CHAPTER 10
GHG BALANCE UNDER BURNED AND UNBURNED SUGARCANE PLANTATIONS IN THAILAND

As reported previously, open burning in agricultural area represents an important source of non-CO_2 greenhouse gases, such as CH_4 and N_2O. It is direct effect to constitute the largest non-fossil fuel of CO_2 emissions. Also, this burning activity has decreased in carbon sequestration in agricultural ecosystem resulting to change on GHG balance in the ecosystem. The conversion of sugarcane area from burning to no-burning systems can avoid emissions of greenhouse gas generated from fire and mitigate global climate change by compensating for some of the CO_2 release to the atmosphere. However, the examination data for this aspect is still lack information. Thus, this study proposes to investigate the GHG balance under burned and unburned sugarcane plantation areas in Thailand. Field experiment was conducted for measuring the emission and removal of GHG from sugarcane plantation system in Nakhon Sawan province in Thailand. The preliminary data for calculating the GHG balance in sugarcane area was presented in Chapters 7-9. This chapter aims to estimate the annual emission balance take into account the major agricultural sources of GHG in one hectare of burned and unburned sugarcane areas.

10.1 Methodology

10.1.1 Assessment of GHG balance in sugarcane plantation systems

The source of GHG emission/removal under sugarcane plantation system is presented in Figure 10.1. The key GHG of concern in this study are CO_2, N_2O and CH_4 fluxes between the atmosphere and sugarcane plantation ecosystems. The main sources of GHG emissions were associated with soils and agricultural practices, i.e., sugarcane field burning, fossil fuel combustion. The emissions are estimated as a net flux occurring over growing season. The major ecosystem stocks and process include sugarcane biomass and soils. There are estimated as a net change in C stocks over one year. The boundary considered in this study encompassed only in the process of sugarcane framing operation during planting to harvesting practices, exclude transportation.

