Soil Carbon Stock and Soil Properties under Different Land Use Types of Agriculture

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ABSTRACT

Agriculture soils play a crucial role in carbon storage and food security. However, uncertainty remains about soil carbon stocks due to spatial variability. This study estimated soil carbon stocks in agricultural land and examined the impact of land use and soil properties on soil organic carbon in Ratchaburi Province, Thailand. Soil samples were collected at three depths (0-10, 10-20, and 20-30 cm) within five different land use types: cassava, coconut, paddy fields, pineapple, and sugarcane. The results revealed that soil organic carbon decreased with increasing depth. Significant differences in soil carbon and soil properties were observed among land uses. The carbon stocks at 0-30 cm depth were as follows: coconut (35.87 mg C/ha), paddy fields (31.17 mg C/ha), sugarcane (28.02 mg C/ha), pineapple (21.79 mg C/ha), and cassava (16.12 mg C/ha). The carbon stocks were significantly correlated with sand, density, clay, silt, and pH. This study highlights the impact of land use types on carbon stocks in agricultural soils and emphasizes the role of soil properties, particularly soil texture, in influencing carbon storage variability. Furthermore, the study highlights the carbon storage potential in agricultural areas, which could guide the formulation of policies to utilize agricultural land to offset CO_2 emissions from other sectors.

1. INTRODUCTION

Soils provide many ecosystem services (Rodrigues et al., 2021). Specifically, they serve as the largest carbon reservoir in terrestrial ecosystems, storing significant amounts of carbon (Lal, 2004; Stockmann et al., 2015; Stockmann et al., 2013). Within the top meter of soil, organic carbon stock is estimated at 1,325-1,408 Pg, which is four times greater than biotic reservoirs and three times greater than atmospheric reservoirs (Batjes, 2016; Lorenz and Lal, 2018; Scharlemann et al., 2014). Given that soil acts as both a source and sink of atmospheric CO_2, particularly in agriculture, soil organic carbon reservoirs have become a critical and challenging subject on a global scale (Amelung et al., 2020; Jobbágy and Jackson, 2000; Todd-Brown et al., 2014).

Recently, the potential of agricultural soil to mitigate climate change and enhance food security has become a critical topic on various political agendas. The 4 per 1,000 initiative was introduced during the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). The core concept of this initiative proposed that an annual increase of 0.4% in soil organic carbon stock in the upper 30 to 40 cm of soil could offset CO_2 emissions resulting from fossil fuel combustion (Minasny et al., 2017). Moreover, an increased soil organic carbon can improve soil quality and contribute to food security (Arunrat et al., 2020a; Pan et al., 2009). For instance, increasing the SOC content by 1 g/kg can lead to a rice yield boost of 302 kg/ha (Arunrat et al., 2020a). Consequently, agricultural soils are increasingly being utilized as a survival door to mitigate and adapt to the effects of climate change and ensure food security (Minasny et al., 2017).

Agriculture accounts for almost half of Thailand's area. Ratchaburi Province is a prominent cultivation hub within the country, covering half the area of the province, or around 263,366 ha (Land Development Department, 2022a). Agricultural lands in the province consist of various land uses such as

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coconut, pineapple, paddy fields, cassava, and sugarcane (Land Development Department, 2022a). Agricultural soils can act as either carbon sources or sinks (Freibauer et al., 2004) due to the significant impact of agricultural practices on soil carbon storage, including tillage, fertilizer use, and land-use changes (Dignac et al., 2017). As a substantial portion of this province is dedicated to agriculture, any alterations in the soil carbon could result in significant environmental consequences, particularly concerning greenhouse gas emissions. However, predicting their effects may be challenging without disclosing the amount of carbon stored in the soil and the factors that influence it.

Soil carbon storage in agriculture is varied depending on many environmental factors, particularly in different land use types (Tan et al., 2004). Previous studies demonstrated variations in soil carbon stocks across various agricultural sites in the country. For instance, paddy fields in Chiang Mai Province exhibited SOC stocks ranging from 21.61 to 21.84 mg C/ha (Arunrat et al., 2022), while the range was 14.9 to 21.3 mg C/ha in Kalasin Province (Bridhikitti, 2017). A corn field in Nakhon Ratchasima Province had a soil carbon storage of 57 mg C/ha (Lichaikul et al., 2006), and diverse agricultural types in Nan Province had a storage of 42.08 mg C/ha (Pibumrung et al., 2008). However, the specific soil carbon storage for land use types in Ratchaburi Province remains poorly understood. Estimation of soil carbon storage is crucial for agricultural soils, particularly in the topsoil layer that significantly influences crop yield (Sun et al., 2010) and is susceptible to land use change (Veldkamp et al., 2003).

Therefore, the objectives of the study were (1) to evaluate and compare soil carbon stocks among different agricultural land use types and (2) to investigate the relationship between SOC and soil properties. This research aimed to provide valuable insights into soil carbon storage in agricultural soils and the influence of land use types on carbon storage. Furthermore, the study offers vital information for policymakers and land managers, enabling them to make informed decisions regarding soil management strategies for climate change mitigation.

2. METHODOLOGY

2.1 Study areas

The study was carried out in Ratchaburi Province, covering an area of over 5,196 km^2, situated between 13°32'21" N and 99°49'11" E. Of the total area, approximately 50.71% is dedicated to agriculture encompassing several land use types. These include paddy field (10.07%), sugarcane (9.45%), cassava (3.42%), coconut (4.81%), and pineapple (4.22%) (Land Development Department, 2022a). The chosen study area represents these agricultural types across ten districts within the province. Figure 1 displays the sampling sites for the five-land uses and provides examples of the study areas.

