CHAPTER 4
BIOMASS CONSUMPTION AND COMBUSTION FACTOR OF SUGARCANE FIELD OPEN BURNING IN THAILAND

Sugarcane field open burning is well-known as a major source of air pollution. However, the assessment of its emission intensity in many regions of the world still lacks information, especially in the ASEAN region where the cultivation of sugarcane is expected to expand during the next decades to assure the energy need for the transport sector of the region. Knowledge about the contribution of such practices on air pollutant emissions is therefore required. Critical parameters to perform such an assessment include the activity data related to the biomass fuel consumed by fire during sugarcane field open burning, which relates to the combustion factor. This chapter describes the methodology and data collection for estimating the amount of sugarcane biomass burned, and the fraction effectively consumed by burning in Thailand.

4.1 Methodology

In this study, a methodology was developed based on existing assessment methods to quantify sugarcane biomass fuel consumption and fraction burned. The proposed methodology and data collection were based on a field survey of representative sites in Thailand.

4.1.1 Estimation of sugarcane biomass fuel consumption

The sugarcane biomass materials subject to open burning are actually the sugarcane residue, including fresh leaves, dry leaves, and dead leaves. The cane stalk is generally not affected by fire. Since the burning of sugarcane biomass by fire is usually not complete, it is important to assess the amount of sugarcane biomass that is effectively burned in the field (referred to as sugarcane biomass field consumption) to be able to estimate the corresponding emissions of air pollutants. The parameters involved in assessing the amount of sugarcane biomass consumed during open burning are shown in Equation (4.1).

$$Q_s = A \ x \ R_s \ x \ C_f \qquad (4.1)$$

where Q_s is the quantity of sugarcane biomass consumed by fire (tonnes y^{-1}); A is the area burnt (ha y^{-1}); R_s is the dry mass of sugarcane residue (tonnes ha^{-1}), and C_f is the combustion factor or combustion efficiency (dimensionless)