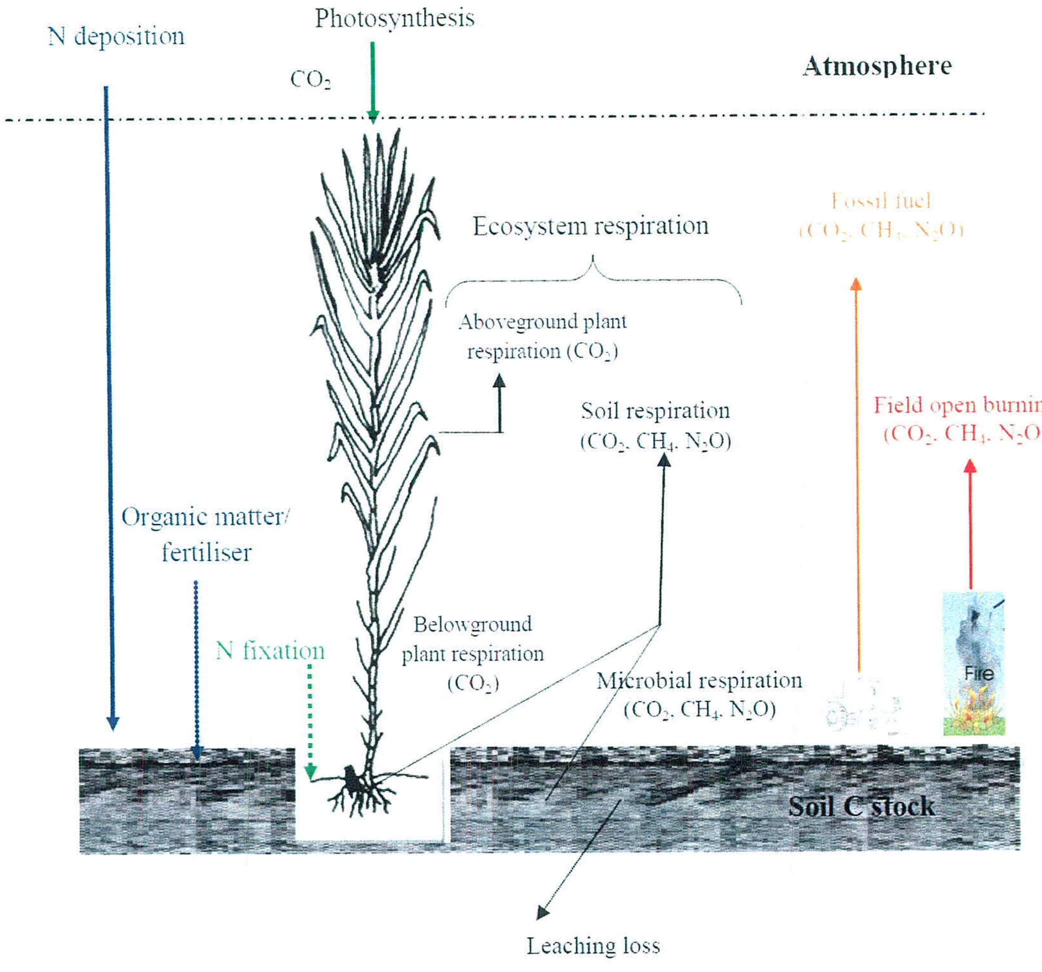

Figure 10.1 Greenhouse gas emissions and removals in the sugarcane plantation system

To compute the annual emission balance (GHG balance), a relation between emissions and removals under a sugarcane plantation system was established in one hectare of sugarcane area over a one-year cycle of plant growth. The following relationships were found:

$$\text{GHG balance} = \text{GHGs Emissions} - \text{GHGs Removals} \quad (10.1a)$$

$$GHG_B = (E_B + E_F + E_{mb} + E_{AG} + E_{BG}) - (R_P + \Delta C_s) \quad (10.1b)$$

$$GHG_B = (E_B + E_F + E_{mb}) + (E_{AG} + E_{BG} - R_P) - \Delta C_s \quad (10.1c)$$

$$GHG_B = (E_B + E_F + E_{mb}) - C_B - \Delta C_s \quad (10.1d)$$

where GHG_B is the GHG balance (kg ha^{-1} y^{-1}), E_B is emissions from field open burning (kg ha^{-1} y^{-1}), E_F is emissions from fossil fuel combustion (kg ha^{-1} y^{-1}), E_{mb} is emission from microbial activity (kg ha^{-1} y^{-1}), E_{AG} is aboveground plant respiration (kg ha^{-1} y^{-1}), E_{BG} is belowground plant respiration (kg ha^{-1} y^{-1}), R_p is plant photosynthesis (kg ha^{-1} y^{-1}) , C_B is annual carbon stock in sugarcane biomass (kg C ha^{-1} y^{-1}), and ΔC_s is annual carbon stock change in soils (kg C ha^{-1} y^{-1}). Change in carbon stocks is converted to unit of CO_2 emissions by multiplying the carbon stock change by 44/12.

According to Equation (10.1), three major sources of GHG emission considered for this assessment were associated with sugarcane field burning (E_B), fossil fuel combustion sources (E_F) and microbial processes (E_{mb}). Regarding GHG removal, changing in soil carbon stock (ΔC_s) and carbon storage (C_P) in sugarcane biomass were determined to estimate the balance of GHG in the sugarcane ecosystem.

10.1.2 Determination of emissions from sugarcane field open burning

The methods used to assess the emissions from sugarcane field burning were based on the Intergovernmental Panel on Climate Change (IPCC) Guidelines 2006 for estimating emissions of GHG, including CO_2, N_2O and CH_4. The basic equation for estimating the emissions from biomass burning is presented in Equation (10.2) (IPCC, 2006).

$$E_B = A \times M_B \times C_f \times G_{ef} \times 10^{-3} \qquad (10.2)$$

where E_B is the amount of greenhouse gas emissions from fire (Mg of each gases), A is the area burnt (ha), M_B is the dry mass of fuel available for combustion (Mg ha^{-1}), C_f the combustion factor (dimensionless), and G_{ef} is the emission factor (g kg^{-1})

