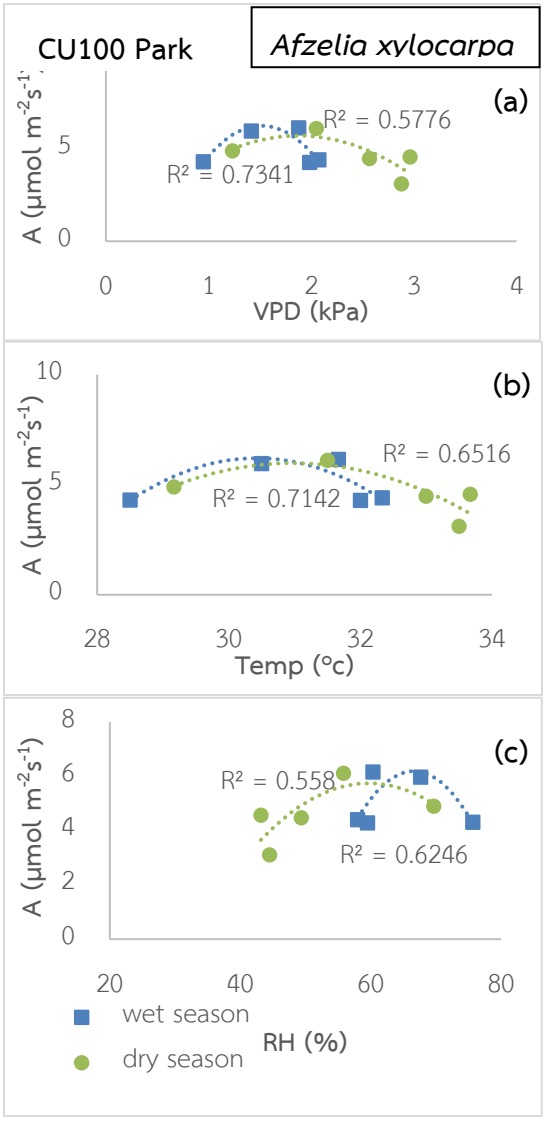

Figure 4.8 Pattern of *Afzelia xylocarpa* between carbon dioxide absorption rate (A) environmental factors that are VPD (a), temperature (b) and relative humidity (c).