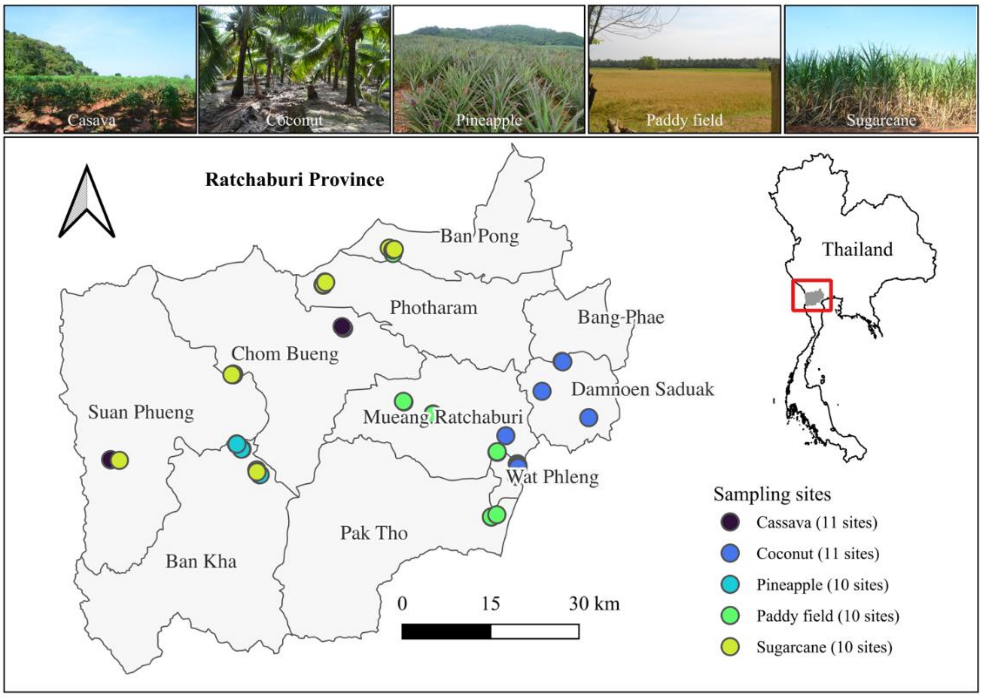

Figure 1. Examples of land use types and locations of sampling sites

In the study sites, 15 different soil series were identified by georeferencing the coordinates of the study sites on the soil series map (Land Development Department, 2022b). These soil series were Tha Yang (Kanhaplic Haplustults), Bangkok (Vertic Endoaquepts), Chan Tuk (Typic Ustipsamments), Alluvial Complex (Fluventic Endoaquepts (Haplustepts)), Thonburi (Vertic Endoaquepts), Lat Ya (Kanhaplic Haplustults), Khao Luang (Typic (Kandic) Paleustults), Khao Phlong (Kanhaplic Haplustults), Damnoen Saduak (Typic Haplaquolls), Chom Bueng (Arenic (Grossarenic) Haplustalfs), Bang Phae (Typic Endoaquolls), Pak Tho (Plinthic Palequults), Tap Salao (Ultic (Typic) Haplustalfs), Bang Khen (Vertic Endoaquepts), and Takhli (Entic Haplustolls). Each land use in this study consisted of multiple soil series as well as land histories and farmer practices (Table 1).

Table 1. Soil series with land history and farmer practices under the agricultural land uses

Land use types	Soil series with land history and farmer practices
Cassava	• Soil series: Tap Salao (18%), Chan Tuk (18%), Chom Bueng (18%), Alluvial Complex (18%), Tha Yang (9%), Khao Luang (9%), Khao Phlong (9%) • Land history: continuous cultivation for over 5 years • Farmer practices: - Heavy tractor soil preparation - plowing, harrowing, and ridge creation - Plant residue practice: removal of residues after harvest - Application of chemical fertilizers
Coconut	• Soil series: Thonburi (36%), Damnoen Saduak (27%), Bang Phae (18%), Bang Khen (9%), Bangkok (9%) • Land history: - Multi-generational coconut cultivation - Age range of coconut trees: 4-10 years • Farmer practices: - Furrow creation between coconut tree rows - Furrow irrigation: Standing water in furrows between tree rows - Plant residue practice: Residue retention in the backyard - Fertilizer use: Utilization of mud from furrows for tree fertilization and weed control
Pineapple	• Soil series: Tha Yang (60%), Chan Tuk (30%), Lat Ya (10%) • Land history: - Cultivated since approximately 2014 or earlier - Located in the foothills and connected to a forested area • Farmer practices: - Heavy tractor soil preparation for planting: o Once every 4 years in Tha Yang and Lat Ya, as pineapples have a lifespan of 4 years o Every year in Chan Tuk, as pineapples have a lifespan of only 1 year - Non-removal of plant residues after harvest - Manual weed control practices involving pulling and digging - Application of chemical fertilizers and plant hormones during the reproductive season
Paddy fields	• Soil series: Bangkok (50%), Pak Tho (20%), Khao Phlong (20%), Alluvial Complex (10%) • Land history: Long-term rice cultivation • Farmer practices: - Rice cultivation twice a year - Long-term presence of standing water during the cultivation period - Two rounds of plowing: one for soil preparation and another before planting - Utilization of chemical fertilizers - Harvesting using a combine harvester - Absence of burning stubble
Sugarcane	• Soil series: Khao Luang (30%), Lat Ya (30%), Alluvial Complex (10%), Tha Yang (10%), Khao Phlong (10%), Takhli (10%) • Land history: Over ten years cultivation • Farmer practices: - Heavy tractor for soil preparation and management - Utilization of chemical fertilizers and sugar factory by-products - Sugarcane burning practiced in some areas before harvesting

Remark: The percentages shown in parentheses for each soil series indicate their proportion, which was calculated by dividing the number of sampling points where the soil series was found by the total number of sampling points within each agricultural area.