In this analysis, the Tier 2 method, using the default values of the emission factor provided by the IPCC was selected to estimate the amount of GHG emissions from sugarcane field burning based on the area burnt in one hectare. The aggregate default values used in this study are 1,515, 2.7 and 0.07 g kg^{-1} for CO_2, CH_4 and N_2O, respectively (IPCC, 2006). The available sugarcane biomass for burning (M_B) was measured from the experiment as reported in Chapter 9. Likewise, the combustion factor (C_f) of the burning before harvesting was also measured from the same experimental site. Sugarcane biomass was sampled before and after burning under the area of 1.13 m^2 with 5 replications as shown in Figure 10.2. Then, the dry mass of sugarcane for pre-burning and post-burning samples is used to estimate the combustion factor, as shown in Equation (10.3).

$$C_f = \frac{(M_B - M_A)}{M_B} \qquad (10.3)$$

where C_f is the combustion factor value (dimensionless), M_B is the dry mass of biomass before burning (Mg ha^{-1}), M_A is the dry mass of biomass after burning (Mg ha^{-1})

(a) (b)

Figure 10.2 Sugarcane biomass sampling (a) before burning and (b) after burning

Finally, each gas is converted into a CO_2 equivalent value using global warming from the 100-year time horizon GWP equivalent factor following the IPCC Guidelines (1 for CO_2, 21 for CH_4, and 310 for N_2O) (IPCC, 2007).

10.1.3 Determination of emissions from fossil fuel combustion sources used in sugarcane plantation systems

The diesel oil used in machinery for agricultural operations, including soil preparation, fertilizer application, watering, and harvesting processes, as shown in Figure 10.3 were taken into account for emission due to fossil fuel combustion. The part of transportation is not considered in this analysis. The GHG emissions is generally determined by the amount of diesel oils as called activity data and emission factor, as shown in Equation (10.4) (IPCC, 2006).

$$E_F = Fuel \; x \; EF \tag{10.4}$$

where E_F is the emissions from farm machinery as classified in off road transportation, Fuel is the fuel consumed as represented by fuel sold (TJ), and EF is the emission factor (kg/TJ).

Figure 10.3 Machinery used for sugarcane plantation system in this study

In this study, the data of diesel oil used was summarized based on farm operations in one seasonal sugarcane cropping system from the experimental sites. The net calorific value of 36.42 MJ L^{-1} was used to determine the diesel consumed in the field in terms of fuel sold (EPPO, 2013). The emission factors associated with diesel consumption including

CO_2, CH_4, and N_2O emissions were 74,100, 4.15, and 28.6 kg TJ^{-1}, respectively (IPCC, 2006).

10.1.4 Determination of emissions from microbial processes

As mentioned in Chapter 6, CO_2 is emitted from soils released by microbial activity and root respiration. To determine the emissions from microbial activity, firstly the CO_2 emissions from below-ground plant respiration (called root respiration) in this experiment was calculated based on the model described in Equation (6.3) in Chapter 6. Then, CO_2 emissions from microbial activity were estimated from the difference between total soil CO_2 emission and the emission from root respiration, as presented in Equation (10.5).

$$E_{M(CO_2)} = E_{T(CO_2)} - E_{BG(CO_2)} \tag{10.5}$$

where, $E_{m(CO2)}$ = Emissions of CO_2 from microbial activity (Mg ha^{-1}), $E_{T(CO2)}$ = Total CO_2 emission from soil (Mg ha^{-1}), $E_{BG(CO2)}$ = Emissions of CO_2 from belowground plant respiration (Mg ha^{-1})

Next, the annual GHG emissions including CO_2, CH_4, and N_2O from sugarcane soil were estimated based on the results presented in Chapter 7 (Eq. 10.6). Furthermore, all values of GHG emissions were converted to CO_2 equivalent following the individual global warming potential for a period of 100 years for each gas using 1 for CO_2, 21 for CH_4, 310 for N_2O (IPCC, 2007).

$$E_M = E_{M(CO_2)} + E_{M(CH_4)} + E_{M(N_2O)} \tag{10.6}$$

where, E_m = Total GHG emissions from microbial activity (Mg ha^{-1}), $E_{M(CO2)}$ = Total CO_2 emissions from soil (Mg ha^{-1}), $E_{M(CH4)}$ = Total CH_4 emission from soil (Mg ha^{-1}), and), $E_{M(N2O)}$ = Total N_2O emissions from soil (Mg ha^{-1})

