

CHAPTER 4

SOIL CARBON BUDGET

4.1 Introduction

Soil organic carbon is one of the key components that affect agriculture production, nutrient availability, soil stability and flux of greenhouse gases between land surface and the atmosphere. It represents a major pool of carbon within the biosphere and acts both as a source and a sink for carbon and nutrients. This chapter focuses on estimation of soil organic carbon in sugarcane production areas using GIS with data derived from two different sources (i.e. the Thai Land Development Department (LDD) and soil survey and analysis). The chapter also compares the results of soil carbon analysis using different analytical techniques (Walkley and Black method and Flash combustion technique).

4.2 Soil characteristics

4.2.1 Soil profile

According to soil survey and soil classification, soil at the sites is classified as Ban Bueng-Sattahip (Bbg-Sh) series. This is the mixed characteristic between Ban Bueng (Bbg) soil series and Sattahip (Sh) soil series (Soil Taxonomy, 2003). In general, Ban Bueng-Sattahip soil series are very deep soils with sandy texture throughout the column (> 200 cm thick) (Sathira *et al.*, 2004). The pH value is within neutral range and increased along soil depth (4.4-6.6) from 0 to 102 cm. It is usually low in fertility, with sandy texture and low in total soil organic carbon content (0.21-0.53 % organic carbon in the upper 30 cm) (Sathira *et al.*, 2004).

The description of soil profile is given in Table 4.2. Soil profile study was made at the CO₂ flux field site at the end of March 2007 after sugarcane planting with assistance from Land Development Department staffs. The soil samples were obtained from 0-100 cm depth at that site. The depth intervals for taking the soil samples were decided based on the color difference among layers (Figure 4.1). After that soil samples were taken to the laboratory, the following parameters were measured: soil pH, organic carbon and nitrogen content, soil bulk density, and soil texture (Table 4.1). For laboratory analysis of soil profile samples, the soil samples were obtained from 0-31, 31-63 and 63-100 cm soil layer.

The laboratory analysis reveals that bulk density values of these layers were 1.58 ± 0.01 , 1.72 ± 0.02 and 1.78 ± 0.02 g/cm^3 , respectively (Table 4.1 and 4.2). Soil reaction at the site was acidic in general. The soil pH at 0-31cm was 5.0, and 5.4, 4.3 for 31-63 and 63-100 cm, respectively. Soil textures were loamy sand in the top two layers, and sandy in the deep layer (Table 4.1). Soil analysis was also carried out for carbon distribution in the profile and later in the study area. At 0-31 cm organic carbon was higher than that at 31-63 and 63-100 soil layer. This may indicate the influence of organic incorporation by plowing annually at the beginning of sugarcane season (Table 4.2).

Table 4.1 Characteristics of the soil underlying the sugarcane crop at the experimental site

Depth (cm)	BD ^a (g/cm^3)	OC (%)	N (%)	pH	Particle size distribution (%)			Texture
					Sand	Silt	Clay	
0-31	1.58 ± 0.01	0.49	0.02	5.0	81.5	14.0	4.5	Loamy sand
31-63	1.72 ± 0.02	0.24	0.01	5.4	82.5	15.5	2.0	Loamy sand
63-100	1.78 ± 0.02	0.23	0.01	4.3	86.0	11.5	2.5	Sandy

^aBD = bulk density ± 3 samples

Table 4.2 Soil profile at the experimental site

Horizon	Depth (cm)	Description
Ap	0-31	Very dark grayish brown (10YR 3/2) loamy sand; weak fine and medium sub angular blocky structures breaking to single grain: friable non sticky and non plastic; common fine and few medium roots; neutral (field pH 7.0); clear smooth boundary.
C ₁	31-63	Light brown (7.5YR 6/4) loamy sand; common fine distinct yellowish brown (10 YR 5/6) mottles; weak fine sub angular blocky structures breaking to single grain; friable non sticky and non plastic; few fine roots: neutral (field pH 7.0); gradual smooth boundary.
C ₂	63-100	Light brown(7.5YR 6/4) sand; common medium distinct yellowish brown (10YR 5/6) few fine distinct pinkish gray and yellowish red (5 YR 5/8) mottles; single grain; loose non sticky and non plastic; no root; slightly acid (field pH 6.5)

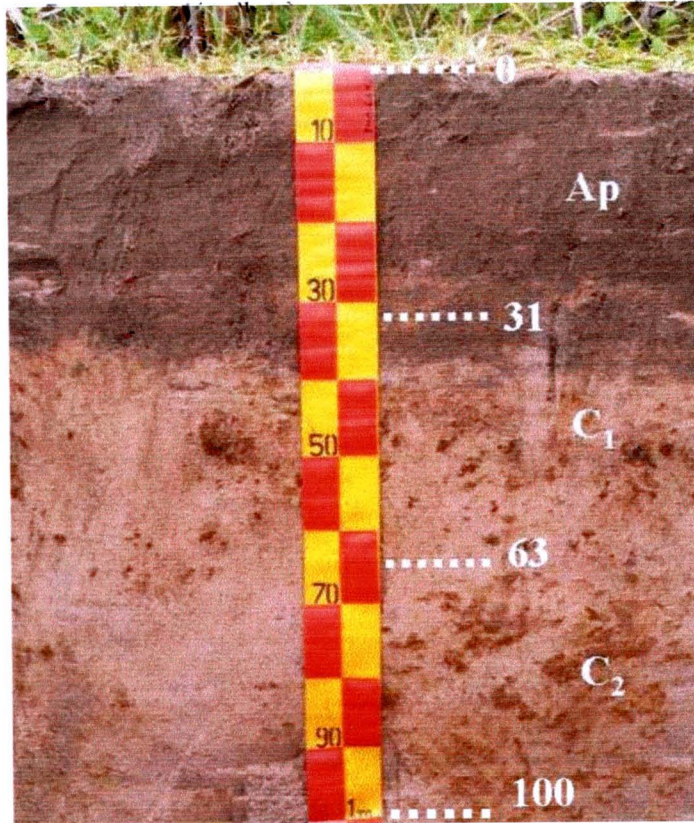


Figure 4.1 Soil profiles of Ban Bueng-Sattahip (Bbg-Sh) soil series

4.2.2 Soil Characteristics before planting and after sugarcane harvest

Table 4.3 shows soil bulk density before sugarcane planting (8 January, 2006) which were 1.44 ± 0.13 at 0-10 cm, 1.42 ± 0.06 at 10-20 cm, 1.48 ± 0.13 at 20-30 cm, respectively. These values were not statistically significant differences between soil depths ($p < 0.05$). In addition, soil bulk densities after sugarcane harvest (at the end of March 2007) were 1.58 ± 0.01 at 0-10 cm, 1.48 ± 0.01 at 10-20 cm, 1.30 ± 0.05 at 20-30 cm, respectively. There were statistically significant differences between soil depths at 0-10 cm and 10-20 ($p < 0.01$), 0-10 and 20-30 cm ($p < 0.01$), 10-20 and 20-30 cm ($p < 0.05$). Soil sample after sugarcane harvest, the soil bulk density was increased from 0-20 cm but decreased from 20-30 cm. However, there were no statistically significant differences between soil bulk density before sugarcane planting and after sugarcane harvest ($p < 0.05$).

