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Student Name Miss Thanaporn Naka Student ID 583 33176 23

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Carbon storage and soil respiration of newly created urban soil in CU Centenary Park

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บทคัดย่อ

ดินเป็นแหล่งกักเก็บคาร์บอนอินทรีย์ (SOC) ที่ใหญ่ที่สุดในระบบนิเวศบก ขณะที่กระบวนการสูญเสียคาร์บอนอินทรีย์ในดินส่วนใหญ่เกิดจากกระบวนการการหายใจของดิน(Rs) ซึ่งปริมาณการกักเก็บและปลดปล่อยคาร์บอนในดินนั้น เชื่อมโยงกับประสิทธิภาพการดูดซับคาร์บอนไดออกไซด์ในอากาศ การกักเก็บคาร์บอนในดินจึงควรมีมากกว่าหรือใกล้เคียวกับอัตราการหายใจของดิน งานวิจัยส่วนมากไม่ได้มุ่งเน้นถึงการศึกษาศักยภาพของการกักเก็บคาร์บอนอินทรีย์และการปลดปล่อยคาร์บอนในพื้นที่สวนสาธารณะในเมือง การศึกษานี้จึงได้ทำการเก็บตัวอย่างดิน 29 จุดที่ระดับความลึก 15 เซนติเมตรเพื่อนำมาวิเคราะห์สมบัติทางกายภาพและเคมีเพื่ออธิบายศักยภาพในการกักเก็บและปลดปล่อยคาร์บอนอินทรีย์ในดินบริเวณอุทยาน 100 ปี จุฬาฯ ผลจากการศึกษาพบว่า คาร์บอนอินทรีย์ในดินมีค่าเฉลี่ย 2.29±1.73 kg C m^{-2} และอัตราการหายใจของดินมีค่าเฉลี่ย 3.44±2.05 kg C $m^{-2}y^{-1}$ ซึ่งค่าเฉลี่ยดังกล่าวมีความแตกต่างอย่างมีนัยสำคัญตามลักษณะพื้นที่ คือ สนามหญ้า, พุ่มไม้/วัชพืช และพื้นที่ที่ล้อมรอบด้วยต้นไม้ใหญ่ เมื่อวิเคราะห์ความสัมพันธ์ของข้อมูลด้วยเทคนิค Principal Component Analysis (PCA) สามารถอธิบายได้ด้วย 2 องค์ประกอบ คิดเป็น 67.7% ของความแปรปรวนทั้งหมด โดยองค์ประกอบแรก (48.7%) ประกอบด้วย ปริมาณอินทรียวัตถุ, คาร์บอนอินทรีย์ในดิน,ปริมาณอนุภาคดินเหนียว และ อุณหภูมิดิน ในขณะที่องค์ประกอบที่สอง (19%) ประกอบด้วย ความหนาแน่นดิน, อัตราการหายใจของดิน และความชื้นในดิน โดยภาพรวมอุทยาน 100 ปี จุฬาฯ มีอัตราการหายใจของดินในระดับที่สูง เมื่อเทียบกับปริมาณการกักเก็บคาร์บอนในดิน และเทียบกับพื้นที่สีเขียวบริเวณอื่น ๆ งานวิจัยนี้เสนอแนะให้เพิ่มการปลูกพืชประเภทไม้พุ่มหรือวัชพืชที่มีประโยชน์ พร้อมทั้งพิจารณาปัจจัยทางสิ่งแวดล้อมอื่นๆ เพื่อเพิ่มการกักเก็บคาร์บอนในดิน และลดอัตราการหายใจของดินในเขตเมือง

คำสำคัญ : คาร์บอนอินทรีย์ การหายใจของดิน สวนสาธารณะในเมือง สิ่งปกคลุมดิน ปัจจัยทางสิ่งแวดล้อม

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Abstract

Soil organic carbon (SOC) is the largest carbon pool in terrestrial ecosystems, whilst the most important process causing carbon loss from soils is soil respiration (Rs). Both SOC and Rs directly link to the atmospheric carbon dioxide absorption. Despite a great deal of research, there currently remains uncertainty whether urban park soils have potential to sequester carbon or release more carbon to the air. Twenty-nine soil samples were collected at a 15-cm depth across the CU Centenary Park. Soil physical and chemical properties were measured to explain SOC stocks and Rs rates. Annually, average SOC stocks and Rs rates were 2.29±1.73 kg C m^{-2} and 3.44±2.05 kg C m^{-2} y^{-1}, respectively. Values of SOC stocks and Rs rates significantly varied across lawn grass, bush/weeds, and soils surrounded by trees. Two principal components, derived by principal component analysis (PCA), occupied 67.7% of the total explained variance. The first principal component was dominated by organic matter, SOC, clay particles, and soil temperature, explaining 48.7% of the total variance. The second component was loaded by soil bulk density, Rs, and soil moisture, accounting for 19.0% of the total variance. Overall, the carbon exchange process highlighted a major mechanism of carbon emissions from the soil systems. This study recommended growing bushes or weeding plants to increase more SOC storage. Controlling factors described by PCA should also be taken into consideration in order to increase SOC stock and reduce CO_2 in the urban atmosphere.

