CHAPTER 2

BIOMASS OF SUGARCANE PLANTATION SYSTEM IN THAILAND

Biomass is an essential component in the climate system due to its role as a carbon sink during the process of photosynthesis. It is a crucial ecological variable for understanding the evolution and potential future climate changes. The change over time of biomass can be used as a direct measurement of sequestration or release of carbon between terrestrial ecosystems and the atmosphere (IPCC, 2006; GTOS, 2009). Estimations of biomass change due to land use and management practices or natural process is becoming increasingly more important to gain a better understanding of ecosystem responses to global change. However, recent studies on biomass change are focused mostly on forest and grassland ecosystems. The understanding on biomass change in cropland is still limited, especially for sugarcane that plays a major role in the mitigation of climate change due to its growing use for bio-energy. For these reasons, this study investigates first the total biomass change under sugarcane plantation in Thailand. These data can be used to calculate the loss of carbon by sugarcane field burning and the carbon stock change to assess the GHG balance in sugarcane plantations system. This chapter presents the data on the quantity of total biomass and carbon storage in biomass under different sugarcane plantation systems in Thailand.

2.1 Methodology

To qualify the amount of sugarcane biomass, this assessment was performed based on a field survey involving selected and representative sites in Thailand. Laboratory analyses were effectuated to determine the carbon content in sugarcane biomass for calculating the carbon storage in biomass.

2.1.1 Site selection

For the sampling of the above-ground biomass, study sites for the field survey were selected using a simple random sampling method. The sampling size was estimated by probability technique using population size and distribution of attributes, as shown in Equation (2.1) (Vanichbuncha, 2011). Sugarcane biomass in Thailand is used as population size and biomass fuel load is a variable for determining variance. The confidence level used in this research is set at 85% with 5% precision.

$$n = \frac{N Z^2 S^2}{NE^2 + Z^2 S^2} \quad (2.1)$$

where, n = sample size, N = population size, Z = z-score at 85% confidence level, E = margin of error (0.05), and S^2 = variance of variable (0.29)

Based on Equation 2.1, the sampling size for this study is 12 sites. With a reserve of 5% of the sample size to collect data, the total sample size works out to 13 sites of sugarcane plantation in Thailand.

Regarding the below-ground biomass collection, an experiment was initiated to investigate the below-ground biomass in a sugarcane plantation using on situ destructive direct biomass measurement, which is the main technique used to monitor biomass and its composition. This is the most of direct and accurate method for quantifying biomass however it can be time and resource consuming and infeasible at large scale. Therefore, two plots at the farmer's site with three different sugarcane cultivars were selected to sampling the below-ground biomass.

2.1.1 Description of field survey sites

Based on the above sampling size estimation, 13 sites were investigated to collect data of the above-ground biomass during December 2011 to March 2012 (see Table 2.1). These sites were selected based on the set of sugarcane farming practices followed in Thailand over the three main regions of sugarcane plantation. The field survey sites can be classified into 4 main farming systems as follows:

(1) No-burning (NB): green-cane harvesting system with no-burning after harvesting;

(2) Pre-harvest burning (B1): burnt-cane system where fire is used before cutting sugarcane to facilitate manual harvest;

(3) Post-harvest burning (B2): green-cane harvesting system where fire is used after harvesting to protect the next ratoon crop from fire;

(4) Post-harvest burning (B3): green-cane harvesting system, where fire is used to burn sugarcane residue after harvesting to clear the land before preparing the soil for a new planting crop.

Table 2.1 Field survey site description for collecting the above-ground biomass in sugarcane areas

Sites	**Residue management**	**Location**	**Irrigation**	**Crop class**	**Sugarcane cultivar**
S1	NB	Khon Kaen	no	Plant crop	K 88-92
S2	NB	Nakhon Sawan	Supplementary	4^{th} ratoon crop	LK 92-11
S3	NB	Nakhon Phathom	Full irrigation	2^{nd} ratoon crop	Uthong 8
S4	B1	Khon Kaen	no	1^{st} ratoon crop	Uthong 1
S5	B1	Nakhon Sawan	Supplementary	2^{nd} ratoon crop	Suphanburi 80
S6	B1	Nakhon Sawan	Supplementary	2^{nd} ratoon crop	LK 92-11
S7	B1	Nakhon Phathom	Full irrigation	Plant crop	LK 92-11
S8	B2	Khon Kaen	no	Plant crop	K 88-92
S9	B2	Nakhon Sawan	Supplementary	1^{st} ratoon crop	LK 92-11
S10	B2	Nakhon Sawan	Supplementary	2^{nd} ratoon crop	K 92-77
S11	B3	Khon Kaen	no	2^{nd} ratoon crop	K 88-9
S12	B3	Nakhon Sawan	Supplementary	2^{nd} ratoon crop	Suphanburi 80
S13	B3	Nakhon Sawan	Supplementary	3^{rd} ratoon crop	LK 92-11

For the collection of the below-ground biomass, 2 sugarcane sites belonged to the same land owner with different farm management practices, especially in sugarcane cultivar, were selected for collecting data at two times of the harvesting period in year 2012 and 2013 (Table 2.2).

