CHAPTER 3
METHODOLOGY

3.1 Introduction

The methodological framework of this study is based on field and laboratory measurements of carbon flow and identifying the flow of carbon using the full carbon accounting concept. This study is divided into two main parts. The first part determines fluxes of CO_2, by using chamber method. This part consists of two experiments; field and laboratory studies. In the field, chamber method was used to determine daily CO_2 flux covering one sugarcane cropping season (1 year). Soil samples were taken to analyze the amount of carbon storage in soil. Laboratory study involves analyzed of soil physical and chemical properties. Other important data support includes study of decomposition rate of sugarcane residues (such as leaf, leaf sheath, shoot and root) and interviews of sugarcane farmers for their farm managements. Determination rate of residue decomposition in the sugarcane field was carried out by using the litterbag technique.

In the second part, carbon flow in sugar factory or industry and energy part was considered. The carbon accounting concepts was used to determine flows and budgets of carbon emission from the sugarcane plantation and bioenergy systems.

In addition, Geographic Information Systems (GIS) and Remote Sensing techniques (Part 3) were applied as trial for soil carbon mapping and aimed at establishing a basis for soil carbon compilation in the future. This was based on overlays of information on sugarcane area, soil types, and soil carbon data. The overall framework of this study is shown in Figure 3.1.

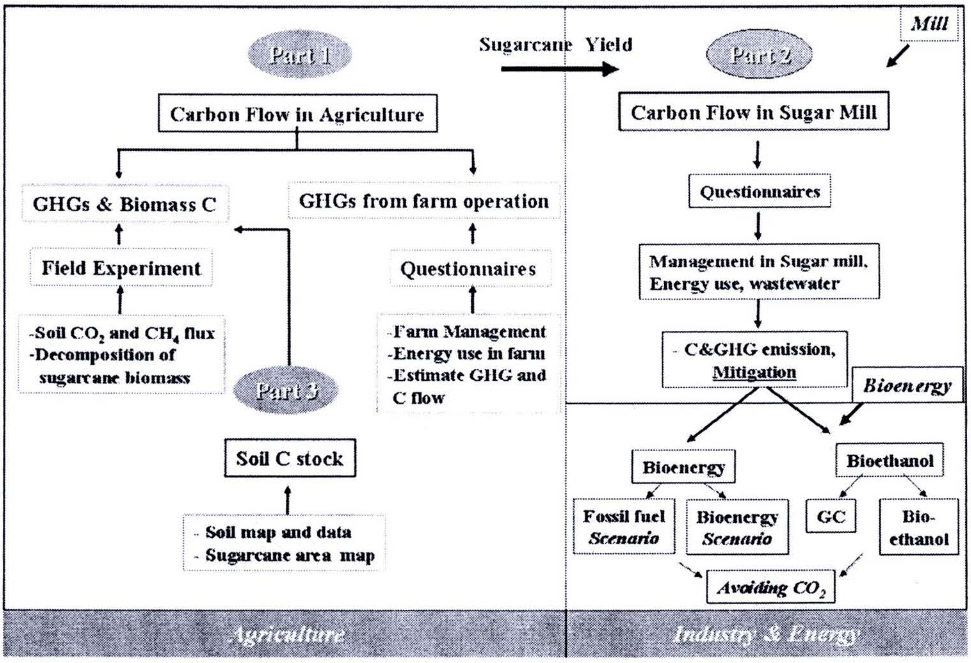


Figure 3.1 Schematic diagram of research framework

3.2 Study site

The study site for daily CO_2 and CH_4 flux measurements and decomposition studies was located in Pluakdang district, Rayong province (Latitude: 12° 58' 42.277" N Longitude: 101° 22' 53.975" E). The selected sugarcane plots were within the main sugarcane planting area in eastern Thailand. The selected sugarcane plots belong to local farmer. This area has been planted with sugarcane only for an approximately 50 years. The study site is approximately 19.2 ha. Within this, 1 site was selected as the 3 study plots (3 replications). The climate is tropical monsoon with the mean annual temperature about 28.5°C, mean monthly minimum and maximum of 22.3°C and 34.5°C in December and April, respectively. The average annual precipitation is 1,340 mm (Figure 3.3, Thai Meteorological Department, 2008).

The soil at the site was classified as Banbueng Satthip soil series (Bbg-Sh) (Pisoot and Hari, 2001). Soil textures at the site are loamy and sandy soil. The soil organic carbon contents of the top soil determined in March, 2006 ranged from 0.42 to 0.49 %. For sugarcane cultivation, soil preparation began in February using a hoe to till topsoil. Sugarcane was planted in March and the harvest was occurred in January of the following year (Table 3.1). Field surveys, flux measurements, soil sampling and decomposition study was performed in this area. The study sites for soil carbon sampling covered the area described above plus the entire area of Chonburi province, since these areas have high density of sugarcane farms (Figure 3.2). Chonburi's agricultural areas are 24,720.16 hectare or 247.16 km^2 or 55.63% of the total lands in the province (436,300 hectare or 4,362 km^2). Majority of the agricultural lands are for crops (50.68 %), followed by perennial fruit trees (38.50 %), and rice fields (8.68 %). The main farming areas are in Ban Bueng District, Sri Racha District, Bang Lamung District, Bo Thong District, and Nong Yai District. Most of the farming is confined to these areas due to its lowland landscape where there are river basins and irrigation areas suitable for farm crops (Office of Agricultural Economics, 2006).

In Chonburi and Rayong provinces, sugarcane areas in 2006/2007 were 26,360 ha or 42.5 % of the total sugarcane area in the Eastern Thailand and 2.51 % of the total sugarcane area in Thailand (Office of the Cane and Sugar Board, (2005). This is the cropping year that field CO_2 flux measurements and decomposition study were carried out.

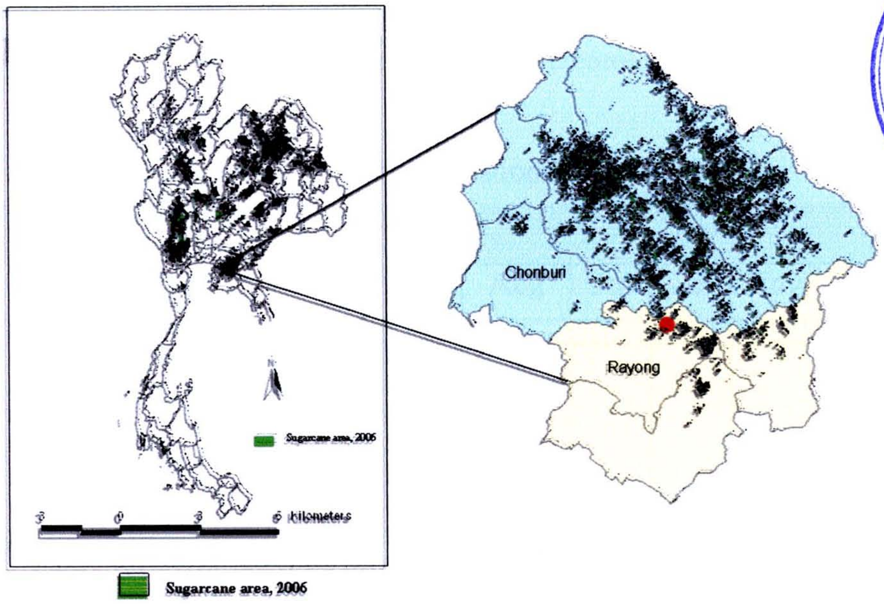


Figure 3.2 Map of Chonburi and Rayong provinces, Thailand, showing the study areas. Red circles show the experimental sites for flux measurements.

