CHAPTER 11
CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the report by highlighting the key findings in this research work and describes the mitigation efforts and techniques that may help to reduce the effects of sugarcane field burning on GHG emissions.

11.1 Overview of the study

Open burning in agricultural land contributes to direct emissions of particulate matter and greenhouse gases (GHG) into the atmosphere. This burning activity has a negative impact on soil, degrading its properties, especially soil organic carbon content, which results in reducing crop productivity and carbon sequestration in the agricultural ecosystem. In Thailand, sugarcane field burning is still a common practice to support production intensification, especially during the harvesting season, from November to April. This corresponds also to the period when the country generally faces the problem of haze pollution from biomass open burning. In view of the above, this study was conducted to assess the contribution of sugarcane field burning on GHG emissions in Thailand and to develop a database to support the improvement of open burning control measures in terms of appropriateness and efficiency. The effects of sugarcane field burning on GHG emissions/removal were studied to gain a better understanding of sugarcane ecosystem responses to global change. The key findings of this study are summarized below.

11.1.1 Sugarcane biomass in Thailand in 2012

Sugarcane biomass, as discussed in Chapter 2, is divided into aboveground and belowground biomass. Firstly, the total aboveground biomass was estimated from a combination of two factors, including the residue-to-product ratio (RPR) and sugarcane crop yield. The data obtained from the field survey, totally 13 sites under different farm management systems, soil conditions and climatic conditions, showed the average RPR value for sugarcane in Thailand ranged from 0.24 to 0.47 with an average value of about 0.37. The annual aboveground biomass produced to amount to 37.57 million tonnes (29.30 tonnes ha^{-1} on average) in 2012, which the average sugarcane biomass fuel subject to open burning, called sugarcane biomass fuel load was estimated to be 7.86 ton ha^{-1}. For the belowground biomass, the result showed a ratio of belowground biomass to aboveground biomass was estimated to be 0.23 for the 0-100 cm soil depth and total belowground biomass is about 8.64 million tons (6.74 tonne $ha^{-1)}$. The total biomass in sugarcane plantation areas, which is equal to the sum of aboveground biomass and belowground biomass, was approximately 46.21 million tonnes (on a dry mass basis) with the average value of 36.05 tonnes ha^{-1} in a cropping season of year 2012.

Furthermore, the carbon storage in sugarcane biomass was determined based on the carbon content measured by the ultimate analysis and the dry mass of sugarcane biomass as mentioned above. The carbon content varied in the difference of sugarcane partitioning, ranged from 40% to 44%. The carbon storage in biomass under sugarcane farming was calculated to be 20 tonnes yr^{-1} or 15.68 kg C ha^{-1}.

11.1.2 Sugarcane area burned in Thailand in 2012

As reported in Chapter 3, questionnaire surveys were conducted to assess the extension of the area burned for the sugarcane cropping in 2012. The results indicated that open burning in sugarcane field is mainly performed by farmers before harvesting to facilitate manual harvesting operations (pre-harvest burning) and also after harvesting (post-harvest burning) for soil preparation and fire protection for the next crop cycle. About 0.99 million ha of sugarcane plantations are burned annually in Thailand, this represents 77% of the total sugarcane harvested area. Pre-harvest burning is contributing the largest share with 82%, post harvest-burning contributing the remaining 18%. For post-harvest burning system, the main reason for burning, 89% of the cases is to protect the next crop from fire, and the remaining 11% being related to clearing the land before preparing the soil for the next crop cycle.

On a regional basis, the Northeast is the region where the largest areas of sugarcane is open burnt (39% of total burned areas), followed by the Northern (31%) and the Central regions (30%). The rankings indicate that Nakhon Sawan is the top first province in the burned area, followed by Nakhon Ratchasima, Kanchanaburi, Khon Kaen, Kampaeng Phet, and Suphanburi. In addition, the season, when sugarcane residues were burned in the field, runs from November to April. However, the months, when open burning occurred with high frequency, are December to March accounted to be 82% of the total area burned.