2.2 Soil sampling and analysis

Sample collection was taken during June-July 2022. Soil samples were obtained from a total of 52 locations representing five different agricultural land use types: cassava (11 sites), coconut (11 sites), pineapple (10 sites), and paddy field (10 sites) (Figure 1). At each site, three soil pits were arranged in a triangular pattern to reduce soil heterogeneity and create composite samples. Soil samples were collected from three consecutive depths (0-10, 10-20, 20-30 cm) using stainless steel corers. Three replicate samples were combined for composite samples for each depth. A core was hammered at the center of triangular plot to obtain an undisturbed sample used in soil bulk density analysis. Then, soil samples were conveyed to a laboratory for preparation and analysis.

The composited samples were air dried at room temperature and were subsequently sieved through a 2-mm mesh before conducting analyses for organic carbon, soil pH, and soil texture. Soil bulk density was determined by assessing the dry weight per unit volume of the soil core after it had been dried at 105°C in a hot oven for 24 h (Blake and Hartage, 1986). Soil texture was analyzed using the hydrometer method (Bouyoucos, 1962). Soil pH was determined by preparing a 1:1 soil-to-water mixture and utilized a pH meter according to the procedure described by Thomas (1996). The wet oxidation method was employed for the analysis of soil organic carbon (Walkley and Black, 1934).

2.3 Estimation of total carbon stocks.

The total carbon stock was determined by calculating the product of SOC content and soil bulk density up to a specified depth. The equation used to calculate the total carbon stock is provided below (Ellert et al., 2007).

$$C_{stock} = \sum_{1}^{N} D \times C \times T \times 0.1 \qquad (1)$$

The term C_{stock} denotes the total carbon stock (mg C/ha), where D refers to soil bulk density (g/cm³), and C represents SOC content (g C/kg) determined using the wet oxidation method developed by Walkley and Black. T represents the thickness of the soil layers (cm), while N represents the number of soil depths, which includes three consecutive depths (0-10, 10-20, and 20-30 cm).

2.4 Statistical analysis

Normal distribution assumption was tested using the Shapiro-Wilk method. Data analysis was performed using R Studio (RStudio Team, 2020). A two-way ANOVA was conducted to examine the effects of land-use type and soil depth on carbon stock, SOC, and soil properties. To determine significant mean differences of soil parameters among land use types and soil depths, the Tukey HSD test was employed. Pearson's correlation was utilized to investigate the relationship between soil properties.

3. RESULTS AND DISCUSSION

3.1 Soil characteristics

The soil properties under five agricultural land uses were examined. The means and standard error for the soil parameters are presented in Table 2.

Table 2. Physicochemical soil characteristics under five agricultural land use

Soil properties	Land use types				
	Cassava	Coconut	Pineapple	Paddy field	Sugarcane
pH (ranges)					
0-10 cm	5.10-7.00	5.90-7.70	4.40-7.20	4.20-7.60	5.00-7.00
10-20 cm	4.80-6.90	5.90-7.70	4.50-7.30	5.20-7.60	4.90-7.10
20-30 cm	5.30-7.00	6.20-7.80	4.50-7.40	5.00-7.80	4.90-7.30
Density (g/cm³)					
0-10 cm	1.47±0.03[ab]	1.29±0.07[b]	1.45±0.04[ab]	1.34±0.07[ab]	1.42±0.04[ab]
10-20 cm	1.51±0.04[ab]	1.27±0.04[b]	1.57±0.04[a]	1.47±0.07[ab]	1.51±0.07[ab]
20-30 cm	1.51±0.06[ab]	1.26±0.05[b]	1.62±0.05[a]	1.45±0.09[ab]	1.50±0.06[ab]
Sand (%)					
0-10 cm	71.81±2.92[a]	24.09±2.73[c]	61.84±4.32[ab]	48.35±5.32[b]	58.71±2.46[ab]
10-20 cm	71.63±2.71[a]	21.71±2.16[c]	61.03±4.38[a]	43.55±5.57[b]	57.72±2.31[ab]
20-30 cm	70.15±2.89[a]	22.44±2.46[c]	60.43±4.75[a]	40.35±6.07[b]	57.72±2.45[a]

Table 2. Physicochemical soil characteristics under five agricultural land use (cont.)

Soil properties	Land use types				
	Cassava	Coconut	Pineapple	Paddy field	Sugarcane
Silt (%)					
0-10 cm	8.20±1.27[c]	42.95±5.28[a]	12.00±2.13[bc]	23.67±4.58[b]	14.57±2.48[bc]
10-20 cm	8.92±1.46[c]	44.75±4.31[a]	12.62±2.08[c]	28.07±3.87[b]	16.98±2.53[bc]
20-30 cm	9.81±1.76[c]	45.29±4.29[a]	13.42±2.31[c]	31.87±4.21[b]	17.13±2.68[c]
Clay (%)					
0-10 cm	19.99±1.89[b]	32.96±3.29[a]	26.16±2.52[ab]	27.99±2.93[ab]	26.72±1.71[ab]
10-20 cm	19.44±1.57[b]	33.55±3.40[a]	26.35±2.56[ab]	28.39±3.87[ab]	25.30±1.64[ab]
20-30 cm	20.04±1.32[b]	32.28±3.53[a]	26.15±2.67[ab]	27.79±3.65[ab]	25.15±1.99[ab]

Remarks: The soil parameters are presented as Mean±SE, except for soil pH, which is shown as ranges. The different letters indicated significant mean differences within each soil property ($p<0.05$).

