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ชื่อโครงการ **Seasonal variation of soil organic carbon stocks and sequestration rates in the CU Centenary Park**

ชื่อนิสิต **Miss Chanapa Julsiriwattanawong**

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คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project Title	Seasonal variation of soil organic carbon stocks and sequestration rates in the CU Centenary Park
Student Name	Miss Chanapa Julsiriwattanawong Student ID 5933309723
Department	Environmental Science
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Faculty of Science, Chulalongkorn University

Seasonal variation of soil organic carbon stocks and sequestration rates in the CU Centenary Park

ความผันแปรตามฤดูกาลของปริมาณคาร์บอนอินทรีย์ในดินและอัตราการกักเก็บ

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Student Name	Miss Chanapa Julsiriwattanawong Student ID 5933309723
Project Advisor	Assistant Professor Pasicha Chaikaew, Ph.D.
Project Co-advisor	Assistant Professor Pantana Tor-negrn, Ph.D.
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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

.... Head of the Department of Environmental Science

(Professor Wanida Jinsart, Ph.D.)

PROJECT COMMITTEE

....

(Assistant Professor Sarawut Srithongouthai, Ph.D.) Chairman

....

(Chidsanuphong Chart-asa, Ph.D.) Committee

....

(Assistant Professor Pantana Tor-ngern, Ph.D.) Project co-advisor

....

(Assistant Professor Pasicha Chaikaew, Ph.D.) Project advisor

ชื่อโครงการ	**ความผันแปรตามฤดูกาลของปริมาณคาร์บอนอินทรีย์ในดินและอัตราการกักเก็บในอุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัย**
โดย	**นางสาวชนาภา จุลศิริวัฒนวงศ์ รหัสประจำตัวนิสิต 5933309723**
อาจารย์ที่ปรึกษา	**ผู้ช่วยศาตราจารย์ ดร.ภศิชา ไชยแก้ว**
อาจารย์ที่ปรึกษาร่วม	**ผู้ช่วยศาสตราจารย์ ดร.พันธนา ตอเงิน**
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บทคัดย่อ

พื้นที่เขตเมืองเป็นแหล่งที่มีการปลดปล่อยก๊าซคาร์บอนไดออกไซด์ (CO_2) ปริมาณมาก แต่ในขณะเดียวกัน พื้นที่สีเขียวของสวนสาธารณะในเมือง ก็สามารถช่วยลด CO_2 โดยการกักเก็บคาร์บอนไว้ในพืชและในดิน อุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัยถูกออกแบบมาเพื่อตอบสนอง การใช้งานหลากหลายรูปแบบตั้งแต่ด้านนิเวศวิทยาไปจนถึงเป็นแหล่งพักผ่อนหย่อนใจของคนในชุมชน อย่างไรก็ตาม ข้อมูลเกี่ยวกับความสามารถในการกักเก็บคาร์บอนของดิน และความเชื่อมโยงกับฤดูกาล ประเภทของพืชที่ปกคลุมดิน รวมถึงปัจจัยด้านสิ่งแวดล้อมในอุทยาน 100 ปียังมีอยู่อย่างจำกัด งานวิจัยนี้จึงออกแบบเก็บตัวอย่างดินชั้นบนจำนวน 27 ตัวอย่าง (0-15 ซม) โดยแบ่งเก็บจำนวนตัวอย่างเท่า ๆ กันภายในพื้นที่ที่ปกคลุมด้วยพืชต่างกัน 3 ประเภท ได้แก่ ไม้ยืนต้น หญ้า และไม้พุ่ม การเก็บตัวอย่างได้ดำเนินการในเดือนกันยายน 2562 (เป็นตัวแทนฤดูฝน) และในเดือนธันวาคม 2562 (เป็นตัวแทนฤดูแล้ง) ปริมาณคาร์บอนอินทรีย์ในดินวิเคราะห์โดยเครื่อง TOC analyzer สำหรับค่าพารามิเตอร์เกี่ยวข้อง อุณหภูมิ, ความชื้น, ค่า pH และความหนาแน่นรวม ใช้วิธีมาตรฐาน ผลการวิจัยพบว่าปริมาณคาร์บอนอินทรีย์ของดินในช่วงฤดูแล้งไม่แตกต่างจากฤดูฝน แต่พบว่า ดินในพื้นที่ไม้พุ่มมีการสะสมอินทรีย์คาร์บอนสูงกว่าในพื้นที่หญ้า (p-value <0.001) ผลการวิเคราะห์จากโมเดลแบบจำลองการถดถอยเชิงเส้นแบบหลายเส้นแสดงให้เห็นว่า อุณหภูมิดินและความหนาแน่นรวม ไม่มีผลต่อปริมาณคาร์บอนอินทรีย์ในดิน (p-value > 0.05) ในขณะที่ ความชื้นในดินเป็นปัจจัยส่งเสริมต่อการกักเก็บอินทรีย์คาร์บอนอย่างมีนัยสำคัญ (p-value <0.001) และสามารถใช้ความชื้นดินในการพยากรณ์ค่าการสะสมอินทรีย์คาร์บอนในดิน งานวิจัยนี้เสนอให้นำปัจจัยด้านสิ่งปกคลุมดินและความชื้นในดินไปใช้วางแผนประเภทพืชพรรณที่ปลูกรวมถึง ระบบการจัดการน้ำที่เหมาะสมในอุทยาน 100 ปี จุฬาลงกรณ์มหาวิทยาลัย เพื่อชดเชยก๊าซคาร์บอนไดออกไซด์ที่เพิ่มขึ้นจากชั้นบรรยากาศ