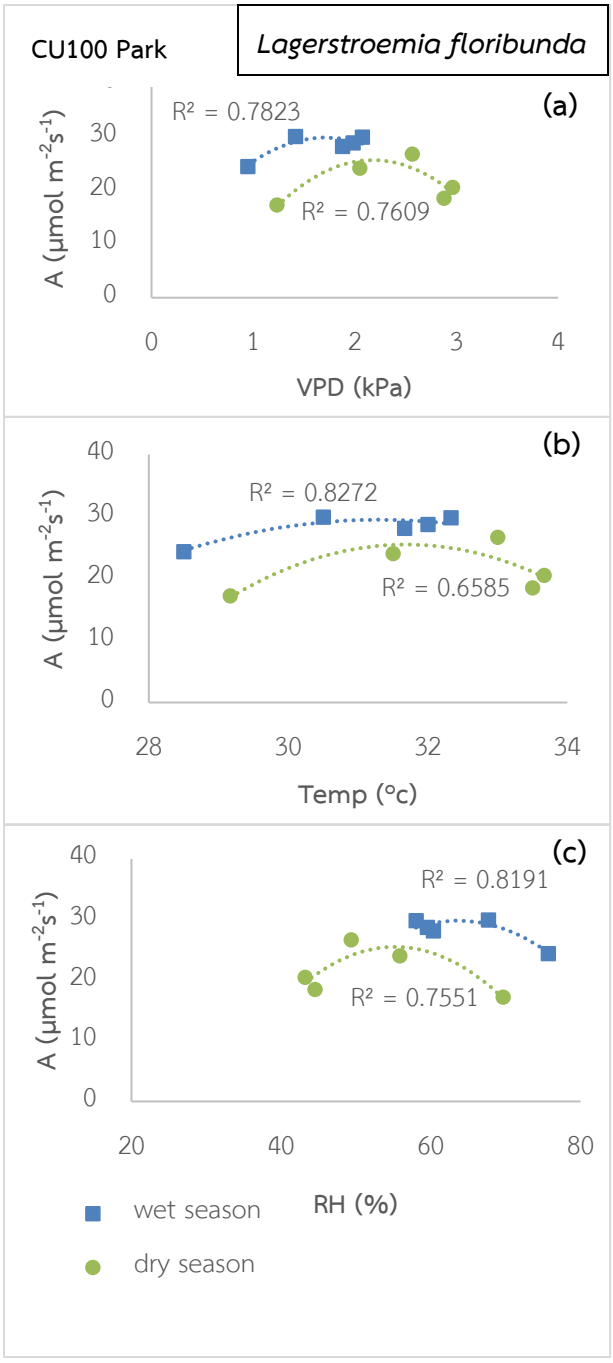

Figure 4.9 Pattern of *Lagerstroemia floribunda* between carbon dioxide absorption rate (A) environmental factors that are VPD (a), temperature (b) and relative humidity (c).

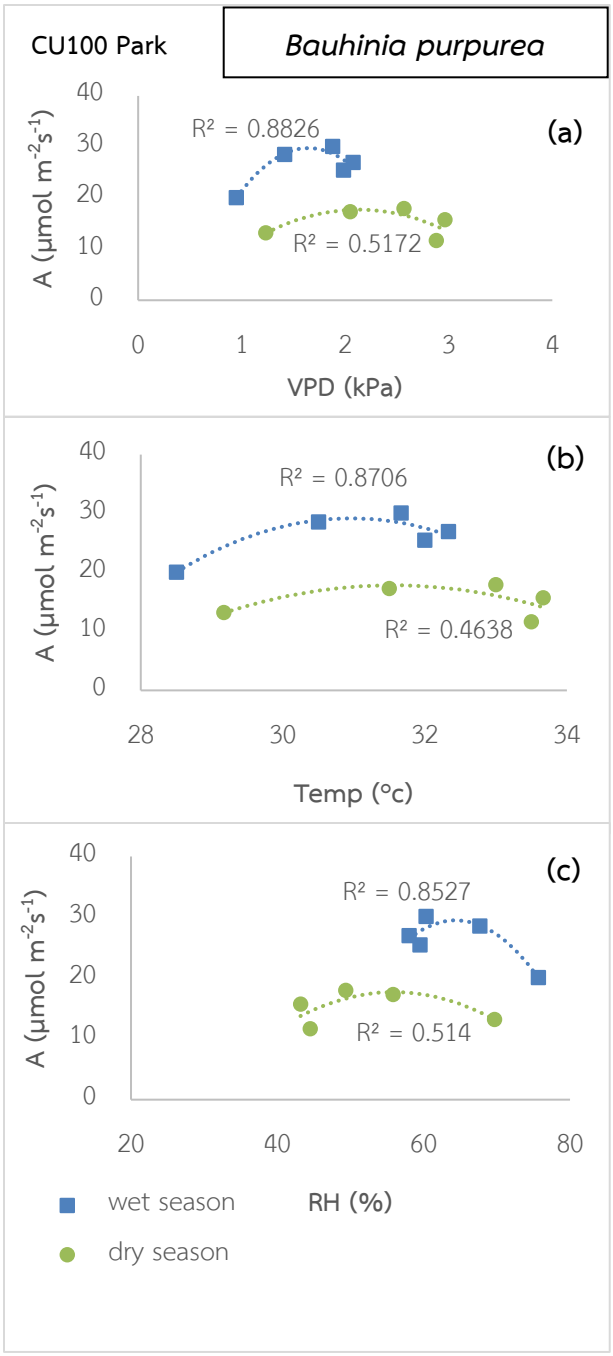

Figure 4.10 Pattern of *Bauhinia purpurea* between carbon dioxide absorption rate (A) environmental factors that are VPD (a), temperature (b) and relative humidity (c).