10.1.5 Determination of annual carbon stock change in soils

Changing in soil carbon stock over one-year cycle of planting was determined based on the methodology set by the Intergovernmental Panel on Climate Change (IPCC) Guidelines 2006. The annual change of soil carbon stock is a relation of soil organic carbon change for mineral soils, CO_2 emissions from organic soils due to enhance microbial decomposition caused by drainage and associated management activity, and carbon stock change for soil inorganic carbon pool (i.e. calcareous soil). The basic calculation for estimating soil carbon stock change is provided in Equation (10.7) (IPCC, 2006).

$$\Delta C_s = \Delta C_{\text{mineral}} - L_{organic} + \Delta C_{Inorganic} \tag{10.7}$$

where ΔC_s is annual carbon stock change in soils (kg ha^{-1} y^{-1}), $\Delta C_{\text{mineral}}$ is annual change in organic carbon stock in mineral soils (kg ha^{-1} y^{-1}), L_{organic} is annual loss of carbon from drained organic soils (kg ha^{-1} y^{-1}), and $\Delta C_{\text{Inorganic}}$ is annual change in inorganic carbon stocks from soils.

For mineral soils, change in soil organic carbon stocks ($\Delta C_{\text{mineral}}$) are estimated as the difference in stocks at two points in time divided by the time dependence of stock change factor, as shown in Equations (10.8a) and (10.8b) (IPCC, 2006).

$$\Delta C_{mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D} \tag{10.8a}$$

$$SOC_{(0-T)} = SOC_{REF} \ x \ F_{LU} \ x \ F_{MG} \ x \ F_I \ x \ A \tag{10.8b}$$

where SOC_0 is soil organic carbon stock in the last year (kg C ha^{-1}), $SOC_{(0-T)}$ is soil organic carbon stock at the beginning (kg C ha^{-1}), T is number of years (y), D is time dependence of stock change factors, SOC_{REF} is the reference carbon stock (kg C ha^{-1}), F_{LU} is stock change factor for land-use systems or sub-system for a particular land-use (dimensionless), F_{MG} is stock change factor for management regime (dimensionless), F_I is stock change factor for input of organic matter (dimensionless), and A is land area (ha).

In this analysis, the soil organic carbon stock in the last year (SOC_0) was measured from the experimental sites in this study and the soil organic carbon stock at the beginning ($SOC_{(0-T)}$) was estimated using Equation (8.3b). The soils in the experiments are classified as the soils with high activity clay and the climate region is the tropical, moist climate. So, the default reference soil organic carbon stock (SOC_{REF}) is about 65 Mg C ha^{-1}. The stock change factors adopted were 0.48 for F_{LU}, 1 for F_{MG}, and 1 for F_I (IPCC, 2006).

10.1.6 Determination of annual carbon stock change in sugarcane biomass

The approach for determining the annual carbon stock change in biomass is based on IPCC mythology called the stock-difference method. Estimating the net carbon change in biomass, it is required that the biomass carbon stock at two points in time. Annual biomass change is the difference between the carbon storage in biomass at time t_2 and time t_1 divided, by the number of years between the measured times (Equation 10.9). Biomass carbon stock considered is the aboveground and belowground biomass at the top 30 cm soil layer (IPCC, 2006).

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \qquad (10.9)$$

where ΔC_B is the annual change in carbon stock in biomass (the sum of aboveground and belowground biomass) (Mg ha^{-1} y^{-1}), C_{t_2} is the total carbon in biomass at time t_2 (Mg ha^{-1}), and C_{t_1} is the total carbon in biomass at time t_1 (Mg ha^{-1}).

Sugarcane is the annual crop and is harvested annually. Thus, the measured time considered in this study is a one-year cycle ($t_1 = 0$ and $t_2 = 1$). The annual carbon stock change is determined from the total carbon stock in sugarcane biomass, as described in Chapter 9.