Keywords: soil organic carbon; soil respiration; urban park; land cover type; environmental factor

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Thanaporn Naka

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CHAPTER 1

INTRODUCTION

Carbon dioxide (CO_2) has been recognized as a cause of global climate change accounting for over 80% of all greenhouse gas emissions. Carbon dioxide has increased from 280 ppm at the beginning of the industrial revolution and reached a level of 400 ppm in 2013. Since then, the annual average CO_2 stayed above 400 ppm and exceeded 410 ppm in April 2018 which hit the first time recorded human history (Monroe, 2018). Soil is the largest terrestrial surface carbon pool (Schlesinger et al., 2000), and it releases a huge amount of carbon. Soil organic carbon (SOC) stocks are a key component in carbon capture and storage to reduce increasing atmospheric carbon dioxide (CO_2) concentration (Shrestha et al., 2004).

There are two ways to reduce CO_2 in the atmosphere. First, is carbon source control; and second is carbon sequestration in green space. The carbon sequestration in green space become more attractive in terms of sustainability environment management because this carbon mitigation medthod does not require energy supply and industrial processes. Moreover, green space served as area for relaxation and recreation not just for carbon sequestration (Lee and Sun, 2018).

Carbon balance is associated with SOC and soil respiration rate (Rs). CO_2 in the atmosphere can be fixed into soil profiles by plants and microorganism and turn CO_2 into carbon compounds through photosynthesis (Yiqi and Zhou, 2006). The amount of SOC depends on soil texture, climate, vegetation and land use pattern (Kr et al., 2009), while Rs is influenced by soil temperature, microbial dynamics, plant phenology, photosynthesis, soil moisture and soil porosity (Epron et al., 1999). Soil respiration is a key ecosystem process that releases carbon from the soil in the form of CO_2.. However, most of soil studies overlook in quantifying both SOC and Rs, as well as lacking linkage between these factors.

Among carbon cycle researches, this study is motivated to lead to breakthrough in better understanding about SOC and Rs of a green space inside the inner city, On the occasion of the 100th anniversary of the establishment of Chulalongkorn University, the Office of the Property Management, Chulalongkorn University has introduced a new approach in land development by allocate land in the university's commercial zone to create a new green landscape in a middle of Bangkok city, called 'CU Centenary Park'. In a newly urban soil ecosystem, it is a great opportunity to learn how the CU Centenary Park can store SOC and to what extent it releases CO_2 through the Rs process in an early stage. Different types of soil have different physicochemical properties and microbial activity, which effect on Rs, and small changes in the magnitude of soil respiration could lead to large consequences on the atmospheric CO_2 concentration (Schlesinger et al., 2000). In a long run, quantifying the Rs and SOC may help decision-makers to come up with efficient management plans by choosing plants for specific soil types or selecting the best way to manage soil treatment. Incorporating data from this study with other environmental aspects across the park can be valuable for educating and promoting environmental value to the public in particular CU community.

Objectives

1. measuring SOC stocks and Rs rate across the CU Centenary Park.
2. assessing relationships between SOC, Rs and environmental covariates.
3. mapping patterns of SOC and Rs within the CU Centenary Park.

Outcomes of research

1. Obtain the quantitative information of current SOC and Rs across CU Centenary Park.
2. Obtain the spatial distribution of SOC and Rs across CU Centenary Park.
3. The results have supported better understanding of the relationships between SOC, Rs and environmental covariates.

CHAPTER 2

LITERATURE REVIEW

2.1 Carbon cycle

Carbon cycle is the processes that explain the locomotion of organic and inorganic carbon across four main reservoirs in environment; biosphere, atmosphere, oceans and fossil carbon from four reservoirs, the terrestrial biosphere plays the most significant role in global carbon cycle. Carbon dioxide (CO_2) enters the terrestrial biosphere through photosynthetic (gross primary production (GPP)). This assimilation encourages the respiration (R) of living organism and some abiotic oxidation. The gross primary production (GPP) that excess called net ecosystem production (NEP), which has two fates first, storage in form of dead biomass or abiotic storage and second, emission. Abiotic storage pathway of CO_2 can be explained by the weathering of carbonate and aluminosilicate minerals into bicarbonate.

Growing season of forest in terrestrial ecosystems has a large efficacy to store atmospheric CO_2 of more than 100 g C m^{-2} y^{-1} for actively growing forested. Therefore, carbon sequestration in plantations plays an important role in decreasing the accumulating of atmospheric CO_2, in which depends on natural and management planning

Carbon sequestration especially capable in the long term. However, it should be considered as one the options that can stabilizing CO_2 concentrations because it's not the optimal solution stabilizing CO_2 concentrations.

2.2 Carbon Sequestration

Carbon sequestration is the process that transpose of carbon dioxide (CO_2) that arising from nature processes or man-made such as combustion of fossil fuels and industrial processes from the atmosphere to store in soil or ocean by microorganism and plants via photosynthesis to produce complex compound in microorganism and biomass in plants such as leaves, roots, and stems. Normally, we report carbon sequestration as a mass of carbon that storage per times. Carbon sequestration potential depends on land use management, parent material, land cover types and climate (McCarl et al., 2007), more than 50% of C in soil appear between 0.3 and 1 m depth. Preservation time of stored C can divide into short-term (ready released back to the atmosphere) and long-term (hardly released back to the atmosphere).