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Abstract

Urban areas are major contributors of CO_2 emissions, but at the same time greenspace in urban parks can offset CO_2 from the atmosphere and store carbon in vegetation and soils. The CU Centenary Park is designed to serve multi-functional purposes from an ecological aspect to human well-being. However, knowledge on the capacity of soils to store carbon that link to effects from seasonal variation, vegetation covers, and environmental factors is limited. Twenty seven soil samples were collected (0-15 cm) and were divided equally within three land cover types: tree, grass, and shrub. The sampling collection was conducted in September 2019 (represented the wet season) and December 2019 (represented the dry season). Soil organic carbon content was measured by the TOC analyzer. Soil temperature, soil moisture, pH, and bulk density were analyzed using standard methods. Between the dry and wet seasons, there was no difference of SOC stocks. Shrub soils dominantly expressed high SOC stocks over grass and tree (p-value < 0.001). While soil temperature and bulk density did not show statistically significance in the multiple linear regression model (p-value > 0.05), soil moisture was significantly positively influenced on SOC storage (p-value < 0.001) and can be a predictor for estimating SOC stocks. To offset more CO_2 from the atmosphere, the results suggested the proper vegetation planning and irrigation system to be placed in the park.

Keywords: soil organic carbon stocks, vegetation cover, urban park, environmental factors, landscape management

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Chanapa Julsiriwattanawong

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CHAPTER 1

INTRODUCTION

The increasing amount of atmospheric greenhouse gases, in particular CO_2, is one of the most challenging situations the world is facing. An increase in CO_2 from 280 ppm before the Industrial Revolution to over 400 ppm currently provides a vital sign to the changing planet. The IPCC's fifth Assessment Report points out the effects from continued emission of GHGs will cause further warming and long-lasting changes in all components of the environmental system, and irreversible impacts for people. Limiting climate change requires substantial and sustained reductions in GHGs emissions (IPCC, 2014). Soil organic carbon (SOC) is considered a key player that can offset carbon emissions because soils store more carbon than the atmosphere and all vegetation.

The nature and quantity of organic carbon in the soil affects a wide range of physical, chemical and biological soil properties as following: 1) soil nutrients; decomposition of organic materials in the soil releases soil nutrients such as nitrogen, phosphorus etc. 2) soil structure; soil organic carbon promotes good soil structure by binding soil particles together in stable aggregates. Improved structure aids aeration, water holding capacity, etc. 3) soil biology, organic matter and organic carbon in the soil are a food source for a range of soil organisms and so enhance soil biodiversity and biological health. A wide range of organisms in the soil also helps release nutrients and create pores and can help protect against crop diseases 4) soil protection; adequate soil carbon reduces the severity and costs of natural phenomena (e.g. drought, flood, and disease) and can increase farm production. By contributing to, or protecting, the soil, soil organic carbon contributes to farm production and increasing soil organic carbon is valuable for a range of soil health, sustainability and production benefits.

Soil organic carbon is a component of soil organic matter, with about 58 % of the mass of organic matter existing as carbon. Because different forms of carbon behave differently, they are often grouped into three distinct pools: labile pool, slow pool and inert pool. Labile carbon includes fresh plant and animal material and micro-organisms which are easily decomposed. The slow pool includes well-decomposed organic materials called humus. The inert pool is the soil carbon fraction that is old, resistant to further breakdown and in the last stage of decomposition. Soils differ not only in total soil organic carbon but also in the composition of the different organic carbon pools (NSW, 2018). SOC content varies upon amount of organic matter (OM) input, land cover types, soil characteristics, depths, climate, latitudes, and human influences. Globally, variation of litter decomposition rates among different vegetation covers from quick to slow are rainforest > swamp > broadleaf forest > mixed forest > grassland > shrub > coniferous > tundra. Turnover of SOC is dynamic and can turn SOC into either a net sink or source of GHGs.

Among the terrestrial soil ecosystems, a human-built urbanization is growing in size and numbers. Urban areas, however, are often missing in carbon sequestration studies. The controversial issue surrounding the potential of urban park to capture or release carbon is still the ongoing debate among scientists. Urbanization, is presumed to degrade natural ecosystems, but many studies notes that urban parks within the urban areas provide a range of multiple ecosystem services that are valuable to both nature and humans. The dominant green space of urban parks has led to research in understanding its carbon sequestration potential in terrestrial system, particularly concerning the management to accumulate organic carbon. Carbon sequestration process in urban parks regulates as same process as other ecosystems. Plants remove CO_2 from the air and convert it to organic compounds through photosynthesis. Some of the organic compounds are used to grow plants, while some are broken down to supply energy. Dead plant materials and animals are decomposed by microorganisms to provide energy for soil microbes. The live microbial biomass is mixed with organic residuals of dead plants and dead microbes to form soil organic matter and store carbon in soils. During the sequestration process, CO_2 is released back to the atmosphere through aboveground plant respiration and soil respiration.

The CU Centenary Park is the first public park in a heart of Chulalongkorn University. The park is multi-functional park with a wide range of ecological functions and contribution to human well-being. The newly established park has drawn researchers' attentions, including this study, to explore its environmental-social benefits to the community.