10.2 Results and discussion

10.2.1 Emissions from sugarcane field open burning

Based on the measurement data, the density of biomass fuel available for burning, called sugarcane biomass fuel load (M_B) and the combustion factor (C_f) were reported in Table 10.1. According to the results, the mean value of sugarcane biomass fuel available for burning is about 8.78 Mg ha^{-1}. The combustion factor of sugarcane field burning varied from 0.20 to 0.90 with the mean value of 0.62. The difference sugarcane partitioning, difference of biomass fuel moisture content, appeared to difference in the actual mass of fuel consumed. That confirmed the moisture content of biomass is an important factor influencing combustion efficiency.

Considering GHG emissions, emissions from the burning of sugarcane residue in the field were estimated using the actual sugarcane biomass fuel load and the combustion factor provided in Table 10.1. Under the Tier 2 approach, the formulation presented in Equation (10.2) can be applied to estimate CO_2 and non-CO_2 emissions from burning, using the default data of the emission factor provided by the IPCC. Results imply that burning of 8.78 Mg of sugarcane residue is the cause of contributing GHG at 8.62 Mg of CO_2 equivalent (Table 10.2).

Table 10.1 Dry mass of sugarcane biomass fuel available for burning (M_B) and the combustion fraction of sugarcane biomass burned at the burning site (C_f)

Sugarcane partitioning	Dry mass (Mg ha^{-1})		Combustion factor (dimentionless)	
	Mean value	SE	Mean value	SE
1. Fresh leaves	3.36	0.25	0.20	0.01
2. Dry leaves	4.30	0.29	0.87	0.01
3. Dead leaves	0.08	0.08	0.90	0.01
Total	8.78	0.42	0.62	0.02

Table 10.2 Emissions from sugarcane field burning in the burned site

GHGs	Emissions from sugarcane field burning	
	Mg ha^{-1}	Mg CO_{2eq} ha^{-1}
1. CO_2	8.1997	8.200
2. CH_4	0.0146	0.307
3. N_2O	0.0004	0.117
Total		8.624

10.2.2 Emissions from fossil fuel combustion sources

The fossil fuel used at the experimental site is normally diesel oil for agricultural machinery. This study considered the emissions related to data for diesel consumption during planting and harvest operations in a one year cycle, taking into account the differences between the consumption in the burned and unburned plots as reported in Table 10.3.

Based on Equation (10.4), the diesel consumption applied to the calculations was 244.31 and 345.82 L ha^{-1} y^{-1} for the burned and unburned plots, respectively. The GHG emission due to fossil fuel use contributes about 738.97 and 1,046.03 kg CO_{2eq} ha^{-1} for the area with and without burning, respectively (Table 10.4). As expected, the higher emissions for the unburned system are due to the higher consumption of diesel, principally at the harvest operation.

Table 10.3 Diesel oil consumption for each agricultural operation at the burned and unburned areas

Farm operations	Diesel consumption (L ha^{-1})	
	Burned area	Unburned area
1. Soil preparation	115.63	115.63
2. Planting	23.44	23.44
3. Fertiliser application	25.18	25.18
4. Watering	49.50	49.50
5. Harvesting		
5.1 Harvester (1)	-	132.08
5.2 Loader machine (2)	30.56	-
Total	244.31	345.82

Note: (1) Diesel consumption for sugarcane harvester is 1.80 liter per ton cane (DOA, 2004)

(2) Diesel consumption for loader machine ranged from 0.42 to 0.50 liter per ton cane (Niti et al., 1997). About 0.46 liter per tonne cane is used for estimating the diesel consumption in this analysis.

Table 10.4 Emissions from diesel consumption for farm operation in the burned and unburned sites.

	Burned area		Unburned area	
GHG emissions	kg ha^{-1}	kg CO_{2eq} ha^{-1}	kg ha^{-1}	kg CO_{2eq} ha^{-1}
1. CO_2	659.31	659.31	933.27	933.27
2. CH_4	0.04	0.78	0.05	1.10
3. N_2O	0.25	78.89	0.36	111.66
Total		738.97		1,046.03

10.2.3 Emissions from microbial processes

The finding shows the total CO_2 emissions from microbial processes at the burned plot were about 29.00 Mg ha^{-1} and 29.39 Mg ha^{-1} for the unburned plots (Table 10.5). No significant difference in C_2O emissions from microbial activity was observed between the burned and unburned sugarcane plantation systems in Thailand.