11.1.3 Sugarcane biomass burned during open burning in Thailand in 2012

To quantify the amount of sugarcane biomass burned in the field, the combustion factor was first evaluated based on field investigation, and this information was processed in combination with the data on the amount of sugarcane biomass fuel subject to open burning and the area of sugarcane burning. The results showed that the combustion factors for the pre-harvest and post-harvest burning systems were estimated to be 0.64 and 0.83, respectively. The difference in biomass fuel moisture content between the two systems appeared to the main factor influencing the amount of fuel consumed by fire. This finding confirmed that the moisture content of biomass is a major factor influencing combustion efficiency. Moreover, the total sugarcane biomass consumed by burning is about 5.30 Tg or 5.36 Mg ha^{-1} on average. It dominates in the Northeastern region (36%) closely followed by the Northern (34%) and Central regions (30%) as presented in Chapter 4.

The major outcome of this research work is a better understanding of the factors that influence the emission of air pollutants and climate forcer agents due to biomass open burning for ASEAN region where the cultivation of sugarcane is expected to expand during the next decades to assure the energy need of the region.

11.1.4 Emissions from sugarcane field burning in Thailand in 2012

To assess the contribution of sugarcane field burning to GHG emissions in Thailand, the country-specific factors involved in the calculation using IPCC 2006 Guidelines for the National GHG Inventory were obtained from the field investigation and questionnaire survey, as mentioned in Chapter 5. The annual GHG emissions from sugarcane burning were calculated to amount to 8.44 Tg CO_{2eq}, accounted to be 8.54 Mg CO_{2eq} ha^{-1}. Only 2.87% of total emissions are non-CO_2 gas; 3.56% as CH_4 emissions and 1.43% as N_2O emissions. The emissions do vary spatially and temporally depending on the area of sugarcane subject to burning, the period of burning, i.e. pre and post-harvest burning, and the amount of biomass fuel consumed. Regarding a regional basis, the amount of GHG emission dominates in the Northeastern region (36%) closely followed by the Northern (34%) and Central regions (30%). The results also showed that the pre-harvest burning possesses the largest share in term of emissions, with 78% of total GHG emission. Therefore, it is recommended to strictly control sugarcane field burning during the harvesting season, in particular for cases where manual harvesting methods are used.

11.1.5 Effects of open burning on GHG balance under sugarcane plantations in Thailand

This study aims to estimate the effects of open burning on the annual emission balance under sugarcane plantation systems in Thailand. A field experiment was conducted on a sugarcane farmer's field in Nakhon Sawan province, northern region of Thailand. Two sites, sugarcane sites with and without burning, were selected for monitoring and measuring GHG emissions/removal over a one-year cycle of the plant crop. The parameters or variables used in monitoring GHG fluxes are the major greenhouse gases including CO_2, CH_4, and N_2O emitted from soils, open field burning and fossil fuel combustion. For the removals of GHG, there are evaluated from the annual carbon stock changes in soils and sugarcane biomass.

Considering the total GHG emission fluxes from the soil, there was no significant difference in the annual GHG emissions fluxes between burned (35.94 Mg CO_{2eq} ha^{-1}) and unburned (36.36 Mg CO_{2eq} ha^{-1}) areas. As described in Chapter 7, approximately 99% of total emission were reported as CO_2. There was virtually no emission flux for CH_4 and there is very small emission flux of N_2O from sugarcane soils, only 0.38 – 0.39 Mg CO_{2eq} ha^{-1}. The results also showed that the emissions from microbial activity is a main dominant of CO_2 emission from soil, accounted for 82% of total CO_2 emission fluxes (29.00 Mg ha^{-1} and 29.39 Mg ha^{-1} for burned and unburned plots, respectively). The emissions from sugarcane filed burning was estimated to be 8.62 Mg CO_{2eq} ha^{-1} under the burned plot in this experiment. In addition, the emission of GHG from fossil fuel combustion sources for the burned area was about 0.74 Mg CO_{2eq} ha^{-1} and 1.05 Mg CO_{2eq} ha^{-1} for the unburned area. Therefore, the total GHG emission fluxes were 38.94 and 30.51 Mg CO_{2eq} ha^{-1} for the burned and unburned areas, respectively. The main cause of high emission in the burned area is the increasing of emissions from burning, accounted of 22% of total emission. The open burning affected to increase emissions of 7.98 Mg CO_{2eq} ha^{-1} in the burned area when compared with the unburned area.