3.1.1 Soil reaction (pH)

The soil pH varied across the different agricultural land uses, ranging from 4.20 to 7.80, which encompassed a wide pH range from extremely acidic to slightly alkaline. The pH values were influenced by land use types. For cassava, the pH ranged from very strongly acidic to neutral (4.8-7.0), while coconut exhibited a range from moderately acidic to slightly alkaline (5.90-7.80). Pineapple showed a pH range from extremely acidic to slightly alkaline (4.40-7.40), and paddy fields exhibited a similar range from extremely acidic to slightly alkaline (4.20-7.80). Sugarcane displayed a pH range from very strongly acid to neutral (4.90-7.30). Overall, these findings indicate high variability in soil pH within agricultural soils, influenced by factors such as land use type and soil depth.

3.1.2 Soil bulk density

Soil bulk density exhibited variations among different land use types and depths. In the 0-10 cm depth, 10-20 cm depth, and 20-30 cm depth, the soil bulk density ranged from 1.29 to 1.47 g/cm^3, 1.27 to 1.57 g/cm^3, and 1.26 to 1.62 g/cm^3, respectively (Table 2). Significant differences in soil bulk densities were observed among the land use types ($p<0.05$), while no significant differences were found among the soil depths ($p>0.05$) (Table 2).

At 0-10 cm depth, coconut exhibited the lowest soil density (1.29±0.07 g/cm^3), while cassava had the highest density (1.47±0.03 g/cm^3). Additionally, pineapple and sugarcane also showed high soil density in this depth range (Table 2). At 10-20 cm depth, coconut displayed the lowest bulk density (1.27±0.04 g/cm^3), whereas pineapple showed the highest bulk density (1.57±0.04 g/cm^3). Pineapple exhibited the highest bulk density at 20-30 cm depth (1.62±0.05 g/cm^3), whereas coconut had the lowest bulk density (1.26±0.06 g/cm^3).

Land used for pineapple, sugarcane, and cassava exhibited higher soil bulk density compared to paddy fields and coconut plantations. Wang et al. (2022) suggested that tillage practices involving the use of large tractor equipment contribute to soil compaction. This finding aligned with our observations, as we found that large tractors are commonly employed in the three land uses in this study.

Alternatively, the lower bulk density of coconut and paddy fields may be attributed to their higher organic matter content. A previous study of Islam et al. (2014) had shown a negative correlation between soil bulk density and SOC content, supporting this explanation.

In addition, soil texture could affect soil bulk density (Díaz-Zorita and Grosso, 2000). Our observations indicated that land use areas characterized by high soil density tend to have a higher sand content. Conversely, land uses with low density exhibit lower sand content.

3.1.3 Soil texture and particle distribution

Sand particle in the top layer (0-10 cm) was highest in cassava (71.81±2.92), followed by pineapple (61.84±4.32), sugarcane (58.71±2.46), paddy fields (48.35±5.32), and coconut (24.09±2.73). The trend was similar at deeper depths (10-20 cm and 20-30 cm), with the lowest sand content in coconut and the highest sand content in cassava.

For silt particles, coconut had the highest silt content in the topsoil (42.95±5.28), followed by paddy fields (23.67±4.58), sugarcane (14.57±2.48), pineapple (12.00±2.13), and cassava (8.20±1.27), respectively. Coconut still had the highest silt content at deeper depths, while cassava had the lowest.

For clay particles, coconut had the highest clay content in the topsoil (32.96±3.29), followed by paddy fields (27.99±2.93), sugarcane (26.72±1.71), pineapple (26.16±2.52), and cassava (19.99±1.89). The trend was similar at the deeper depths, with the highest clay content in coconut and the lowest clay content in cassava (Table 2).

Across land uses and soil depths, cassava exhibited the highest sand content, followed by pineapple, sugarcane, paddy fields, and coconut, respectively. Both coconut and paddy fields displayed higher silt content compared to the other land uses, while cassava and pineapple showed lower soil bulk density. Coconut had the highest clay content, whereas cassava had the lowest. Overall, these results suggested that soil particle composition varied among land use types. The soils in coconut and paddy fields contained higher silt and clay content but lower sand content compared to the soils in pineapple, cassava, and sugarcane.

The soil textures studied here were primarily categorized as sandy loam, clay, loamy sand, clay loam, loam, sandy clay loam, silty clay loam, sand, and silt loam. Soil with a higher proportion of coarse particles may limit the accumulation of SOC (Arunrat et al., 2020a). However, soil with a higher proportion of fine particles have a greater capacity to store carbon as silt and clay particles influence the maximum carbon storage level in soils (Matus, 2021).

3.2 Soil organic carbon content

A two-way ANOVA was conducted to analyze the impact of land use type and soil depth on soil organic carbon (SOC) content levels in agricultural soils. The results indicated that land use type and soil depth contributed to statistical differences in the mean of the SOC content ($p<0.05$). The means and standard error of the SOC contents are presented in Figure 2 and Table S1.