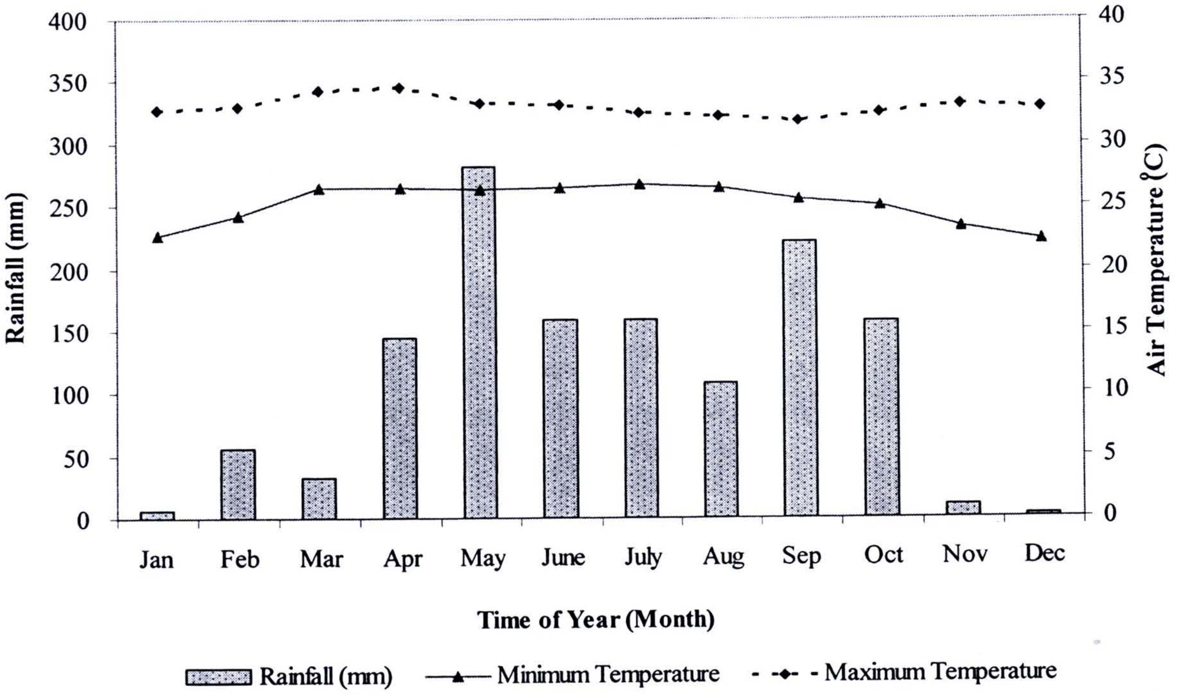


Figure 3.3 Some important climatological data for the study areas in 2006 and 2007 in Chonburi and Rayong provinces (Thai Meteorological Department, 2008).

Table 3.1 Crop calendar for sugarcane plantation in 2006-2007

2006											2007	
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
↔ Land preparation, Irrigation	←					Planting					→	↔ Harvest
	♣●▲		▲		●	▲	■					

♣ Organic fertilizer adding (filter cake)

● Chemical fertilizer addition

▲ Herbicide and Insecticide application

■ Liquid swine manure addition

3.3 Field Experiments

3.3.1 *In situ* gas flux measurements and instrumentation

CO_2 exchange between soil and the atmosphere was determined in terms of flux. Several methods are available for use. However, close chamber technique is the most simple and yet reliable (Zinnaida *et al.,* 1997). Thus, in this study, this technique was employed. The greenhouse gas (GHG) fluxes measured in this study are CO_2, and CH_4 for N_2O did not measured in this study.

3.3.1.1 Closed-automatic chamber

This study applied a close-automated chamber technique for soil CO_2-C flux. The measuring system consists of a chamber and data-storing unit (Figure 3.4). The chamber consists of 2 parts: the cover and base. The cover is made from acrylic of 0.3 m width × 0.3 m length × 0.15 m height and the base is made from stainless steel with dimension of 0.3 m width × 0.3 m length × 0.15 m height. The base was permanently inserted into the soil where gas sampling was conducted throughout the study period. To monitor the net CO_2 exchange through soil respiration and to prevent the effects of photosynthesis, the opaque chamber was used and installed in the area without plant.

CO_2-C flux was measured every two weeks which covered one crop of sugarcane plantation (from planting to harvest). This allowed the study of some factors including seasonal variations, the effects of weather conditions such as, temperature, moisture, and organic residue inputs to CO_2-C flux under field conditions.

When the measurement was performed, the chamber was closed for a period of 15 min. During 15 min period of chamber closure, air sample inside the chamber's headspace was pumped into the measurement unit where CO_2 concentration was determined and stored in data logger (Campbell Scientific CR10x, Logan, Utah, USA). After 15 min, the chamber was automatically opened to the ambient air for about 10 min to allow the chamber to be flushing with ambient air. Measurements were then continued. These procedures were performed repeatedly throughout the measurement periods. The flow rate of pump is 1.5 l/min. The length of tubing is 5 meters from chamber and measurements unit. The calibration with standard CO_2 gas (415 ppm, 382 ppm and 443 ppm, Innovative-Instruments, USA) was performed every time before flux measurements.

The soil and air temperature, and soil moisture were measured every two weeks when *in situ* gas flux measurements were performed. The soil temperature was measured at 2 and 5 cm. depth level and air temperature outside the chamber was measured by using thermometer. Simultaneously, air temperature inside the chamber was measured in real time with in situ gas fluxes by using an automatic temperature probe. The probe was fixed inside the chamber and the data were collected by using a data logger.

Soil moisture was determined along soil depth down to 1 meter (10 cm-depth intervals) by using the automatic soil moisture sensor (Profile probe type PR1, Delta-T Devices Ltd, Burwell, UK). Theta probe type ML2 (Delta-T Devices Ltd, Burwell, UK) was used to measure soil moisture at 6 cm from the soil surface. Moisture meter showed soil moisture content in unit % by volume (cm^3 of water per cm^3 of bulk soil).

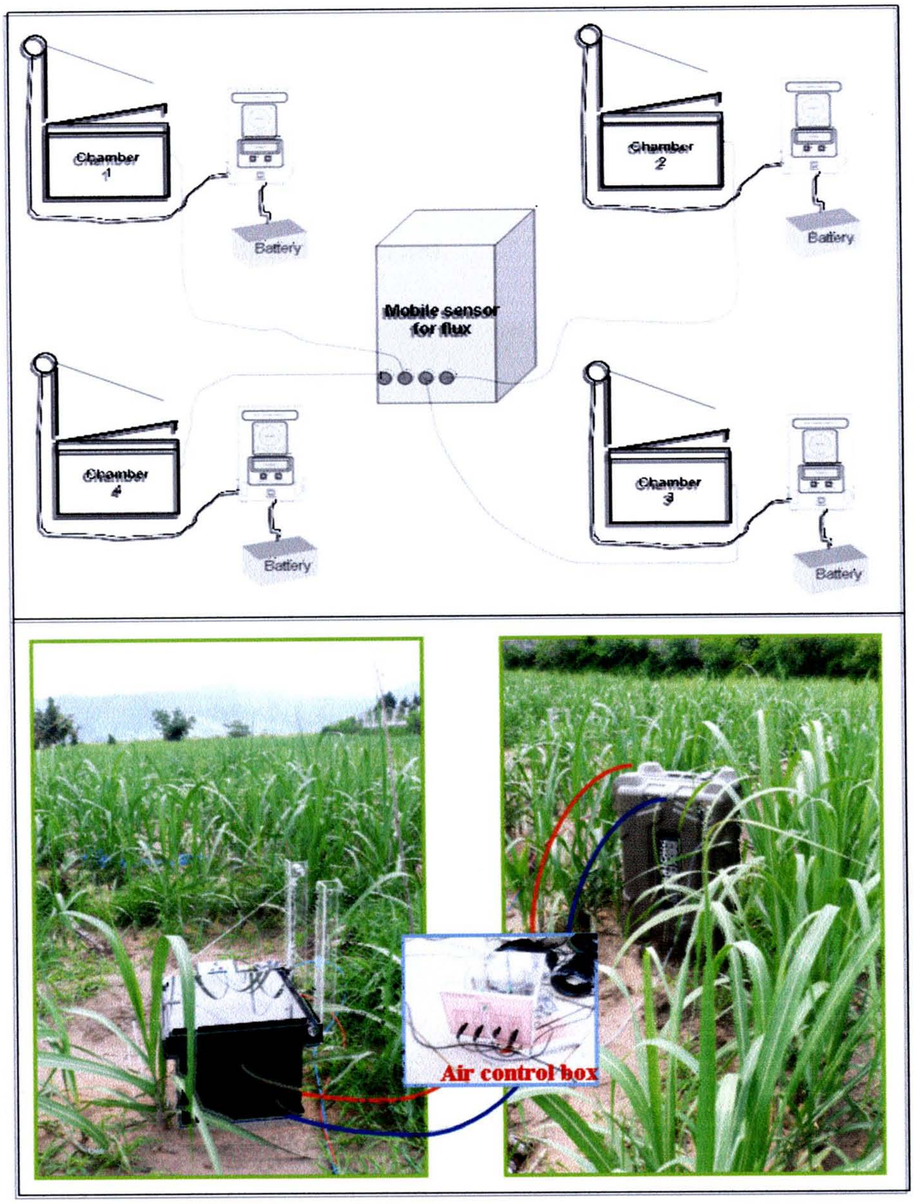


Figure 3.4 Illustration of closed-automatic chamber and a flux measurement setting.