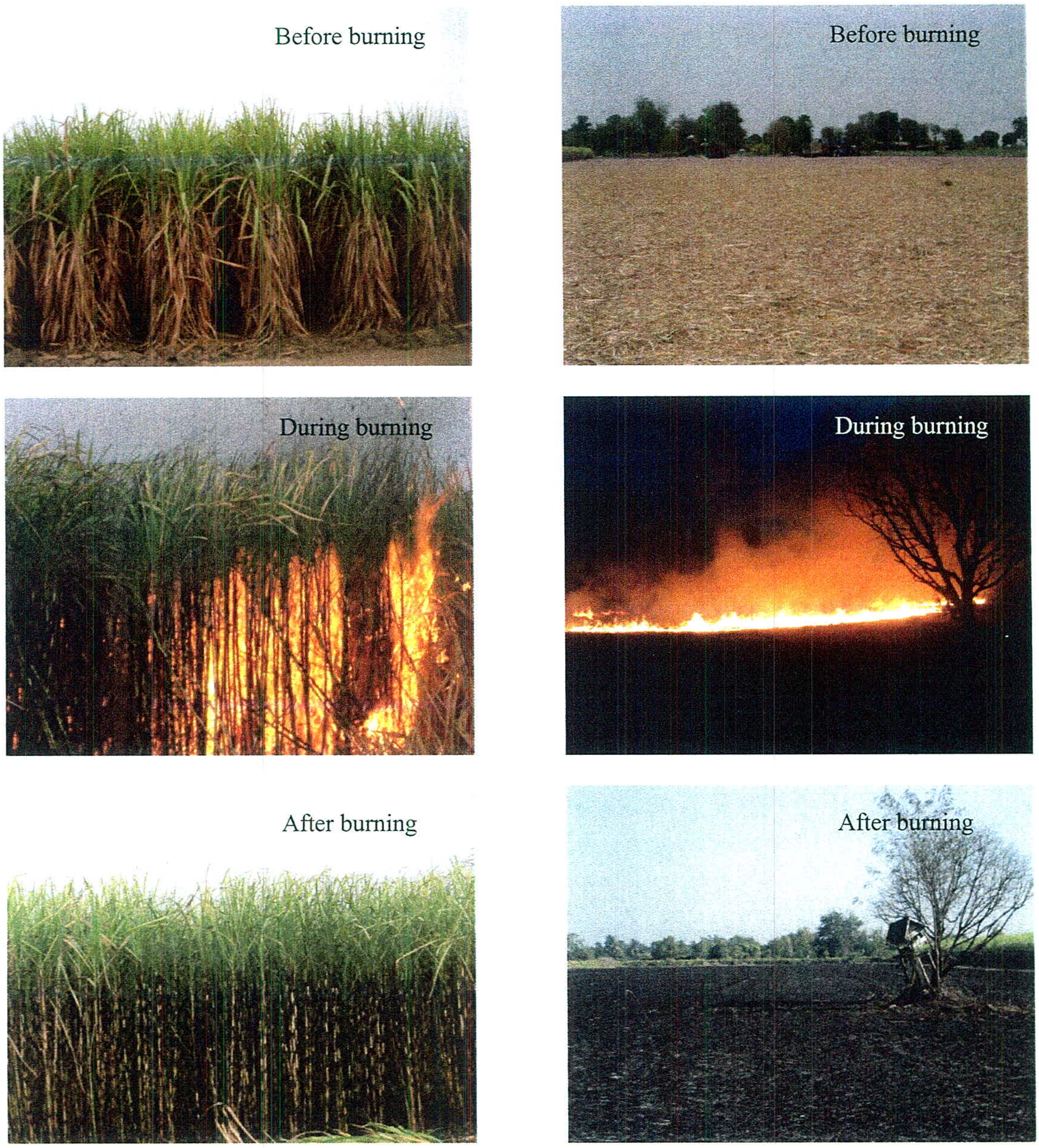
In this assessment, the area of sugarcane that was burned was obtained from the questionnaire survey as reported in Chapter 3. The sugarcane biomass subject to burning (or sugarcane residues) was derived from the field investigation, as presented in Chapter 2. The combustion factor associated with sugarcane biomass consumption by fire was measured from sugarcane sites in Thailand that were subject to different burning systems, as the following Section 4.1.2.

4.1.2 Determination of combustion factor from sugarcane field burning

As defined in Chapter 3, sugarcane field open burning in Thailand is performed by farmers before harvesting to facilitate manual harvesting operations (B1), and after harvesting for fire protection for the next crop cycle (B2) and for clearing the land before soil preparation (B3). Figure 4.1 showed the sugarcane biomass before and after burning in the experimental sites. To measure the combustion factor associated to open burning of sugarcane biomass fuel, 10 sites were sampled including 4 plots for pre-harvest burning system and 6 plots for post-harvest burning system as summarized in Table 4.1.

Table 4.1 Site descriptions for measuring the combustion factor of sugarcane field burning in Thailand

Sites	Residue management	Location	Irrigation	Crop class	Sugarcane cultivar
S1	B1	Khon Kaen	no	1st ratoon crop	Uthong 1
S2	B1	Nakhon Sawan	Supplementary	2nd ratoon crop	Suphanburi 80
S3	B1	Nakhon Sawan	Supplementary	2nd ratoon crop	LK 92-11
S4	B1	Nakhon Phathom	Full irrigation	Plant crop	LK 92-11
S5	B2	Khon Kaen	no	Plant crop	K 88-92
S6	B2	Nakhon Sawan	Supplementary	1st ratoon crop	LK 92-11
S7	B2	Nakhon Sawan	Supplementary	2nd ratoon crop	K 92-77
S8	B3	Khon Kaen	no	2nd ratoon crop	K 88-92
S9	B3	Nakhon Sawan	Supplementary	2nd ratoon crop	Suphanburi 80
S10	B3	Nakhon Sawan	Supplementary	3rd ratoon crop	LK 92-11



(a) (b)

Figure 4.1 Sugarcane biomass in (a) pre-harvest burning sites and (b) post-harvest burning sites

Sugarcane biomass samples were collected a day before open burning to determine their mass on a dry weight basis. At each experimental site, biomass samples were collected from 5 replication plots with a sampling size area in the range 0.59 to 1.15 m^2 depending on the spacing between rows and between plant clumps. Within a day after subjecting the sampling plots to fire, burnt sugarcane biomass samples were collected and their dry mass assessed.