Objectives

1. To compare soil organic carbon stocks between wet and dry seasons and different land covers in the CU Centenary Park.
2. To determine the relationships between SOC stocks and environmental factors e.g. temperature, moisture, and soil bulk density.

Outcomes of research

1. This research could provide the CU Centenary Park and general public with beneficial database and information on soil organic carbon stocks in wet and dry seasons.

2. The results could deliver better understanding of the relationships between soil organic carbon stocks and physico-chemical properties of soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil organic carbon

Soils contain a good amount of carbon in organic and inorganic or mineral forms. The amount of soil organic carbon depends on soil texture, climate, vegetation and land use pattern. Soil texture affects SOC. Organic matter can be trapped in the very small spaces between clay particles making them inaccessible to micro-organisms and therefore slowing decomposition. Clay offers chemical protection to organic matter through adsorption onto clay surfaces that indicates more organic matter in clayey soil. Soils under natural forests or grassland tend to have higher SOC content than soils under cropland. The conversion of cropland back to forest or grassland is likely to increase SOC (Eleanor, 2008). Lal (2004) estimated that with appropriate use and management, soils have the potential to sequester ~ 0.9 Pg C per year. This is roughly equal to 13 % of the anthropogenic CO_2 C produced annually. Ravindranath et al. (1996) reported that mean soil carbon in top 30cm for tropical moist deciduous and tropical dry deciduous forests were estimated 57.1 and 58.0 Mg C/ha, respectively. The estimate of average carbon content (in the biomass and forest soil) in Indian forests is 126 Mg C /ha of which 36% (45.8 Mg C /ha) is in biomass and 64% (79.8 Mg C /ha) in forests soil (Haripriya, 2003). SOC is the largest terrestrial carbon pool which holds a very significant role in global terrestrial ecosystem carbon balance. Eswaran et al. (2000) estimated soil organic carbon stock to 580 Pg in global forest. Based on the average global or regional soil carbon densities, Indian forest soil organic carbon pool estimated in the range between 5.4- 6.7 Pg C (Ravindranath et al., 1997; Dadhwal et al., 1998). Dadhwal et al. (1998) also estimated forest soil organic carbon pools of 4.9 and 4.6 Pg C for 1980 and 1990, respectively, using FAO (1993) forest area. Chhabra et al. (2003) estimated that total soil organic carbon pools in top 50 cm and top 1m soil depth were 4.13 Pg C and 6.81 Pg C, respectively.

2.2 Soil carbon sinks and sources

Land-based sinks have moderated the increase in atmospheric uptake of CO_2, with a progressive increase in annual uptake/absorption from 1 Pg C/year in 1960 to 3.1 Pg C/year in 2010. World soils have a large total C pool, but finite C sink capacity. The soil carbon pool has two distinct components: soil organic carbon and soil inorganic carbon (SIC). The SOC pool is highly dynamic, reactive, and sensitive to land use, climate change, and management. Measured to 3-m depth [and including the recent estimates of the large C pool in permafrost soils (Cryosols)], total soil C pool is estimated at 4,000 Pg. The SOC pool in the surface 0–1 m depth (1,550 Pg) has numerous functions, and generates a range of ecosystem services (Lal et al. 2013).

Terrestrial ecosystems are an important source and sink of atmospheric greenhouse gases, and are closely related to human production activities, among which land use change and land management measures are important factors influencing greenhouse gas emissions (Smith et al., 2004). Changes in land use and land cover caused by human activities have increased during the last three centuries (Jesse et al., 2018). The contribution of land use/cover changes to carbon emissions had clearly exceeded that of fossil fuels by the 1930s (Bai et al., 2018). Therefore, the response of carbon balance cycle in terrestrial ecosystems and global climate change driven by carbon emissions has become a focal point as well as a point of contention in current research (Zhao et al., 2015). Land use/cover changes affect ecosystem carbon cycling and human health development by changing the structure and function of ecosystems, and are primarily in the form of carbon sources and sinks (Tao et al., 2014; Arowolo and Deng, 2018). For example, fossil fuel combustion and certain land-use activities have changed the carbon balance, resulting in an increase in atmospheric CO_2 concentrations and contributing to climate change (Donato et al., 2011). About half of the earth's carbon is stored in tropical forests, which accounts for 14% of the world's soil carbon, the tropics have greater potential for reducing atmospheric CO_2 (Neto et al., 2018). Therefore, a comprehensive and reliable carbon emissions inventory can help us understand the relationship between land use/cover changes and carbon balance, and implement effective strategies to reduce carbon emissions.

2.3 Urban carbon management

Urban areas occupy and supplant landscapes that historically sequestered carbon with buildings, impervious land cover uses, and disproportionately high carbon emission producing systems. Automobiles, home heating, and industrial operations and power plants concentrate the carbon emissions in urban areas. At the same time increased erosion and sedimentation, stream and other water body deterioration from this erosion and sedimentation, and discharge of warmed waters (e.g., rainwater washing over pavements, from industrial operations, and so forth) all accelerate and contribute to disproportionately increased emissions of carbon and other GHGs from urban areas. On a per-acre basis, excluding coal-fired and oil-burning power plants and such natural emitters as volcanoes, urban areas by far exceed all other human sources of carbon emissions and contribute significantly to soil carbon losses. Sprawling subdivisions remove productive lands and soils in the Midwestern United States and elsewhere. They are replaced with global climate deteriorating land uses and landscapes. More, and accelerated, stormwater runoff from these lands contributes significantly to erosion of uplands and riparian corridors.