3.3.1.2 Determination of CO_2 concentrations using sensor-based approach

Concentration of CO_2 inside the chamber headspace was determined by NDIR detector (LiCor 8000, Licor Corporation, Lincoln, Nebraska, USA), (Figure 3.5). Calibration using proper standards was performed occasionally in the field. Three standard gas concentrations with CO_2 and CH_4 concentrations were used. Typical calibration curve is shown in Figure 3.6. The exponential relationship between output (mV) and methane concentration (ppm) was then used to calculate methane concentration of unknown sample and linear relationship between output (mV) and CO_2 concentration (ppm) was then used to calculate CO_2 concentration of unknown sample. The measured parameters were stored in data logger and subsequently transferred to working computer for data analysis. The main advantage of using this sensor unit over the conventional gas chromatography method includes large numbers of samples that can be effectively processed and reliably measured within relatively short time period.

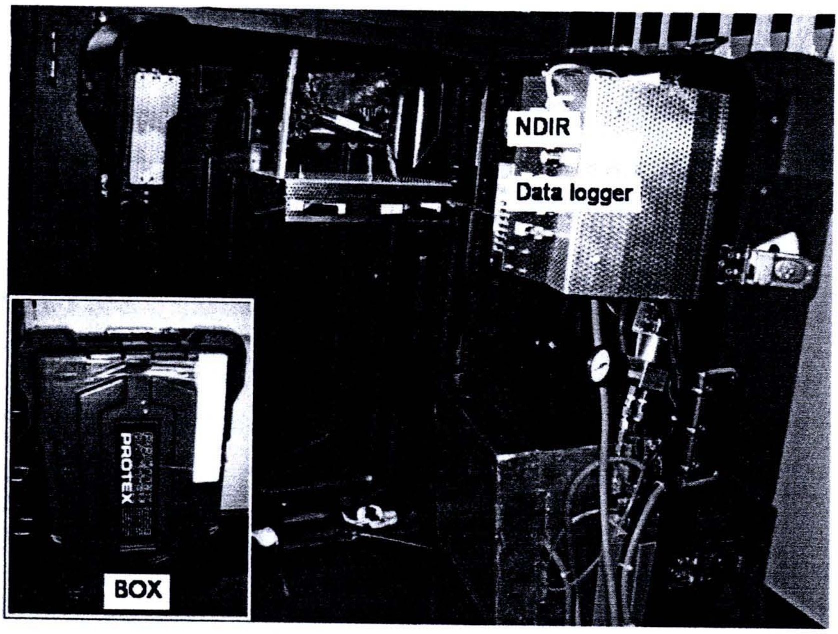


Figure 3.5 The suitcase-sized box for determining of CO_2.

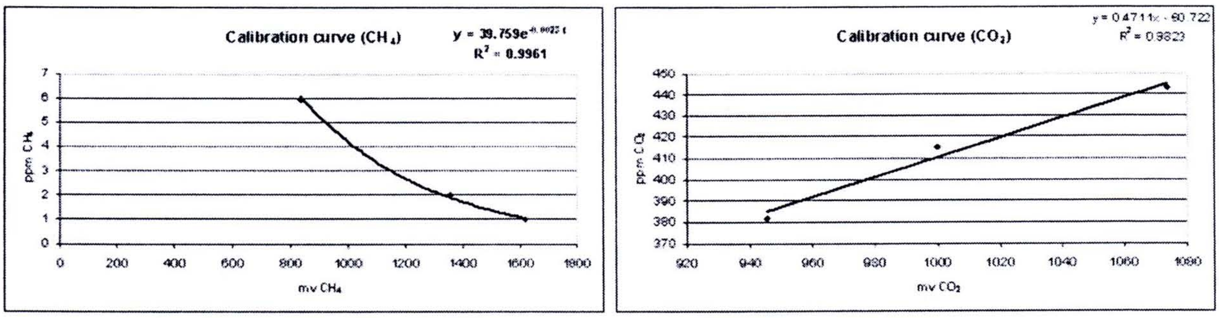


Figure 3.6 Example of calibration curve used to calculate CO_2 and CH_4 concentration, left for CH_4 and right for CO_2.

3.3.1.3 Flux calculations

Greenhouse gas fluxes are expressed in terms of mass per unit area per unit of time (e.g. mg $CO_2/m^2/h^1$). First, the mixing ratio or concentration obtained from the chamber headspace must be converted to a mass or molecular basis using the ideal gas law, thus, depending on temperature and pressure of the enclosed air as shown Equation 3.1:

$$C_i = \frac{q_i MP}{RT} \tag{3.1}$$

Where:

C_i = Mass/volume concentration (g CO_2/m^3)

q_i = Volume/volume concentration (m^3/m^3)

M = Molecular weight (g) of CO_2 (44 g/mol^1)

P = The atmosphere pressure (1 atm)

T = Temperature (K)

R = Universal gas constant ($8.2058 \times 10^{-5} . m^3 . atm. K^{-1} . mol^{-1}$)

Normally, linear and non-linear models have been proposed to describe the relationship between trace gas concentration and time. If the enclosure dimensions, development period and measurement protocol are suitably matched to the rate of trace gas exchanges and sites characteristic, a linear model maybe adopted, which assumed a constant exchanges rate over the period of observations. In this study the flux of these greenhouse gases then were estimated according to this linear model. Accordingly, fluxes were estimated according to the relationship shown in Equation 3.2:

$$F = \frac{dc_i}{dt}\frac{V}{A} \tag{3.2}$$

Where:

F = flux on the aerial basis ($g/m^2/h^1$)

V = enclosure volume or volume of chamber (m^3)

A = basal area (m^2)

$\frac{dc_i}{dt}$ = the observed rate of concentration/mass change over the measuring period of time t (a slope of plot between closure time vs. gas concentration in chamber's headspace) (g CO_2/m^3/min)

It is noted that the regression results were used to select the appropriate data from the field measurement of gases concentration.

3.3.2 Soil property analysis

Soil property is an important parameter controlling CO_2-C fluxes. Collecting soil property is also necessary for soil carbon mapping and analyzing carbon distribution in the study area. Soil parameters that were determined included bulk density, soil porosity and soil texture. The soil chemical parameters were organic C, organic N by flash combustion method and soil pH by Glass-electrode pH meter (Hach, Sension 378, Karava, Finland).

Soil samples were collected from the field experiments at the depths of 0-31, 31-63 and 63-100 cm. The depth level was decided based on color difference of soil layers. Soil samples were taken to the laboratory, air-dried, separated and screened out the gravel and roots by hand. Then, they were sieved through a 2 mm sieve and stored at room temperature for further analysis.

3.3.2.1 Physical parameters

Texture, bulk and particle densities are physical properties of soils that control many important soil processes. Texture affects the total water holding capacity of the soil, percentage of plant-available water, cation exchange capacity and many other soil properties and processes. Bulk and particle density are related to soil porosity, degree of compaction, movement of air and water into and through the soil, related of root growth as well as other properties. Bulk density is the mass of a dry soil sample per unit bulk volume as compared with the mass of an equal volume of water. On the other hand, porosity is the percentage of pore space in soil. The soil samples for bulk density and porosity measurements were taken by using a corer. The soil samples from core with approximately 7 cm. in diameter and the same height (4 cm) was inserted to full height into the soil, broken out and the bottom cut neatly across with the end of the core so that the sample can be retained. Bulk density of each soil samples was determined by weighting the sample after oven dry at 105 °C for 48 hours. Bulk density was expressed as grams per cubic centimeters (Equation 3.3).

$$\text{Bulk density, } \rho_b \text{ (g/cm}^3\text{)} = \frac{\text{Weight of oven dry soil (g)}}{\text{Total volume of soil (cm}^3\text{)}} \qquad (3.3)$$

Total soil porosity is a measure of the volume percentage of pore space and is usually derived from bulk density and soil particle density (weight of oven-dried soil/volume of soil particle only). Soil porosity was computed by Equation 3.5:

$$\text{Porosity} = [1-(\text{Bulk density/Particle density})]*100 \qquad (3.5)$$

Soil texture, which is the relative proportion of the three soil fraction separates (sand, silt and clay), was calculated by using Bouyoucos method in combination with textural triangle (Bouyoucos, 1936, Figure 3.7).