The combustion factor, which corresponds to the fraction of the total sugarcane biomass consumed by fire during an open burning event, was estimated based on the dry mass of the sugarcane biomass sampled before and after burning, as described by Equation (4.2).

$$C_f = \frac{(M_B - M_A)}{M_B} \qquad (4.2)$$

where C_f = combustion factor value (dimensionless), M_B = mass of biomass before burning (kg m^{-2}), M_A = mass of biomass after burning (kg m^{-2})

4.2 Results and discussion

4.2.1 Combustion factor from sugarcane field open burning

Based on the experimental data collected from the field survey, the combustion factor for the pre-harvest and post-harvest burning system was estimated to be 0.64 and 0.83, respectively (Table 4.2). Considering pre-harvest burning system, the value found in this study is lower than the default value provided in the IPCC 2006 Guideline of 0.80. From field observations, it was found that the moisture content of sugarcane biomass fuel component is an important variable as it affects the fraction of residue consumed by fire. For the pre-harvest burning system, the fraction of each component of sugarcane biomass fuel consumed by fire was estimated. The results showed that dryer components of sugarcane biomass including dry leaves and dead leaves were consumed by fire with higher combustion efficiency in the range 0.83–0.95, while fresh sugarcane biomass fuel components were combusted with 73 to 82% lower efficiencies as displays in Table 4.3.

Table 4.2 Combustion factor of sugarcane field burning in Thailand

Residue management practices	Combustion factors	
	Mean value	SE
B1: Pre-harvest burning	0.64	0.05
B2: Post-harvest burning system before new plant re-growth	0.83	0.03
B3: Post-harvest burning system before soil preparation	0.83	0.04

Table 4.3 Fraction of sugarcane biomass burned under pre-harvest burning system in Thailand

Sites	Combustion factors			
	Fresh leaves	Dry leaves	Dead leaves	Overall
S4	0.24	0.88	0.92	0.64
S5	0.21	0.83	0.89	0.61
S6	0.21	0.93	0.95	0.71
S7	0.17	0.88	0.95	0.60
Mean	0.21	0.88	0.93	0.64
SE	0.02	0.05	0.03	0.05

This study found that the combustion factor varied among the surveyed experimental sites. These differences demonstrate the dynamic relationship that exist between biomass fuel moisture content, biomass fuel load, and environmental conditions, as presented in Figure 4.2. The moisture content of biomass is the major influencing factor of the combustion efficiency. It is observed that fresh sugarcane leaves with 40% moisture content (among the highest values recorded in the field experiments) are consumed by fire with 60% combustion efficiency. On the other hand, dry leaves with 20% moisture content (among the lowest experimental values recorded from field survey) are consumed by fire with almost 90% combustion efficiency. This is a clear indication of the major impact of moisture content on combustion efficiency, and hence the composition and intensity of resulting emissions of pollutants to the air. Relative humidity was also observed to play a role in affecting the combustion behavior almost similarly to biomass moisture content but with much lesser significance (see R^2 = 0.2341 vs. 0.92 in the case of moisture content). For the biomass fuel load, the data gathered that there is virtually no influence of the biomass fuel load on the combustion factor.

Also, field observation indicated that the lower biomass fuel bed compactness tended to be associated with higher combustion efficiency. The fuel bed characteristics are driven by the fraction of fresh leaves, dry leaves and dead leaves available for combustion. In systems where dry residues dominate, the overall combustion efficiency is increasing. This factor is influenced by sugarcane cultivars and sugarcane harvest burning systems (pre and post-harvest burning systems) and their proportion in the samples that were representatively selected for Thailand. Therefore, the combination of low fuel moisture content, low relative humidity, and low biomass fuel load compactness would lead to high combustion efficiency, i.e. high combustion factor. However, it is important to point that it was observed from field experiments that coarse sugarcane biomass fuel generated by manual harvesting were easily ignited due to their high surface-to-volume ratio, and hence, led to a lower smoldering combustion comparatively to the fine biomass fuel materials produced by mechanical harvesting. This confirms that the size distribution of biomass fuel plays a key role in the combustion process, and therefore, its efficiency.