Soil carbon pool can divide into two part first, soil inorganic carbon (SIC) pool and second, soil organic carbon (SOC) pool. The dominant of SIC forms in soil are carbonate minerals, that include carbonate ions (Co_3^{2-}) joined with positively charged matal ions such as Calcite ($CaCO_3$) and Dolomite ($MgCO_3$ or $CaCO_3$) and SIC pool comprises of 950 Pg C in the top 1 m. soil organic carbon (SOC) pool comprises of 1325

Pg C in the upper 1 m and 3000 Pg C for deeper soil layers. Differentiation of SOC pool depend on chemical, physical and biological properties with biotic and abiotic factors (Lal et al., 2015).

2.3 Soil respiration

Soil respiration is processes that CO_2 released back into the atmosphere. Soil respiration includes respiration of roots and soil micro and macro-organisms.

There are two types of chamber that use to estimate soil respiration. First, Dynamic closed chambers and second, Static closed chambers. Dynamic closed chambers that can calculate soil respiration rate by concentration difference, flow rate, volume and area by chamber which, gas samples were continually collected through the chamber. Static, closed chambers that can calculate soil respiration by measure gas samples and comparing gas concentration with time. Which, gas samples were not continually collected through the chamber. Using two types of gas chamber have disadvantage which should be considered. Dynamic closed chamber may overestimate fluxes (30–50%) because the disruption laminar boundary layer over the soil by air motion inside the chambers. Static, closed chambers may underestimate fluxes because the concentration gradient between atmosphere and soil.

Soil respiration changes under the influence of soil temperature, soil moisture, vegatation, net ecosystem production (NEP), population and communities of microorganism and landuse. Old evidence believes that soil respiration depends on temperature sensitivities. However, there is the new evidence explain that soil respiration is more sensitive on carbohydrate than temperature (Luo et al., 2006).

2.4 Soil organic carbon and soil respiration in different terrestrial ecosystems

Kr et al. (2009) compared SOC and Rs in two different area of urban forests in the lower Gangetic plain India. The first area is Banobitan, soil carbon, soil organic carbon and soil respiration rate was 24.2-36.5 g kg^{-1}, 2.8-8.3 g kg^{-1} and 2.07 t C h^{-1} yr^{-1}respectively where soil in this area was slightly alkaline; moisture content ranged between 7.26-9.74% and soil texture was sandy loam. The second area is Indian Botanic Garden, soil carbon, soil organic carbon and soil respiration rate was 58-80.1 g kg^{-1}, 8.3-12.6 g $kg^{-1}$and 3.34 t C h^{-1} yr^{-1} respectively, where soil in this area was slightly acidic; moisture content ranged between 16.2-21.7% and soil texture was clayey loam (Kr et al., 2009)

In a recent study, SOC stocks (up to 30 cm depth) and Rs from 32 plots on primary and secondary rainforests were measured in the southern part of Yucatan Peninsula, Mexico. PP systems EGM-4 were used for estimate Rs. The data were used Analysis of variance (ANOVA), correlation and regression to test the differences between forest age groups (independent variable) with SOC stocks and Rs (dependent variable). The results showed that SOC did not increase with forest age in A-Horizon and Rs correlated with carbonate concentration in soil more than SOC. This can be explained by the slow mixing of organic matter in an A-Horizon but have the fast degeneration. To understand the Rs better in the future, it needs to divide Rs into abiotic, heterotrophic and autotrophic fluxes (Aryal et al., 2017).

Soil carbon stocks in the topsoil (0–5 cm) of the clear area and undisturbed forest at Barro Colorad Island, Central Panama were not difference in the statistical test and the highest carbon stock in top soil (29 Mg C ha^{-1}) was appeared in parkland. Soil respiration rates in forest, clear area and parkland (5–6 µmol CO_2 m^{-2} s^{-1}) were significantly lower than in pasturage (8 µmol CO_2 m^{-2} s^{-1}). This can be explained by high production of biomass at belowground that, bring high root respiration rates. Moreover, the result presented that Rs is predicted by active pool carbon which, easily decompose by microorganism in soil and in pasturage and clear area had a higher ratio of active pool carbon than parkland and forest. Changing of land use and soil organic carbon are sensible impact of active soil organic carbon (Schwendenmann, 2007).

Among four different land cover types (wetland, forest, lawn, and bare soils) in a constructed Seoul Forest Urban Park, the results showed that at depth of 1 m wetland had the highest SOC stocks (13.99 ± 1.05 kg m^{-2}) and the lowest SOC stocks was appeared in bare soils (1.58 ± 0.12 kg m^{-2}). For temporal variations, the concentrations of SOC in topsoil were three times higher in 2013 than in 2003 (256 ± 130%). This can be explained by normalized difference vegetation index (NDVI) from MODIS and Landsat satellite. NDVI showed the expansion of green areas over the 10 year which, can help to increase SOC in soil by addition organic matter. These findings could support that urban park soils can perform as a carbon sink and it's actually important for choosing land cover-types in an urban park (Bae et al., 2015).