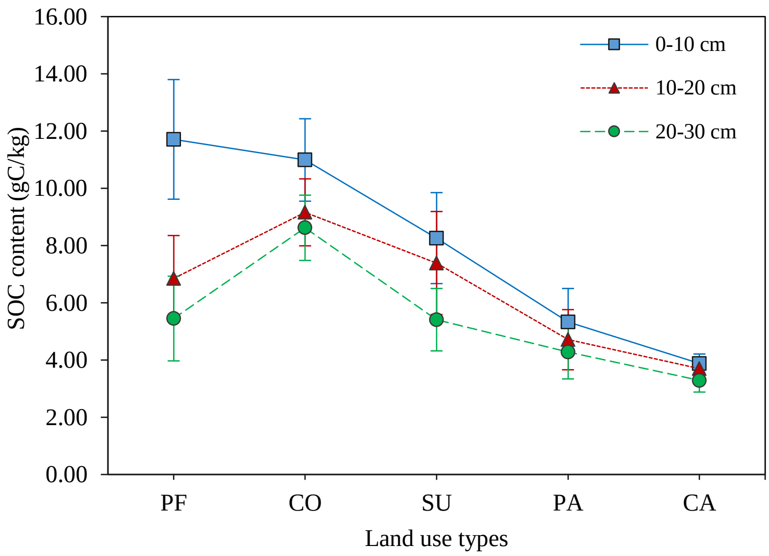

Figure 2. Soil organic carbon content among soil depth and land use types including CA=cassava, CO=coconut, PA=pineapple, PF=paddy fields, and SU=sugarcane

The SOC content was highest at the 0-10 cm depth and lowest at the 20-30 cm depth. Remarkably, the SOC content varied significantly among land use types at each soil depth (Figure 2). The mean SOC ranges were as follows: 3.88±0.33 to 11.71±2.09 g C/kg (0-10 cm), 3.70±0.39 to 9.16±1.17 g C/kg (10-20 cm), and 3.29±0.41 to 8.62±1.14 g C/kg (20-30 cm) (Table S1). Specifically, paddy fields exhibited the highest SOC at the 0-10 cm depth (Figure 2), while cassava had the lowest content. In contrast, coconut plantations displayed the highest SOC levels at both the 10-20 cm and 20-30 cm depths, while cassava plantations consistently demonstrated the lowest SOC content (Figure 2).

The findings supported the objective to investigate the impact of land use type and soil depth on SOC content in agricultural soils. The results clearly demonstrated a significant impact of both land use type and soil depth on SOC levels. In the present study, findings demonstrated a consistent decrease in SOC content with increasing soil depth across agricultural land use types, highlighting the significant impact of soil depth on SOC levels. Previous studies have also reported higher SOC levels in the topsoil of agricultural lands, indicating a greater deposition of organic matter in the topsoil (Pibumrung et al., 2008). This effect was particularly pronounced in paddy soil, where organic matter tended to accumulate more compared to other areas. Our observation revealed that stubbles were commonly left in the paddy fields, resulting in a high amount of organic matter after decomposition. This practice might explain the significant accumulation of organic carbon.

Although the topsoil had higher SOC content, there were no significant differences in mean SOC across the 0-20 cm depth in both cassava and sugarcane (Table S1), indicating similar SOC content throughout the soil profile. Frequent tillage using large tractors with large blades disrupted the soil layers up to 20 cm deep, likely contributing to the absence of carbon variations between the 0-10 cm and 10-20 cm soil layers. Tillage reduced soil structure stability and led to soil erosion, diminishing organic matter retention (Berhe et al., 2018; Nunes et al., 2020). Soil erosion and deep tillage could result in lower SOC levels, especially in cassava soil with prevalent leaching marks in the topsoil.

3.3 Relationship between SOC and soil properties

The correlation pattern between total carbon stock (SOC stocks) and SOC content with soil properties was similar. Significant positive correlations were observed with silt, clay, and soil pH, while negative correlations were found with sand and soil bulk density (Table 3). In addition, the analysis unveiled significant relationships among soil properties, including positive correlations between soil density and sand, negative correlations with silt, clay, and soil pH, a positive association between soil pH and silt (Table 3).

Table 3. Coefficient value of Pearson's correlation

	SOC stock	SOC content	Density	pH	Sand	Silt	Clay
SOC stock	1						
SOC content	0.959**	1					
Density	-0.232**	-0.455**	1				
pH	0.260**	0.314**	-0.296**	1			
Sand	-0.508**	-0.590**	0.520**	-0.470**	1		
Silt	0.382**	0.509**	-0.572**	0.567**	-0.897**	1	
Clay	0.446**	0.402**	-0.134	0.033	-0.620**	0.209**	1

**Correlation is significant at the 0.01 level (2-tailed).

The coefficients indicated significant correlation between SOC and silt, clay, soil pH, sand, and density, supporting the hypothesis that soil properties influence soil organic carbon (Wiesmeier et al., 2019). The positive correlations indicated that soil pH, silt, and clay content could contribute to higher soil organic carbon in agricultural systems. Tu et al. (2018) suggested that soil pH played a dominant role in determining SOC levels. Similarly, Fujisaki et al. (2018) reported that fine particles (silt and clay) were crucial in increasing the maximum saturation of organic carbon.

However, significant negative correlations indicated that both sand and soil bulk density could contribute to lower soil organic carbon in agricultural systems. In particular, sand was found to have a stronger relationship with both SOC and SOC stock compared to other soil parameters, indicating its greater influence on soil carbon in agricultural systems. Arunrat et al. (2020a) suggested that soils with dominant coarse particles or sandy soils had low fertility and poor soil aggregation, leading to a low potential for carbon storage. Other studies also demonstrated a negative relationship between soil density and SOC (Islam et al., 2014). The ability of SOC to accumulate was likely limited by the increase in soil bulk density caused by a reduction in porosity (Arunrat et al., 2020a).