Table 2.2 General information about the experimental sites for collecting belowground biomass in sugarcane areas in Thailand

Sites	Residue management	Location	Irrigation	Crop class	Sugarcane cultivars
S1[1]	B1	Nakhon Sawan	Supplementary	2^{nd} ratoon crop	Suphanburi 80
S2[1]	UB	Nakhon Sawan	Supplementary	4^{th} ratoon crop	LK 92-11
S1[2]	B1	Nakhon Sawan	Supplementary	Plant crop	Khon Kaen 3
S2[2]	UB	Nakhon Sawan	Supplementary	Plant crop	Khon Kaen 3

Remark: (1) Biomass sampling was done during harvesting season in year 2011

(2) Biomass sampling was done during harvesting season in year 2012

2.1.3 Assessment of total biomass in sugarcane plantation system in Thailand

The total biomass of sugarcane crop in this study was divided into above-ground and below-ground biomass. Aboveground biomass is defined as all sugarcane biomass above the soil including cane stalks and sugarcane residue which includes fresh leaves, dry leaves, and dead leaves. Belowground biomass includes all sugarcane biomass in the soil, i.e. stool and root. The quantity of total biomass under sugarcane plantation system is estimated using Equation (2.2).

$$TB = AG + BG \tag{2.2}$$

where TB = Total sugarcane biomass (tonnes y^{-1}); AG = Total aboveground biomass in sugarcane areas (tonnes y^{-1}); BG = Total belowground biomass of sugarcane crop (tonnes y^{-1})

As mentioned above, the total above-ground biomass is equal to the sum of cane stalk and sugarcane residue as represented in Equation 2.3.

$$AG = C_p + R_s \tag{2.3}$$

where C_p = Sugarcane production on a dry weight basis (tonnes y^{-1}); R_s = Sugarcane residue on a dry weight basis (tonnes y^{-1})

Based on Equation (2.3), the amount of sugarcane residue is needed to clarify for calculating total above-ground biomass. This assessment estimated sugarcane residue using a combination of two factors: residue-to-product ratio (RPR) and sugarcane crop yield (dry weight basis), as shown in Equation (2.4). The RPR value was obtained from the field experiments performed in this study and the cane yield data from the Office of Agricultural Economics of Thailand (OAE, 2012).

$$R_S = C_p \times RPR_s \tag{2.4}$$

where RPR_s = Sugarcane residue-to-cane production ratio

To determine the RPR value, the field surveys were carried out during the harvesting period of sugarcane between December 2011 and March 2012. To ensure representative sampling, field measurements of sugarcane biomass in the area of no-burning and pre-harvest burning systems, a total of 7 sites, were made using the crop experimental plots of 4 rows with a size ranging from 4.00 to 6.64 meters in width and 10 meters length. At each site, the sugarcane area was divided into five replicated plots. The total aboveground biomass in each experimental plot was determined by collecting cane stalk, fresh leaves, dry leaves, and dead leaves at 1 day before harvesting (Fig. 2.1a). Sub-samples of each component were weighted and then dried at 70°C to constant weight to determine moisture content. The dry mass of each component was calculated based on their respective fresh mass and moisture content as shown in Equation (2.5). The dry mass of each plant part was summed to obtain the total dry mass of above-ground biomass. Finally, a sugarcane residue to product ratio (RPR) was determined based on each experimental site surveyed.

$$M_D = \left(1 - \frac{MC}{100}\right) x\, M_F \qquad (2.5)$$

where M_D = dry mass of sugarcane biomass (kg m^{-2}), M_F = fresh mass of sugarcane biomass (kg m^{-2}), MC = moisture content in wet weight (%)

(a) (b)

Figure 2.1 Above-ground biomass sampling under (a) no-burning and pre-harvest burning plots and (b) post-harvest burning plots

For post-harvest burning plots, sugarcane residues generated by green-cane harvesting system are homogenous over the plantation area. Biomass samples were collected 3 to 5 days after harvesting in each experimental plot with 5 replications for a total of 6 sites, as shown in Figure 2.1 (b). The sampling area varied in size from 0.59 to 1.15 m^2 based on spacing between rows and between plant clumps. Sugarcane fresh residues were weighted, dried in oven at 70 °C to constant weight, and dry mass was then measured. For cane production, the total cane yield within a defined area was obtained from sale slips of sugar mill factories. Then, the ratio of sugarcane residue to cane production (RPR) was estimated for each site.