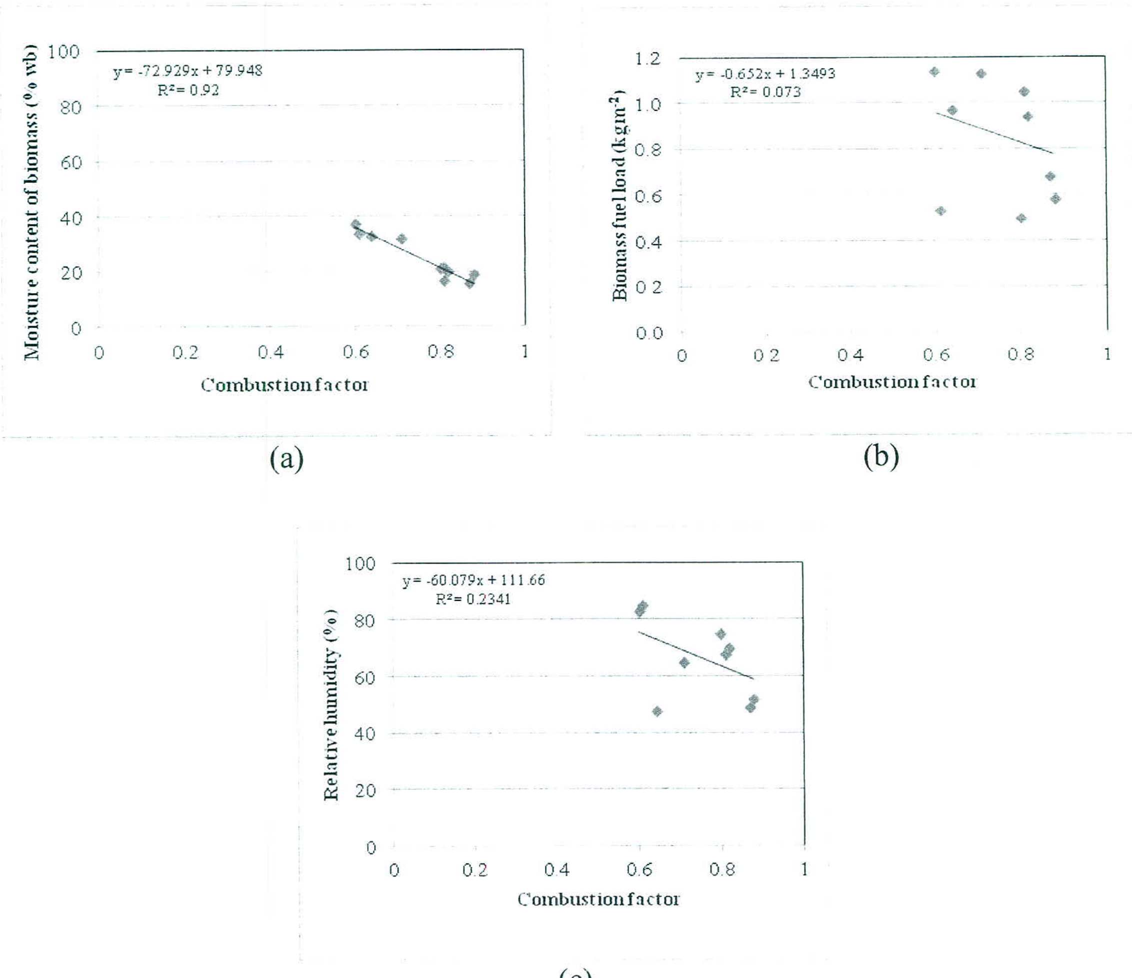


Figure 4.2. The relationship between combustion factor and (a) biomass fuel moisture content, (b) biomass fuel load, and (c) relative humidity under sugarcane field open burning in Thailand

. This finding indicates that there is a distinct relationship between biomass composition and environmental conditions. The high degree of variation in the combustion factor is likely due to a combination of fuel composition, bulk density or compactness, and combustion conditions. This highlights the importance of having acceptable test data for the combustion factor from sugarcane field open burning so that contributions of sources to the overall sugarcane biomass burning emissions inventory can be better quantified.

