CHAPTER 8
EFFECTS OF SUGARCANE FIELD BURNING ON SOIL CARBON STOCK

During sugarcane field burning, large amounts of carbon as well as nitrogen and sulfur are lost from crop residue via volatilization (Raison, 1979). The continuous burning had been identified as one of soil degradation practice that results to decrease soil organic matter and nutrient (Ball-Coelho et al, 1993; Graham et al., 2002; Hubbert et al., 2006, Kayode et al., 2009). A loss of soil organic matter has negative effects on soil physical, chemical, and biological properties results in environmental damage, since soil organic matter has been reported as an importance source and sinks in the global carbon cycle (Ellert and Bettany, 1995). The decrease in soil organic matter due to burning process results to decrease of soil organic carbon by increase loss of carbon input to soil, which is of great importance to the global carbon balance and to agricultural productivity. The dynamic of soil organic carbon, therefore, has an important implication for agricultural production system and the impacts of global climate change.

Recent studies have indicated that sugarcane burning has physical, chemical and biological effects on the soil. A positive correlation between the burning and the decrease in soil organic matter content has been observed in several studies (Galdos et al., 2009; Cerri et al., 2011; Roberson, 2009). Currently, most of studies in the literature are focused on the carbon content in soils under different soil and sugarcane residue management systems, not in carbon stocks, which is the mass of carbon in a specific volume of soil. In addition, soil carbon in cropland depends on local climatic and other site-specific conditions, as well as on the type of land-use and land management (Leifeld et al., 2005). It is necessary, therefore, to study the effect of field burning on soil carbon stock, in order to provide a valuable data for studying on carbon sequestration in agricultural soils. This study proposes to evaluate the soil carbon stock under burned and unburned sugarcane plantation system as report in this chapter.

8.1 Methodology

8.1.1 Study site description

The study site covering 3,000 m^2 of sugarcane plantation area is located in Nakhon Sawan province, the northern region of Thailand where is the site for measuring GHG emissions from soils, as described in Chapter 7. The climate is tropical moist affected by an annual monsoon with a rainy season from May to October and a dry season in the rest of the year. Mean annual temperature is 28.8°C and precipitation was 1,187 mm during the experimental period in 2012 (TMD, 2013). The soil was classified as Mollisols, which is clay at the depth of 0-55 cm and clay loamy soil for the 55-100 cm layer. Soil pH is within range of moderately alkaline and increased along the depth of 0-100 cm (Table 8.1).

Table 8.1 Soil profile description at the experimental site

Genetic horizontal	Depth (cm)	Description
Ap1	0-25/30	Very dark grayish brown (10YR 3/2) (70%), mixed with brown (7.5 YR 4/2) (25%) and prominent red (2.5YR 4/6) (5%) mottles; clay; moderate fine and medium subangular blocky parting to fine granular structure; very hard dry, friable moist, very sticky and very plastic; many very fine and common fine root; few marl fragment about 5% (0.3-1 cm in diameter); moderately alkaline (filed pH 8.0) ; clear and wavy boundary to Ap2
Ap2	25/30-49/55	Dark brown (7.5YR3/2)(70%), mixed with grayish brown (10YR 5/2)(25%) and prominent reddish brown (5YR4/4)(5%) mottles; clay; moderate coarse and medium subangular blocky structure: very hard dry, friable moist, very sticky and very plastic; common medium root; common marl fragment about 10-15% (0.3-1 cm in diameter); moderately alkaline (filed pH 8.0); clear and wavy boundary to Bw
Bw	49/55-68/72	Brown (7.5 YR4/2)(80%), mixed with grayish brown (10YR 5/2)(20%); clay loam; moderate fine and medium subangular blocky structure; hard dry, friable moist, moderately sticky and moderately plastic; few fine and few medium root; many marl fragments about 25-30% (0.3-1 cm in diameter); moderately alkaline (filed pH 8.0) ; clear and wavy boundary to Ck1
Ck1	68/72-95/100	Brown (7.5 YR4/2)(60%), mixed with grayish brown (10YR 5/2)(40%); very gravelly clay loam; weak fine and medium subangular blocky structure; hard dry, friable moist, moderately sticky and moderately plastic; gravels composed of marl about 40-55% (0.3-1 cm in diameter); moderately alkaline (filed pH 8.0); clear and smooth boundary to Ck2

The sugarcane areas under similar soil, climate, and topography with different sugarcane residue management practices (burned and unburned systems) were selected 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 area had a continuous burning sugarcane residue over 20 years, and the unburned area in the adjacent site of the burned area had no-burning of residues in four years before conducting the experiment. Both treatments had different conditions in terms of residue management practices and harvesting methods. Other farm management practices were controlled with the same conditions, i.e. a cultivar of sugarcane planted, tillage methods, water supply, fertilizer and pesticide application, etc.