Table 4.3 Soil bulk density of the soil samples at the study sites of Ban Bueng-Sattahip (Bbg-Sh) soil series at 0-10, 10-20 and 20-30 cm depth

Soil Sampling	Soil bulk density at soil depth (cm)		
	0-10 cm	10-20 cm	20-30 cm
Before planting (N=12)	1.44±0.13	1.42±0.06	1.48±0.13
After harvest (N=3)	1.58±0.01	1.48±0.01	1.30±0.05

4.3 Soil C stock

4.3.1 Field survey study

Soil carbon stocks were estimated to the depth of 100 cm. The estimated amount of soil carbon stock was 24±0.01, 13.21±0.02 and 15.15±0.02 ton C/ha at 0-31 cm, 31-63 cm and 63-100 cm depth level (Table 4.4).

Table 4.4 Soil C stock of the soil samples at soil profile

Depth (cm)	BD ^a (g/cm ³)	OC (%)	Soil C stock (ton C/ha) ^b
0-31	1.58±0.01	0.49	24.00±0.01
31-63	1.72±0.02	0.24	13.21±0.02
63-100	1.78±0.02	0.23	15.15±0.02

^aBD = bulk density, the 3 samples was determine standard deviation

^bSoil C stock= standard deviation was determine the uncertainty from bulk density

In Table 4.5 organic carbon content of soil samples were compared between before sugarcane planting and after sugarcane harvest. Soil carbon concentration before sugarcane planting was 0.49±0.13 % and on the end the experiment soil organic carbon was 0.44±0.06 % (± of 4 replications). Thus, soil carbon content decreased after sugarcane planting, but this is statistically not different ($p < 0.05$) (Table 4.5). Thus, estimations of soil C stock before sugarcane plating were 7.06 ±0.58 ton C/ha at 0-10 cm, 6.96± 0.14 ton C/ha at 10-20 cm and 7.25±0.58 ton C/ha at 20-30 cm. In addition after sugarcane harvest the soil C stock was 6.95 ±0.06 ton C/ha at 0-10 cm, 6.51± 0.06 ton C/ha at 10-20 cm and

5.72±0.07 ton C/ha at 20-30 cm, respectively. There was not statistically significant difference between soil depths. It means soil organic carbon has been maintained by this sugarcane field in one cropping season.

Table 4.5 General characteristics and soil C stock of the soil samples in study sites Ban Bueng-Sattahip (Bbg-Sh) soil series 0-10, 10-20 and 20-30 cm depth (\pm of 4 replications)

Soil Sampling	pH	% OC	Soil C stock (ton C/ha) (0-10 cm)	Soil C stock (ton C/ha) (10-20 cm)	Soil C stock (ton C/ha) (20-30 cm)
Before planting	6.53±0.07	0.49±0.13	7.06±0.58	6.96±0.14	7.25±0.58
1 month	6.67±0.04	0.43±0.08	6.19±0.15	6.11±0.09	6.36±0.15
After harvest	6.74±0.10	0.44±0.06	6.95±0.06	6.51±0.06	5.72±0.07

Table 4.6 Soil bulk density of the soil samples at the study sites of Ban Bueng-Sattahip (Bbg-Sh) soil series at 0-30 cm depth

Soil Sampling	pH	% OC	Bulk density (g/cm ³)	Soil C stock (ton C/ha) (0-30 cm)
Before planting	6.53±0.07	0.49±0.13	1.55±0.16	22.79±0.21
After harvest	6.74±0.10	0.44±0.06	1.59±0.01	20.99±0.06

4.3.2 Soil Carbon budget in the sugarcane planting of eastern Thailand

4.3.2.1 Sugarcane area and error estimation

The majority of sugarcane plantation areas are located in Eastern Thailand. The soil organic carbon and soil carbon stock of these areas were estimated. The study site of this part is located in Chonburi and Rayong provinces (Figure 3.2 Chapter 3). The area under investigation covers 531,810 ha or 5,318 km². This area is characterized by high density of sugarcane farms and it is regarded as the largest sugarcane production area in the Eastern Thailand. Chonburi and Rayong sugarcane areas were covered 26,360 ha or 42.5 % of the total sugarcane area in the Eastern Thailand and 2.51% of sugarcane area in the whole area of Thailand in 2004/05 cropping years (Office of the Cane and Sugar Board, 2005).

In this part, sugarcane areas from ten soil series were included, covering more than 84% (22,164 ha) of the total sugarcane production area in this region (26,360 ha). Field

surveys were carried out during November to December 2005 to check the accuracy of GIS-based land use map (Landsat-5 TM) for December 2004 (Office of the Cane and Sugar Board, 2005).

The actual accuracy of sugarcane area classification should be evaluated because it was impossible to perfectly identify the true class of every pixel or polygon. Fieldwork for checking on the sugarcane area was completed during September to December 2005. The total number of sample points used for analysis was 555 (312 points for sugarcane area class and 243 points for non-sugarcane area class) based on the 2004 sugarcane area map dataset (Figure 4.2). The overall accuracy was calculated to be 87.7 %. The observed misclassification was 68 sample points or 12%. Producer and user accuracies varied according to the class and were reported with 90% confidence limit (Table 4.6). Thus, the overall sugarcane planting area in this region was about 11 % less in 2005 than in 2004. This indicates that accurate information on the sugarcane planting area is one of the necessary steps if soil carbon stock is to be reliably estimated (Hey, 1979).

An average of accuracy estimated in this study was 87.9% and an overall accuracy was 87.7 %, with a Kappa coefficient of 0.75. The average accuracy indicates whether the sampling points in each class (planting and non-planting) are correctly identified and perfect. On the other hand, the overall accuracy was estimated from all sampling points without recognizing that they are planting or non-planting points. Both average and overall accuracies indicate that there is relatively small error in identifying the sugarcane planting area. The Kappa valued of 0.75 means the sugarcane area map we used was moderately accurate and thus reliable for estimate the overall planting area (Table 4.6).

The error from this map probably occurred as the time lag between satellite image, GIS data and field verification was 1 year. The error may be occurred with the instrument (Global Position System: GPS). In general, a GPS receiver can provide position information with ± 25 m error and velocity information with an error of less than 5 m/s (Mukunda *et al.*, 2004). The error in the overall mapping may also arise from misclassification in types of vegetation or plant and error from the digitized. Normally, in remote sensing projects, error assessments are only performed after completion of data analysis and usually only address thematic and location accuracy.