2.4 Related research reviews

Edmondson et al. (2012) investigated the contribution of urban areas to SOC stocks in Leicester. U.K. city, across a range of impervious surface types. SOC was estimated to the depth of 1 m. The city-wide SOC storage was 17.6 kg m^{-2}. In this amount soil accounted for 85% and un-sampled 15% of the city under buildings assumed to hold minimal or zero SOC.; Urban soils contained the majority of organic carbon (82%), followed by vegetation (18%), and under impervious surfaces (13%). Edmondson et al. (2014) further analyzed the effects of land covers on the SOC storage to 21 cm depth. The results revealed that soils under trees and shrubs in domestic gardens stored OC greater than other land-cover types in domestic greenspace (garden herbaceous), non-domestic greenspace (tree, shrub, herbaceous), and in arable land. Edmondson et al.'s (2014) explained that tree cover type did not influence soil bulk density or C:N ratio, properties which indicate the ability of soils to provide regulating ecosystem services such as nutrient cycling and flood mitigation. However, their study suggested that genus selection is important to maximize long-term SOC storage under urban trees, but emerging threats from genus-specific pathogens must also be considered.

Sun et al. (2018) pointed out the importance of urban green space to mitigate future climate change, but little attention has been received. The aboveground carbon storage was studied in Beijing and was estimated to absorb 956.3 Gg C through the green area, with an average carbon density of 7.8 Mg C ha^{-1}. Their findings highlighted the potential for carbon sequestration. However, the carbon density in green space decreased with the urban development intensity. When the urban development intensity reached a threshold of 60%, this level signified the great amount of carbon loss from the urban space. Not only aboveground but below ground carbon storage should be merged and be represented as inclusive carbon cycle in the urban landscape design and planning to maximize carbon storage

In Milan, Italy, Conedoli et al. (2019) estimated the top-soil OC stock and compared between land uses (park versus non-park) and land covers (woodland versus grassland). The study found higher SOC stocks in urban parks (7.9±2.4 kg m^{-2}) than non-parks (5.3±2.5 kg m^{-2}). Comparable SOC stocks were discovered in urban parks, forest, pasture, and grasslands of the same region. Low SOC storage was contained in urban non-parks. Land covers did not determine differences of SOC content in wooded areas and grasslands. Positive SOC correlations were detected with N content, percentage of silt, and soil thickness, while negative association was related to percentage of sand and pH. This study concluded that Milan urban topsoil (0-40 cm) can be used as carbon sink in both urban parks and urban non-parks. Other studies reported SOC stock values of different urban soils investigated in Asia (Table 2.1).

Table 2.1. A review of urban SOC stock studies in Asian countries.

Area	Land use	Depth (cm)	SOC stock (kg C m^{-2})	Reference
Bangkok, Thailand	Recreational park	0-15	2.29±1.73	Naka (2018)
Singapore	Roadside	0-100	1.1-42.5	Ghosh et al. (2016)
Urumqi, Xinjiang China	Impervious surface	0-80	8.1	Yan et al. (2015)
Seoul, Korea	Recreational park	0-100	6.02	Bae and Ryu (2015)
Kolkata eastern, India	Banobitan park	0-100	0.8	Jana et al. (2009)
West Bengal, India	Botanical garden	0-100	1.46	Jana et al. (2009)

CHAPTER 3

METHODOLOGY

3.1 Study site

The CU Centenary Park is sited in the center of Bangkok, Thailand, latitude 13.7392 N longitude 100.5249 E. The park is surrounded by high dense of residential community and shopping mall. The park covers 46,400 m^2 (29 rais) that was created to serve as green space and for water management in the future.

3.2 Sampling design

We collected a total of 27 soil samples comprising three land cover types: i) trees (9 samples), ii) shrubs (9 samples), and iii) lawn or grass (9 samples). Each sampling location was recorded using a handheld GPS in a WGS84 geographic coordinate system. Soil collection in September represented the wet season and December represented the dry season. In both seasons, soils were sampled at the same locations for a comparison purpose. Figure 3.1 shows the study site and soil sampling locations where CU01-CU09 denote “shrub-soils”, CU10-CU18 refer to “grass-soils”, and CU19-CU27 represent “tree-soils”.

Figure 3.1 Soil sampling locations within the study site across different land cover types

3.3 Soil sampling collection and on-site measurements

A cylindrical core with an inner diameter 5 cm wide, 5 cm high was engineered to collect soil samples to a depth of 15 cm. Nine soil samples were collected from each land-cover type in wet and dry seasons, made up a total of 54 soil samples. Once soil were collected into the core and graded the surface at both ends, they were then covered by core lids. Soil samples were placed in a zip lock bag for further preparation. All soil samples were prepared for laboratory analysis by drying with natural air under the shade for a week. In the field, soil temperature is measured with a thermometer. The method of determining soil pH was by a litmus paper.

3.4 Analysis of soil moisture and bulk density

To measure bulk density, the core method was applied using a cylindrical metal drilled into the soil at a depth of 15 cm. After drying a core that filled with soil samples at 105°C for 24 hours, the dried weight of soil was weighed to calculate as compared with the core volume to achieve a g cm^{-3} unit. The difference number between wet weight and dry weight was further used for soil moisture measurement.