Table 10.5 CO_2 emissions from soils under burned and unburned plots

	Burned area		Unburned area	
Sources	Mg ha^{-1}	Mg CO_{2eq} ha^{-1}	Mg ha^{-1}	Mg CO_{2eq} ha^{-1}
Sugarcane roots	6.57	6.57	6.60	6.60
Microbial activity	29.00	29.00	29.39	29.39
Total CO_2 emissions	35.56	35.56	35.99	35.99

Regarding soil GHG emissions, the total GHG emissions from soils were not significantly different between the burned and unburned plots. It is estimated to be 29-30 Mg CO_{eq} ha^{-1}, as shown in Table 10.6. The emissions of CO_2 are a main dominant of GHG emissions from soils, accounted for 99% of total GHG emissions. In addition, the results shown it is virtually no soil emission fluxes of CH_4 due to dry crop soils and low emission fluxes of N_2O, accounted only 1% of total emissions.

Table 10.6 Annual GHG emissions from sugarcane soils in this experiment

	Burned area		Unburned area	
GHGs	Mg ha^{-1}	Mg CO_{2eq} ha^{-1}	Mg ha^{-1}	Mg CO_{2eq} ha^{-1}
- CO_2	29.00	29.00	29.39	29.39
- CH_4	-0.0005	-0.0102	-0.0005	-0.0099
- N_2O	0.0018	0.3865	0.0018	0.3764
Total GHG emissions		29.3717		29.7552

10.2.4 Annual carbon stock change in soil

Based on the examination data in Chapter 8, the carbon stocks in the experimental soil of the 0-30 cm layer were 32.97 and 39.81 Mg ha^{-1} for the areas with and without burning respectively. Based on Equations (10.7) and (10.8), the annual carbon stock change in the burned soil was 0.09 Mg C ha^{-1} y^{-1} (0.32 Mg CO_2 ha^{-1} y^{-1}), and 0.43 Mg C ha^{-1} y^{-1} (1.58 Mg CO_2 ha^{-1} y^{-1}), for the unburned soil. The unburned practice performed during 5 years consecutively enabled to increase the carbon stock in soil at a rate of 0.34 Mg ha^{-1} y^{-1} (1.25 Mg CO_2 ha^{-1} y^{-1}), when compared with the burned practice. The annually increased in soil carbon stock under the unburned area has increased about 3.87 times when compared with that in the burned area. It should be noted that a change in crop residue management affected the potential of carbon sequestration in soil and also resulted in changes in the GHG balance of the agricultural ecosystem.

10.2.5 Annual carbon stock change in sugarcane biomass

The carbon storage in sugarcane biomass has 1.65 Mg C ha^{-1} (6.04 Mg CO_2 ha^{-1}) reduction due to the effect of sugarcane field burning. The annual change in carbon storage in sugarcane biomass under the burned area is about 14.05 Mg C ha^{-1} (51.51 Mg CO_2 ha^{-1}) and 15.70 Mg C ha^{-1} (57.55 Mg CO_2 ha^{-1}) for the unburned area. The result showed that the increasing of carbon stock under the area without burning accounted for 12% when compared with that under the burned area.

10.2.6 The GHG balance in the burned and unburned sugarcane plantation system

Table 10.7 presents the estimates of GHG emissions (in Mg CO_2 equivalents per hectare per year) for each agricultural source, as well as GHG removals. Basically, GHG emissions in sugarcane field are emitted from microbial activity in the soils, open burning, and fossil fuel combustion from farm machinery used. While, the GHG emitted are absorbed by soils and sugarcane plants. In this study, the source that most impacted to the GHG emission in sugarcane plantation areas were the microbial activity, corresponding to 76% of total emission for the burned area and 97% for unburned area. The major source for GHG removals in this assessment is sugarcane biomass, accounted for 97-99% of total removal. In addition, this finding confirmed that sugarcane plantation area is a one of important source for reducing GHG emissions to the atmosphere.