For GHG removals, the observation data shows that sugarcane field burning could lead to a substantial loss of ecosystem carbon sequestration. The annual carbon stocks change in the top 30 cm soil under the burned area was 0.09 Mg C ha^{-1} (0.32 Mg CO_2 ha^{-1}), and 0.43 Mg C ha^{-1} (1.58 Mg CO_2 ha^{-1}) for the unburned area. Also, total storage in sugarcane biomass was 14.05 Mg C ha^{-1} (51.51 Mg CO_2 ha^{-1}) for the burned area and 15.70 Mg C ha^{-1} (57.55 Mg CO_2 ha^{-1}) for the unburned area. Totally, the net GHG removal was about 14.14 Mg C ha^{-1} (51.84 Mg CO_2 ha^{-1}) and 16.13 Mg C ha^{-1} (59.13 Mg CO_2 ha^{-1}) for burned and unburned sites, respectively. This finding indicates that the area with burning system has 14% lower in the net GHG removal by carbon sink when compared with the area without the burning system.

Regarding the annual GHG budget as discussed in Chapter 10, a preliminary result of this study indicates that sugarcane field burning causes a decrease in the emission reduction, approximately 15.27 Mg CO_{2eq} ha^{-1}. This could be affected by increasing in the emission from sugarcane field burning and decreasing in the carbon sequestration under the burning management system. The conversion from burning management to no-burning management could be mitigated GHG emission. This finding confirmed that agricultural activities are recognized as potential GHG mitigation option. Good agricultural practices can reduce and avoid the atmospheric buildup of the GHGs directly emitted by human option.

11.2 Policy measures and recommendations

This section provides a detail of guidelines for potential policy measures to reduce the effects of sugarcane field burning on GHG emissions based on the key findings of this study. The approaches that best reduce emissions depend on local conditions and key emitting sectors. In this study, two broad categories including the reduction of emissions from present sources, and the creation and strengthening of carbon sink are used as baseline to develop policy measure guidelines. Moreover, in this study measures are suggested that maximize both emission reduction and sugarcane productivity. The available control technologies and alternative strategies considered for achieving this proposes are discussed below.

(1) Reducing emissions: this study showed that the key emission sources of GHGs for sugarcane are open burning and the soil. The cultivation of sugarcane is responsible for releasing a significant amount of CO_2 and N_2O into the atmosphere. These emissions can be reduced by improving agronomic practices. The appropriate practices and managements for reducing GHG emissions from those sources are listed below.

(1.1) Reducing the area burned: the findings indicate that the pre-harvest burning contributes the highest share of the overall open burning of sugarcane in Thailand. Therefore, it is recommended to strictly control sugarcane open burning in particular where manual harvesting methods are employed and promote harvesting systems without burning; for example promoting the use of sugarcane harvester for green-cane harvest, providing price additional price incentives for non-burned cane at least more than the current which quite close to that of the burned cane, supporting a cooperation of farmers for planning the harvesting (zoning the harvested area) and protecting fire, giving official recognitions and awards to farmer who distinctly comply and cooperate for no-burning system, and marking and enforcing legislation to restrict open burning in agriculture. Similarly, promotion of no-burning after harvest is necessary to avoid expanding post-harvest burning in the future. The basic knowledge on the management of sugarcane residues and the techniques used for protecting fire during cane regrowing should be provided to farmers and governmental officers in local offices. Also identifying appropriate incentives encouraging farmers to adequately manage sugarcane residues after harvesting are needed.

(1.2) Reducing sugarcane biomass fuel load: crop residues are seen as a potential source of feedstock for energy to displace fossil fuels. Expanding the use of sugarcane residues for energy purposes is one good alternative to reduce the occurrence of open burning after harvesting and provide a complementary source of income to farmers. However, other environmental impacts related to the removal of biomass from the field, such as loss of soil organic matter from not returning biomass to soil need also to be carefully taken into consideration.