3.4 Total carbon stocks

The results of the ANOVA tests indicated a significant differences in total carbon stocks among the five land use types (Figure 3). Soil carbon stock across three depths also revealed a trend similar to the SOC content (Table S2). Total carbon stock at a depth of 30 cm for all agricultural land use types was 26.54±2.11 mg C/ha, with a range of 16.12 to 35.87 mg C/ha (Figure 3). Among these types, coconut exhibited the highest total carbon stock (35.87±4.25 mg C/ha), followed by paddy fields (31.17±4.93 mg

C/ha), sugarcane (28.02±5.72 mg C/ha), pineapple (21.79±4.77 mg C/ha), and cassava (16.12±1.54 mg C/ha), respectively.

The findings support the hypotheses that land use types might have a significant difference of total carbon stocks. Theoretically, soil carbon storage is determined by many factors, such as clay mineralogy, specific surface area, aggregation, texture, soil type, natural vegetation, land use and management, topography, parent material, and climate (Wiesmeier et al., 2019). In addition to the effect of land use examined in this study, other factors were also considered. The variation in total carbon stock between land use types could be attributed to the distinct soil series with varying soil textures and compositions of soil particles, as well as their management practices.

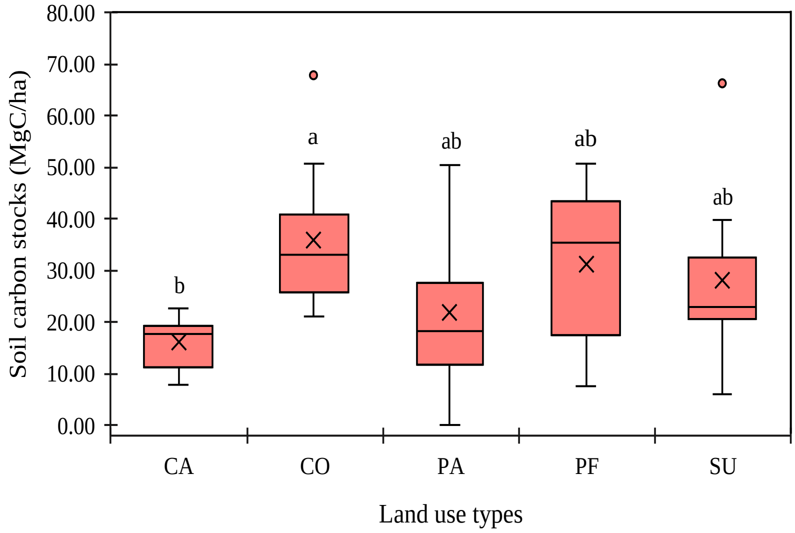

Figure 3. Total carbon stocks at depths of 0-30 cm under five agricultural land-use types: CA=cassava, CO=coconut, PA=pineapple, PF=paddy fields, and SU=sugarcane. The cross inside each box represents the mean value of total carbon stocks. Different letters on the whiskers indicate significant mean differences ($p<0.05$).

The highest total carbon stock in coconut was likely associated with soil series such as Bang Khen, Bang Phae, Bangkok, Damnoen Saduak, and Thonburi, which are characterized by the highest clay content, supported by the results presented in Table 2. The correlation analyses further revealed a positive relationship between soil organic carbon and fine particles (silt and clay), while a negative relationship was observed between soil organic carbon and sand particles (Table 3). Consequently, the significantly higher proportion of fine particles in coconut plantations may account for their greater carbon stock potential. This finding aligned with previous research, which demonstrated that an increased presence of fine particles in aggregated soil can enhance carbon protection, retention, and sequestration (Arunrat et al., 2020b; Conforti et al., 2016).

Paddy fields showed the second highest carbon. The land use consisted of various soil series, including Alluvial Complex, Khao Phlong, Pak Tho, and Bangkok, with different soil textures such as sandy loam, loamy sand, and clay. Although the soil texture could have some influence on soil carbon stocks, the management practices in this land use were likely to have a greater impact on carbon stocks than soil properties alone. A presence of anaerobic conditions during the wet season can reduce decomposition and promote carbon accumulation in paddy soils (Sahrawat, 2005). Additionally, the rich organic matter sediment could settle into the topsoil during the late harvest season (Sahrawat, 2003). The rice straw could provide higher levels of soil organic matter (Kunlanit et al., 2020), while residues from cassava and sugarcane were typically removed after harvest. This phenomenon explains the greater total carbon stock observed in paddy soils.

The total carbon stocks in sugarcane and pineapple were similar (Figure 3). Both land use types showed comparable soil series composition. Pineapple soils primarily consisted of Chan Thuk, Tha Yang, and Lat Ya soil series, which were predominantly sandy loam or loamy sand. Similarly, sugarcane fields included Khao Luang, Lat Ya, Alluvial Complex, Tha Yang, Khao Phlong, and Takhli soil series, mostly sandy loam, or loamy sand, except for Thakhi, characterized by a clay loam or silty clay texture. The similarity in soil series and their properties may explain the comparable potential of soil carbon stocks between these land use types.