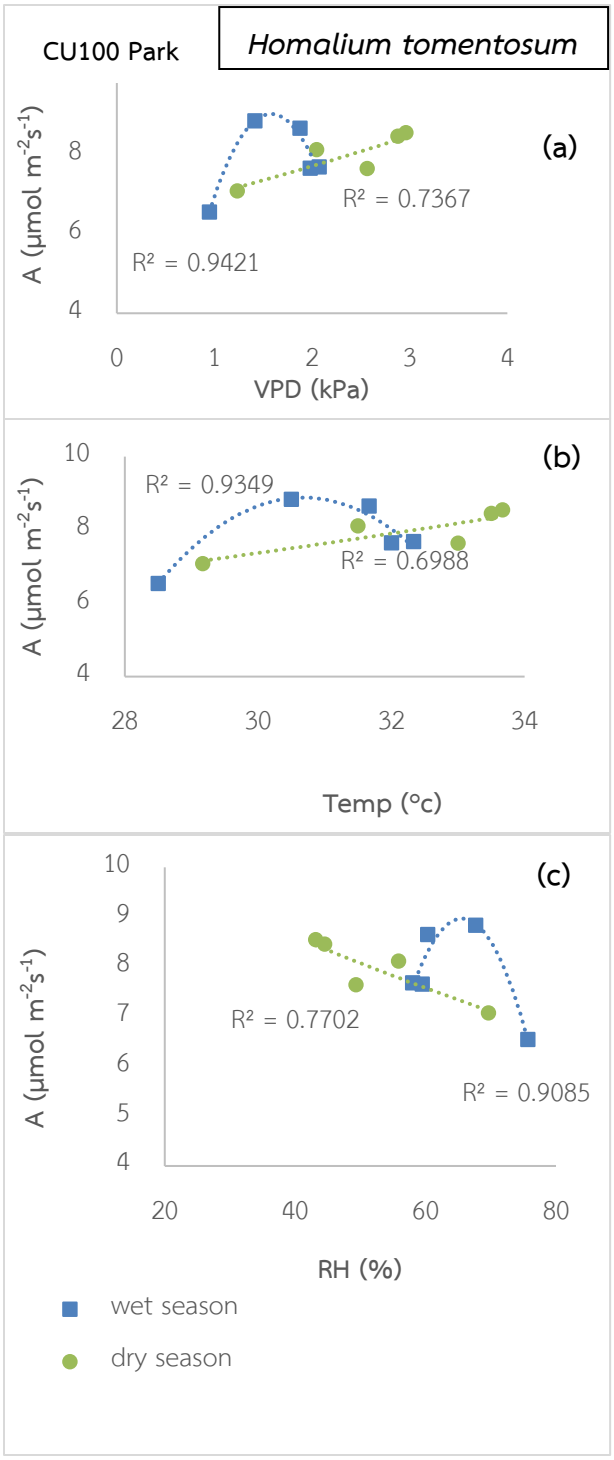

Figure 4.11 Pattern of *Homalium tomentosum* between carbon dioxide absorption rate (A) environmental factors that are VPD (a), temperature (b) and relative humidity (c).

Regression statistics of relationship between carbon dioxide absorption rate and environmental factors in the studied species that are vapor pressure deficit (VPD, kPa), temperature (°c) and relative humidity (RH, %) are shown in Table 4.6. - 4.8.

Table 4.6 Regression statistics of carbon dioxide absorption rate (A) to VPD of studied trees species in wet and dry season.

Species	Equation	R^2	P-value
Afzelia xylocarpa	$y_{Wet} = -6.2146x^2 + 18.845x - 8.0246$	0.7341	0.234
	$y_{Dry} = -1.7449x^2 + 6.5453x - 0.4193$	0.5776	0.447
Lagerstroemia floribunda	$y_{Wet} = -8.635x^2 + 26.659x + 4.2998$	0.7823	0.218
	$y_{Dry} = -9.6883x^2 + 42.182x - 20.327$	0.7609	0.219
Homalium tomentosum	$y_{Wet} = -6.1571x^2 + 19.454x - 6.3598$	0.9421	0.058
	$y_{Dry} = 0.7321x + 6.2575$	0.7307	0.065
Bauhinia purpurea	$y_{Wet} = -20.015x^2 + 65.886x - 24.425$	0.8826	0.117
	$y_{Dry} = -5.6961x^2 + 24.263x - 8.1133$	0.5172	0.482

Table 4.7 Regression statistics of carbon dioxide absorption rate (A) to temperature of studied trees species in wet and dry season.