3.5 Analysis of soil texture

Nine samples, three from each land cover types, were analyzed to represent soil texture for the specific area. Analysis of soil texture was analyzed by hydrometer method. This was done by weighing 50 g soil samples size 2 mm in size and soaked with sodium hexametaphosphate for 24 hours. The prepared samples were spinned for 5 minutes in a blender machine. Soil solution was added into hydrometer flask and adjusted the volume to 1000 ml. After that, mixed soil solution for 1 minute measured temperature and the volume from hydrometer at 40 second and 2 hours to bring to 2 for particle size calculation.

3.6 Analysis of total organic carbon

The analysis of SOC content was employed by the ai-analyzer multi N/C 3100. Analyzed two replicates at each sample. An approximate 250 mg of soil samples was prepared for the analysis. To test whether the soil still contains organic carbon or not, we used 1 drop of H_3PO_4 and tested the soil samples in the oven for 2 hours in order to eliminate organic carbon. After that, soil organic carbon content expressed in % TOC were analyzed at 1199°C.

3.7 Estimation of soil organic carbon stocks

The computation of SOC stock required soil carbon content (%), bulk density (g cm^{-3}), and the thickness of a soil sample (cm). An equation can be written as follows:

$$SOC_{stock} = SOC(\%) \times BD_{sample} \times depth \times 10 \quad \text{.....................................} \quad (1)$$

Where SOC_{stock} is soil organic carbon stocks in kg C m^{-2} unit, SOC is soil organic carbon content in %, BD_{sample} is the bulk density of the soil sample (g cm^{-3}), depth is soil sampling depth (0.15 m in this study). The number 10 is a unit conversion factor.

3.8 Statistical analysis

Land covers were classified into three types: tree, grass and shrub. Thus, to compare the average amount of SOC stocks between wet and dry seasons, we applied the Student's t test method. An effect of different land covers on SOC stocks was determined by one-way ANOVA. The relationships between SOC stocks and environmental covariates consisting of soil temperature, soil moisture and bulk density were analyzed by multiple linear regression method.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Environmental data

The majority of soil texture across the study site was sandy while shrub area represented sandy loam to sand texture (sand: 59.72-98.2%, silt: 1.08-27.16% and clay: 0.28-35.84%). In the wet season, soil bulk density varied from 0.86-1.70 g cm^{-3}, soil temperature ranged from 28.0-36.0°C, soil moisture content ranged from 5.13-55.05% and SOC content ranged from 0.01-5.97%. In the dry season, soil bulk density varied from 0.43-2.01 g cm^{-3}, soil temperature ranged from 27.0-32.5°C, soil moisture content ranged from 2.25-35.15% and SOC stocks ranged from 0.45-2.03 kg C m^{-2}. Soil pH varied from slightly acidic to neutral (pH: 5-7).

Table 4.1. A comparison of urban SOC stocks of different land uses.

Area	Land use	Depth (cm)	SOC stock (kg C m^{-2})	Reference
Bangkok, Thailand	Recreational park	0-15	1.96±1.55	This study
Bangkok, Thailand	Recreational park	0-15	2.29±1.73	Naka (2018)
Singapore	Roadside	0-100	1.1-42.5	Ghosh et al. (2016)
Urumqi, Xinjiang China	Impervious surface	0-80	8.1	Yan et al. (2015)
Seoul, Korea	Recreational park	0-100	6.02	Bae and Ryu (2015)
Kolkata eastern, India	Banobitan park	0-100	0.8	Jana et al. (2009)
West Bengal, India	Botanical garden	0-100	1.46	Jana et al. (2009)

Changes in SOC can determine how much biomass is grown and retained in soils. SOC changes generally occur slowly over several years and it is often a challenge to detect small changes. However, the amount of mean SOC stocks have been showing an increase in the CU

Centenary Park within one year as compared to Naka's (2018) study. The SOC stocks across this newly park decreased by 14.4% which accounted for SOC sequestration rate of -0.03 kg C m^{-2} mo^{-1}, approximately. A short term variability of SOC have also been acknowledged by a few studies. Leinweber et al. (1994) found a 15% relative change of SOC content increase in one year period in an agricultural experiment. Wuest (2014) conducted a study about seasonal variation in SOC and reported 14-16% change in a wheat field during 39 months. It is generally can be observed in the topsoil. For further reliable SOC measurement of long-term trends, consistent data from sufficient time scale and sampling points are required.

4.2 Comparison of SOC stocks between wet and dry seasons and among land cover types

Overall, the SOC stocks across land cover types were 2.01±1.73 kg C m^{-2} in the wet season, and 1.92±1.37 kg C m^{-2} in the dry season. Table 4.2 shows that there was no difference in SOC stocks between the wet and the dry season (paired Student's t test: t = 0.33, df = 26, p-value = 0.75). This minor difference was probably due to a short time experiment. For the 55-year-old-forest land, Dluzewski et al. (2019) recognized that seasonality played an important role in the soil surface horizon. In the autumn and winter months, higher SOC content were characterized than found in spring and summer.