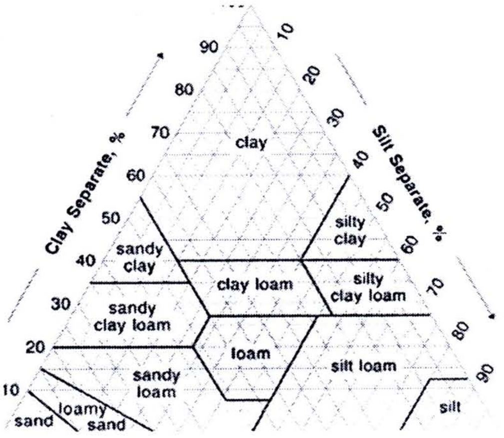


Figure 3.7 Textural triangle used to determine soil texture

3.3.2.2. Chemical parameters

Fresh soil samples were air-dried for 5-7 days (in a room with a dehumidifier) and passed through a 2 mm sieve. These were sub-sampled and used for analyzing soil organic carbon by two different techniques. First, Walkley and Black method was used to quantify soil organic carbon. This technique quantifies the amount of oxidized organic matter in which OM is oxidized with a known amount of $Cr_2O_7^{2-}$ in the presence of sulfuric acid. The remaining Cr^{3+} chromate is determined by titration method. The calculation of organic matter is based on 1.724 index value (Walkley and Black, 1947).

Second, the flash combustion method (Flash 1112 series EA NC-soil, Thermo Finnigen Italia, S.p.A., Italy) was used to analyze organic C and organic N in soil sample. Each sample was ground to fine powder using Retsch 100 PM sample mill. Organic C and organic N in all forms in soil were determined using a dynamic flash combustion system coupled with a gas chromatographic (GC) separation system and thermal conductivity detector (TCD) system. Concentration was determined from calibration curve of C and N standards (Standard; Montana soil on C concentration of 2.003% and N concentration 0.193%). Organic C was determined after carbonate removal from soil samples with hydrochloric acid (HCl). Inorganic C was estimated from the difference between total and organic C contents (Official Methods of Analysis of AOAC International, 1997).

Soil pH was measured with glass-electrode pH meter (Hach, Sension 378, Karava, Finland) on 1:1 ratio soil-water suspension of air-dried soil samples which had been passed through a 2 mm sieve (Schofield and Taylor, 1955).

3.3.2.3 Statistical analysis

CO_2-C fluxes, soil carbon content, soil temperatures and soil moisture of the sites and time of the year were compared using analysis coefficient of variance. Linear regression was used to evaluate the relationship between soil respiration rates and soil temperature and soil moisture. Significant differences for all statistical tests were evaluated at the level of $\alpha = 0.05$.

The comparison between soil carbon stock from Walkley and Black method and flash combustion technique were analyzed at 90% confidence level by t-Test: Paired Two Sample for Means.

3.3.3 Sugarcane biomass decomposition

3.3.3.1 Decomposition study

There are many methods to estimate rate of decomposition. The most popular is by weighing the sample of litter and putting it in nylon bags, fiber glasses, and glass wool or wire boxes. The litter bag technique has been most commonly used to measure rates of decomposition (Paul and Polglase, 2004). This study used litter bags method to study decomposition rate. The plant parts were separated into leaf, leaf sheath, shoot and root and their decomposition nature was studied individually. Litter bags each (25 × 25 cm) with a mesh size of 3.0 mm were prepared. Each bag contained 100 g of air dry litter of each sugarcane components. The exact weight of litter was re-calculated from the oven-dried litter. Decomposition was studied at two different depths; at 0 cm and 15 cm. Totally 864 samples were placed in the field (Figure 3.8). Three litter bags per sugarcane component and depths were brought back to laboratory to quantify moisture content and mass loss. The sugarcane components were sorted and weighted before and after oven dried (70 °C) to calculate percentage of moisture content. Sub-samples were also taken for lignin, holo-celluloses, total C and total N analysis.

In litter bags study, mass loss is described by exponential decay functions. The single exponential decay model is the most widely used (Paul and Polglase, 2004). Thus, decomposition rate constant (k) of the component samples was calculated by using the equation of Olson (1963) as follows:

$$Y_t = Y_o.e^{-kt} \tag{3.10}$$

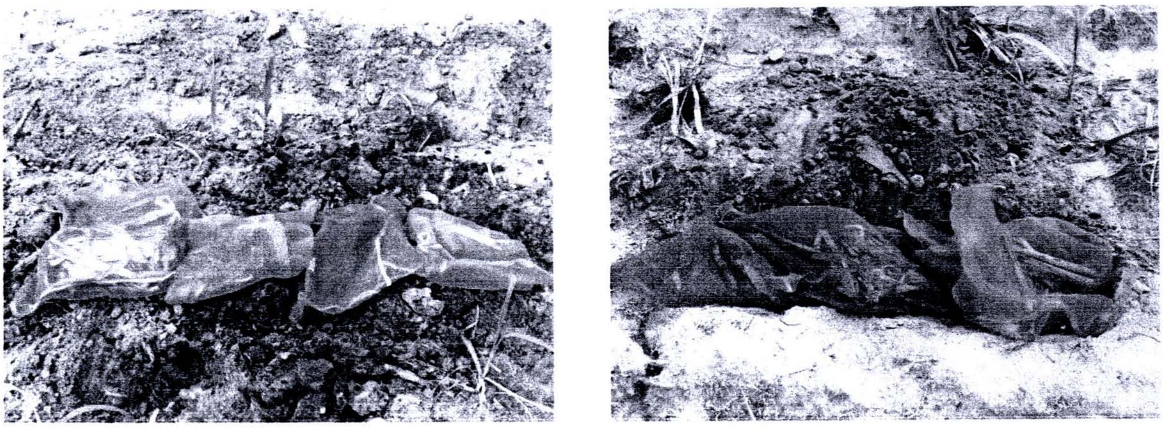
Where:

Y_t = Weight of litter at that time t

Y_o = Initial weight of litter

k = Decomposition rate constant

The decomposition rate constant (k) was measured per unit of time (per day, month or year).



0 cm 15 cm

Figure 3.8 Litter bag placements at 0 and 15 depths.

3.3.3.2 Lignin and Holo-cellulose analysis

Samples were taken for lignin and holo-cellulose analysis at the first and the last month of the study. Lignin content was determined using the protocol in laboratory of Tappi T222 and holo-cellulose fraction was determined by using Tappi section (Tappi Test Method T222 om-88).

The procedure of lignin fraction was determined as follow:

(a) 1 gram sample digest with 72 % H_2SO_4, 15.0 ml. for 2 hours

(b) Add 560 ml. of water and auto cave at 121 °C, 60 minutes

(c) After cool the sample, filtrations with glass filter NO. 4 then wash with 250 ml. with hot water

(d) Dry the filtering in an oven at 105 °C for 6 hours, cool and weight

The dried weight was % of lignin. The holo-cellulose was the original weight minus % of lignin.

Total carbon and total nitrogen were determined using the flash combustion technique as mentioned earlier (Flash 1112 series EA NC-soil, Italy). Each litter sample was homogenized and ground to fine powder using a Retsch 100 PM sample mill before used for its total carbon analysis.

3.3.3.3 Root density

Sugarcane root density was measured by using core technique (Kücke, *et al.,* 1995). There was sampled at inter row and row of sugarcane plantation. A stainless steel tube (5 cm inner diameter and 5.1 cm height) was driven into the soil at 15 cm depth. Root were separated and carefully washed free of soil by placing the soil in a large-sieved container. Washed root were then oven dried and weight. Sugarcane root density was calculated.

3.3.3.4 Sugarcane plant part

The fraction and ratio of sugarcane plant parts were determined. They were separated into leaf, leaf sheath, shoot, root and stalk. The sampled were recorded before sugarcane harvesting. In each sugarcane plant, there was separated into leaf, leaf sheath, shoot, root and stalk then were oven dried and weight. Therefore, the moisture content in sugarcane plant part was determined.

3.4 Full carbon accounting analysis

3.4.1 Carbon flow in sugarcane plantation

In sugarcane plantation system, carbon flow can be divided into two parts: carbon in soil system (for example: CO_2 and CH_4 flux, crop residue input, sugarcane biomass decomposition, sugarcane plantation) and carbon flow in sugarcane farm management (Figure 3.9). Carbon flows are made up of many processes: carbon is released by decomposition of crop residues and soil organic carbon (SOC), from direct use of fossil fuels in farm machinery, and from burning or other oxidation of biomass and carbon sequestration in soil.

The first part of soil carbon was studied in field experiments and described in section 3.4. Then this combined those data about carbon flow and budget in sugarcane plantation system with sugarcane farm management, and with the data from CO_2-C flux measurements to estimate CO_2 flux between soil and atmosphere. Soil organic carbon contents were also estimated. The ways to reduce carbon emission such as: improved soil management, reduce tillage and fertilization was not included in this study but such information may be obtained from other sources.

The study on sugarcane farm management focused on a synthesis of available information on energy use in sugarcane farm operations and managements, sugarcane biomass burning, and its conversion into equivalent carbon emission (CE). All data from the interview were used as a basis to calculate the fossil fuel use and C-base emissions. When applicable and available, secondary data such as methane emissions occurring during the burning of sugarcane before harvesting from literature reviews were also used.