Sugarcane in the experiment was planted in January 2012 with a distance of 1.7 m between the rows. Three types of plowing, namely: subsoiler, moldboard plow and disk harrow, respectively, were done at this site before planting. Chemical fertilizers were applied four times during the year as a composite of fertilizer and urea. Water supply was perfomed only four times during the planting time for plant emergency. Sugarcane harvesting was done on January in 2013.

8.1.2 Soil sampling and analysis

Soil samples were collected in fields on 2 occasions: (1) before conducting experiments on December 2011 (before tillage) and (2) at the harvesting time on January 2013 (after tillage), from burned and unburned sugarcane plantation areas. The soil sampling was conducted with three replications at 5 layers of the 0-100 cm soil depths following soil profile (Table 8.1). The soil testing methods and sampling procedures generally followed the standard methods described below:

(1) Soil bulk density was measured using the core methods. Soil samples were taken from the undisturbed soil with rings with internal volume of 177 cm^3 (Fig. 8.1). All soil samples were oven-dried at 105 °C over 24 hours. Then, the soil bulk density of each sample was determined using Equation (8.1).

$$BD = \frac{W_d}{V} \tag{8.1}$$

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 2-mm screen, ground to fine soils, and sieved again to less than 100 microns. Then, eight-milligram 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 based on Walkley and Black methods. Fresh soil samples were air-dried for 7 days and passed through 2 mm sieve. Thereafter, one-gram subsample from each soil sample was used to analyse organic carbon content.

(4) Soil inorganic carbon was estimated from the difference between total carbon and organic carbon.

Figure 8.1 Soil sampling at the experimental sites

8.1.3 Calculation of soil carbon stocks

Before conducting the experiment, soil carbon stocks under burned and unburned plots were determined based on a depth base approach as for previous soil inventories (Ellert and Bettany, 1995; Lee et al., 2009; Toriyama et al., 2011) as shown in Equation (8.2) and (8.3).

$$C_{i,depth} = conc_i \ x \ BD_i \ x \ T_i \ x \ 10^4 \quad (8.2)$$

$$C_{T1}(n) = \sum_{i=1}^{n} C_{i,depth} \quad (8.3)$$

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 *i*th layer, $conc_i$ is the soil carbon content in the *i*th layer, BD_i is the soil bulk density in the *i*th soil layer (Mg m^{-3}), and T_i is the thickness of *i*th 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 has been described in the literature (Ellert and Bettany, 1995; Lee et al., 2009; Toriyama et al., 2011) and 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 were conducted, firstly, soil mass at each sampling time were calculated from the thickness and bulk densities as presented in Equation (8.4a). Soil carbon stocks for a fixed depth of soils were determined as provided in Equation (8.4b).

$$M_i = BD_i \ x \ T_i \ x \ 10^4 \tag{8.4a}$$

$$C_{i,fixed} = conc_i \ x \ M_i \tag{8.4b}$$

where M_i is dry soil mass in the *i*th layer (Mg ha^{-1}), $C_{i,fixed}$ is the carbon mass in a fixed depth of the *i*th layer (kg C ha^{-1}), and $conc_i$ is the carbon concentration in the *i*th 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 Equations (8.4c) – (8.4f).

$$M_{i,add} = M_{i,,equiv} - (M_i - M_{i-1,add}) \tag{8.4c}$$

$$C_{i,equiv} = C_{i,fixed} - (conc_i \ x M_{i-1,add}) + (conc_{i,equiv} \ x \ M_{i,add}) \tag{8.4d}$$

$$conc_{i,\ equiv} = \begin{cases} conc_{i+1} & \text{when } i \neq 1 \\ conc_i & \text{when } i = 1 \end{cases} \tag{8.4e}$$

$$C_{T2}(n) = \sum_{i=1}^{n} C_{i,equiv} \tag{8.4f}$$

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 *i*th layer (kg C ha^{-1}), $M_{i,\ equiv}$ is the selected equivalent soil mass in the *i*th layer (Mg ha^{-1}), $M_{i,add}$ and $M_{i-1,\ add}$ are the additional soil masses that attain the equivalent soil mass in the *i*th and (*i-1*)th layer (Mg ha^{-1}), $conc_i$ and $conc_{i,equiv}$ are the carbon concentrations for additional soil mass (kg C Mg^{-1}).

