# CHAPTER 7
# SUMMARY AND RECOMMENDATIONS

Increasing concentrations of greenhouse gases in the atmosphere, especially $CO_2$, has increased 280 ppmv in 1800 to 381 ppmv in 2005, is one of the most important environmental concerns. Understanding of the carbon cycle and it dynamics for emission sources is urgently needed in order to find the appropriate mitigation options. Agriculture is one of promising sectors with some potential to mitigate emission. However, before achieving the goals of finding appropriate options to reduce greenhouse gases emissions, thorough understanding of carbon flow in the important agricultural sub-sectors need to be established.

In Thailand, sugarcane plantation is economically important with high potential to produce bioenergy from waste generated from the sugar process. However, the complete figure of carbon and energy flow under sugarcane cultivation is not well established. Such information is important for evaluating the greenhouse gas emission reduction potential, as well as for analysis of other aspects related to sugarcane cultivation and sugar-related products manufacture. Accordingly, the main objectives of this thesis study are; (1) to determine the flows and budgets of carbon in a sugarcane crop production system, and (2) to evaluate the greenhouse gas emission reduction potential by using sugarcane by-products for bioenergy production.

This study investigated full carbon accounting during sugarcane production and utilization in Eastern region of Thailand. The study was focused on carbon flows and budgets in sugarcane production and utilization, specifically referring to the balance between sources (loss) and sinks (gain) of carbon within the considered system boundary (farming and sugar mills). The data were collected from field and laboratory experiments, and from sugarcane farm management and sugar mill factory through questionnaires. The filed site was located within sugarcane area in Chonburi and Rayong provinces. This field was used for measuring $CO_2$-C, $CH_4$-C flux, sugarcane biomass decomposition study, soil carbon budget and GIS soil carbon mapping. The study period was from March 2006 to February 2007. For investigation in sugar mills, 4 out of 5 mills in the eastern Thailand were included. The findings of this study can be summarized as follows.

### 7.1 Carbon budget and GHGs emission reduction potential

#### 7.1.1 Soil carbon budget

The data from field measurements and laboratory experiments on $CO_2$-C flux, $CH_4$-C flux and sugarcane biomass decomposition were concluded. During the 2006/07 cropping years, measuring surface emissions of greenhouse gases result in loss of $CO_2$ and sink of $CH_4$. The $CO_2$ flux was equivalent to 16.39 ton C/ha/yr and sink of $CH_4$ was -0.059±0.145 mg $CH_4$/m/hr or equivalent to -0.11 ton $CO_2$-eq/ha/yr. Thus the net soil carbon emission was 16.39 ton C/ha/yr. This balance is a function of loss and carbon gain through organic inputs including sugarcane biomass, organic fertilizer and sugarcane root density. The results show that sugarcane biomass input was 6.68 ton C/ha/yr, root system was 4.75 ton C/ha/yr and organic fertilizer was 4.98 ton C/ha/yr. Most of sugarcane biomass were released back to the atmosphere within the cropping year through decomposition processed, which was detected as surface $CO_2$ emissions. The decomposition rate was different among components of sugarcane plant part (leaf, leaf sheath, shoot and root) and carbon contents (i.e. total C, lignin and holo-cellulose contents). In addition, placing sugarcane biomass (on the surface vs. in the soil) also significantly influences the decomposition. Placing biomass at 15 cm depth, for example, has resulted in the more rapid decomposition, thus the faster release of biomass as $CO_2$, when compared with that placing on the soil surface.

The results of the study indicate that there was a net soil carbon sequestration of 0.02 ton C/ha/yr. There are quite balance between input and output, and this affects the sink or source magnitude of sugarcane soil. Analyzing soil carbon status in the sugarcane area of the eastern regions indicates that there is a net loss of soil organic carbon at the rate of 91.12 kg C/ha/yr after 37 years cultivation. It was also found that sugarcane in Eastern Thailand is cultivated on the low fertility and low soil organic carbon content. Therefore, there is an urgent need to improve soil fertility to sustain the productivity. Increasing soil carbon content through organic carbon input and managements may be one of the potential options, as demonstrated by the results of this study.