Table 4.2 Paired Sample t-test for difference in SOC stocks between wet and dry seasons

Paired Samples Statistics

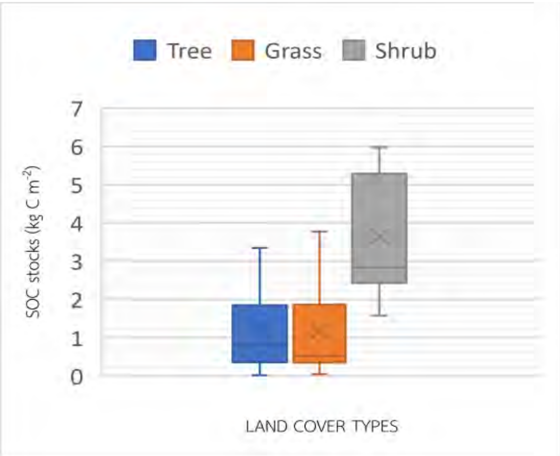
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SOCst_W	2.005	27	1.731	0.333
	SOCst_D	1.917	27	1.374	0.264

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 SOCst_W - SOCst_D	0.087	1.378	0.265	-0.458	0.632	0.329	26	0.745

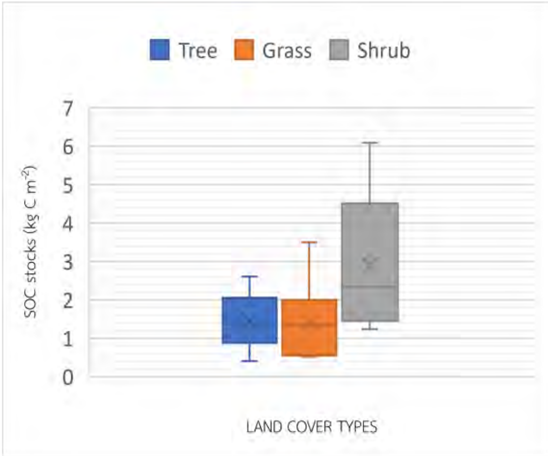
In addition to the seasonal effect that we focused but did not discover a significant difference between seasons, the effect of land covers on SOC stocks was analyzed. Understanding the land covers impact on SOC stocks was important for implementing park management to increase carbon sequestration and reduce carbon emission. The descriptive statistics of soil physical-chemical properties and SOC stocks in different land covers were shown in Table 4.3 and Figure 4.1.

Table 4.3 Descriptive statistics of soil properties

Land covers and soil properties	Max	Min	Mean	SD	Max	Min	Mean	SD
Tree	Wet season				Dry season			
Soil bulk density (g cm^{-3})	1.70	1.51	1.62	0.07	1.81	1.26	1.47	0.17
Soil temperature (°C)	29.78	28.34	29.06	0.52	30.36	27.64	28.94	1.01
Soil moisture (%)	14.13	5.13	9.13	2.98	8.94	3.94	6.81	1.60
SOC stocks (kg C m^{-2})	1.35	0.02	0.49	0.42	1.10	0.19	0.67	0.34
Grass	Wet season				Dry season			
Soil bulk density (g cm^{-3})	1.70	1.40	1.53	0.10	2.01	1.14	1.57	0.26
Soil temperature (°C)	30.20	27.94	29.24	0.68	31.57	27.38	29.06	1.59
Soil moisture (%)	22.47	7.88	15.01	4.50	11.47	2.25	6.26	3.37
SOC stocks (kg C m^{-2})	1.73	0.02	0.45	0.53	1.68	0.20	0.63	0.48
Shrub	Wet season				Dry season			
Soil bulk density (g cm^{-3})	1.68	0.86	1.28	0.25	1.48	0.43	1.15	0.29
Soil temperature (°C)	33.28	29.34	30.42	1.26	29.64	27.38	28.72	0.71
Soil moisture (%)	55.05	18.55	30.34	11.41	35.15	3.99	15.98	9.29
SOC stocks (kg C m^{-2})	3.22	0.83	2.03	0.95	3.62	0.71	1.86	1.17



(a)



(b)

Figure 4.1 Boxplots display the measured SOC stocks distribution in the areas covered by tree, grass, and shrub for the (a) wet season and (b) dry season.

To compare SOC stocks across land cover types, the one way ANOVA method was conducted. The p-value of overall model was < 0.001, indicating that at least one group differs significantly from overall mean of the SOC stocks. Tukey's post hoc tests and pairwise multiple comparison determined which groups differ. From the Table 4.4, the results showed that SOC stocks in shrub land cover (3.27 kg C m^{-2}) were significantly higher than tree (1.33 kg C m^{-2}) and grass-covers (1.28 kg C m^{-2}).

Table 4.4 One-way ANOVA and Tukey's Post Hoc comparison of SOC stocks and land cover types based on tree, grass, and shrub.

ANOVA

SOCstock

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	46.372	2	23.186	14.653	0.000
Within Groups	80.702	51	1.582		
Total	127.074	53			

Multiple Comparisons

Dependent Variable: SOCstock

Tukey HSD

(I) LCtype	(J) LCtype	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tree	Grass	0.051	0.419	0.992	-0.961	1.060
	Shrub	-1.940*	0.419	0.000	-2.952	-0.928
Grass	Tree	-0.051	0.419	0.992	-1.063	0.961
	Shrub	-1.991	0.419	0.000	-3.003	-0.979
Shrub	Tree	1.940	0.419	0.000	0.928	2.952
	Grass	1.991*	0.419	0.000	0.979	3.003

*. The mean difference is significant at the 0.05 level.

SOCstock

Tukey HSD[a]

LCtype	N	Subset for alpha = 0.05 1	2
Grass	18	1.281	
Tree	18	1.331	
Shrub	18		3.271
Sig.		0.992	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 18.000.