Soil organic carbon and soil respiration rate (Rs) were explored in tropical forest in northern Thailand, from 1998 to 2000. The annual Rs was 2560 g C $m^{-2}year^{-1}$ and Rs in rainy reason was higher than in dry season. As a result, soil moisture is the most important factor of changing in soil respiration, not soil temperature. Carbon dioxide concentration in soil was decreased in dry season and increased in rainy season (Hashimoto et al., 2004).

CHAPTER 3

METHODOLOGY

3.1 Study site

The study was conducted in CU Centenary Park, the center urban park in Bangkok, Thailand. The CU Centenary Park is located at latitude 13°44’N and longitude 100°31’E, which surrounding with high dense of residential community and shopping mall. This park was created to serve as green space and for water management in the future.

Figure 3.1 Chulalongkorn University Centenary Park (CU Centenary Park)

3.2 Sampling design

We stratified twenty-nine plots in this park. Geographic coordinates of the CU Centenary Park were recorded by GPS in a WGS84 system.

Figure 3.2 Soil sampling locations within the study site

Figure 3.3 Soil sampling locations within the study site among different land cover types

3.3 Sampling Collection Procedure

Twenty-nine soil samples were collected by disturbed soil sampling method and ten soil samples were collected by undisturbed soil sampling method using soil cylinder (diameter, 5 cm diameter; high, 5 cm height) in September 2018 to estimate bulk density of soil. While, pH and temperature were analysed on site by pH meter and thermometer respectively. Observations were operated during the daytime, from 9.00 AM to 16.00 PM. All soil samples were brought into zipped bags for the laboratory analysis. Soil samples were dried by air-drying for 7 day, then, pounded with mortar and sieved through a 2 mm and 0.5 mm size.

3.4 Laboratory analysis

3.4.1 Analysis of soil texture

Soil texture was analyzed to determine particle size by hydrometer method by weighing 50 g soil samples size 2 mm and soaked with sodium hexametaphosphate for 24 hours. The prepared samples were spined for 5 minutes in blender machine and mixed the soil solution into hydrometer jar and adjusted the volume to 1000 ml. After that, we used stirring rod to mixing soil solution for 1 minute. Next we measured temperature and the volume from hydrometer at 40 second and 2 hours to bring to the equation for calculate particle size.

3.4.2 Analysis of organic matter and organic carbon

Organic matter and organic carbon in soil from CU Centenary Park were determined by using Walkley and Black method. We weighed 0.5 g of the soil samples size 0.5 mm and put into an Erlenmeyer flask. Next, added 10 mL of 1 N potassium dichromate solution and 20 mL concentrated of sulphuric acid. Then, shaked the soil solution for 1 minute and left them to cool down for 30 minutes. After that, diluted the soil solution with 200 mL of deionized water and fitter papers number 1 of whatman used to filter soil solution into Erlenmeyer flask. The most important process was to add 0.2 g of sodium fluoride, 10 mL of phosphoric acid and 5 drops of diphenylamine indicator. Soil solutions was titrated with 0.5 N ferrous ammonium sulphate and at the end-point the color of solution became red-brown (Van, 2002).

After organic carbon concentration was determined in a % unit, SOC stocks were then calculated as follows:

$$\text{SOC stocks} = \%\text{OC} \times \text{BD}_{\text{sample}} \times \text{depth} \times 10 \quad (3.1)$$

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

3.4.3 Analysis of soil respiration

Soil respiration rate (g CO_2 m^{-2} hr^{-1}) was measured by TARGAS-1 pp system with soil respiration chamber, which is a closed dynamic chamber method. This method measured the concentration of CO_2 inside the chamber,which increase over the period of time. Soil respiration from CU Centenary Park were determined at the same location of soil samples in the study site in January 2019, which made up a total of 29 samples. The Rs was calculated to a unit of kg C m^{-2} y^{-1}.

3.5 Statistical and Geostatistical Analyses

Soil organic carbon, soil respiration, and related parameters were explained by mean, median, standard deviation and variance. Soil bulk density and soil moisture (n=10) were estimated across the area using the inverse distance weighting (IDW) method and extracted values based on all soil sampling points. Spatial patterns of SOC and Rs were conducted by IDW technique. Analysis of variance (ANOVA) was employed to test the differences of SOC stocks and Rs means in different land cover types. The principal component analysis (PCA) was applied to emphasize variation and bring out groups of variables with strong relationships in a dataset.

The descriptive statistical analysis, ANOVA, and PCA were run in SPSS software. The IDW was modeled in ArcMap 10.5 software. Visual graphics were created using R packages.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General physical and chemical soil properties

The major of soil type represented sandy texture (sand: 59.72 -98.2%, silt: 1.08-27.16% and clay: 0.28-35.84%). Soil in the area varied from neutral to strongly alkaline (pH: 6.70 – 8.70); soil moisture content ranged between 3.91-24.67%, soil temperature ranged between 26.19-33.85°C and bulk density varied between 1.24-1.73 g cm^{-3}. SOC and Rs ranged from 2.29±1.73 (kg C m^{-2}) and 3.44± 2.05 (kg C $m^{-2}y^{-1}$), respectively.