To reduce error from thematic maps, field surveys need to be calculated. Field surveys for interpretation and verification are complicated in areas of land use change or conversion subsequent the time of photo acquisition. The observation may lead to

recorded error in the classification accuracy estimation. Three types of in accuracy were area misclassification; line error and control point location error need to be address and procedure for quantitatively specifying each types of an error. For this study error for sugarcane area was identified and used to explore the sugarcane area map for soil carbon estimation in the next step.

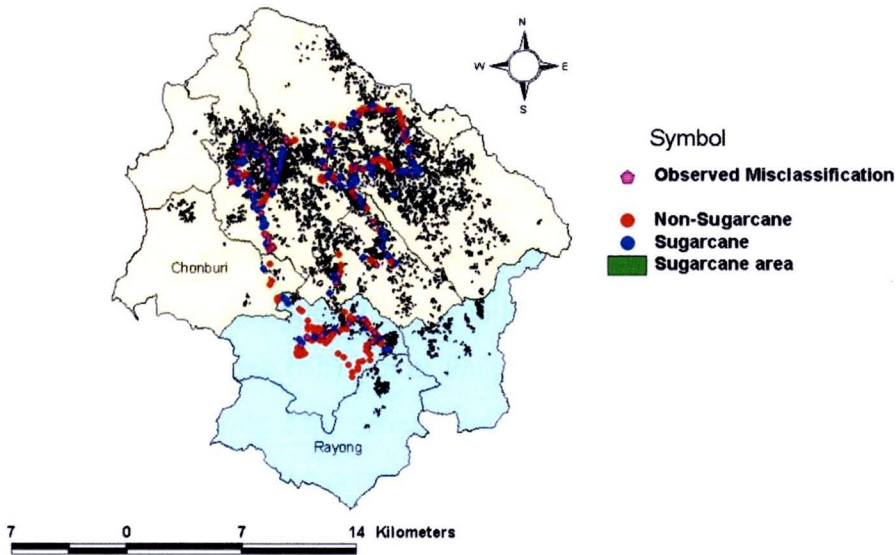


Figure 4.2 Sugarcane area and non-sugarcane area with all points sampled from the 2005 accuracy assessment

Table 4.7 Error matrix analysis in sugarcane and non-sugarcane area map evaluation

Class name	Sugarcane	Non-Sugarcane	Total	User's accuracy	Commission error
Sugarcane	258	54	312	82.7	13.7
Non-Sugarcane	14	229	243	94.2	5.8
Total	272	283	555	-	-
Producer's accuracy	94.9	80.9	-	-	-
Omission error	5.1	19.1	-	-	-

Total sampled	555
Observed misclassification	68
Overall accuracy	87.7 %
Average accuracy	87.9 %
Kappa coefficient	0.75

4.3.2.2 Soil classification and characteristics

Soil at the study sites was classified into several orders. Udisols and Paleustults sub-order covers about 45% of study area. These soils were generally sandy loam and loamy sand. Quartzipsaments covers approximately 20% of the area and are sandy soil. Tropaqualfs, Tropaqupts and Hydraquenta cover approximately 16% of the area. In fact, the whole study area consists of about 60 soil series (Soil Survey Staff, 1998; Land Development Department, 1993; Pisoot and Hari, 2001; Sathira *et al.*, 2004; Kiti *et al.*, 2004; Wutticart *et al.*, 2004; Aniwru *et al.*, 2004; Land Development Department, 2005a; Land Development Department, 2005b). Chonburi province covered for 41 soil series and Rayong 33 soil series. However, the 10 soil series that were selected cover about 84 % of sugarcane area in the study region. These soils included Satuek series (Suk), Ban Bueng Series (Bbg), Sattahip series (Sh), Phon Phisai series (Pp), Chon Buri series (Cb), Hup Kraphong series (Hg), Nong Mot series (Nm), Thung Wa series (Tg), Phang Nga series (Pga) and Khlong Nok Krathung series (Knk). Their soil characteristics and properties are given in Figure 4.3, Table 4.9. The area under investigation of ten soil series was represented in Table 4.8. Therefore, Satuek series (Suk) was the largest for sugarcane area in the study area and Khlong Nok Krathung (Knk) series was the smallest for sugarcane area in this region. It covers less than 1 percentage of the whole sugarcane area at the study site.

Figure 4.3 shows the spatial distribution of all ten soil series and the levels of their soil organic carbon obtained from the LDD data sheet. The level of organic carbon ranged from 0.27 to 1.68%. According to the LDD, these soils are considered as the low to moderate fertility (low; < 1.5, medium; 1.5-3.5 and high; > 3.5) (Pisoot and Hari, 2001). It seems that the organic carbon content is related to the soil clay percentage (Table 4.5). However, from the information presented, it can be said that sugarcane planting area in this study was low in soil organic carbon contents when compared to the other area not used for sugarcane planting. The soil pH in all soil series was near neutral, which is similar to those reported by the LDD (Table 4.8).

In other countries: study on soil carbon in agriculture area especially on sugarcane area was low to moderate fertility depended on receiver fertilizer, land management and soil fraction. Changes in soil chemical and physical properties indicated that land management is not sustaining the resource base for sugarcane cultivation in the long-term.

The organic carbon declined from 5.5 to 3.2 g/kg from 1979 to 1996 in the sugarcane area in Papua New Guinea were strong recommended organic carbon changed depend on sugarcane cultivation practices (Alfred, 1998).

Table 4.8 Ten-major soil series that were planted to sugarcane in the study region (Chonburi and Rayong provinces)

Soil series	Sugarcane area (ha)	% of sugarcane area in two provinces
Satuek series (Suk)	9,271.43	31.64
Ban Bueng Series (Bbg)	6,610.00	22.56
Phon Phisai series (Pp)	2,426.71	8.28
Chon Buri series (Cb),	2,200.73	7.51
Sattahip series (Sh)	2,270.00	7.75
Nong Mot series (Nm)	1,742.59	5.95
Hup Kraphong series (Hg)	1,751.02	5.98
Thung Wa series (Tg),	41.33	0.14
Phang Nga series (Pga)	36.44	0.12
Khlong Nok Krathung series (Knk).	10.87	0.04
Total	~ 26,361.12	~ 89.97



Land Development Department, 2005a; Land Development Department, 2005b; Office of the cane and sugar board, 2005

4.3.2.3 Estimate of soil organic carbon

Results of soil bulk density, soil carbon analysis and estimate of soil carbon stock for these ten soil series are summarized in Table 4.10. The bulk density was ranged from 1.35 to 1.60 g/cm³ and soil bulk density map is shown in Figure 4.4. The results of soil organic carbon analysis by using different techniques are also given (Walkley and Black method and Flash combustion technique). The data were arranged to replicate the mean value of the difference determination, soil organic carbon techniques and by soil series. More than 50 % of sugarcane area in this study covered by Satuek soil series (Suk) and Ban Bueng soil series (Bbg), 28 % and 24 % of total sugarcane area in the region, respectively. It was shown that soil organic carbon is generally quite low (0.27 to 0.53%).