4.2.2 Quantity of sugarcane biomass consumption by open burning

According to Table 4.4, 5.30 Tg of sugarcane biomass residue were burnt in the field during November 2011 to April 2012. About 78% is burned before harvesting and the remaining 22% after harvesting (20% for fire protection and 2% to facilitate soil preparation for next crop). The Northeast is the region where the largest amount of sugarcane biomass residue is open burnt (36% of total biomass consumption), followed by the Northern (34%) and the Central regions (30%). Sugarcane biomass residue consumption was in the range 4.74-7.10 Mg ha^{-1}, with an average of 5.36 Mg ha^{-1}. The spatial distribution of the amount of sugarcane biomass consumed by fire during open burning is presented in Figure 4.3 and Appendix E.

Table 4.4 Quantity of sugarcane biomass materials consumed by open burning in Thailand during harvesting season (November 2011-April 2012)

Regions	Biomass fuel consumption in dry mass (Mg)			
	B1	B2	B3	Oveall
Northern region	1,247,831	520,180	29,214	1,797,225
Northeast region	1,542,143	317,642	41,829	1,901,615
Central region	1,328,245	216,490	55,117	1,599,853
Whole Kingdom	4,118,220	1,054,312	126,161	5,298,692

As expected, the amount of sugarcane biomass consumed by fire follows a similar trend with that of the area burnt, as displayed in Figure 4.4 (a) to (d). This is because the amount of sugarcane biomass open burned is assessed based on the area of sugarcane subject to burning, as shown in Equation (4.1). It is also noticed that most of the burning occurs during December to March, although some burning activities are observed in November and April, but contributing only 8% of the total amount of sugarcane biomass burned (4% of the total area burned for each month).