8.2 Results and discussion

The result shows that soil bulk density before tillage was higher than in after tillage, at soil depths of 10-30 cm and 30-55 cm, which are plough soil layers. The bulk density increased with the depth in a plough layer (0-55 cm), then declined in the depth of lower plough layer (55-100 cm). There was no significantly difference between the burned and unburned plots both two times of measurement, as shown in Table 8.2.

Table 8.2 Soil bulk density in the sugarcane area with and without burning in Thailand

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

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 soil depths ($p \leq 0.05$).

As expected, a significant difference in organic carbon content on the top soil was observed between the areas with and without burning, while there were found no significant differences in a deep soil layers, as shown in Table 8.3. Soil organic carbon content in the 0-10 cm 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 (1991) who stated that the sugarcane areas without burning in Australia were 20% higher in organic carbon content in the top 20 cm 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 (Galdos et al., 2011; Cerri et al., 2011; Razafimbelo et al, 2006).

In addition, total carbon content in the soil surface was found to have a significant difference between burned and unburned treatments, while there was no significant difference in the inorganic carbon content between the two treatments. Soil carbon contents were not significantly different between before tillage and after 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 (2009) reports the increase of soil carbon content in the 0-10 cm 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 noted that the sugarcane area without burning accumulates carbon in the soil surface as compared to the area with burning, and the positive correlation between no-burning and increased organic carbon can be influenced by the time of the adoption of no-burning system.

Table 8.3 Soil carbon content in the sugarcane areas with and without burning in Thailand

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

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 soil depth s ($p \leq 0.05$).

As seen in Table 8.4, the increase in soil organic carbon stocks was observed in the top 30 cm soil layer of the sugarcane area after 5-years of no-burning management, similar to the organic carbon content, as mentioned 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 0-30 cm 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 (2009) and Panosso et al (2011), which show a more marked difference in total carbon stocks between burned and unburned treatment in the soil surface.

Table 8.4 Soil carbon stocks before-tillage and after-tillage under different sugarcane residue management techniques

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

Different capital letters in the same row indicate a significant difference between treatment, as well as the difference of lower-case letters in the same column mark a significant difference between soil depths ($p \leq 0.05$).

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. Also, this finding shows no difference of soil inorganic carbon stock over measurement period, corresponding to the IPCC guideline 2006 which stated that the annual change in inorganic carbon stocks is assumed to be zero (IPCC, 2006).

This finding shows that a change in sugarcane residue management practice can increase carbon sequestration in agricultural soil. Increasing the carbon stocks of terrestrial ecosystem could mitigate global climate change by compensating for some CO_2 released into the atmosphere from other sources (Marland et al., 2003). In addition, increasing carbon sequestration can provide environmental benefits, i.e. decreased soil erosion, increased soil water capacity, increased retention of soil nutrients and increased crop productivity (Follett, 2001).

8.3 Summary of findings

In this study, field experiments to investigate soil carbon stocks under burned and unburned sugarcane plantation systems in Thailand were conducted. 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 amounts of carbon to the soil. This shows that sugarcane fields burning caused about 15% reduction of the total carbon stock in the 0-30 cm soil layer. The carbon stocks in the experimental soil of the 0-30 cm were 32.97 and 39.81 Mg ha^{-1} for the burned and unburned sugarcane areas. That shows the unburned practice performed during 5 years consecutively enabled to increase the carbon stock in soil at a rate of 6.84 Mg ha^{-1}.

The overall increase in soil carbon under unburned practice is mainly due to the large input of organic material from sugarcane residues. The results of this study confirmed that open burning sugarcane field is recognized as a practice having a negative impact on soil by degrading its properties, especially soil organic carbon (SOC) content. However, the present study was carried out in a site-specific under clay soils in a plant crop. To improve the country-specific data, 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.