There was similarly to soil organic carbon content in the case study as mentioned above. The results for pH were higher than to those reports for soil of Thai Land Development Department data sheet (Table 4.9).

The results of carbon analysis performed by the LDD and this study were based on the Walkley and Black method. In most case, the results of LDD were higher than the current study by a factor of two. On the other hand, the flash combustion technique significantly gives higher value than that of Walkley's method (Table 4.10). However, a good relationship between the results obtained by Walkley's and flash combustion method under current study was observed, indicating the systematic consistency between these two techniques. Thus, the discrepancy between the data and that of LDD is not caused by using different technique but rather by other factors. There are several reasons for the discrepancy between the results obtained from this study and that of the LDD. One example is the time of soil sampling. It is known that organic carbon in soil under cultivation decreases along with the history, unless intensive management such as farmyard manure fertilization is applied.

Thus, taking sample in different year would result in different carbon content. In addition, along soil cultivation chronology, the soil organic carbon would change according to variations in cultivation practices. However, the results indicate that flash combustion has a tendency to overestimate carbon content when compared to the conventional Walkley's method. In the soils with significant amount of carbonates, the flash combustion technique can overestimate if carbonates are not removed before analysis or accounted for by analysis. These occurs inorganic constituent, primarily hydrated clays, loss weight during heating along with the organic material. High temperature heating (>500 °C) can result in loss of CO₂ from carbonates. On the other hand, soil organic carbon estimation can be underestimated by the Walkley's method. The procedures have several errors to be evaluated and corrected by using correction (oxidation and conversion) factors. Moreover, the main sources of errors in the soil organic carbon are erratic field sampling and the need to express results on a volumetric basis by using the soil bulk density taken at sampling (Lai *et al.*, 2001). Although, this study corrected all factor that influence to soil organic carbon error from these two methods, however, in most case the soil organic carbon from flash combustion gave higher value than Walkley's method.

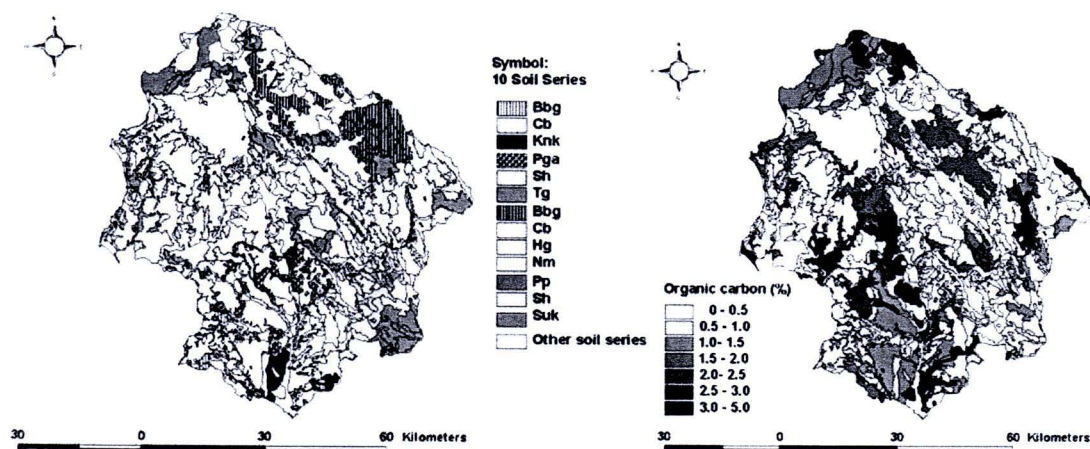


Figure 4.3 Map of the ten soil series that are included in this study and their soil organic carbon levels

Table 4.9 Characteristics and properties of the soils used in the present study (\pm the standard deviations from composite sample/3 replications)

Soil series	Soil series code	% OC	pH 1:1 (soil: water)	pH (Lab)	Sand (%)	Silt (%)	Clay (%)	Characteristic, Soil Taxonomy, 1998
Satuek	Suk	0.27	4.8	7.2 \pm 0.29	73.7	21.8	4.5	Fine-loamy, Siliceous, subactive, Isohyperthermic, Typic Paleustults
Ban Bueng	Bbg	0.53	5.2	6.8 \pm 0.07	81.5	13.5	5.0	Isohyperthermic, Coated, Oxyaquic Haplorthods
Sattahip	Sh	0.36	5.1	5.6 \pm 0.01	91.7	3.8	4.5	Isohyperthermic, Coated, Typic Quartzipsamments
Phon Phisai	Pp	1.23	5.4	6.2 \pm 0.38	49.2	40.2	10.6	Clayey skeletal, Kaolinitic, Isohyperthermic Typic Paleustults
Chon Buri	Cb	0.41	5.1	6.8 \pm 0.03	65.2	28.2	6.6	Fine-loamy, mixed, semiactive, Isohyperthermic, Typic Endoaqualfs
Hup Kraphong	Hg	0.34	5.8	5.8 \pm 0.34	76.8	18.7	4.5	Coarse-loamy, mixed, active, Isohyperthermic, Typic Haplustalfs
Nong Mot	Nm	1.68	5.1	5.5 \pm 0.14	41.4	31.1	27.5	Fine, kaolinitic, Isohyperthermic, Typic Kandistults
Thung Wa	Tg	0.66	4.4	6.0 \pm 0.10	79.0	15.0	6.0	Coarse-loamy, siliceous, suactive, Isohyperthermic, Typic Paleudults
Phang Nga	Pga	0.97	5.1	5.9 \pm 0.18	56.0	37.0	7.0	Fine, kaolinitic, Isohyperthermic, Typic Kandiuults
Khlong Nok Krathung	Knk	1.32	4.3	5.6 \pm 0.09	64.2	21.2	14.6	Fine-loamy, kaolinitic Isohyperthermic, Typic Kandiuults

Sources; (Soil Survey Staff, 1998; Land Development Department, 1993; Pisoot and Hari, 2001; Sathira *et al.*, 2004; Kiti *et al.*, 2004; Wutticart *et al.*, 2004; Aniwru *et al.*, 2004; Land Development Department, 2005a; Land Development Department, 2005b)