Regarding the effects of open burning, this finding confirmed that sugarcane field open burning affected the increase of GHG emissions from sugarcane plantation systems. The emissions from burning accounted of 22% of total GHG emissions from the burned area. It is direct effect to increase the amount of GHG emission of 8.72 Mg CO_{2eq} ha^{-1} in the burning system compared to the unburned system. On the other hand, the burning has affected to decrease of the GHG emission reduction by reducing GHG absorbed by soils and plants as shown in Table 10.7. For an indirect effect of open burning, the area with burning has 14% lower in the net GHG removal by carbon sink when compared with the area without burning. Account for GHG removal from the burned area was found to decrease approximately 7.29 Mg CO_{2eq} ha^{-1} when compared with that from the unburned area. This may be explained by losing of greater amount of sugarcane residue returned to the soil in order to decrease in soil organic carbon and crop productivity. It should be noted that sugarcane field burning could lead to a substantial loss of ecosystem carbon storage.

However, in terms of an indirect effect on GHG emissions, the unburned system has about 30% higher in the emission from diesel combustion than the burned system due to use of a sugarcane harvester, but it is not a significant difference in the change of the net GHG emissions.

Table 10.7 GHG emissions and removal in the sugarcane areas with and without open burning. Emissions are marked with a positive (+) sign and removals are marked with a negative (-) sign.

Sources	GHG (Mg CO_{2eq} ha^{-1} y^{-1})	
	Burned area	Unburned area
1. Direct effects of open burning		
1.1 GHG Emissions		
(a) Sugarcane burning	8.62	0.00
1.2 GHG Removals	0.00	0.00
1.3 Overall	8.62	0.00
2. Indirect effects of open burning		
2.1 GHG Emissions		
(a) Diesel combustion	0.74	1.05
(b) Microbial activity	29.37	29.76
2.2 GHG Removals		
(a) Soils	-0.32	-1.58
(b) Plants	-51.51	-57.55
2.3 Overall	-21.73	-28.33
3. Net GHG balance (1+2)	-13.10	-28.33

Furthermore, this finding shows that the net GHG emission reduction is about 13.10 and 28.33 Mg CO_{2eq} ha^{-1} y^{-1} for the burned and unburned areas, respectively. Open burning causes to decrease in the reducing emissions, accounting for 15.23 Mg CO_{2eq} ha^{-1} y^{-1}. While, the unburned practice performed during 5 years consecutively enabled to removal greater amount of CO_2 than the burned practices around 2 times. It should be noted that the conversion from burning management to no-burning management could mitigate GHG emissions.

10.3 Summary of findings

This study focuses on the change in the greenhouse gas balance under burned and unburned sugarcane plantation systems in Thailand. The GHG emissions/removals were estimated from soils and plants using the directing measurement method, and from burning and mobile consumption using the calculation method of IPCC 2006 Guideline. The system boundary covered GHG emission/removal from sugarcane cultivation during planting to harvesting over a one-year cycle, excluded the emissions from raw material used and from mobile consumption during transportation. Three major greenhouse gases including CO_2, CH_4, and N_2O were considered in this analysis and there are presented in term of CO_2 equivalent.

It was found sugarcane plantations are a potential source for reduction in GHG emissions. The annual GHG balance in the burned area was about -13.10 Mg CO_2 ha^{-1} and -28.33 Mg CO_2 ha^{-1} for the unburned area. This result showed a net removal. Sugarcane field burning causes to decrease in the emission reduction of 15.23 Mg CO_{2eq} ha^{-1} y^{-1}. The difference could be affected by increasing in the emission from sugarcane field burning and decreasing in the carbon sequestration under burning management system. This result clearly showed that the burning system has a reduction potential of the net GHG removal by carbon sink in the sugarcane ecosystem. This preliminary data could be used to improve the current state of knowledge for determining GHG emission/removal under burned and unburned sugarcane plantation systems in Thailand. However, this finding is still to be confirmed since the results obtained from this experiment are site-specific and may not be applicable to other areas. Further studies should be done on the differences in soil conditions, farm management practices, and climate conditions, in order to compare the different effects of open burning on GHG balance.