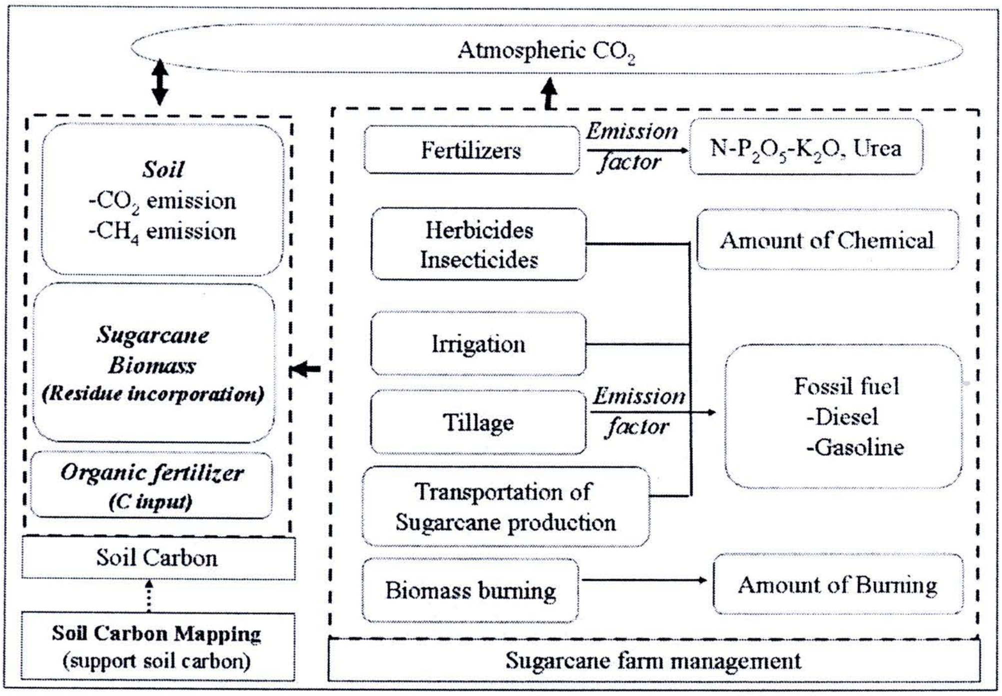


Figure 3.9 Flow diagram of carbon flow in sugarcane plantation system

3.4.1.1 Data collection

The data used in this study were collected from questionnaires (Appendix A) by interviewing sugarcane farmer, and from secondary data: emission factors from other relevant publications (West and Marland (2002), Department of Agriculture (2004), Khonkhen University (2006), Office of the Cane and Sugar Board (2007), IPCC (1996), IPCC (2006)).

The information about the general features of farms, farm operations and energy utilization was obtained through a questionnaire. The energy types considered include gasoline and diesel for herbicide, insecticide, irrigation, tillage and sugarcane transportation. In addition, carbon emission from chemical utilization; chemical fertilizer, herbicide and insecticide application was considered. Moreover, sugarcane biomass burning was also included (Figure 3.9). In the interview, the following information was recorded:

(1) Estimate of electricity use in farm per one sugarcane crop.

(2) Estimate of fertilizer use such as Nitrogen (N), Phosphorus (P_2O_5) and Potassium (K_2O) or application of crop residues per area per crop.

(3) Estimate of irrigation application in farm, which means fuel use in power pump in farm.

(4) Estimate of fossil fuel for transportation sugarcane production to factory and the average distance traveled.

(5) Estimate of sugarcane production per area.

(6) Estimate of fossil fuel in tillage on farm operation.

(7) Methods of cultivation and harvesting such as burning before harvesting.

3.4.1.2 Conversion coefficient for fossil fuel consumption (Diesel & Gasoline)

The energy utilization of farm management was calculated. The energy utilization included energy for transportation, herbicide, insecticide, irrigation and tillage on land preparation. The conversion coefficients vary within a fuel sources (i.e. diesel and gasoline) and diverse energy units used in the literature were converted to kg CE using the conversion factor as presented in Table 3.2. Most data in the questionnaires were calculated and represented by using median, minimum and maximum value.

Table 3.2 Carbon emissions for different fuel sources and the energy conversion units (IPCC, 2006)

Fuel source/energy units	Descriptions
(a) Fuel	
Diesel	20.2 (t C/TJ)
Gasoline	18.9 (t C/TJ)
(b) Units	
1 gallon of Diesel oil	139,000 BTU
1 gallon of Gasoline	124,000 BTU
1 BTU	1,055.87 Joules
1 liter	0.264172 gallons
Tera Joules (TJ)	10^{12} Joules

The emissions in unit of carbon equivalents of energy utilization from farm operations were calculated from Equation 3.11 and Table 3.2.

$$Emissions_{GHG,fuel} = Fuel \quad Consumption \quad fuel * Emission \quad Factor_{GHG,fuel} \tag{3.11}$$

Where;

Emissions $_{GHG, fuel}$ = emission of a given GHG by type of fuel (kg GHG),

Fuel Consumption = the amount of fuel combusted (TJ),

Emission factor $_{GHG, fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). The GWPs (time span of 100 years) of CO_2 is 1 (IPCC, 2001a).

3.4.1.3 Conversion coefficients for chemical utilization

(1) Chemical fertilizer (N-P-K)

Emission factors for fertilizers are divided according to types of fertilizer (N-P-K) and are presented in Table 3.3 (IPCC, 2006). The amounts of inorganic fertilizer input were used to estimate C emission in the field by using emissions factor (carbon equivalent of fertilizer) for the production of fertilizer (N, P_2O and K_2O). The value are 857.5 g CO_2-eq/kg N, 165.1 g CO_2-eq/kg P_2O_5 and 120.28 g CO_2-eq/kg K_2O for N, P_2O_5, K_2O application, respectively (West and Marland, 2002; Lal, 2004). Equation for this purpose is given below (IPCC, 2006).

$$CO_2 - C \quad Emission = M \cdot EF \tag{3.12}$$

Where:

CO_2-C Emission = Annual C emissions from N, P_2O_5 or K_2O Fertilizer application (tonnes C per year)

M = Annual amount of N, P_2O_5 or K_2O fertilization (tonnes N, P_2O_5 or K_2O per year)

EF = Emission factor (g CO_2-eq/kg N, P_2O_5 or K_2O)

(2) N_2O Emissions from synthetic fertilizer and manure application-direct emission

N_2O Emissions from N fertilizer utilization are represented in Equation 3.13 (IPCC, 2006).

$$N_2O–NN_{input} = F_{SN} + F_{ON} \bullet EF_1 \qquad (3.13)$$

Where:

$N_2O\text{-}N\,N_{inputs}$ = annual direct N_2O-N emissions from N inputs to managed soils (kg N_2O-N/yr)

F_{SN} = annual amount of synthetic fertilizer N applied to soils (kg N/yr)

F_{ON} = annual amount of manure applied to soils (kg N/yr)

EF_1 = emission factor for N_2O emissions from N inputs (kg N_2O-N /kg N input). This is 0.01 kg N_2O-N/kg N input (IPCC Guidelines for National Greenhouse Gas Inventories 2006, Volume 4, Equation 11.1 and Table 11.1)

(3) N_2O from atmospheric deposition of N volatilized from managed soil

N_2O Emissions from atmospheric deposition of N volatilized from managed sugarcane soil were represented in equation 3.14. Equation for this purpose is given below (Equation 11.9, IPCC, 2006).

$$N_2O_{(ATD)}–N = [(F_{SN} \bullet Frac_{GASF}) + ((F_{ON} + F_{PRP}) \bullet Frac_{GASM})] \bullet EF_4 \qquad (3.14)$$

Where:

$N_2O_{(ATD)}$–N = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O–N/yr

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N/yr

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied)$^{-1}$; 0.10 kg NH_3-N + NO_x-N (Table 11.3)

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to sugarcane soil soils, kg N/yr

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N/yr

$Frac_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$; 0.20 kg NH_3-N + NO_x-N (Table 11.3, IPCC 2006)

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH_3–N + NO_x–N volatilised)$^{-1}$]; 0.010 kg N_2O-N (Table 11.3, IPCC 2006)

(4) N_2O from leaching/runoff from managed soils in regions where leaching/runoff

N_2O Emissions from N fertilizer utilization and manure by leaching and runoff in sugarcane farms were estimated according to the methodology of IPCC (2006) and were represented in Equation 3.15. Equation for this purpose is given below (IPCC, 2006).

$$N_2O(L)\text{–}N = (F_{SN} + F_{ON}) \bullet Frac_{LEACH-(H)} . EF_5 \tag{3.15}$$