4.3.2.4 Estimate of Soil carbon stock

The calculation results of soil carbon stock were compared between LDD data (Walkley's method) and from soil survey (Walkley's method). The same bulk density from the survey were used for soil carbon stock calculation. There were not significantly different on soil carbon stock from LDD data sheet and that from this study by Walkley and Black at 95% confidence level by t-Test: Paired two Samples for Means ($p=0.13$). In most case soil carbon stock from LDD data sheet give higher values than the current values. It can be concluded that soil organic carbon decreased after intensive cultivation for longer period. Because LDD conducted there soil organic carbon analysis during 1961-1974 (Table 4.11), the difference between those reported by LDD and the present study could be interpreted as the lost of soil organic carbon according to land use activity. Based on this assumption, it is estimated that after 37 years of cultivation, the soil carbon stock was decreased about 91.12 kg C/ha/yr. The soil C stock losses is about 77.02% of total soil C stock and increase is about 22.98% of total soil C stock (Table 4.11). The reason for such increase is not known. But this indicates that sugarcane cultivation is not necessarily lead to loss of soil carbon. In addition, it was found that soil carbon stock change was related to the soil physical properties (% sand, silt and clay) (Figure 4.6).

The estimated carbon stock based on LDD, Walkley and Black method, and flash combustion data were 548, 374 and 596 Tg C ($Tg = 10^{12}$ g C), respectively. Thus, carbon stock based on the flash combustion technique was $37.04 \pm 15.56\%$ higher than that of Walkley and Black method. The soil C stock was 14.61 ± 3.79 ton C/ha by Walkley and Black Method and 24.36 ± 5.49 ton C/ha by Flash combustion method at 30 cm depth.

Table 4.10 Estimation of carbon stock in different soil organic carbon techniques (\pm standard deviation from composite sample/3 replications)

Soil series	Sugarcane area (ha)	Sugarcane of total area (%)	Bulk density (g/cm ³)	LDD data sheet (Walkley)		This study (Walkley)		This study (Flash)	
				OC*	C stock (Tg C)	OC*	C stock (Tg C)	OC*	C stock (Tg C)
Suk	7,470	28.3	1.43 \pm 0.01	0.27	87 \pm 0.01	0.47 \pm 0.01	151 \pm 0.01	0.68 \pm 0.01	218 \pm 0.01
Bbg	6,204	23.5	1.58 \pm 0.19	0.53	156 \pm 0.19	0.28 \pm 0.003	82 \pm 0.19	0.5 \pm 0.08	147 \pm 0.21
Sh	1,812	6.9	1.49 \pm 0.14	0.36	70 \pm 0.14	0.38 \pm 0.01	39 \pm 0.14	0.58 \pm 0.01	69 \pm 0.14
Pp	1,781	6.8	1.35 \pm 0.04	1.23	30 \pm 0.04	0.48 \pm 0.01	29 \pm 0.04	0.85 \pm 0.06	44 \pm 0.07
Cb	1,526	5.8	1.38 \pm 0.08	0.41	23 \pm 0.08	0.40 \pm 0.005	24 \pm 0.08	0.61 \pm 0.08	37 \pm 0.11
Hg	1,210	4.6	1.52 \pm 0.05	0.34	129 \pm 0.05	0.49 \pm 0.004	14 \pm 0.05	0.64 \pm 0.04	30 \pm 0.06
Nm	1,207	4.6	1.34 \pm 0.16	1.68	16 \pm 0.16	0.25 \pm 0.01	24 \pm 0.16	0.55 \pm 0.08	31 \pm 0.18
Tg	445	1.7	1.48 \pm 0.01	0.66	13 \pm 0.01	0.27 \pm 0.01	5 \pm 0.01	0.51 \pm 0.05	10 \pm 0.05
Pga	392	1.5	1.60 \pm 0.04	0.97	18 \pm 0.04	0.24 \pm 0.01	5 \pm 0.04	0.45 \pm 0.04	8 \pm 0.06
Knk	117	0.4	1.45 \pm 0.04	1.32	7 \pm 0.04	0.31 \pm 0.01	2 \pm 0.04	0.39 \pm 0.05	2 \pm 0.06
Total	22,164	84.1	-	-	548	-	374	-	596

Remark: LDD=Land Development Department, Walkley= Walkley and Black method, Flash = Flash combustion method,

OC = Organic Carbon, Bulk density at 0 to 30 cm depth level and Tg = 10¹² g C., * = Unit = g C/100 g soil

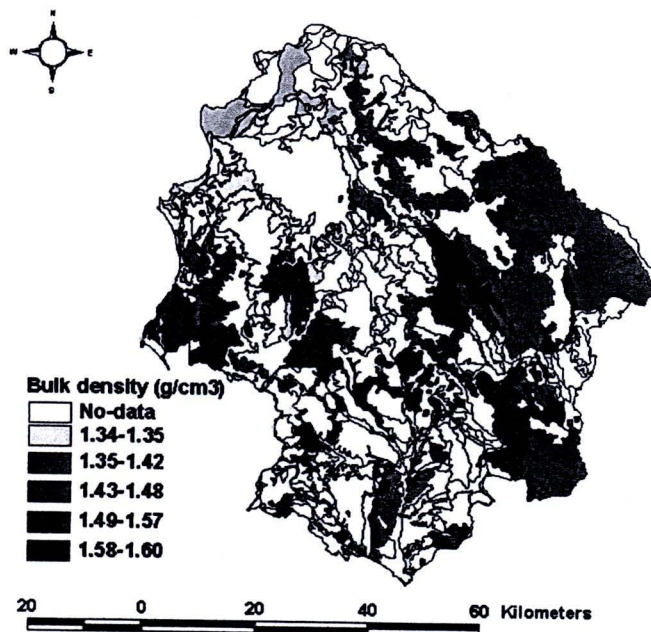
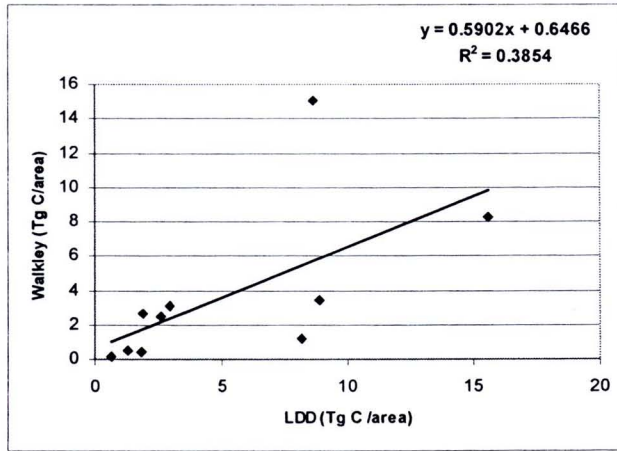
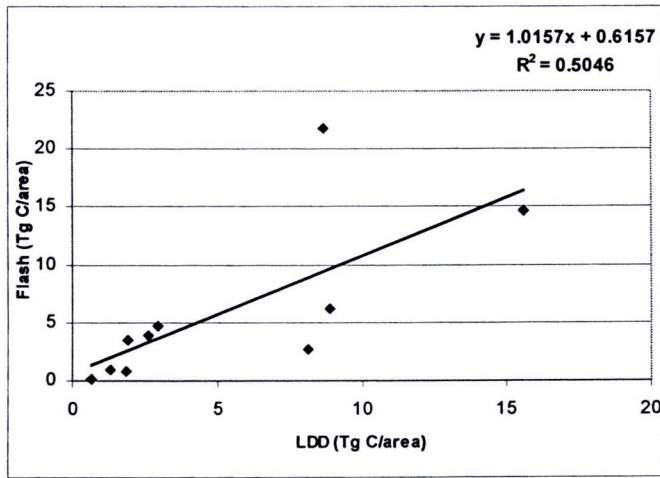