Species	Equation	R^2	P-value
Afzelia xylocarpa	$y_{Wet} = -0.5167x^2 + 31.448x - 472.26$	0.7142	0.284
	$y_{Dry} = -0.3155x^2 + 19.545x - 296.74$	0.6516	0.351
Lagerstroemia floribunda	$y_{Wet} = -0.6295x^2 + 39.415x - 587.51$	0.8272	0.173
	$y_{Dry} = -1.3391x^2 + 84.875x - 1319.4$	0.6585	0.337
Homalium tomentosum	$y_{Wet} = -0.4925x^2 + 30.222x - 454.71$	0.9349	0.065
	$y_{Dry} = 0.2695x - 0.702$	0.6896	0.082
Bauhinia purpurea	$y_{Wet} = -1.5156x^2 + 93.836x - 1423.2$	0.8706	0.129
	$y_{Dry} = -0.827x^2 + 52.187x - 805.49$	0.4638	0.535

Table 4.8 Regression statistics of carbon dioxide absorption rate (A) to relative humidity (RH) of studied trees species in wet and dry season.

Species	Equation	R^2	P-value
Afzelia xylocarpa	$y_{Wet} = -0.0234x^2 + 3.1221x - 97.799$	0.6246	0.382
	$y_{Dry} = -0.0076x^2 + 0.9125x - 21.485$	0.558	0.428
Lagerstroemia floribunda	$y_{Wet} = -0.0364x^2 + 4.6292x - 117.52$	0.8191	0.167
	$y_{Dry} = -0.0406x^2 + 4.4872x - 98.436$	0.7551	0.255
Homalium tomentosum	$y_{Wet} = -0.024x^2 + 3.1516x - 94.407$	0.9085	0.092
	$y_{Dry} = -0.0494x + 10.558$	0.7628	0.053
Bauhinia purpurea	$y_{Wet} = -0.0744x^2 + 9.5887x - 279.25$	0.8527	0.148
	$y_{Dry} = -0.024x^2 + 2.6865x - 57.464$	0.514	0.486

The variations of carbon dioxide absorption rate (A) response to VPD are the same for *Afzelia xylocarpa*, *Lagerstroemia floribunda* and *Bauhinia purpurea* (Figure 4.8 - 4.10) while *Homalium tomentosum* is different from others in dry season (Figure 4.11). Overall increased and reached some peak and decreased but increasing and decreasing rate in wet season seemed to be faster than dry season in *Afzelia xylocarpa*, *Lagerstroemia floribunda* and *Bauhinia purpurea* but, in the dry season, *Homalium tomentosum* increased linearly with VPD.

Because VPD is calculated from relative humidity (RH) and temperature, we examined the relationships between these two variables and A to see which one contributes to the VPD responses. Results showed that RH seemed to affect the VPD because the response patterns were similar in all species (compare panel (a) and (c) in Figure 4.8-4.11) except in dry season of *Homalium tomentosum* results showed that temperature seemed to affect the VPD due to the response patterns were similar (compare panel (a) and (b) in Figure 4.11). This implies that stomata responded to air humidity than air temperature and therefore influencing A at this site.

According to Fauset *et al.* (2019), they find temperature and CO_2 impacts on photosynthesis, the elevated temperature treatment had no discernible effect on A or photosynthetic capacity and their responses to elevated temperatures. The high temperature tolerance of both A and photosynthetic capacity was marked, with no decline in A found even at 40 °C. It is worth noting that such high leaf temperatures are often considered to be detrimental to photosynthetic functions (e.g. Rubisco activase activity is strongly temperature sensitive with inhibition found above 35 °C (Crafts-Brandner & Salvucci, 2002).

Slot *et al*. (2017), found that temperature optima measured in the field in Panama was around the mean maximum daily temperature (30–32 °C) for all 4 species

are *F. insipida, L. speciose, C. longifolium and G. madruno* measured, and that, for a smaller sample of four species, it was g_s rather than Rubisco activase, photosynthetic capacity ($J_{\max}$, $V_{c\max}$) or light respiration that limited the photosynthetic rates at high temperatures. The rate of A of 4 species in Panama are 21.6, 19.7, 16.2 and 7.2 μmol $m^{-2}s^{-1}$, respectively. The measured rates are also pretty similar to our study even different trees species and biomes.