(1.3) Improving nutrient management: the observation data in this study showed that the application of nitrogen fertilizer to sugarcane soils is a key determinant of N_2O emissions. The soil emissions of N_2O were found to increase after fertilizer application. This may be explained by the nitrogen in fertilizers not being efficiently consumed by the crop. Therefore, adjusting the application rate based on precise estimation of sugarcane plant needs (avoid excess nitrogen application) could reduce emissions of N_2O from soil. Applying the nitrogen fertilizer more precisely into the soil, which is more accessible to crop root, may also decrease the rate of N_2O emissions, as well as adjusting the timing of fertilizer application.

(2) Enhancing removal: this study confirmed that a sugarcane cropping system is recognized as a potential net carbon sink. Atmospheric CO_2 can be removed and sequestered in crop biomass and soil under sugarcane cultivation. Agricultural

management practices can also enhance removal. The following list provides some of the practices that may enable to enhance removal.

(2.1) Increasing soil carbon stock: the systems in which crop residues are retained in the field tend to increase the carbon stock in soils. Incorporating sugarcane residues into the soil or leaving residues on the soil surface can avoid the emissions from open burning and also increase soil carbon storage. In addition, applying organic fertilizer, i.e. manure and green manure, is also a good alternative method to increase the soil carbon stock. This also affects the improvement of soil fertility and crop productivity.

(2.2) Increasing crop productivity: avoiding the burning of sugarcane residues increases crop productivity which in turn generate higher carbon storage in the sugarcane biomass. Moreover, improved agronomic practices can also contribute to enhance carbon storage. Examples of such practices include: improving sugarcane cultivar; developing in soil preparation, weed control and fertilser application methods.

For the selected area approach to control sugarcane field open burning, measures as mentioned above should be promoted in priority in the provinces identified as the burned areas in Chapter 3, in particular in the top first 10 provinces, including Nakhon Sawan, Nakhon Ratchasima, Kanchanaburi, Khon Kaen, Kampaeng Phet, Suphanburi, Chaiyaphum, Uon Thani, Phetchaboon, and Uthai Thani (see Appendix D). Also, the guidelines for promoting the no-burning in agricultural areas are summarized as follows:

(1) Educating farmers: provide training and giving knowledge to change the attitudes of the farmers to stop the burning of crop residue, parallel to educating of alternately methods in using the advantage of agricultural residue instead of eliminating crop residue as the waste.

(2) Establishing the non-burning agricultural network by supporting farmers' collaboration for preventing and controlling burning in sugarcane areas. The aims are to increase the efficiency of developing the no-burning system in agriculture.

(3) Supporting the sharing of agricultural machinery among farmers for the no-burning process, such as sugarcane harvester for instance, as it is characterized by a high investment cost.

(4) Campaigning for non-burning before haze pollution events occur. It may be set up in terms of the field day for promoting the zero open burning in agriculture and

sharing knowledge on the alternative methods for stop burning, together with using other communication channel such as printed material, radio, television and video are also used.

11.3 Recommendations for further research studies

Based on the findings in this study, further research works are recommended.

(1) Monitoring and assessing extent of open burning in sugarcane areas. Ground surveys should be conducted every year in order to assess the change in sugarcane burned areas and also to use as references to estimate corresponding air pollutant emissions. These databases could be used for planning and controlling open burning activities in the agricultural sector.

(2) The field experiments should be continued over a long period of time, at least three years following the cropping cycle because agricultural management practices, especially residue management practices for unburned crops, are different for a new plant and for a ratoon. In addition, the results obtained from the experiments of this research are site-specific and may not be applicable to other areas. To confirm the findings of this research, it is recommended to investigate the effects of open burning on other typical sugarcane growing soil types at ecologically different locations.

(3) For GHG monitoring, gas samples should be collected 2 or 3 times a week during the early period of growing during intensively farming activity and once or twice a week afterwards. Because GHG exchanges between the soil and the atmosphere are influenced by management practice currently used in farming system.

(4) The water-filled pore space in soils is an important factor influencing soil GHG emissions. Further studies should therefore monitor soil water filled pore space in the same time of GHG measurement.

(5) To devise effective farming management strategies for minimizing GHG emissions, the modeling should complement field-based studies to establish generality and inform future sustainable sugarcane farming.

(6) Studies based on the economic returns and environmental impacts of burned and unburned systems are necessary and should further be investigated.