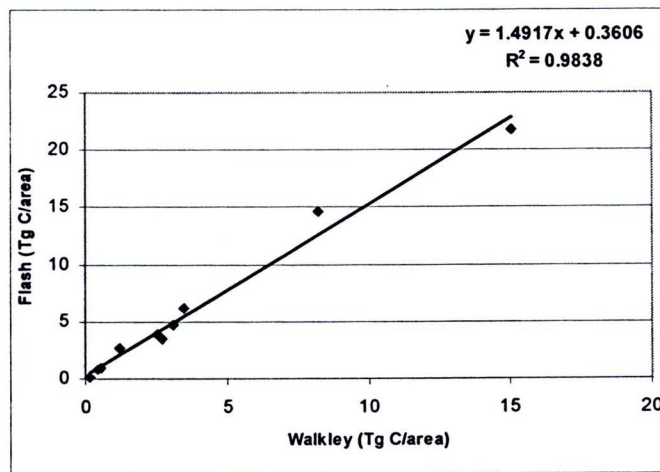
Figure 4.4 Soil bulk density in the study area



a



b



c

Figure 4.5 Comparison between SOC analysis methods by t-Test: Paired Two Sample for Means at 99% confidence level

Table 4.11 Soil carbon stock changes at 30 cm depth, compare between LDD data sheet and our field by Walkley’s method, LDD and Flash combustion

Soil series	Year of soil survey			Soil C stock change (kg C/ha/yr)
	LDD	This study	Time Change	
Suk	1971	↑ 2005 ↓	34	+25.24
Bbg	1973		32	-37.03
Sh	1961		44	-39.62
Pp	1964		41	-0.99
Cb	1964		41	+2.02
Hg	1969		36	-263.47
Nm	1964		41	+14.71
Tg	1966		39	-44.40
Pga	1974		31	-113.03
Knk	1972		33	-133.14

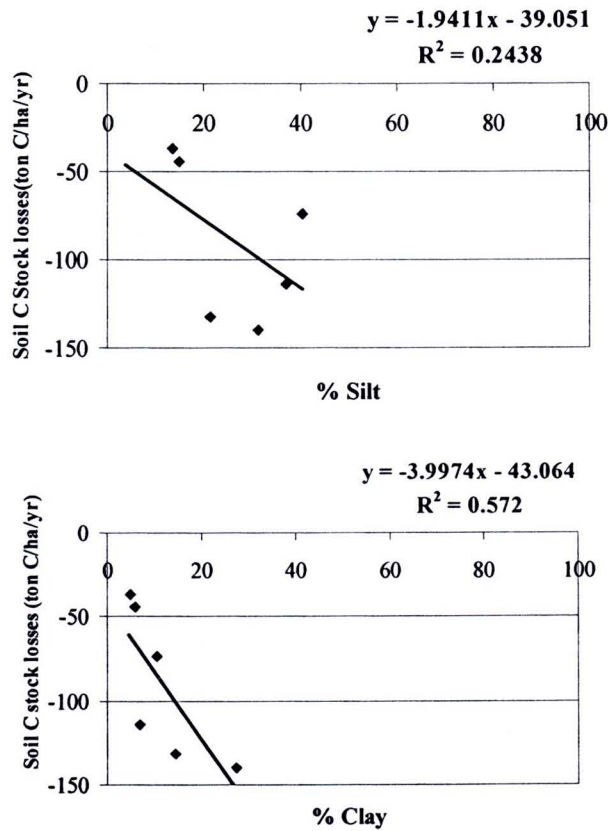


Figure 4.6 Relationship between soil carbon stock change and % sand, silt and clay from LDD data sheet

4.3.2.5 Summary of soil carbon stock in Eastern Thailand

The investigations of soil characteristics indicate that majority of soils under sugarcane plantation in this region are low in fertility, with sandy texture and being low in total soil organic carbon content (4-9 mg C /g soil in the upper 30 cm). When used the database from LDD (Soil Survey Staff, 1998; Land Development Department, 1993; Pisoot and Hari, 2001; Sathira *et al.*, 2004; Kiti *et al.*, 2004; Wutticart *et al.*, 2004; Aniwru *et al.*, 2004; Land Development Department, 2005a; Land Development Department, 2005b) which determined the carbon content by Walkley and Black method (Walkley and Black, 1947), the soil carbon stock in the area (22,164 ha) was estimated at 548 Tg C (Tg = 10^{12} g C). Using the data of soil analysis (bulk density and soil carbon content measured by flash combustion) from the field soil surveys, it was estimated that the carbon stock for the whole area was at 596 Tg C. In addition, the effects of the choice of carbon analytical techniques on the carbon stock estimates, i.e. flash combustion vs. Walkley and Black method) was also compared. The estimated value using the Walkley and Black method was 11% lower than that by the flash combustion technique. Thus, the discrepancy in soil carbon stock estimates between that of LDD's and the current study may arise from both different technique for C analysis and changes in certain soil properties (mainly soil organic carbon that changes according to mode of cultivation practices and time).

To scale up the estimate of soil carbon from field surveys to the whole sugarcane planting area in Eastern Thailand, a land use map, already checked for accuracy, was used. The map overall accuracy for the map used in this study was 87.7 %, which is acceptable according to the standard of 80% set by the National Park service (Environmental Systems Research Institute, 1994). Firstly, soil carbon data reported by the LDD need to be updated. The preliminary results of soil carbon analysis suggest that the data reported by the LDD may not be accurately used to estimate soil carbon in the sugarcane area in the present situation. This may be due to the fact that soil properties and characteristics such as carbon content have been changes since the time that the LDD conducted their studies (from 1961-1974). Therefore, more updated data may be needed. Moreover, the result was shown that different analytical techniques may contribute to different soil organic carbon value and soil carbon stock. However, the current study indicated that both Walkley's and flash combustion techniques can be used to estimate the soil carbon content, but the flash combustion technique tends to give a higher value when to the conventional Walkley's method. Among three data set that are used to estimate carbon stock from the

available soil map, the flash combustion gave the highest (596 Tg C), followed by that the LDD's (548 Tg C using Walkley's technique) and the analysis using Walkley's technique in the present study (374 Tg C).