Where:

$N_2O\ (L)\text{–}N$ = annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O–N/yr

F_{SN} = annual amount of synthetic fertiliser N applied to soils in regions where leaching/runoff occurs, kg N/yr

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N/yr

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff = 0.30

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)-1 (Table 11.3) = 0.0075 kg N_2O-N (kg leaching/runoff)

(5) Emissions from herbicide and insecticide

Emission factors of herbicides and insecticides that were used in the field are given in Table 3.3. Emission factors of herbicides and insecticides were 4.4 and 4.6 kg CE/kg herbicide or insecticide, respectively and equivalent carbon emission for common herbicide and insecticide ranged from 1.7 to 10.4 kg CE/kg (West and Marland, 2002; Kramer *et al.,* 1999; Sam and Annette, 2004; Lal, 2004). Carbon dioxide from production of herbicide and insecticide consists of contributions to manufacture and active ingredient. Moreover, the estimate for specific herbicide and insecticide classes by calculated average values of energy input for production and application of individual pesticide was considered (West and Marland, 2002). At the same condition as emission factor of fertilizer, emission factor of herbicide and insecticide ranged in average of all emission factor data for herbicide and insecticide (Table 3.3). This studied used emission factor for fertilizer production, herbicide and insecticide production from West and Marland (2002). These factors include the energy consumed during production, GHG emission from processes and energy for all transport. These are considered reasonable to be used for Thailand, since majority of chemical fertilizer (more than 90%) in Thailand are imported. (Thaipattana Fertilizer Fund, 2008).

Table 3.3 Emission factors for production, transportation, storage and transfer of organic chemicals (Kramer *et al.,* 1999; West and Marland, 2002; Sam and Annette, 2004; Lal, 2004)

Types	Equivalent carbon emission (g CE/kg)		This study
	Range	Mean ± S.D.	
(A)Fertilizers			
Nitrogen (N)	900-1,800	1,300±300	857.54 g CO_2-eq/kg N
Phosphorus (P_2O_5)	100-300	200±60	165.1 gCO_2-eq/kg P_2O_5
Potassium (K_2O)	100-200	150±60	120.28 gCO_2-eq/kg K_2O
	Equivalent to carbon emission (kgCE/kg)		
	Range	Mean ± S.D.	
(B)Pesticides			
Herbicide	1.7-12.6	6.3±2.7	4.4 kg CE/kg of herbicide
Insecticide	1.2-8.1	5.1±3.0	4.6 kg CE/kg of insecticide

3.4.1.4 Organic fertilizer input (filter cake)

Information on organic fertilizer inputs (i.e. filter cake is organic fertilizer that is a by-product from sugar industry process) was obtained from interviews of sugarcane farmers for the whole period of sugarcane planting. Total C content of filter cake was determined in the filter cake sample in the laboratory by using the flash combustion method as mentioned above (Flash 1112 series EA NC-soil). Based on the information obtained, then, the quantity of carbon inputs during one crop of sugarcane cultivation was estimated.

3.4.1.5 Sugarcane biomass estimation

Sugarcane biomass (leaves and trash) in experimental plots are measured by ten representative random plots of 1 m^2 at sugarcane harvest. They were oven-dried at 70 °C for 24 hours and weighted and the moisture content was then determined. The plant samples were taken to analyze for total C using the flash combustion method as mentioned above (Flash 1112 series EA NC-soil) (Official Methods of Analysis of AOAC International, 1997).

3.4.1.6 Conversion coefficients for sugarcane biomass burning

Emission factors for sugarcane biomass burning was 0.80 (Table 2.6 IPCC, 2006) for agriculture residues (post harvest field burning) (IPCC, 2006 and Equation 2.27).

$$L_{fire} = A \cdot MB \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad (3.17)$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, tonnes of each GHG e.g., CH_4, N_2O, etc.

A = area burnt, ha

MB = mass of fuel available for combustion, tones/ha.

C_f= combustion factor, dimensionless (default values in Table 2.6, IPCC 2006)

G_{ef}= emission factor, g/kg dry matter burnt (default values in Table 2.5, IPCC 2006)

The following values of emission factor were applied:

-CO_2 emission factor (g/kg dry matter burnt) for sugarcane is 1,515 ±131.

-CH_4 emission factor (g/kg dry matter burnt) for sugarcane is 2.7.

-N_2O emission factor (g/kg dry matter burnt) for sugarcane is 0.07.

All CH_4 and N_2O values were converted to CO_2 equivalent amount by multiplying with the global warming potentials, which are 21 for CH_4 and 310 for N_2O (IPCC, 2006).

3.4.2 Carbon flow in sugar mill

In the sugar mils, the carbon flow was analyzed. CO_2 emission and reduction from sugar processing and bioenergy systems include those from waste in the process: bagasse, fossil fuel used in the industrial production of sugar and the operation process, and sugar mill production: sugar (raw sugar, white sugar and refine sugar), molasses, filter cake, water, bagasse and etc. Sugarcane bioenergy systems, the emissions and reductions by substituting sugarcane bagasse for fuel in sugar production, were considered. The flow diagram for carbon flow in sugar mill is shown in Figure 3.10.

There were two energy scenarios that were compared for energy utilization in sugar process. First the baseline scenario is based on the assumption that 100 % electricity was supplied from grid, which is originally generated from Bang Pa Kong power plant (Mainly generated from natural gas combustion) (EGAT, 2005).

Second the bioenergy scenario where the sugar mill factory uses the electricity supplied both from grid and that produced from the bagasse (bioenergy). The bioenergy scenario is the current situation. The sugar mill used the waste from the sugar process (bagasse) to produce electricity. The surplus electricity was sold to commercial grid. The data were obtained from sugar mill factory in Eastern Thailand for the case study.

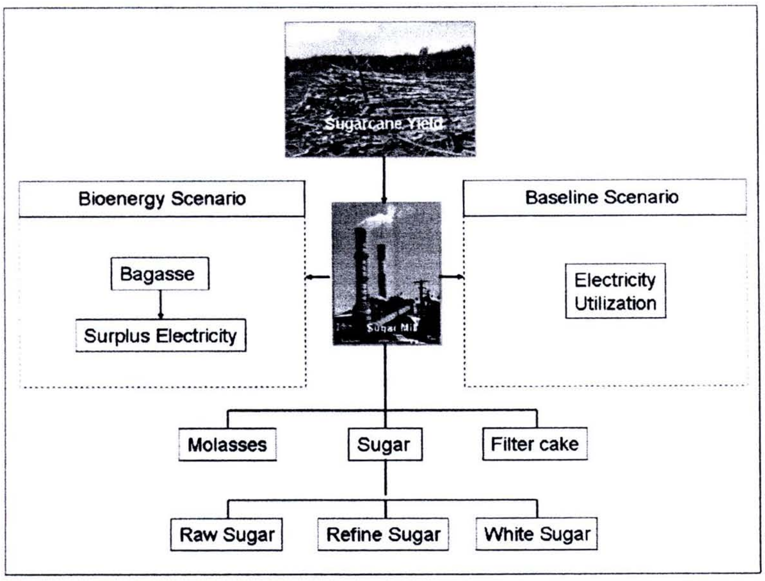


Figure 3.10 Flow diagram of carbon flow in sugar mill process

3.4.2.1 Data collection

The data used in this study were collected from questionnaires (Appendix B) by interviewing sugar mill officers, and from secondary data in relevant publications (Office of the Cane and Sugar Board, 2007). The sugar mill case study covered in Eastern Thailand (4 out of total 5 factories in the region) and 15 samples of 4 factories from 2003/04 to 2007/08 production years. The information obtained were sugar mill process, sugarcane yield, electricity utilization from grid, the production of sugar process: sugar, molasses, and bagasse for surplus electricity. The information from the questionnaire was then calculated and converted into carbon emission equivalent (CE).

3.4.2.2 Conversion coefficient for electricity utilization

The carbon emission equivalents from electricity utilization from sugar process were calculated from Equation 3.18.

$$Emissions_{GHG,fuel} = Fuel\ \ Consumption\ \ fuel * Emission\ \ Factor_{GHG,fuel} \tag{3.18}$$

Where:

$Emissions_{GHG,fuel}$ = emission of a given GHG by type of fuel (kg GHG),

Fuel Consumption = the amount of fuel combusted (TJ), *Emission factor* $_{GHG, fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO_2, it includes the carbon oxidation factor, assumed to be 1.

Emission factor for electricity produced from Natural gas for surplus electricity is 0.0564 kg CO_2/MJ, 1 kg CH_4/TJ, 0.1 kg N_2O/TJ and the emission factor from bagasse combustion is 30 kg CH_4/TJ, 4 kg N_20/TJ (IPCC, 2006).

