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Effect of Open Burning on Soil Carbon Stock in Sugarcane Plantation in Thailand

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Abstract—Open burning of sugarcane fields is recognized to have a negative impact on soil by degrading its properties, especially soil organic carbon (SOC) content. Better understating the effect of open burning on soil carbon dynamics is crucial for documenting the carbon sequestration capacity of agricultural soils. In this study, experiments to investigate soil carbon stocks under burned and unburned sugarcane plantation systems in Thailand were conducted. The results showed that cultivation fields without open burning during 5 consecutive years enabled to increase the SOC content at a rate of 1.37 Mg $ha^{-1}y^{-1}$. Also it was found that sugarcane fields burning led to about 15% reduction of the total carbon stock in the 0-30 cm soil layer. The overall increase in SOC under unburned practice is mainly due to the large input of organic material through the use of sugarcane residues.

Keywords—Soil organic carbon, Soil inorganic carbon, Carbon sequestration, Open burning, Sugarcane.

I. Introduction

SUGARCANE field burning is a common method widely used in Thailand to facilitate manual harvesting, to protect the ratoon-cane from open fires during the growth period, and to facilitate soil preparation for a new crop. Large amount of carbon as well as nitrogen and sulfur are loss from crop residue via volatilization during burning [1]. In this context, the continuous burning had been identified as one of soil degradation practice that results in a decrease in soil organic matter and nutrient [2]-[5]. A loss of soil organic matter has negative effects on soil physical, chemical, and biological properties leading to environmental damage, since soil organic matter has been reported as an important source and sink in the global carbon cycle [6]. The decrease in soil organic matter due to burning process contributes to a decrease in soil organic carbon due to loss of carbon input to soil plays a key role in the global carbon balance and agricultural productivity. The dynamic of soil organic carbon, therefore, has a critical implication to agricultural production system and global climate change.

Recent studies have indicated that sugarcane burning has physical, chemical and biological effects on soil, e.g. a positive correlation between the burning and the decrease in soil organic matter content has been observed in several studies [7]-[9]. Currently, most of research studies focused on the carbon content in soil under different soil and sugarcane residue management systems, and not on carbon stock that represents the mass of carbon in a specific volume of soil.

As soil carbon content in cropland depends on local climatic and other site-specific conditions, as well as on the type of land-use and land management [10]; it is necessary, therefore, to study the effect of field burning on soil carbon stock and not only the soil carbon content, in order to provide a valuable data set for studying on carbon sequestration in agricultural soils. This study proposes to evaluate the soil carbon stock under burned and unburned sugarcane plantation system. Preliminary results from field experiments are presented and discussed.

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II. Materials and Methods

A. Study Site

The study site covering $3,000m^2$ of sugarcane plantation area is located in Nakhon Sawan province, northern region of Thailand (Fig. 1). The climate in this part of the country is tropical moist with an annual monsoon corresponding to a rainy season from May to October, and a dry season in the rest of the year. The mean annual temperature is 28.8°C, and precipitation amounted 1,187mm during the experimental period in year 2012 [11]. The soil was classified as Mollisols which is clay at the depth of 0-55cm and clay loamy soil for the 55-100cm layer. Soil pH is within the range of moderately alkaline which increases along the depth of 0-100cm.

Fig. 1 Study area located in Nakhon Sawan province

The sugarcane plantations under similar soil, climate, and topography with different sugarcane residue management practices, i.e. burned and unburned systems were selected in order to study the effects of sugarcane field burning on soil carbon stock. All fields had been cropped with sugarcane for approximately 20 years. The burned system had a continuous field burning of sugarcane residues over 20 years, and the unburned system in the adjacent plantation of the burned one had no-burning of residues during four years before conducting our experiment. Both treatments had different conditions in terms of residue management practices and harvesting methods. Other farm management practices were controlled to be exactly the same, including cultivar of planted sugarcane, tillage methods, water supply, fertilizer and pesticide application etc.

In this study, the sugarcane was planted in January 2012 with a distance of 1.7m between rows. Three types of plowing namely; sub-soiler, moldboard plow and disk harrow; were effectuated at this site before planting. Chemical fertilizers were applied four times during the year as a composite of chemical fertilizer and urea. Water was supplied only three times during the planting time for plant emergency use. The planted sugarcane was harvested in January 2013.