For the whole study area in Chonburi and Rayong provinces (26,360 ha), the estimation for carbon stock based on LDD, Walkley and Black method and flash combustion data were 62.38, 44.50 and 70.68 Tg C, respectively.

4.3.3 Soil C Stock in sugarcane plantation

4.3.3.1 Stock of soil organic carbon in Thailand

This section tries to compile soil organic carbon stock in the land area where sugarcane is planted, partly based on the filed survey and plot study in Eastern Thailand as mentioned above. In Thailand, there were not many studies about soil carbon stock and its changes, especially over the long term period. The previous studies usually focused on short term experiment and related to soil fertility and input crop productivity (Moncharoen, *et al.*, 2001). Nevertheless, there are some studies in Thailand that document the soil organic carbon content (Moncharoen, *et al.*, 2001). There were studies on the amount of soil carbon from different environments, soil classification etc. (Figure 4.7, 4.8 and 4.9).

The results suggested that 43.3 % of country area (222,210 km²) at depth of 0-25 cm contained 4-8 kg/m² of carbon (6.4-12.8 tons/rai or 40-80 ton/ha), 33.3 % of country area contained 2-4 kg/m² and 7.03 % of country area contained < 2 kg/m². Totally soil carbon stock at 1 meter depth, in the whole area of Thailand is 6,211,706 Gg or approximately 0.046% of total organic carbon in the world (Moncharoen, *et al.*, 2001).

These results were calculated from the land use map with the resolution of 1:2,000,000. Evaluation had been made from all data available in the Department of Land Development from 1968 to 1989. It consists of 631 profiles from 187 soil series collected from difference part of the country. The data consists of analytical and environmental aspects related to the differences in soil organic matter content. The study has shown that about 65%, 3% and 1 % of country's area are classified as low, moderate and high in soil organic matter content, respectively. However, the area with organic matter content lower than 1.5% is mainly found in the northeast, where low land for rice is the main land use activity (Anandana, 1989).

4.3.3.2 Stocks of soil organic carbon in sugarcane-planting area in Thailand

Most of soil carbon stock in sugarcane areas in Thailand ranged from < 2 to 20 kg/m^2 at depth 0-25, 0-50 and 0-100 cm. These are based on sugarcane area (Office of the cane and Sugar Board, 2006) and overlaid with organic carbon data and area from Moncharoen (2001). In the Central and Eastern regions have the relative high range of soil carbon stock (Table 4.12).

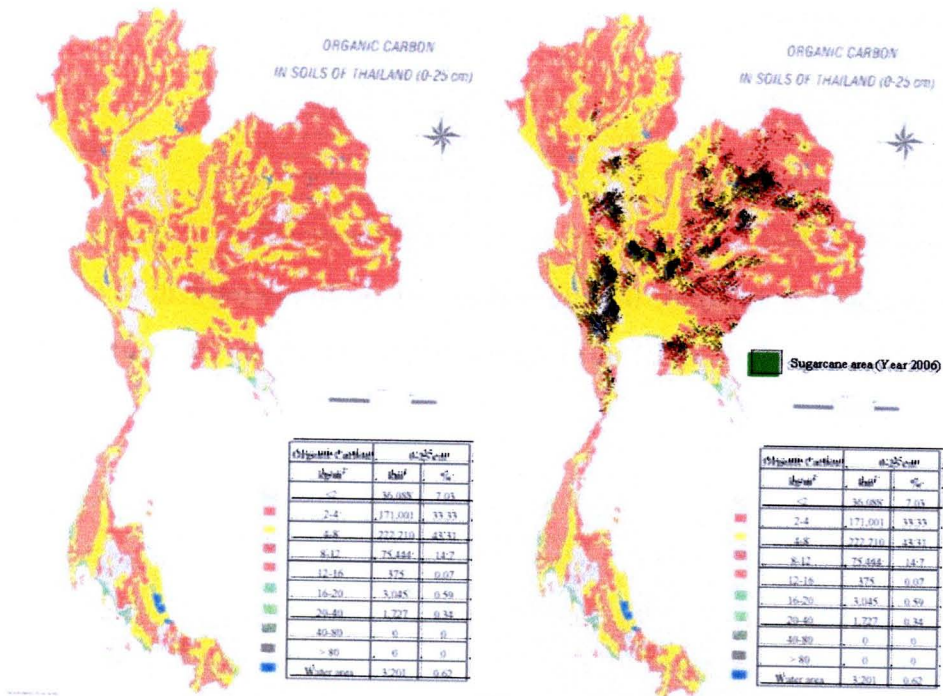


Figure 4.7 Map of distribution of organic carbon at 0-25 cm depth in Thailand (modified from Moncharoen, *et al.*, 2001) and sugarcane area (Office of the cane and Sugar Board, 2006)

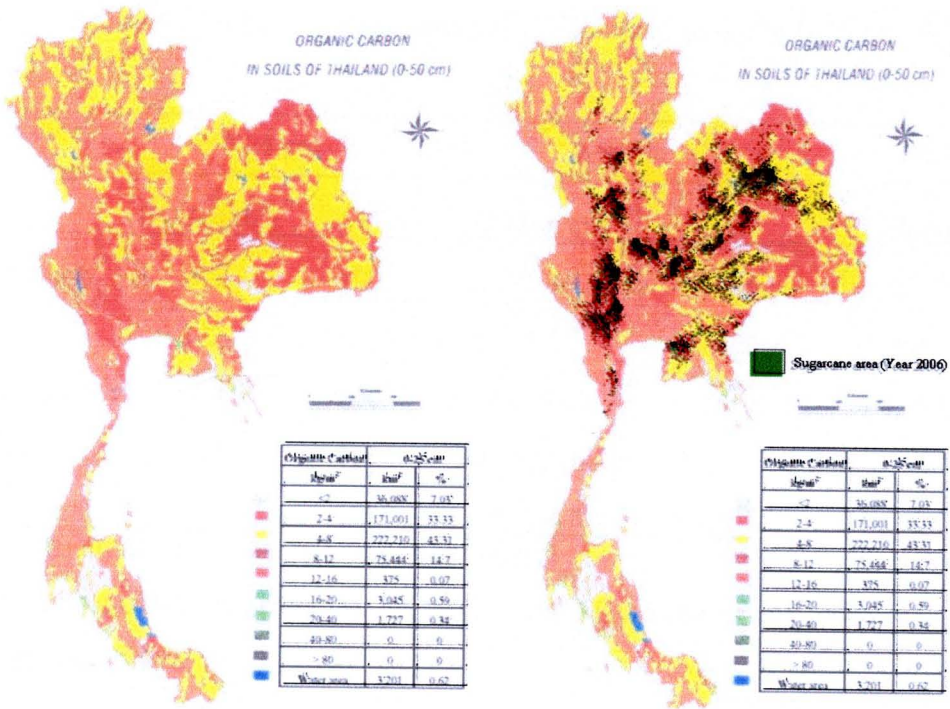


Figure 4.8 Map of distribution of organic carbon at 0-50 cm depth in Thailand (Modified from Moncharoen, *et al.*, 2001) and sugarcane area (Office of the cane and Sugar Board, 2006)