Out of the total biomass carbon produced in the sugarcane farm of 17.05 ton C/ha/yr 11.43 ton C/ha/yr (67%) was remained on farm and the rest (5.62 ton C/ha/yr) was processed in sugar mills, and subsequently stored in sugar products and waste materials.

### 7.1.2 Net carbon budget in sugarcane cultivation

Net carbon budget in sugarcane production (agriculture system) was estimated from soil carbon budget (carbon loss-gain), and GHGs emissions from sugarcane farm operation and management. Firstly, soil carbon budget was a net gain of 0.02 ton C/ha/yr. These were included total soil surface emission or loss as 16.39 ton C/ha/yr and total soil carbon input or gain of 16.41 ton C/ha/yr (Figure 7.1). Secondly, carbon budget from sugarcane farm operation and management was 0.60 ton/ha/yr. These included GHGs emission from chemical fertilizer, especially and of fossil fuel utilization. Accordingly, the overall system carbon budget is a net release of 0.58 ton C/ha/yr {(16.39+0.60) - 16.41 ton C/ha/yr}.

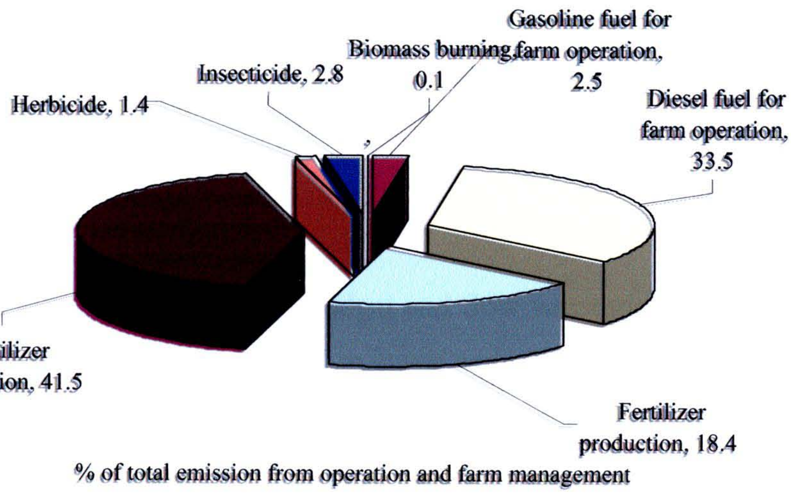


**Figure 7.1** Greenhouse gas emissions from activities involved sugarcane farm managements

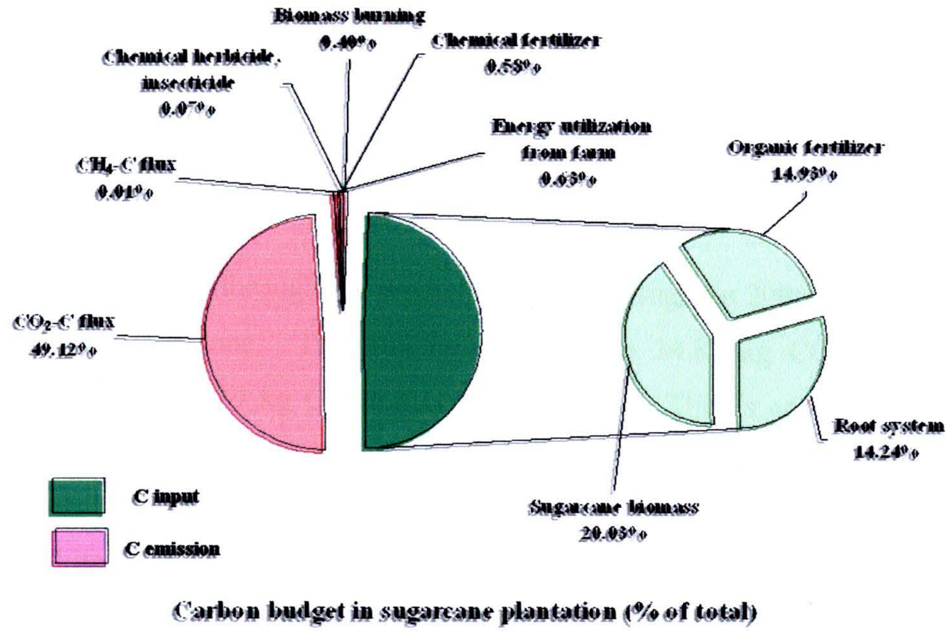


**Figure 7.2** Carbon budget in sugarcane plantation (% of total budget)

### 7.1.3 Net carbon budget in sugar mill factory

In the sugar mill factories, carbon budget and flow was estimated based on use of carbon-based energy and on carbon storage in sugar and sugar products, and waste. The products considered included sugars, molasses, filter cake and bagasse.

Based on cane yield during 2003-2008 in Eastern Thailand, the total carbon uptake for 1 hectare of sugarcane yield a total was 5.62 ton C/ha/yr. These were allocated in various products as followed; sugar (1.45 ton C/ha/yr), molasses (0.69 ton C/ha/yr), filter cake (0.22 ton C/ha/yr) and bagasse (3.26 ton C/ha/yr). From the surveys of sugar mill operation, it was found that most of electricity energy used was generated from using bagasse. If it is assumed that the baseline emissions of sugar mills is from use of fossil energy, using bagasse thus significantly help offset GHG emissions (around 95% emissions were reduced from all energy consumption processes within the mills). Calculation