4.2 Variation of SOC stocks and Rs rates

SOC stock was estimated based on the soil organic carbon content, bulk density of the soil and depth of soil collection *(*Aryal et al., 2017*)*. In the CU Centenary Park, the average±SD SOC content in the top 0-15 cm was 1.01± 0.78%. accounted for 2.29±1.73 kg C m^{-2} (Table 4.1). SOC stocks stored in the CU Centenary Park was close to that observed in Cambou et al. (2018) in sealed soil, NYC at depth 0-30 cm. (Table 4.2)

The average measured Rs rate in all land cover types was 1.44± 0.86 g CO_2 m^{-2} hr^{-1}, accounted for 3.44± 2.05 kg C m^{-2} y^{-1}.

The rates of Rs observed in the CU Centenary Park was higher than those found in Seoul Forest Park (Bae and Ryu, 2017), urban park in Kolkata and Western Bangal, India (Jana et al., 2009), and New York City urban soils (Cambou et al., 2018).

The Office of the property management, Chulalongkorn University has operated approximately 2 years to present. The newly constructed soil was expected to contain low organic carbon content. Turnover time need for full decomposition and the derived residence time of the SOC in the soil can take months to a few years for active carbon pool and up to thousand years for passive carbon pool (Gougoulias et al., 2014) Our study was limited to detect SOC stock change over time; it was assumed that SOC accumulation showed no significant change annually.

Our study pointed out that newly created urban soil in the CU Centenary Park released carbon in form of Rs more than SOC sequestration. When the balance of carbon in soil depend on carbon input and carbon releasing during decomposition (Jandl et al., 2007), the initial low SOC storage and high Rs after urban development contributed to the carbon offset potential of the park. Newly added carbon input can be stabilized in the soil by a number of mechanisms. Through proper management regimes, the CU Centenary Park can reach a maximum capacity for green quality area to serve its surrounding community.

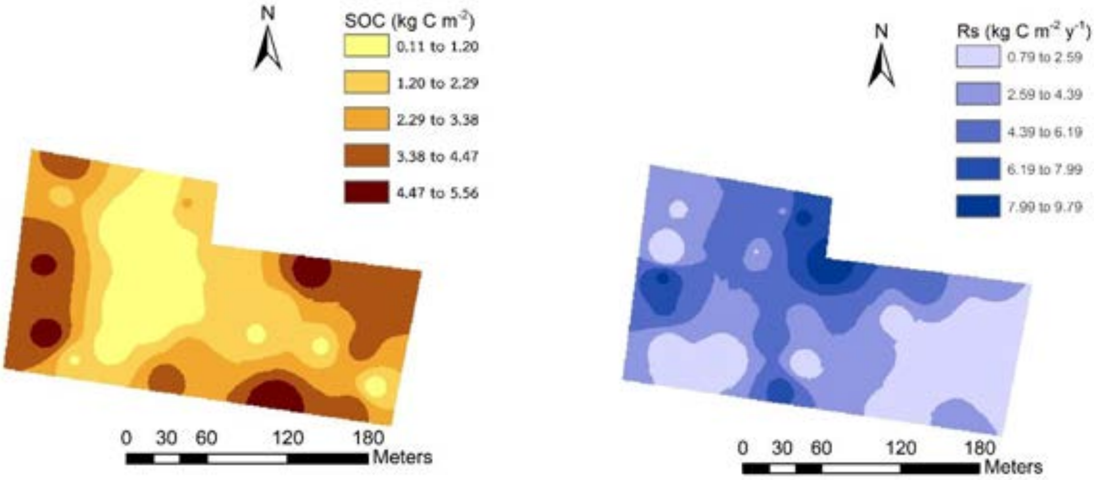


Figure 4.1 The spatial distributions of soil organic carbon stock and soil respiration rates in the CU Centenary Park.

Table 4.1 Descriptive statistics of soil properties

Number of samples (n)	Parameters	Maximum	Minimum	Mean	Median	Range	Variance	Std. Deviation
29	pH	8.70	6.70	-	-	2.00	-	-
29	SOC (%)	2.50	0.04	1.01	0.73	2.46	0.60	0.78
29	Rs (gCO_2 m^{-2} hr^{-1})	4.10	0.33	1.44	1.17	3.77	0.73	0.86
29	SOC stocks (kg C m^{-2})	5.57	0.11	2.23	1.74	5.46	2.53	1.59
29	Rs (kg C $m^{-2}y^{-1}$)	9.80	0.79	3.44	2.80	4.20	4.19	2.05
25	Soil temp (°C)	33.85	26.19	29.60	29.35	7.66	2.87	1.69
29	Air temp (°C)	46.58	33.29	38.34	38.06	13.29	7.952	2.820
10	Soil Moisture (%)	24.67	3.91	13.18	13.08	20.76	28.822	5.369
10	Soil bulk density (g cm^{-3})	1.73	1.24	1.52	1.58	0.49	0.027	0.165

Table 4.2 Mean comparison of SOC and Rs with other studies.