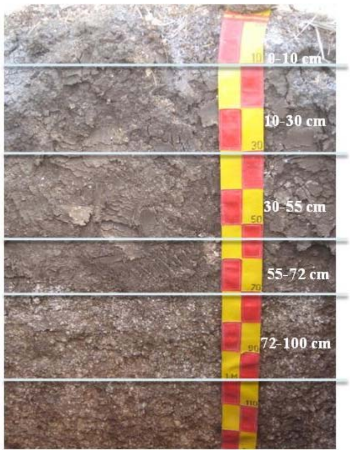

Fig. 2 Soil profile of the experimental site

B. Soil Sampling and Analyses

Soil samples were collected from study sites twice: (1) before the start of the experiment in December 2011 (before tillage), and (2) at the harvesting time in January 2013 (after tillage), from burned and unburned sugarcane plantation areas. The soil sampling was conducted with three replications at 5 layers of the 0-100cm soil depths following soil profile (Fig. 2). The soil testing methods and sampling procedures were generally followed those standard methods as described in the following:

(1) Soil bulk density was measured using the core methods. Soil samples were taken from the undisturbed soil with rings with internal volume of 177cm^3. All soil samples were oven-dried at 105ºC over 24 hours. Then, soil bulk density of each sample was determined using (1):

$$BD = \frac{W_d}{V} \qquad (1)$$

where BD is soil bulk density (g cm^{-3}), W_d is the mass of oven dried soil sampling (g), and V is the volume of wet sample (cm^3)

(2) Total carbon content in soil, which is the sum of both organic and inorganic carbon, was determined using a dry combustion method. All soil samples were air-dried, homogenized, sieved in a 2mm screen, ground to fine soils, and sieves again to lesser than 100 micron. Then, eight-miligarm subsample from each sample was taken to analysis total carbon using Perkin-Elmer 2400 series II CHNS/O element analyser.

(3) Soil organic carbon was quantified base on Walkley and Black methods. Fresh soil samples were air-dried for 7 days and passed through 2mm sieved. Thereafter, one-gram subsample from each soil sample was used to analyze organic carbon content.

(4) Soil inorganic carbon was estimated from the different of total carbon and organic carbon.

C. Calculation of Soil Carbon Stocks

Before conducting the experiment, soil carbon stocks under burned and unburned plots were determined base on a depth base approach as for previous soil inventories [12]-[14] as shown in (2) and (3).

$$C_{i,depth} = conc_i \ x \ BD_i \ x \ T_i \ x \ 10^4 \quad (2)$$

$$C_{T1}(n) = \sum_{i=1}^{n} C_{i,depth} \quad (3)$$

where: C_{T1} is the cumulative soil carbon stocks in the first sampling, before tillage (kg ha^{-1}), $C_{i,depth}$ is the soil carbon stocks at the fixed depth in the ith layer, $conc_i$ is the soil carbon content in the ith layer, BD_i is the soil bulk density in the ith soil layer (Mg m^{-3}), and T_i is the thickness of ith soil layer (m)

Due to the soil mass change after tillage, the concept and methodology for calculating soil carbon stocks base on equivalent soil mass presented in the literatures [12]-[14] were used to determine the carbon stocks change in soils at the second time of soil sampling in the harvesting periods. The same soil mass corrections were applied for calculating soil carbon stocks. Soil mass at the second time (after tillage) was adjusted according to the soil mass at the initial or original sampling time (before tillage) as the equivalent soil mass for the layer. A series of calculation was conducted, firstly, soil mass at each sampling time were calculated from the thickness and bulk densities as presented in (4a). Soil carbon stocks for a fixed depth of soils were determined as provided in (4b).

$$M_i = BD_i \ x \ T_i \ x \ 10^4 \quad (4a)$$

$$C_{i,fixed} = conc_i \ x \ M_i \quad (4b)$$

where M_i is dry soil mass in the ith layer (Mg ha^{-1}), $C_{i,fixed}$ is the carbon mass in a fixed depth of the ith layer (kg C ha^{-1}), and $conc_i$ is the carbon concentration in the ith soil layer (g C kg^{-1})

Thereafter, the soil carbon stock, originally calculated for a fixed soil depth, was adjusted to an equivalent soil mass basis as described in (4c) and (4f).