In natural condition, the process of soil formation depends on soil forming factors namely climate (cl), organisms (o), relief (r), parent material (p) and duration of the soil-forming process (t). In a man-made system like urban park, on the contrary, the anthropogenic factor can impose a significant influence on SOC sequestration when compare to natural factors. Edmonson et al. (2014) conducted a similar research to compare the effect of herbaceous, shrub and tree covers on SOC storage. They reported that the average SOC storage in the city's greenspace was significant higher under trees and shrubs as compared to other land covers. The explanation for high

SOC content under some land covers, i.e. shrub in this study as well as shrub and trees in Edmonson et al's work was due to low disturbance. In case of the CU Centenary Park, specific treatment interactions were implemented with different land cover types. Organic matter is a key component of soil that affects amount of organic carbon directly. Adding organic residues and inputs from biomass production were usually removed from soil surface under trees and lawns for an aesthetic reason, but not applied for shrubs. Soil organic matter was therefore present in the top 15 cm of shrub-soils, and was essential for retaining SOC.

4.3 Relationships between SOC stocks and environmental covariates

Environmental factors that were expected to relate with SOC stocks in this study include soil temperature, soil moisture and bulk density. We applied multiple linear regression to detect their relationships between SOC stocks and these parameters. The multiple regression model with all three predictors produced R-square = 0.255, p-value < 0.001, indicating that a model accounted for about 30% of variability and showed a good fit for the data. Temperature and bulk density were found to be tightly connected with SOC amount in many areas; however, due to low variation of soil temperature and bulk density among dataset in this study, the relationships of these parameters were not statistically significant. As can be seen, soil moisture was significantly positively correlated with SOC stocks (p-value = 0.016), implying that soils with higher moisture content tend to have higher SOC stocks (Table 4.5).

Table 4.5 Results of multiple linear regression of three factors (soil temperature, soil moisture, and soil bulk density) influencing SOC stocks

Model Summary

Model	R	R Square	Adjusted R Square	Std .Error of the Estimate
1	0.545[a]	0.297	0.255	1.33716

a .Predictors) :Constant(, Db, Temp, Moisture

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	37.740	3	12.580	7.036	0.000[b]
	Residual	89.400	50	1.788		
	Total	127.140	53			

a .Dependent Variable :SOCst

b .Predictors) :Constant(, Db, Temp, Moisture

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std .Error	Beta		
1	(Constant)	-0.555	3.308		-0.168	0.867
	Temp	0.099	0.111	0.119	0.889	0.378
	Moisture	0.058	0.023	0.390	2.490	0.016
	Db	-0.854	0.827	-0.147	-1.033	0.307

a .Dependent Variable :SOCst

Soil temperature and bulk density were then removed from the model. This stud considered the soil moisture as the only useful predictor for predicting SOC stocks in this urban park (p-value < .001) (Table 4.6).

Table 4.6 Results of a linear regression model of soil moisture influencing SOC stocks

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std .Error	Beta		
1	(Constant)	0.874	0.305		2.863	0.006
	Moisture	0.078	0.018	0.523	4.422	0.000

a .Dependent Variable :SOCst

Since there was a strong significant positive correlation between SOC stocks and moisture, an equation to predict SOC stocks in the Centenary Park can be framed as follows:

$$\text{SOC stocks (kg C m}^{-2}\text{)} = 0.875 + 0.078 \text{ (soil moisture)}$$

Where predicted SOC stocks amount in kg C m^{-2} unit and soil moisture presents in % unit. For a situation where soil moisture is 20%, the predicted SOC stocks would be 2.435 kg C m^{-2}. It should be noted that the equation was built based on the data available in this study. The application of formula would be appropriate for the area where the environmental conditions are similar.

Of the three factors, soil moisture was a predominant indicator for measuring SOC stocks and was closely involved with seasonality and the gardening management. It was observed in our database that high moist was clustered around the shrub soils. As a result of the moist to water-saturated conditions and the dense of vegetation cover, a high amount of organic matter was potentially accumulated under this condition. In the dry season when precipitation is low, irrigation plan should be a key to enhance SOC storage. A significant correlation between SOC stocks and soil moisture was also found in Dörfer et al. (2013) with a high correlation of R^2=0.74 and a weak correlation (R^2=0.05) for different sites on the northeastern Tibetan Plateau. In the same province, Qinghai Province, the Tibet Plateau (Alhassan et al., 2018), confirmed that SOC content significantly correlated positively with soil water content, aboveground biomass, and belowground biomass; however, it was significantly correlated with soil temperature and bulk density in a negative direction with p-value < 0.05. Many studies proved the influence of moisture SOC accumulation and vice versa. Parajuli and Duffy (2013) claimed that SOC amount was not influenced by soil moisture but soil moisture could be influence by SOC. The feedback causation is reasonable because the amount of SOC is dependent on management pressures and the source of input (organic matter). Organic inputs contribute to soil fertility by helping to retain soil moisture.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Soils in the CU Centenary Park contained a SOC stocks of 1.96±1.55 kg C m^{-2} across the area. There was a meniscal decrease of SOC stocks from 2.00±1.73 kg m^{-2} in the wet season (September) to 1.92±1.37 kg C m^{-2} in the dry season (December). From the comparison test of SOC stocks, there was no statistical difference between the SOC of the wet and dry seasons. SOC stocks differed under different vegetation coverage. The average SOC storage under shrub was statistically significantly higher than the grass and tree. Soil moisture performed a significant positive relationship with SOC stocks, it thus acted as a predictor of SOC stocks in this park. The overview results highlighted the potential contribution of urban park to store carbon budget. This study pointed to the management pressure involving the vegetation planning and the irrigation system. With a good management the park can offset some of the associated carbon losses by retaining stable organic carbon in the soils. Shrubs seemed to be a good choice as response to the carbon offset purpose. Keeping moisture high to a limit of saturated level was another factor to be considered. One cycle of season was conducted, therefore, the results may change by having more factors to explain these interactions as time scale increases.