Location	Land use types	Descriptive parameter	Soil depth (cm)	SOC (kg C m^{-2})	Rs (kg C m^{-2} y^{-1})	References
CU centenary park, Thailand	All land cover types	Range; mean± SD	0-15	5.80; 2.29±1.73	9.01; 3.44± 2.05	This study
Banobitan, Kolkata, eastern India		mean	0-100	0.8	0.33	Jana et al. (2009)
Botanical Garden, West Bengal, India		mean	0-100	1.46	0.21	Jana et al. (2009)
New York City	Road	mean±SD	0-30	2.9 ±2.6		Cambou et al. (2018)
New York City	Road	mean±SD	30-100	6.7 ±6.1		Cambou et al. (2018)

Paris	Sidewalk	mean±SD	0-30	3.4±1.2		Cambou et al. (2018
Seoul Forest Park, Korea	Mixed Forest	mean±SD			1.45 ± 0.11	Bae & Ryu (2017)
	Deciduous Broadleaf Forest	mean±SD			1.13 ± 0.09	Bae & Ryu (2017)
	Evergreen Needleleaf Forest	mean±SD			1.22 ± 0.08	Bae & Ryu (2017)
	Lawn	mean±SD			1.05 ± 0.09	Bae & Ryu (2017)
	Wetland	mean±SD			1.22 ± 0.09	Bae & Ryu (2017)
	Bare land	mean±SD			0.48 ± 0.1	Bae & Ryu (2017)
	Deciduous Broadleaf Forest	mean±SD	0-100	7.27 ± 0.55		Bae & Ryu (2017)

	Evergreen Needleleaf Forest	mean±SD	0-100	7.27 ± 0.58	Bae & Ryu (2017)
	Lawn	mean±SD	0-100	3.74 ± 0.75	Bae & Ryu (2017)
	Wetland	mean±SD	0-100	13.99 ± 1.05	Bae & Ryu (2017)
	Bare land	mean±SD	0-100	1.58 ± 0.12	Bae & Ryu (2017)

4.3 Comparison of SOC stocks and Rs among different land cover types

Table 4.3 summarizes descriptive information of SOC stocks across three different land cover types in the CU Centenary Park. Land covers were classified into three types: lawn grass, bush/weeds and soil surrounded by trees. The SOC stocks across various types of land covers differed substantially According to ANOVA and Tukey's post hoc tests, Lawn grass performed a significant lower SOC storage than bush/weeds and soil surrounded by trees (p-value < 0.001). While soils surrounded by trees had a significant highest Rs rate as compared to lawn grass and bush/weeds (p-value < 0.05). There was no surprise that lawn grass or turfgrass contained low SOC. Biomass from grass often removed by clippings and that reduced carbon input in lawn grass system for aesthetic scenery. Irrigation and fertilization are two of the major factors that influence high root and shoot biomass productivity, and high carbon input into soils as roots, litters, and exudates (Qian and Follett, 2012). Soils under bush/weeds stored the highest organic carbon with a mean value of 3.56±1.59 kg C m^{-2}, and did not differed significantly from soil surrounded by trees.

This can be explained by the location of bush/weeds areas where they are far away from activity area and less maintenance with less disturbance from human (Bae and Rye, 2017), all these resulted in high organic matter inputs from plant residues, and stabilized in the soil.

Table 4.3 SOC concentrations (kg C m^{-2}) across three different land cover types in CU Centenary Park

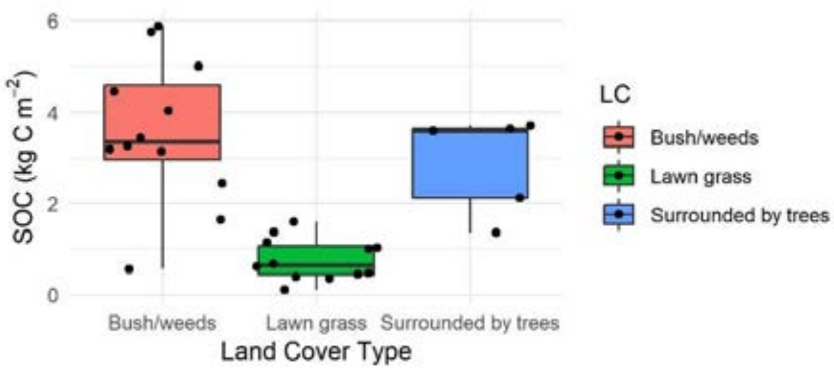
N	Land cover types	Maximun	Minimum	Mean	Median	Range	Std. Deviation
12	Bush/weeds	5.90	0.56	3.56	3.34	5.34	0.46
12	Lawn grass	1.59	0.10	0.76	0.64	1.49	0.13
5	Surrounded by trees	3.70	1.35	2.88	3.59	2.35	0.48

Table 4.4 demonstrates Rs rates across three different land cover types in the CU Centenary Park. The highest annual mean of Rs appeared in soil surrounded by trees (5.83±2.84 kg C m^{-2} y^{-1}). This value was significantly higher than lawn grass area (3.01±0.96 kg C m^{-2} y^{-1}) and soils under bush/weeds (2.87±1.92 kg C m^{-2} y^{-1}). Though surrounded by trees area have the highest Rs rate but small sample may not well represent the population of this type of soil. However, high rates of Rs could be explained by live root respiration of big tress.