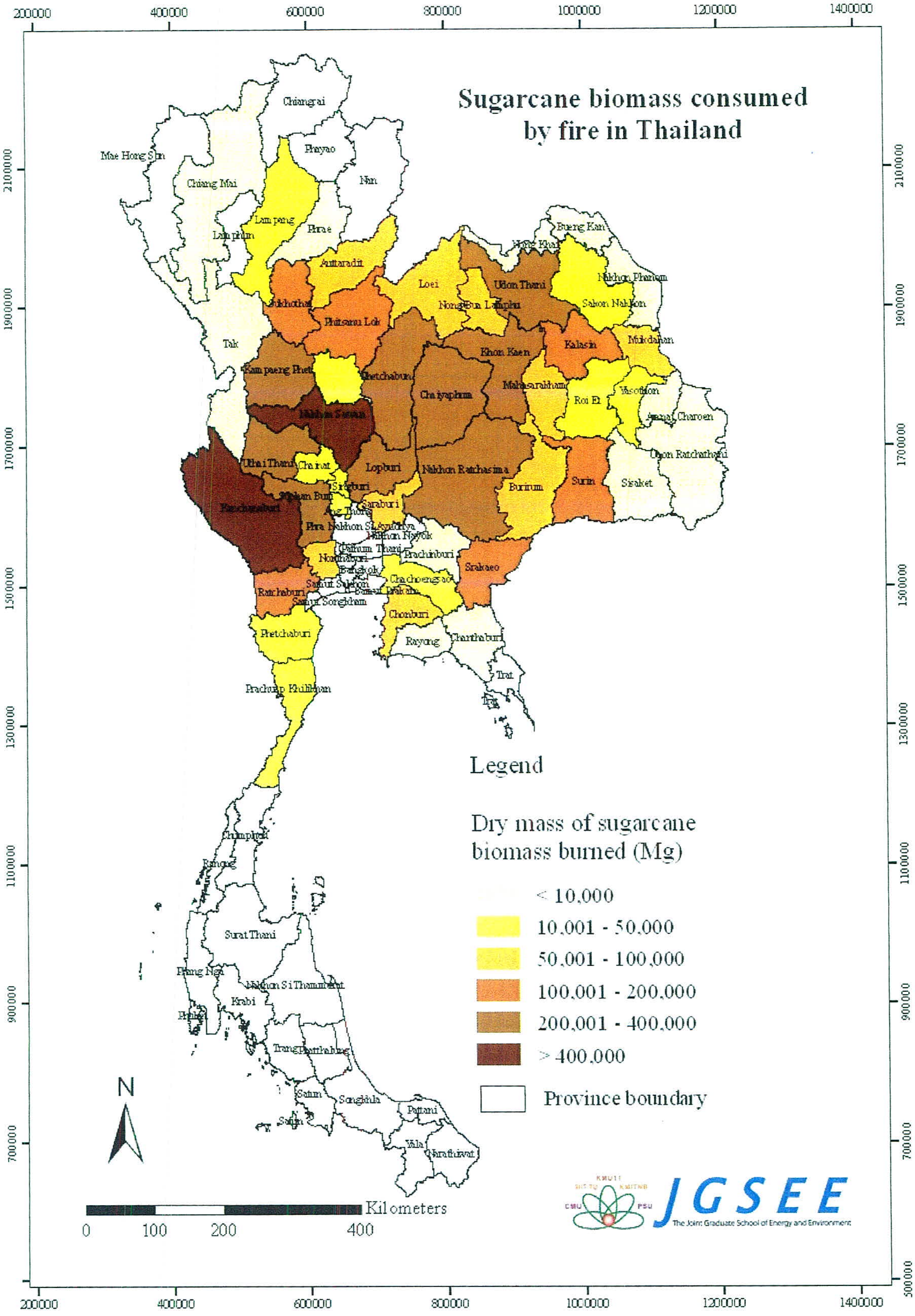


Figure 4.3 Spatial distribution of the amount of sugarcane biomass burned in Thailand during cropping season in year 2012