based on per tone cane processed indicates that in the case of use of fossil fuel for sugar production, $CO_2$ emission would be 5.80 kg $CO_2$-eq/ton cane. Utilization of bagasse significantly helps offset this emission to 0.27 kg $CO_2$-eq/ton cane. The net avoided $CO_2$ emission in this case, thus, is equal to 5.53 kg $CO_2$/ton cane. In addition to emissions from energy consumption, based on the current waste water treatment methods employed by sugar mills, 5.12 kg $CO_2$-eq/ton cane was emitted.

### 7.1.4 Summary of net carbon in sugarcane plantation and sugar mill factory

The carbon budget through the production chain of sugar in 2006/07 cropping years was 40.26 kg $CO_2$/ton cane. This can be divided into 34.87 kg $CO_2$/ton cane from cultivation system, and 5.39 kg $CO_2$/ton cane from mills. This is equal to 2,254.56 kg $CO_2$/ha/yr for cultivation system, 301.84 kg $CO_2$/ha/yr from sugar mills. As mentioned above, relatively low emission from sugar mills was due to use of bagasse to substitute fossil fuel. While large emission from cultivation part is due to soil surface emission that was much larger than organic carbon inputs from biomass and fertilizer. In term of carbon intensity that considers emission from cultivation of sugarcane until raw sugar, the current sugar production chains emitted 0.464 kg $CO_2$/kg sugar.

## 7.2 Recommendations for future research

Based on the finding of this study, further research areas are recommended as follows.

*Sugarcane plantation system:* in the part of soil respiration, it would be more accurate to study in details of root respiration and microbial activity and factors that influence to soil respiration. Furthermore, $N_2O$ emission from soil should be measured. In addition, the results of sugarcane biomass decomposition gave a good relationship between depth level and decomposition rate, sugarcane biomass fraction and the contents of carbon (lignin contents: highest portion on this fraction will be difficult to decompose), but turnover time should be study for repeat in many sugarcane cropping season.

*Sugar milling*: the efficiency of sugar mill, the chemical properties in each by product of sugar in each sugar mill should be studied in more details.