$$M_{i,add} = M_{i,,equiv} - (M_i - M_{i-1,add}) \quad (4c)$$

$$C_{i,equiv} = C_{i,fixed} - (conc_i \ x M_{i-1,add}) + (conc_{i,equiv} \ x \ M_{i,add}) \quad (4d)$$

$$conc_{i,\ equiv} = \begin{cases} conc_{i+1} & when\ i \neq 1 \\ conc_i & when\ i = 1 \end{cases} \quad (4e)$$

$$C_{T2}(n) = \sum_{i=1}^{n} C_{i,equiv} \quad (4f)$$

where C_{T2} is the cumulative soil carbon stocks in the second sampling, after tillage (kg ha^{-1}), $C_{i,equiv}$ is the equivalent carbon mass in the ith layer (kg C ha^{-1}), $M_{i,\ equiv}$ is the selected equivalent soil mass in the ith layer (Mg ha^{-1}), $M_{i,add}$ and $M_{i-1,\ add}$ are the additional soil masses that are to attain the equivalent soil mass in the ith and (i-1)th layer (Mg ha^{-1}), $conc_i$ and $conc_{i,equiv}$ are the carbon concentration for the additional soil mass (kg C Mg^{-1}) .

III. Results and Discussion

The result shows soil bulk density in the pre-tillage was higher than in the post-tillage, in soil depths of the 10-30cm and 30-55cm, which are a plough soil layer. The bulk density increased with the depth in a plough layer (0-55cm), then declined in the depth of lower plough layer (55-100cm). There was no significantly difference between the burned and unburned plots both two times of measurement as shown in Table I.

As expected, a significant difference in organic carbon content on the top soil was observed between the area with and without burning, while there were found no significant difference in a deep soil layers as shown in Table II. Soil organic carbon content in the 0-10cm depth was 38% higher in the unburned system than in the burned system in the harvesting time. This finding consistent with the work of Wood, [15] who stated that the sugarcane areas without burning in Australia were 20% higher in organic carbon content in the top 20cm soil layer compared with the area with burning. As well as other previous studied that reported a steady increase in soil organic carbon in soil surface of sugarcane area with no-burning [7], [8], [16].

TABLE I
Soil Bulk Density in the Sugarcane Area with and without Burning in Thailand

Soil depths	Soil bulk density (Mg cm^{-3})			
	Pre tillage: before planting		Post tillage: harvesting	
	Burned	Unburned	Burned	Unburned
0-10 cm	1.23Ab	1.24Ab	1.23Ab	1.23Ab
10-30 cm	1.42Aa	1.43Aa	1.32Bab	1.33Ba
30-55 cm	1.44Aa	1.48Aa	1.34Ba	1.35Ba
55-72 cm	1.27Ab	1.25Ab	1.27Ab	1.24Ab
72-100 cm	1.21Ab	1.23Ab	1.25Ab	1.24Ab

Note: Different capital letters in the same row indicate a significant difference between treatment, as well as the different of lower-case letter in a same column mark a significant difference between depth layers ($p \leq 0.05$).

In addition, total carbon content in soil surface was also found a significant difference between burned and unburned treatments, while no significant difference in the inorganic carbon content between two treatments. Soil carbon contents were found no significant difference between pre-tillage and post-tillage. There are relatively constant over one-year of measurement and it indicates that sugarcane burning effect on soil carbon could be observed in long-term period. As similar to Roberson [9] reports the increase of soil carbon content in the 0-10cm soil layer of the area with no-burning after 4 to 6 years, but not in areas recently converted to the no-burning system. It should be note that sugarcane area without burning accumulates carbon into the soil surface compared with the area with burning, and the positive correlation between no-burning and increased organic carbon can be influence by a time of adoption of no-burning system.

From Table III, the increase in soil organic carbon stocks was observed in the top 30cm soil layer of the sugarcane area after 5-years of no-burning management, similar to organic carbon content as mention previously. At this soil layer, the organic carbon stock in the unburned area increased about 21% compared with the burned area. The difference between soil organic carbon stock in the burned area (32.97 Mg ha^{-1}) and unburned area (39.81 Mg ha^{-1}) represents an annual increase rate of 1.37 Mg ha^{-1} in the 0-30cm soil layer. Likewise, soil total carbon stock in unburned area (90.70 Mg ha^{-1}) had 15% higher than those in the burned area (78.86 Mg ha^{-1}).

These results are in agree with the results presented in study of Glados et al. [7] and Panosso et al. [17], which show a more mark difference in total carbon stock between burned and unburned treatment in the soil surface. The overall increase in total soil carbon stocks under the unburned area is mainly related to the large input of organic material from sugarcane residue, results to higher in carbon stock in the soil surface under the area without burning. However, the change in soil organic carbon stock was no significant difference over a one-year cycle. That confirmed the soil carbon stock was no changed in a short term period of conversion the burning practice to no-burning practices.