The lowest carbon stock in cassava soils was likely due to the characteristics of the sandy loam and sandy loam soil series used for cassava cultivation (Table 2). The soils with predominant sand particles tended to be low in carbon storage capacity (Arunrat et al., 2020a). Additionally, a higher proportion of sand particle in cassava soils (Table 2) were also consistent with the previous study. The management practices in cassava, such as frequent soil tillage, could further contribute to the lower carbon content. Previous studies suggested that tillage alters and depletes soil carbon (Mehra et al., 2018), which is common in cassava cultivation,. Therefore, the combination of natural soil properties and continuous soil disturbance were key factors affecting the limited carbon sequestration potential of cassava soils.

4. CONCLUSION

The present study investigated soil carbon in agricultural systems within Ratchaburi Province. Each type of agricultural land exhibited distinct carbon storages, with coconut plantations showing the highest potential, followed by paddy fields, sugarcane, pineapples, and cassava. The correlations between soil carbon and soil properties indicated that these soil properties might influence soil carbon within agricultural soils. The discussion revealed the contribution of soil series and management practices to the differences in carbon storage across different land use types. Therefore, the type of land use alone is not the sole factor that results in differences in carbon storage potential. Other factors, including soil series, soil properties, and management practices, also made significant contributions.

Based on the research findings, the following recommendations are advised regarding climate change mitigation and planning policy contribution: Coconut plantations appeared to show high potential for carbon storage in Ratchaburi Province. The plantations are unique to the region, covering almost 5% of the province's land area. As perennial vegetation, they can absorb greenhouse gases similar to forest ecosystems. In the long term, coconut plantations could have a greater potential for carbon storage compared to other agricultural systems in this study. This was primarily due to their management practices, which involve minimizing soil disturbance compared to tillage-based agriculture. This study mainly focused on assessing the potential of soil carbon storage. Conducting further research on carbon sequestration and the carbon footprint within coconut plantations, as well as other agricultural systems, would contribute to a more comprehensive understanding of their role in the regional carbon cycle. Given Ratchaburi Province a model agricultural area in Thailand under the Bio-Circular-Green Economy (BCG) model, coconut plantations could have significant potential for carbon absorption. The plantation might contribute to offsetting carbon emissions from other sectors, supporting the achievement of carbon neutrality in line with the Sustainable Development Goals (SDGs).

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REFERENCES

Amelung W, Bossio D, de Vries W, Kögel-Knabner I, Lehmann J, Amundson R, et al. Towards a global-scale soil climate mitigation strategy. Nature Communications 2020;11:Article No. 5427.

Arunrat N, Kongsurakan P, Sereenonchai S, Hatano R. Soil organic carbon in sandy paddy fields of Northeast Thailand: A review. Agronomy 2020a;10:Article No. 1061.

Arunrat N, Pumijumnong N, Sereenonchai S, Chareonwong U. Factors controlling soil organic carbon sequestration of highland agricultural areas in the Mae Chaem Basin, Northern Thailand. Agronomy 2020b;10:Article No. 305.

Arunrat N, Sereenonchai S, Kongsurakan P, Hatano R. Assessing soil organic carbon, soil nutrients and soil erodibility under terraced paddy fields and upland rice in Northern Thailand. Agronomy 2022;12:Article No. 537.

Batjes NH. Harmonized soil property values for broad-scale modelling (WISE30sec) with estimates of global soil carbon stocks. Geoderma 2016;269:61-8.

Berhe AA, Barnes RT, Six J, Marín-Spiotta E. Role of soil erosion in biogeochemical cycling of essential elements: Carbon, nitrogen, and phosphorus. Annual Review of Earth and Planetary Sciences 2018;46:521-48.

Blake GR, Hartage KH. Bulk density. In: Klute A, editor. Methods of Soil Analysis Part 1. Physical and Mineralogical Methods. Madison: American Society of Agronomy-Soil Science Society of America; 1986. p. 363-75.

Bouyoucos GJ. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal 1962;54:464-5.

Bridhikitti A. Soil and biomass carbon stocks in forest and agricultural lands in tropical climates. Songklanakarin Journal of Science and Technology 2017;39:697-707.

Conforti M, Lucà F, Scarciglia F, Matteucci G, Buttafuoco G. Soil carbon stock in relation to soil properties and landscape position in a forest ecosystem of Southern Italy (Calabria region). Catena 2016;144:23-33.

Dignac M-F, Derrien D, Barré P, Barot S, Cécillon L, Chenu C, et al. Increasing soil carbon storage: Mechanisms, effects of agricultural practices and proxies. A review. Agronomy for Sustainable Development 2017;37(2):Article No. 14.

Díaz-Zorita M, Grosso GA. Effect of soil texture, organic carbon and water retention on the compactability of soils from the Argentinean pampas. Soil and Tillage Research 2000;54: 121-6.

Ellert BH, Janzen H, Vandenbygaart B, Bremer E. Measuring change in soil organic carbon storage. In: Carter M, Gregorich E, editors. Soil Sampling and Methods of Analysis. Boca Raton: CRC Press; 2007. p. 25-38.

Freibauer A, Rounsevell MDA, Smith P, Verhagen J. Carbon sequestration in the agricultural soils of Europe. Geoderma 2004;122:1-23.

Fujisaki K, Chapuis-Lardy L, Albrecht A, Razafimbelo T, Chotte JL, Chevallier T. Data synthesis of carbon distribution in particle size fractions of tropical soils: Implications for soil carbon storage potential in croplands. Geoderma 2018;313: 41-51.

Islam KK, Anusontpornperm S, Kheoruenromne I, Thanachit S. Relationship between carbon sequestration and physico-chemical properties of soils in salt-affected areas, Northeast Thailand. Agriculture and Natural Resources 2014;48:560-76.