The conversion of bagasse for surplus electricity was computed by using emission factor of electricity. Moreover, conversion coefficient of bagasse utilization bases bioenergy system was compared between net CO_2 emission in baseline scenario and net CO_2 emission in bioenergy scenario in the next step.

3.4.2.3 Conversion coefficient for wastewater treatment

The methane emission from wastewater of sugar mill processing was calculated using Equation 3.19, IPCC 2006 method (equation 6.4, IPCC 2006). The general equation to estimate CH_4 emissions from industrial wastewater is as follows.

$$CH_4\ Emissions = \Sigma_i\ [(TOW_i - S_i)\ EF_i - R_i] \qquad (3.19)$$

Where;

CH_4 Emissions =Total CH_4 emissions from wastewater (kg CH_4/yr)

TOW*i* = Total organically degradable material in wastewater from type *I* (kg COD/yr)

i = industrial sector

S_i = organic component removed as sludge in inventory year, kg COD/yr

EF_i = emission factor for type *i*, kg CH_4/kg COD for treatment/discharge pathway or system(s) used in inventory year

R_i = amount of CH_4 recovered in inventory year (kg CH_4/yr)

Emission factor for CH_4 emission from wastewater was calculated from equation (3.20). This was calculated by multiply the maximum CH_4 producing capacity (Bo) with methane conversion factor. The general equation was represented in Equation 3.20.

$$EFj = Bo \bullet MCFj \qquad (3.20)$$

Where;

EFj = emission factor for wastewater treatment (kg CH_4/kg COD) (Table 6.8, IPCC 2006)

j = each treatment/discharge pathway or system

Bo = maximum CH_4 producing capacity, kg CH_4/kg COD; 0.25 kg CH_4/kg COD (IPCC, 1996)

MCF_j = methane correction factor (fraction): 0.80 (Table 6.8, IPCC 2006)

3.4.2.4 The carbon contents in products from sugar processing

The products from sugar processing include sugar, molasses, filter cake and bagasse. The data products from sugar process were recorded and averaged from 4 sugar mill factories in Eastern Thailand through questionnaire. These parts were recorded and computation that is based on the CO_2 equivalent to the carbon contained in each component of product from sugar process. In other words, all CO_2 produced will be re-absorbed by the system resulting in a zero net carbon in close system. How much CO_2 absorbed by products was determined. It is estimated by percentage of carbon contents in dry basis in each product (i.e. sugar, molasses, filter cake and bagasse) multiply by share of millable cane. Then, it can be assuming the carbon absorbed in each product and total product. The carbon absorbed can be determined as show in Equation 3.21 below.

$$E = C * A \tag{3.21}$$

Where:

E = Equivalent CO_2 uptake or carbon absorbed (ton/ha)

C = Carbon contents dry basis (%), it is estimated by carbon contents in each product (sugar, filter cake, molasses and bagasse), by (i) assuming sugar in pure sucrose [$C_{12}H_{22}O_{11}$], (ii) Brix = 0.88 (sucrose/dry/solids), assume to be 76% sucrose in molasses (Sombat, 2003), (iii) Carbon content in filter cake, data from field observation and laboratory analysis

A = The amount of product, it is estimated by the multiplying share of millable cane (%); estimated from data in 4 of total 5 sugar mill in Eastern Thailand, and cane yield (56,000 kg/ha/yr); based on calculation from 2003-2008 production years in Eastern Thailand

3.4.2.5 Net carbon and calculations

When collection of data was completed, the CO_2 balance (Net C balance) was calculated. In this study, emission reduction potential was compared between baseline (fossil fuel) and bioenergy scenarios. The net C can be determined by in Equations 3.22 and 3.23 below.

$$\text{Net } CO_2 \text{ emission} = \text{C emissions} - \text{C reductions} \qquad (3.22)$$

Emission reduction potential in bioenergy system = {Net CO_2 emission in baseline scenario} - {Net CO_2 emission in bioenergy scenario} (3.23)

3.5 Geographic information (GIS) data and analysis for soil carbon mapping

This part mainly concerns the data collection from the secondary data sources and field studies. These data were used for analysis and evaluation of soil carbon in the study area. The base techniques were geographic information system and remote sensing. The research framework of this part was presented in Figure 3.11.

3.5.1 Study region and materials

The study area covers 531,810 ha or 5,318 km^2 in Chonburi and Rayong provinces (Figure 3.2). In this area, sugarcane plantation is the main type of crop. Carbon flow and stock in this area were characterized. The output was a GIS for soil carbon mapping for estimating carbon stock in sugarcane production system.

To estimate sugarcane plantation carbon, data were collected, both from the interview and from secondary data sources such as the Office of Agriculture Economics. Data of sugarcane production per area, soil type and land use were obtained from other published data, official documents or technical reports.

Soil samples in the study area were collected for analyzing soil organic carbon content. The techniques were compared both analyzed by using Walkley and Black method and flash combustion technique. Soil organic carbon contents data were then incorporated into Geographic Information System (GIS) map. When, available the data support from the official documents or technical reports was also being used (Table 3.4). To validate the data used, field check was carried out occasionally. Below are summarized the methodology and details (Figure 3.11).

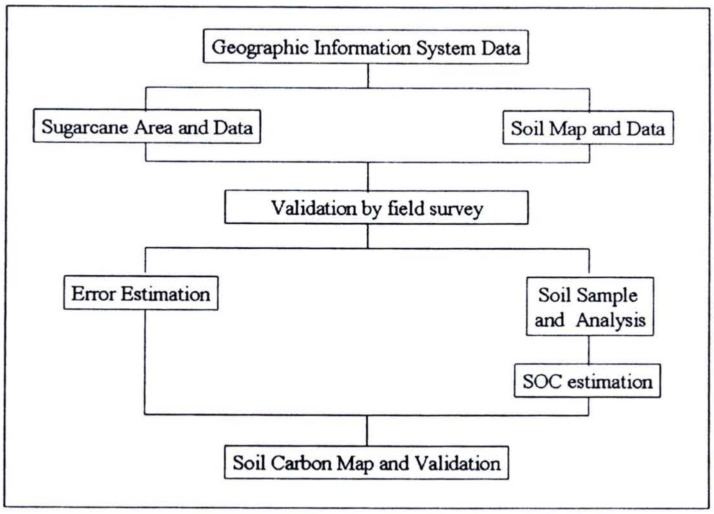


Figure 3.11 Schematic diagram of research framework in part of GIS and remote sensing.

3.5.2 Data support, materials and equipment

Data required were land use maps, sugarcane areas, soil types, soil carbon and GIS. The collect data were combined between in primary and secondary data from the others official and data sources. The details were shown in Table 3.4 and Figure 3.11.

The soil series map and soil profile descriptions were taken from *Thai Land Development Department, 2004* (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). Sugarcane area and land use map were obtained from Thai Office of the Cane and Sugar Board (2005).

Table 3.4 Materials and data required in the GIS part.

Activity and Properties	Material - Source
1. Mapping by GIS techniques	Computer, Printer, Scanner Software: Arcview, Envi
2. Soil samples	
Bulk density	Gravimetric method (drying at 105 ^{0}C)
Soil carbon	Walkley and Black and Flash combustion methods
3. GIS data	
Soil map scale 1:1,000,000	Department of Land and Development
Land use map : Sugarcane area	Department of Land and Development and Office of Agriculture Economics

3.5.3 Sugarcane area and error evaluation

Thematic maps produced with the technology of geographical information systems (GIS) have enormous potential to provide detailed information to the users. Key to the usefulness of a map for any user is the degree of quality or accuracy of the map (Congalton, 1991). This study applied the accuracy assessment to determine error from the sugarcane area map. Accuracy assessment determines how useful sugarcane area map is used to estimate carbon stock in the study area. A principle assumption of accuracy assessment is that the reference data, usually collected by the assessor in the form of plot data, is the truth when compared to the map classification.

A sugarcane area dataset was created from satellite image LANDSAT-5 (TM) imagery (data time during November- December, 2004) (Office of the Cane and Sugar Board, 2005). Field check for sugarcane plots which serves as the truth reference was completed during November to December, 2005. The approximate sample sizes were determined using the following Equation (3.24) (Fizanpatrick-Lins, 1981).

$$N = \frac{Z^2 pq}{E^2} \qquad (3.24)$$

Where:

N =the total number of samples

p = the expected percent accuracy

q $= 1 - p$

Z = 1.96 is the standard normal deviate for 95 percent two-sided confidence level

E = the allowable error

For p =0.9 (the accuracy required under contract specifications) and an allowable error of 4 percent, an estimated minimum sampled size of 216 was calculated. A minimum for each class of interest must be 50 samples (Hey, 1979).