References

Alhassan, A., Ma, W., Li, G., Jiang, Z., Wu, J., & Chen, G., (2018). Response of soil organic carbon to vegetation degradation along a moisture gradient in a wet meadow on the Qinghai–Tibet Plateau. *Ecology and Evolution*, Volume 8, Issue 23.

Bae, J., & Ryu, Y., (2015). Land Use and Land Cover Changes Explain Spatial and Temporal Variations of the Soil Organic Carbon Stocks in a Constructed Urban Park. *Landscape and Urban Planning*, 57-67.

Canedoli, C., Ferre, C., Khair, D., Padoa-Schioppa, E., & Comolli, R., (2019). Soil organic carbon stock in different urban land uses: high stock evidence in urban parks. *Springer Science+Business Media.*

Dörfer, C., Kühn, P., Baumann, F., He, J., & Scholten, T., (2013). Soil Organic-Carbon Pools and Stocks in Permafrost Affected Soils on the Tibetan Plateau. *journal.pone.*

Dłuzewski, P., Wiatrowska, K., & Kozłowski, M., (2019). Seasonal changes in organic carbon content in post-arable forest soils. *Soil Science Annual,* 60-649.

Edmondson, J., Davies, Z., McCormack, S., Gaston, K., & Leake, J., (2014a). Land-cover effects on soil organic carbon stocks in a European city. *Science of The Total Environment,* 444-453.

Edmondson, J., O'Sullivan, O., Inger, R., Potter, J., McHugh, N., Gaston, K., & Leake, J., (2014b). Urban Tree Effects on Soil Organic Carbon.

Edmondson, J., Stott, I., Potter, J., Lope-Capel, E., Manning, D., Gaston, K., & Leake, J., (2015). Black Carbon Contribution to Organic Carbon Stocks in Urban Soil. *Environ. Sci. Technol*, 8339–8346.

Ghosh, S., Scharenbroch, B. C., Ow, L. F., (2016). Soil organic carbon distribution in roadside soils of Singapore. *Chemosphere*, 163–172.

Gundimeda, H., (2003). Carbon Budget of the Indian Forest Ecosystem. *Climatic Change.*

Jana, B., Biswas, S., Sonkar, S., Majumder, M., Roy, P., & Mazumdar, A., (2009). Soil Carbon and Soil Respiration Rate of Urban Forests in Lower Gangetic Plain. *International Journal of Applied Agricultural Research,* 103–113.

Lal, R., (2004). Soil Carbon Sequestration Impacts. *Global Climate Change and Food Security.*

Leinweber, P., Schulten, H-R., & Körschens, M. (1994). Seasonal variations of soil Organic matter in a long-term agricultural experiment. *Plant and Soil*, 225–235.

Naka, T., (2018). Carbon storage and soil respiration of newly created urban soil in CU Centenary Park. *Senior Project. Department of Environment Science, Faculty of Science, Chulalongkorn University*.

Pachauri, R., & Meyer, L. (2014). Climate Change 2014 Synthesis Report. *Ipcc Intergovernmental Panel on Climate Change.*

Parajuli, P., & Duffy, S., (2013). Evaluation of Soil Organic Carbon and Soil Moisture Content from Agricultural Fields in Mississippi. *Open Journal of Soil Science,* 81-90.

Sohel, S., Rana, P., Alam, M., & Alamgir, M., (2009). The Carbon Sequestration Potential of Forestry Sector. *Bangladesh Context.*

Schwandt, T., (2008). Evaluation foundations revisited. *Cultivating a Life of the Mind For Practice.*

Sun, Y., Xie, S., & Zhao, S., (2018). Valuing urban green spaces in mitigating climate change: A citywide estimate of aboveground carbon stored in urban green spaces of China's Capital. *Glob Change Biol,* 1717–1732.

Wuest, S., (2014). Seasonal variation in soil organic carbon. *Soil Science Society of America Journal*.

Yan, Y., Kuang, W., Zhang, C., & Chen, C., (2015). Impacts of impervious surface expansion on Soil organic carbon–a spatially explicit study. *Sci Rep*, 5:17905.

BIOGRAPHY

Name: Miss Chanapa Julsiriwattanawong

Date of birth: July 23, 1996

Current address: 151/12 Chaopraya Village 2, Soi Takhian Tia 14,
Takian Tia Subdistrict Bang Lamung District, Chonburi
Thailand 20150

Email: chanapa_patcp@hotmail.com

Phone number: +66 86787 4564

Educational background: 2016-2019, Bachelor’s degree of Environment
Science, Chulalongkorn University, Bangkok Thailand

2010-2014, Secondary School Diploma in
Mathematics and Science major,
Saint Paul Convent school, Chonburi, Thailand