Jobbágy EG, Jackson RB. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications 2000;10:423-36.

Kunlanit B, Khwanchum L, Vityakon P. Land use changes affecting soil organic matter accumulation in topsoil and subsoil in Northeast Thailand. Applied and Environmental Soil Science 2020;2020:Article No. 8241739.

Lal R. Soil carbon sequestration to mitigate climate change. Geoderma 2004;123:1-22.

Land Development Department. Report on the state of land-use for the year 2021 [Internet]. 2022a [cited 2023 Jan 28]. Available from: https://webapp.ldd.go.th/lpd/LandUseInfor.php (in Thai).

Land Development Department. Soil series dataset [Internet]. 2022b [cited 2023 May 27]. Available from: https://tswc.ldd.go.th/DownloadGIS/Index_Soil.html (in Thai).

Lichaikul N, Chidthaisong A, Havey NW, Wachrinrat C. Carbon stock and net CO_2 emission in tropical upland soils under different land use. Kasetsart Journal 2006;40:382-94.

Lorenz K, Lal R. Carbon Sequestration in Agricultural Ecosystems. Cham, Switzerland: Springer International Publishing; 2018.

Matus FJ. Fine silt and clay content is the main factor defining maximal C and N accumulations in soils: A meta-analysis. Scientific Reports 2021;11:Article No. 6438.

Mehra P, Baker J, Sojka RE, Bolan N, Desbiolles J, Kirkham MB, et al. Chapter five: A review of tillage practices and their potential to impact the soil carbon dynamics. In: Sparks DL, editor. Advances in Agronomy. Delaware, USA: Academic Press; 2018. p. 185-230.

Minasny B, Malone BP, McBratney AB, Angers DA, Arrouays D, Chambers A, et al. Soil carbon 4 per mille. Geoderma 2017;292:59-86.

Nunes MR, Karlen DL, Moorman TB. Tillage intensity effects on soil structure indicators: A US meta-analysis. Sustainability 2020;12:Article No. 2071.

Pan G, Smith P, Pan W. The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. Agriculture, Ecosystems and Environment 2009; 129:344-8.

Pibumrung P, Gajaseni N, Popan A. Profiles of carbon stocks in forest, reforestation and agricultural land, Northern Thailand. Journal of Forestry Research 2008;19:11-8.

Rodrigues AF, Latawiec AE, Reid BJ, Solórzano A, Schuler AE, Lacerda C, et al. Systematic review of soil ecosystem services in tropical regions. Royal Society Open Science 2021;8:Article No. 201584.

RStudio Team. RStudio: Integrated Development Environment for R [Internet]. 2020 [cited 2023 Jan 28]. Available from: https://posit.co.

Sahrawat KL. Organic matter accumulation in submerged soils. In: Sparks DL, editor. Advances in Agronomy. Delaware, USA: Academic Press; 2003. p. 169-201.

Sahrawat KL. Fertility and organic matter in submerged rice soils. Current Science 2005;88:735-9.

Scharlemann JPW, Tanner EVJ, Hiederer R, Kapos V. Global soil carbon: Understanding and managing the largest terrestrial carbon pool. Carbon Management 2014;5:81-91.

Stockmann U, Adams MA, Crawford JW, Field DJ, Henakaarchchi N, Jenkins M, et al. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems and Environment 2013;164:80-99.

Stockmann U, Padarian J, McBratney A, Minasny B, de Brogniez D, Montanarella L, et al. Global soil organic carbon assessment. Global Food Security 2015;6:9-16.

Sun W, Huang Y, Zhang W, Yu Y. Carbon sequestration and its potential in agricultural soils of China: SOC sequestration and potential in China. Global Biogeochemical Cycles 2010; 24:Article No. GB3001.

Tan ZX, Lal R, Smeck NE, Calhoun FG. Relationships between surface soil organic carbon pool and site variables. Geoderma 2004;121:187-95.

Thomas GW. Soil pH and soil acidity. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, et al, editors. Methods of Soil Analysis: Part 3 Chemical Methods. Madison: American Society of Agronomy-Soil Science Society of America; 1996. p. 475-90.

Todd-Brown KEO, Randerson JT, Hopkins F, Arora V, Hajima T, Jones C, et al. Changes in soil organic carbon storage predicted by earth system models during the 21st century. Biogeosciences 2014;11:2341-56.

Tu C, He T, Lu X, Luo Y, Smith P. Extent to which pH and topographic factors control soil organic carbon level in dry farming cropland soils of the mountainous region of Southwest China. Catena 2018;163:204-9.

Veldkamp E, Becker A, Schwendenmann L, Clark DA, Schulte-Bisping H. Substantial labile carbon stocks and microbial activity in deeply weathered soils below a tropical wet forest: Carbon in deep soils below tropical wet forest. Global Change Biology 2003;9:1171-84.

Walkley A, Black IA. An examination of the Degtjareff Method for determining soil organic matter, and proposed modification of the chromic acid titration method. Soil Science 1934;37:29-38.

Wang X, He J, Bai M, Liu L, Gao S, Chen K, et al. The impact of traffic-induced compaction on soil bulk density, soil stress distribution and key growth indicators of Maize in North China Plain. Agriculture 2022;12:Article No. 1220.

Wiesmeier M, Urbanski L, Hobley E, Lang B, Von Lützow M, Marin-Spiotta E, et al. Soil organic carbon storage as a key function of soils: A review of drivers and indicators at various scales. Geoderma 2019;333:149-62.