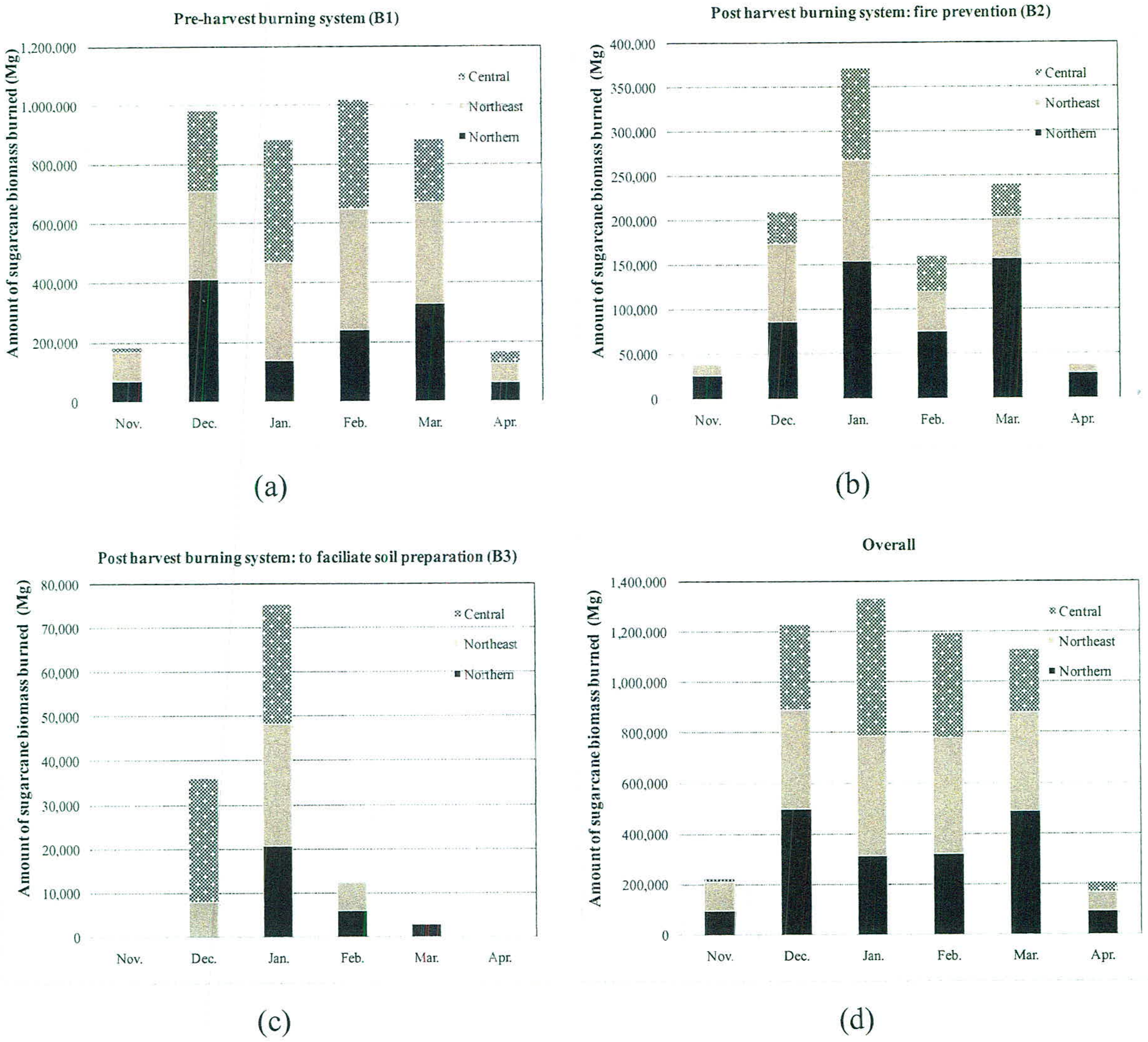


Figure 4.4 Monthly distribution of sugarcane biomass consumption in Thailand classified based on harvest burning systems: (a) pre-harvest burning, (b) post-harvest burning to protect fire burning the new plants, (c) post-harvest burning to facilitate soil preparation, and (d) summary of all burning systems

4.3 Summary of findings

To quantify the amount of sugarcane biomass materials burnt in the field, the combustion factor was first evaluated based on field surveys. This information was then processed in combination with the data on the amount of sugarcane biomass fuel subject to burning and the area of sugarcane field open burning, as reported in Chapters 2 and 3.

The results of these investigations showed that the combustion factor of the post-harvest burning system was found to be higher than the pre-harvest burning system, i.e. 0.83 versus 0.64. The dry sugarcane biomass fuel was consumed by fire with higher combustion factor, 0.88 for dry leaves and 0.93 for dead leaves, while the fresh sugarcane biomass fuel was consumed at a lower combustion factor (0.21). The difference in biomass fuel moisture content between the two systems appeared to constitute the main factor influencing the amount of fuel consumed by fire. Also, a correlation between combustion factor, biomass fuel load and relative humidity was observed. In order to evaluate the significance of each factor on biomass consumption by fire, further statistical analyses are required. Additional investigations on fire behavior and burning conditions are also needed to better estimate resulting air pollutant emissions.

In addition, the average amount of sugarcane biomass open burning over a growing season amounts to 5.36 Mg ha^{-1} and dominates in the Northeastern region (36%), closely followed by the Northern (34%) and Central regions (30%). From this amount, pre-harvest burning is contributing 78% of the total amount of biomass burned, and post-harvest burning for the remaining fraction. It was also shown that pre-harvest burning had contributed a smaller amount of air pollutant emissions per unit area as compared to post-harvest burning because its combustion factor is lower than that of post-harvest burning.