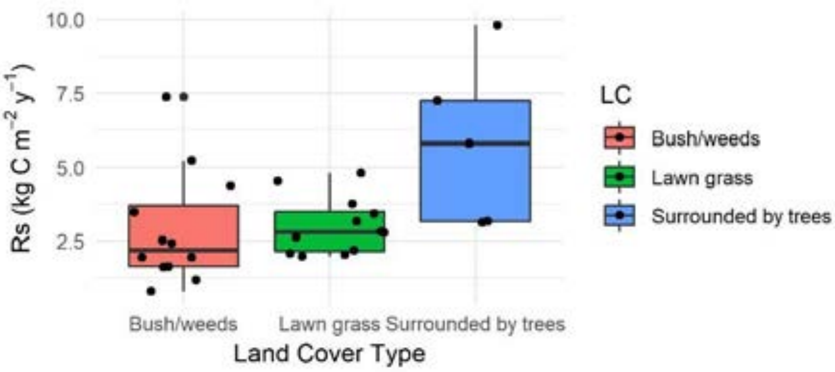
For park management we recommend to growing bushes, shrubs, or useful weeds for SOC enhancement alongside with regular irrigation and low-N fertilizer could help increase amount of SOC.

Table 4.4 Rs (kg C m^{-2} y^{-1}) across three different land cover types in CU Centenary Park

N	Land cover types	Maximun	Minimum	Mean	Median	Range	Std. Deviation
12	Bush/weeds	7.37	0.79	2.87	2.18	6.58	1.92
12	Lawn grass	4.80	1.99	3.01	2.78	2.81	0.96
5	Surrounded by trees	9.80	3.12	5.83	5.80	6.68	2.84



(a)



(b)

Figure 4.2 Boxplots display variations of soil organic carbon stocks (a) and soil respiration rates (b) in the three different land cover types: bush/weeds, lawn grass and soils surrounded by trees.

4.4 Relationships between SOC, Rs and environmental covariates

The relationships between SOC, Rs and environmental covariates i.e., soil temperature, soil bulk density, clay particles, soil moisture and organic matter were investigated, but there were neither clear linear relationships nor mathamatical functions that can express these relationships. The principal component analysis (PCA) was further applied to uncover hidden patterns in the dataset. PCA seeks a linear combination of variables such that the maximum variance is extracted from the variables. The dataset was measured for sampling adequacy using the Kaiser-Meyer-Olkin (KMO) and the strength of interrelationship between variables by Bartlett's test of Sphericity. The KMO value of 0.57 and Bartlett's test with a p-value <0.05 provided a minimum standard to proceed for PCA, informing there may be a statistically significant interrelationship between variables. The Eigen values identified the variance of factors, thus components with Eigen value larger than 1 were selected for this study. The varimax orthogonal rotation and factor loading over 0.45 were applied for meaningful interpretation. A scree plot (Figure 4.3) informed how much variation each principal component captured from the dataset.

Two principal components derived by PCA occupied 67.7% of the total explained variance. The first principal component was dominated by organic matter, SOC, clay particles, and soil temperature, explaining 48.7% of the total variance and the second component was loaded by soil bulk density, Rs, and soil moisture, accounting for 19.0% of the total variance.