CHAPTER 5

RESEARCH CONCLUSIONS

5.1 Conclusions

In our study we conclude that all species were no statistically significant differences of carbon dioxide absorption rate (A) between wet and dry season during the experimental period. The values of carbon dioxide absorption rate are, from the highest to the lowest, *Lagerstroemia floribunda*, *Bauhinia purpurea, Homalium tomentosum* and *Afzelia xylocarpa*, respectively. Relationship between carbon dioxide absorption rate (A) and environmental factors found that carbon dioxide absorption rate (A) of *Afzelia xylocarpa*, *Lagerstroemia floribunda* and *Bauhinia purpurea* response to VPD are the same while *Homalium tomentosum* is different. Relative humidity (RH) and temperature are two variables that affect to VPD, we found that carbon dioxide absorption rate (A) of *Afzelia xylocarpa*, *Lagerstroemia floribunda* and *Bauhinia purpurea* depend on by RH and *Homalium tomentosum* depend on temperature. Additionally, using the results from this study to increase planting trees that can choose maximize carbon dioxide absorption rate by selecting appropriate species i.e. *Lagerstroemia floribunda*, *Bauhinia purpurea, Homalium tomentosum*, *Afzelia xylocarpa*, etc. leading to sustainable urban greening management.

5.2 Research Recommendations

5.2.1 Other parameter that can affect to carbon dioxide absorption rate i.e. sunlight, rainfall, wind speed, should be also considered to improve the understanding of environmental conditions response to carbon dioxide absorption rate.

5.2.2 To confirm this result should be study more species in this park.

REFERENCES

Berdanier, B.A., Miniat F.C., and Clark S.J. Predictive models for radial sap flux variation in coniferous, diffuse-porous and ring porous temperate trees. Tree Physiology (2016): 1-10.

Crafts-Brandner, S. J., & Salvucci, M. E. Rubisco activase constrains the photosynthetic potential of leaves at high temperature and CO2. Proceedings of the National Academy of Sciences. 2002 (24): 13430–13435.

Du, W. C., and X. H. Xia. How Does Urbanization Affect GHG Emissions A Cross-Country Panel Threshold Data Analysis. Applied Energy 2018(229): 872–83.

Fauset, S., Oliveira, L., Buckeridge, M. S., Foyer, C. H., Galbraith, D., Tiwari, R., & Gloor, M. (2019). Contrasting responses of stomatal conductance and photosynthetic capacity to warming and elevated CO2 in the tropical tree species Alchornea glandulosa under heatwave conditions. Environmental and Experimental Botany. 2019(158): 28–39.

Kätterer, T., O. Andrén, and P. E. Jansson. Pedotransfer Functions for Estimating Plant Available Water and Bulk Density in Swedish Agricultural Soils. Acta Agriculturae Scandinavica Section B: Soil and Plant Science 2006(56): 263–276.

Katul, G. G., Ellsworth, D. S., & Lai, C. T. Modelling assimilation and intercellular CO2 from measured conductance: A synthesis of approaches. Plant, Cell and Environment. 2000(12): 1313–1328.

Li, Y., Zhou, L., Wang, S., Chi, Y., & Chen, J. (2018). Leaf temperature and Vapour Pressure Deficit (VPD) driving stomatal conductance and biochemical processes of leaf photosynthetic rate in a subtropical evergreen coniferous plantation. Sustainability (Switzerland). 2018(11): 1–13.

Mathur, S., Agrawal, D., & Jajoo, A. Photosynthesis: Response to high temperature stress. Journal of Photochemistry and Photobiology B: Biology. 2014: 137, 116–126.

Rizwan, A.M., Dennis, L.Y.C., Liu, C., 2008. A review on the generation, determination and mitigation of Urban Heat Island. Ecol. Environ. Sci. 2008(20): 120–128.

Slot, M., & Winter, K. In situ temperature relationships of biochemical and stomatal controls of photosynthesis in four lowland tropical tree species. Plant Cell and Environment. 2017(40): 3055–3068.

TMD. Climate satistic (30 years 1981-2010) . Retrieved December 2, 2018 from http://climate.tmd.go.th/statistic/stat30y?lang=en

United States – Environmental Protection Agency (US-EPA). (2008). Trees and vegetation. In Reducing urban heat islands: Compendium of strategies. USA: Climate Protection Partnership Division—EPA's Office of Atmospheric Programs.

Velasco, Erik, Matthias Roth, Leslie Norford, and Luisa T. Molina. Does Urban Vegetation Enhance Carbon Sequestration. Landscape and Urban Planning (2016) 148 Elsevier: 99–107.

Weissert, L. F., Salmond, J. A., & Schwendenmann, L. A review of the current progress in quantifying the potential of urban forests to mitigate urban CO2emissions. Urban Climate. 2014 (8): 100–125.

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