After that, the field survey for all reference sampled point for the field assessment data were transcribed to a Microsoft Excel spreadsheet and checked for transcription errors. The file was imported into ArcView 3.1, where the point coordinates and identifying code were joined spatially to polygon attributes from the 2004 sugarcane area map. Error matrix was generated to calculate the overall classification accuracy, percentage of omission and commission (Error of commission and omission could be expressed in terms of producer's accuracy and user's accuracy), and ***Kappa coefficient*** (an index that relays the classification accuracy after adjustment for chance agreement) (Watts *et al.,* 1999; Cohen, 1960; Congalton, 1983). ***Error of commission*** is resulted when the incorrectly identified pixels are associated with a class as others classes. Therefore, ***error of omission*** occurred whenever the sample do not recognize the pixels that should have identified as belonging to a particular class.

The ***overall accuracy*** was determined from the percentage of correctly mapped samples. This is defined as the sum of the main diagonal elements of the error matrix divided by the total number of sampled (Watts *et al.,* 1999). The approximate ***overall accuracy*** was determined using the following Equation (3.25).

$$\textit{Overall accuracy} = \frac{\textit{Total number of reference samples chosen}}{\textit{Total number of correctly classified samples}} \times 100 \qquad (3.25)$$

Producer's accuracy is a reference-based accuracy that is computed by looking at the produced map for a class and determining the percentage of correct predictions (Watts, *et al.,* 1999). The approximate ***producer's accuracy*** was determined using the following equation (3.26).

$$\textit{Producer's accuracy} = \frac{\textit{Number of samples correctly classified in a given class}}{\textit{Total number of samples chosen for that class}} \times 100 \qquad (3.26)$$

User's accuracy is a map-based accuracy that is computed by looking at the reference data for a class and determining the percentage of correct predictions for these samples (Watts *et al.,* 1999). The approximate ***user's accuracy*** was determined using the following equation (3.27).

$$\text{User's accuracy} = \frac{\text{Number of samples correctly classified in a given class from the selected samples in that group}}{\text{Total number of samples classified in that group out of entire samples selected}} \times 100 \quad (3.27)$$

Kappa coefficient is a measure of the difference between the observed agreements between the reference data and the subject map and the chance agreement. Kappa values are characterized into 3 groups; a value greater than 0.75 (75%) represented strong agreement, a value between 0.40 and 0.75 (40 to 75%) represents moderate agreement, and a value below 0.40 (40%) represent poor agreement (Congalton, 1991). The Kappa equation was computed as described by Congalton (1991) following the Equation (3.28) below.

$$Kappa = \frac{N \sum_{i=1}^{r} Xii - \sum_{i=1}^{r} (X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+} \times X_{+i})} \quad (3.28)$$

Where:

r = the number of rows in the error matrix,

X_{ii} = the number of observations in row *i* column *i*,

X_{i+} = the marginal total of row *i* (right of matrix),

X_{+i} = the marginal total of column *i* (bottom of the matrix),

N = the total number of observations included in the matrix

3.5.4 Soil sampling

Soil sampling was conducted in January 2006. Soil samples were taken to represent all ten soil series that covers 84% of sugarcane area in study site, 45 soil samples were measured and it cover on ten soil series in the study region as details for soil sample was described below (Figure 3.12). Additionally, the available literatures and documentations provided the data for a low to high rang of percent organic carbon content (0.27-1.68%) for the surface layer (0-30 cm) in 2004 (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). Sugarcane area soil samples were collected from true sugarcane area and from the soil map overlay. The methodology relies upon the

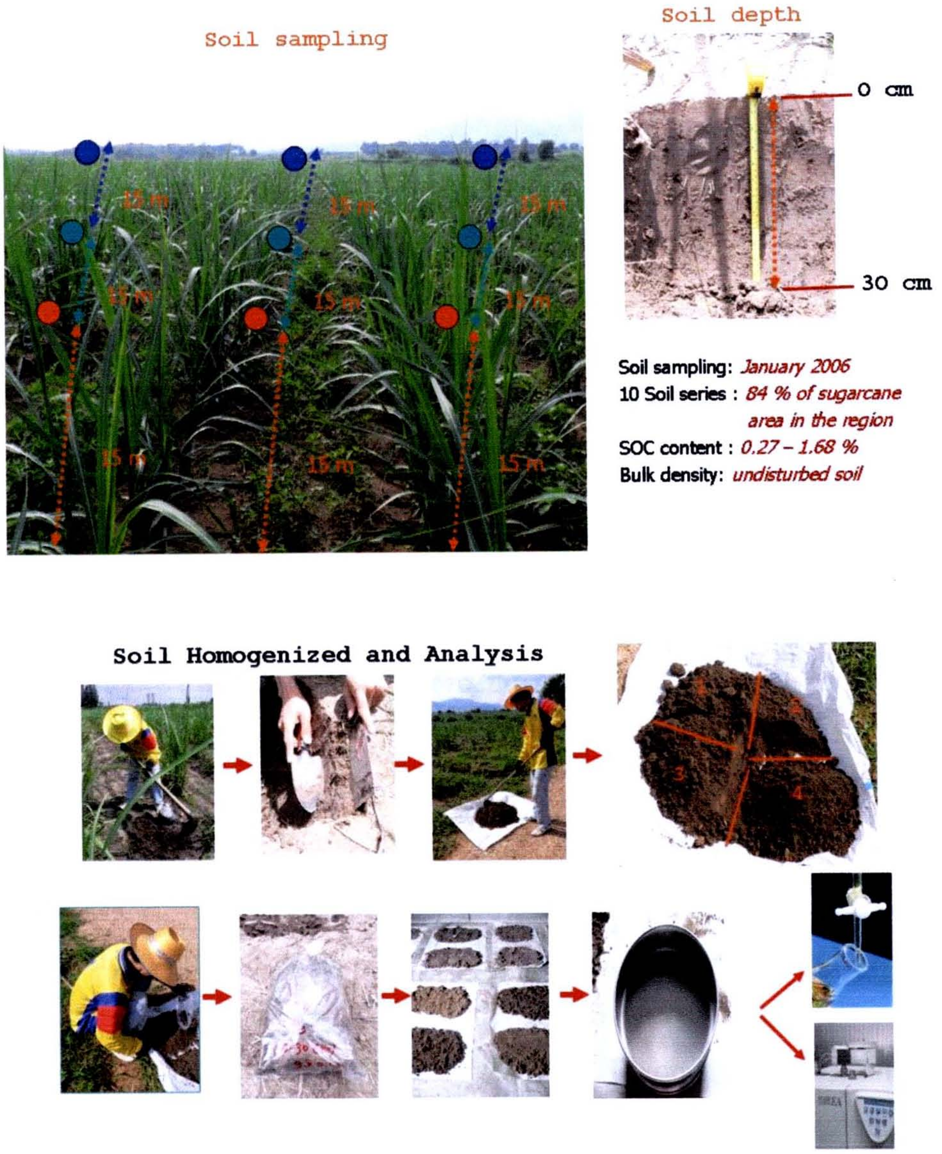
Global Positioning System (GPS) technology that allows targeting of initial soil sampling and the ability to return to the same spots in the future. The soil testing methods and sampling procedures were generally followed those described by the LDD (Land Development Department, 2004). Composite and disturbed samples were collected for analyzing the soil organic carbon content and other soil chemical properties. The undisturbed soil samples were collected for soil bulk density measurements. A composite soil sample should include at least 15 sample sites per sugarcane field and soil sample replication number should be included along with the sugarcane area soil series size. Soils sampled were collected within 15 m of a center point at each sampling site and 0-30 cm soil depths were sampled. In this technique the whole soil sampled in each soil series was homogenized and a sub-sampled was taken for laboratory analysis (Figure 3.12).

The soil organic carbon was determined using two difference techniques: Walkley and Black method (Walkley and Black, 1947) and flash combustion techniques (Flash 1112 series EA NC-soil, Italy) as mentioned earlier.

Then, the calculations of soil organic carbon in the sugarcane area were given by the formula as follow in Equation (3.29):

$$\textit{Soil C stock (g C/m}^2\textit{) =Bulk density (g soil/m}^3\textit{)} \times \textit{soil C content (g C/g soil)} \qquad (3.29)$$

Thus, the soil carbon budgets in Eastern Thailand and the whole area of Thailand were estimated.



Soil sampling: *January 2006*
10 Soil series : *84 % of sugarcane area in the region*
SOC content : *0.27 – 1.68 %*
Bulk density: *undisturbed soil*

Figure 3.12 Method of soil sampling and preparation for soil carbon analysis.