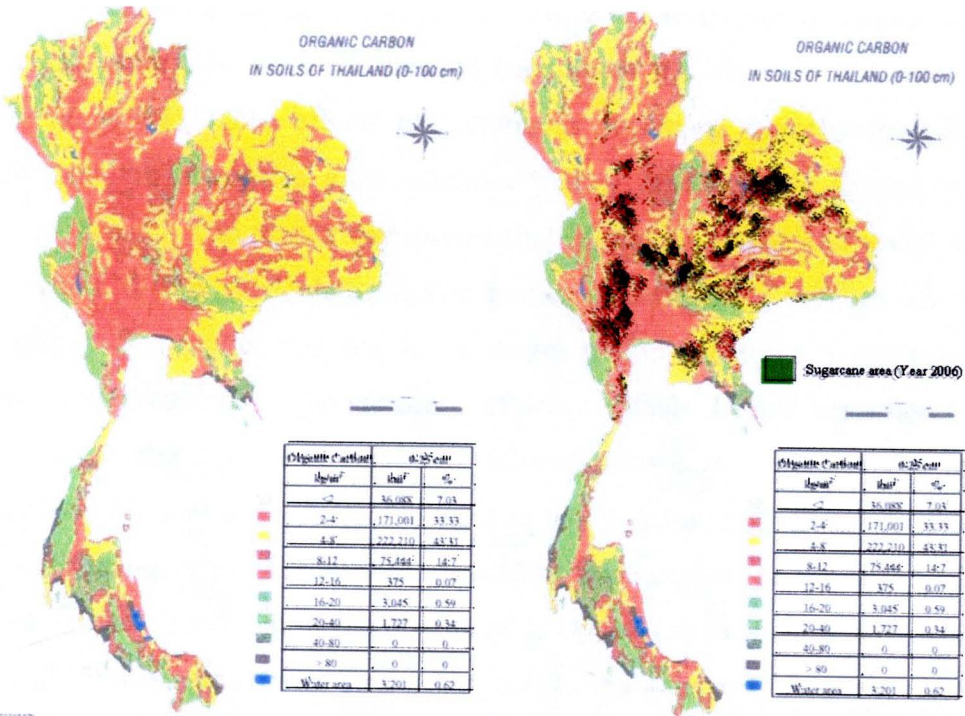


Figure 4.9 Map of distribution of organic carbon at 0-100 cm depth in Thailand (Modified from Moncharoen, *et al.*, 2001) and sugarcane area (Office of the cane and Sugar Board, 2006)

Table 4.12 Organic carbon in sugarcane soil of Thailand at depth 0-25 cm, 0-50 cm and 0-100 cm

Location	0-25 cm		0-50 cm		0-100 cm	
	OC (kg/m ²)	% ^a	OC (kg/m ²)	% ^a	OC (kg/m ²)	% ^a
West/North	< 2	100	2-4	100	2-4	100
West	<2, 2-4	50, 50	2-4	100	2-4	100
Central	4-8	100	2-4, 8-12	75, 25	4-8, 8-12	50, 50
East	2-4	100	2-4, 4-8, 16-20	35, 50, 15	4-8, 16-20	90, 10
East/North	2-4	100	2-4, 4-8	25, 75	4-8, 8-12	20, 80

^a% of total area in the region (an approximately)

Modified from (Moncharoen, *et al.*, 2001) and sugarcane area (Office of the cane and Sugar Board, 2006)

4.3.3.3 Soil C stock change in sugarcane-planting area

Many studies have shown that as much as 40% to 60% of the soil organic carbon in many soils has been lost as result of converting the soil from its natural to agriculture production, especially when the soil has been under the intensive and repeat cultivation (Lal *et al.*, 1998). The effects of continuous sugarcane (*Saccharum officinarum* L.) cropping on the properties of a cohesive Yellow Latosol were studied in the region Northeast Brazil. The results determined that in relation to the soil under native forest, total organic C and particulate organic matter contents were reduced after 2 years of cultivation. Sugarcane cropping for a longer period promoted a recuperation of soil organic matter content. The decrease of total organic C and reduction in aggregate stability limit after 2 years of sugarcane cultivation rendered the soil more susceptible to compaction (Silva *et al.*, 2007). Changes in soil C following afforestation of sugarcane fields with fast-growing Eucalyptus plantations were studied in Hawaii. Using stable C isotopes, it was found that the contributions to changes in total soil C that were due to the loss of C from the prior cane cultivation, and to the gain of C from the new Eucalyptus plantations. Total soil C at 10-13 years after afforestation was 114 and 113 Mg/ha, respectively, in the Eucalyptus and cane plantation. Eucalyptus increased total soil C in the 0-10 cm layer by 11.5 Mg/ha, but that was offset by a loss of 10.1 Mg/ha of cane-

derived C from the 10-55 cm layer (Bashkin and Binkley, 1998). Thus, taking sample in different year would result in different carbon content. In addition, along soil cultivation chronology, the soil organic carbon would change according to variations in cultivation practices.

According to Yoneyama *et al.* (2006) who studied the effects of sugarcane cultivation on soil carbon, the organic C content was significantly decreased after the conversion from forest to sugarcane fields. The soil organic carbon was decreased to a steady state and sugarcane cropping for a longer period promotes to maintain of soil organic carbon contents.

4.3.4 Summary of the results

The analysis of soil samples taken from sugarcane planting area and the synthesis of soil organic carbon data from studies in the past in this chapter can be concluded that soil organic carbon in sugarcane area in Thailand is decreasing. After 37 years of intensive cultivation, 85% of soil organic carbon was lost. The loss rate for sugarcane planting area in the eastern region of Thailand was estimated at 91.12 kg C/ha/yr at the depth of 0-1 m. The results also reveals that the amounts and loss rate depends on what analytical techniques are used. Example given in this study is that the flash combustion gives a higher value than Walkley's method of about 11%.