TABLE II
SOIL CARBON CONTENT BURNED AND UNBURNED SUGARCANE PLANTATION AREAS

Soil depths	Carbon concentration (g kg^{-1})			
	Pre tillage: before planting		Post tillage: harvesting	
	Burned	Unburned	Burned	Unburned
Soil organic carbon				
0-10 cm	10.17Ba	12.95Aa	9.78Ba	13.49Aa
10-30 cm	7.54Ab	8.12Ab	7.77Bb	8.47Ab
30-55 cm	2.71Ac	2.71Ac	2.52Acd	2.78Ac
55-72 cm	3.29Ac	3.29Ac	3.09Ac	3.25Ac
72-100 cm	2.51Ac	2.79Ac	2.13Ad	2.76Ac
Soil inorganic carbon				
0-10 cm	9.00Ad	8.28Ad	8.68Ad	7.87Ae
10-30 cm	13.03Ad	11.65Ad	10.73Ad	12.57Ad
30-55 cm	34.66Ac	36.16Ac	35.42Ac	36.58Ac
55-72 cm	52.88Ab	54.45Ab	54.01Ab	53.22Ab
72-100 cm	62.49Aa	61.98Aa	62.03Aa	62.17Aa
Soil total carbon				
0-10 cm	19.17Bd	21.23Ad	18.47Bd	21.37Ad
10-30 cm	20.57Ad	19.77Ad	18.50Bd	21.03Ad
30-55 cm	37.37Ac	38.87Ac	37.93Ac	39.37Ac
55-72 cm	56.17Ab	57.73Ab	57.10Ab	56.47Ab
72-100 cm	65.00Aa	64.77Aa	64.17Aa	64.93Aa

Note: Different capital letters in the same row indicate a significant difference between treatment, as well as the different of lower-case letter in a same column mark a significant difference between depth layers ($p \leq 0.05$).

IV. CONCLUSIONS

A preliminary results of this study indicated that sugarcane field burning causes a decrease in soil carbon stock, especially soil organic carbon, while sugarcane area with no-burning returns great amount of carbon in soil. The area with 5 years of no-burning management system present 15% higher soil total carbon stock at the 0-30cm depth compared to the area with burning. However, the present study was carried out in a site-specific under clay soils in a plant crop. To improve tier lever of country-specific, specific field experiment aiming at better-understanding effect of sugarcane field burning on carbon sequestration should be developed over a productive cycle of sugarcane cropping at different soil conditions.

TABLE III
SOIL CARBON STOCK IN THE EXPERIMENTAL SITE

Soil depths	Carbon stock (Mg ha^{-1})			
	Pre tillage: before planting		Post tillage: harvesting	
	Burned	Unburned	Burned	Unburned
Soil organic carbon				
0-10 cm	12.51Bb	16.15Ab	11.99Bb	16.74Ab
10-30 cm	21.35Aa	23.29Aa	20.98Ba	23.07Aa
30-55 cm	9.77Ac	10.00Ac	9.31Ab	10.56Bc
55-72 cm	7.07Ac	6.97Ac	6.29Ac	6.65Bcd
72-100 cm	8.50Ac	9.61Ac	7.22Ac	9.56Bd
Soil inorganic carbon				
0-10 cm	11.09Ad	10.32Ae	10.60Ad	9.88Ae
10-30 cm	37.03Ac	33.18Ad	35.29Bc	41.00Ad
30-55 cm	125.14Ab	133.52Ab	135.82Ab	144.64Ab
55-72 cm	114.73Ab	115.55Ac	121.35Ab	117.52Ac
72-100 cm	211.79Aa	213.98Aa	210.26Aa	214.50Aa
Soil total carbon				
0-10 cm	23.60Bd	26.47Ae	22.59Be	26.63Ae
10-30 cm	58.38Ac	56.47Ad	56.26Bd	64.07Ad
30-55 cm	134.91Ab	143.51Ac	145.13Ab	155.20Ab
55-72 cm	121.81Ab	122.51Ab	127.64Ac	124.17Ac
72-100 cm	220.29Aa	223.58Aa	217.48Aa	224.06Aa

Note: Different capital letters in the same row indicate a significant difference between treatment, as well as the different of lower-case letter in a same column mark a significant difference between depth layers ($p \leq 0.05$).

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