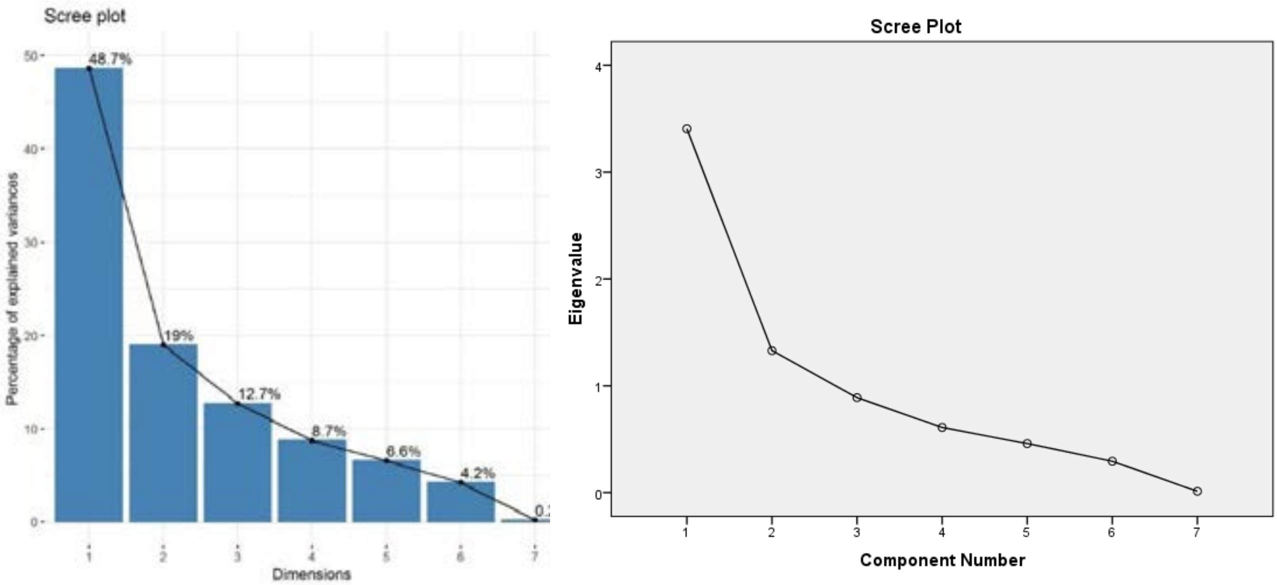


Figure 4.3 The scree plot displaying 67.7% of the information (variance) contained in the dataset are retained by the first two principal components.

4.4.1 First component – SOC related factors

Organic matter, SOC, clay particles were positively correlated, but these factors exposed a negative relationship with soil temperature. The correlations might be explained by the increasing of organic matter inputs to the soils through plant residues. A direct relationship between SOC and the percentage of silt and clay has been reported in many studies (Arrouays et al,2006; Feng et al, 2013; Matus et al.,2016). Besides adsorption of OM onto clay surfaces, OM can be trapped in very small spaces between clay particles that would not allow microorganisms access easily and therefore slowing decomposition process, stabilizing SOC content. In addition, SOC increases with decreasing temperature (Harold et al.,2104; Follet et al., 2012; Jobbagy and Jackson, 2000). Soil temperature significantly affected the soil enzyme activities and hence high temperature in Bangkok may stimulate decomposition rate and reduce SOC stabilization.

4.4.2 Second component – Rs related factors

The second component was loaded by Rs, soil bulk density and soil moisture. A direct negative relationship involved Rs and soil bulk density. These two factors, on the other hand correlated positively with soil moisture. Soil bulk density and soil moisture associated with air-filled pores and water-filled pores that affect Rs. The amount of water and air in soil pores affect exchanges of CO_2 and O_2 that may influence soil microbial activity, motility of microbial propagules, supply of moisture and air to microbial growth and root activities.

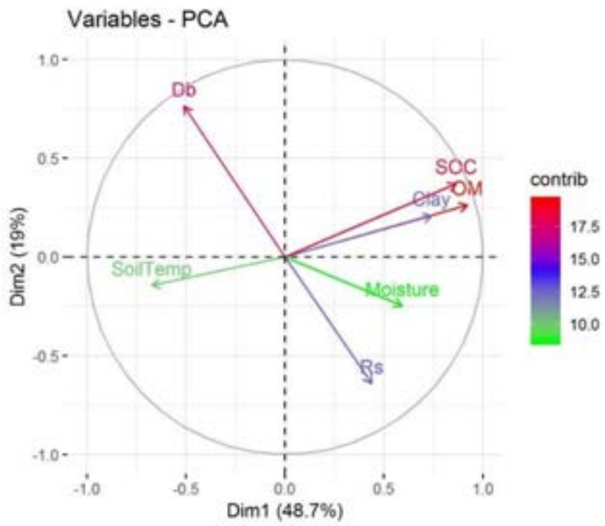


Figure 4.4 Two principal components, derived by principal component analysis (PCA). Dimension 1 presents the first principal component (organic matter, SOC, clay particles, and soil

temperature) explaining 48.7% of total explained variance. Dimension 2 presents the second component (soil bulk density, Rs, and soil moisture) explaining 19.0% of total explained variance.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Our study shed the light on an imbalance in carbon cycle of the newly created urban soil within the CU Centenary Park. The park released carbon (3.44±2.05 kg C^{-2} y^{-1}) through Rs more than the amount of carbon stored in soil (2.29±1.73 kg C m^{-2}). We found that land cover types played a major role in carbon management. Among different land cover types, lawn grass stored significant low SOC, while bare soil surrounded by trees emitted carbon to the atmosphere the most. The relationship between SOC, Rs and environmental covariates was explained by PCA analysis, accounted for 67.7% of total variance. The first component was SOC related factors, included SOC, OM, clay particles, and soil temperature. The second component was Rs related factors, included Rs, soil bulk density, and soil moisture. Based on the results, the feasible options to achieve better carbon balance condition is to growing more bush plants, useful weeds, herbs, or shrubs that can turn into carbon input and need less maintenance. Regular irrigation on lawn grass may influence root and shoot biomass productivity, and high carbon input into soils. Application of low-N fertilizer should be considered to reduce mineralization process. All these strategies can help increase carbon sequestration in soil and reduce CO_2 emission

This study provided an important message for the Office of Property Management that allows the CU Centenary Park to enhance its ecosystem functions and fulfill the main propose of this green area space, “The Oasis of Bangkokians”.

5.2 Recommendations

Limitations of this study is long-term data collection and soil samples for analyzing SOC stocks were collected at different times with Rs because the problem of Rs instrument and negligently plan. To achieve a better understanding about SOC stocks, Rs and environmental covariates is to collecting long-term data of SOC, Rs and environmental covariates at the same period.

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