In addition, the total below-ground biomass of sugarcane was calculated base on the combination of two factors, belowground-to-aboveground biomass ratio and above-ground biomass, as presented in Equation 2.6.

$$BG = AG \times BAR \qquad (2.6)$$

where BG = Total below-ground biomass on dry mass basis (tonnes y^{-1}); AG = Total above-ground biomass in sugarcane areas (tonnes y^{-1}); BAR = Sugarcane below-ground biomass to above-ground biomass ratio

Figure 2.2 Below-ground biomass sampling in sugarcane field experiments

Field trials were used to quantify the proportion of above-ground and below-ground biomass. At the harvesting, both above-ground and below-ground biomass measurement was done on a single-set of sugarcane plant basis. The sampling area varied 0.98 m^2 to 1.15 m^2 to take into accounted the spacing between rows and between plant clumps (Fig. 2.2). Total above-ground biomass was collected with three replications for each site, and then below-ground biomass was sampled into to the depth of 1 m with two soil layers: 0-30 and 30-100 cm. The below-ground biomass samples were washed free of soils, and separated carefully by hand. Then, all biomass samples were air-dried for 7 days and dried again in oven at 70 °C to constant mass to determine the dry mass of sugarcane biomass. Finally, the ratio of below-ground to above-ground biomass was estimated for each site.

2.1.4 Estimation of carbon storage in sugarcane biomass in Thailand

Carbon storage in sugarcane biomass is divided into two carbon storage pools that are above-ground biomass and below-ground biomass. These compartments were already been defined in Section 1.1.3. The basic methodology for estimating carbon storage in biomass is multiply a mass of biomass by the carbon content. The annual carbon storage in sugarcane biomass is equal the sum of carbon storage in each partitioning as summarized in Equation (2.7).

$$C_{TOTAL} = \sum_{i=1}^{n} \frac{(D_{AG} \text{ x } \%C_{AG}) + (D_{BG} \text{ x } \%C_{BG})}{100} \quad (2.7)$$

where C_{TOTAL} = Total carbon storage in sugarcane biomass (ton C yr^{-1}); D = Total dry mass of sugarcane biomass (ton yr^{-1}); %C = Carbon concentration in sugarcane biomass (%); AB = Above-ground biomass including cane stalks, fresh leaves, dry leaves, and dead leaves; BG = Below-ground biomass, including stools and roots.

In this assessment, the total above-ground and below-ground biomass was obtained from field investigations perform in this research and the carbon content of sugarcane biomass was measured using ultimate analysis. To preparing the biomass sample for ultimate analysis, all sugarcane biomass samples were cut to 2 cm-lengths using a cutting mill (SM 2000, Retsch, Germany), and oven-dried at 70 °C over 24 hour. The 2 cm-length samples were then ground in a ball mill (SM 100, Retch, Germany), and sieved to lesser than 100 micron size. Then, about 3 mg of biomass samples was wrapped in the universal tin container and put in the Elemental analyzer (Thermo Fisher Scientific, Model Flash EA

112 NC Series, UK). The principle of this element analyzer is based on a dynamic flash combustion reactor coupled to a gas chromatographer. The ultimate analysis was done with three replications for determination of carbon content in the biomass. Equations for calculating carbon content in biomass are presented in Equations (2.8) and (2.9) (Kanokkanjana, 2010).

$$K = \left[\frac{A_{STD} - A_{Blank}}{\%STD \times W_{STD}}\right] \times 100 \quad (2.8)$$

$$\%C = \left[\frac{A_{Unk} - A_{Blank}}{\%STD \times W_{Unk}}\right] \times 100 \quad (2.9)$$

where %C = Percentage of carbon content in biomass; K = Constant value for calculating carbon content; A_{STD} = Area under curve of standard chemical; A_{Blank} = Area under curve of blank; A_{Unk} = Area under curve of unknown; %STD = Percentage of carbon in a standard chemical; W_{STD} = Weight of standard chemical sample; W_{Unk} = Weight of unknown sample.

2.2 Results and discussion

2.2.1 Sugarcane biomass in Thailand

During the field survey of the 13 sites, data were collected on the above-ground biomass including cane stalk, fresh leaves, dry leaves, and dead leaves of the top five sugarcane cultivars cultivated in Thailand. The moisture content of each sugarcane part was determined as shown in Table 2.3. The average value of cane stalk moisture content is found to be about 72.13%, which is consistent with the work of Alexander (1985), who reported that the stalk moisture content were ranged from 70 to 75%. From observation, the variation in moisture content of sugarcane biomass is directly influenced by sugarcane cultivar and farm management system. In addition, dry mass partitioning to various above-ground sugarcane components were examined at a broad level. The results showed the dry mass fraction of sugarcane biomass grown in a wide range as shown in Table 2.4. Fraction of cane stalk was found to be highest, ranged from 0.68 to 0.81. Similarly, previous studied indicated that stalk fraction varied from 0.66 to 0.85 (Robertson et al., 1996; Evensen et al., 1997; Inman-Bamber and Thompson, 1989; and Inman-Bamber et al., 2002). The fraction of green leaves was estimated to be 0.09

which is close to the fresh leave value of 0.1 reported by Inman-Bamber et al. (2002). For dry components of sugarcane including dry leaves and dead leaves, its fraction is about 0.17, range from 0.12 to 0.21. It should be note that variation in sugarcane biomass in this study was largely. The sugarcane cultivar was a one of an important factor influencing to dry mass of sugarcane. However, variations in growing conditions also influence biomass regardless of crop age.

Table 2.3 Moisture content of sugarcane biomass in Thailand

Sites	Sugarcane cultivars	Moisture content (% wb)			
		Cane stalks	Fresh leaves	Dry leaves	Dead leaves
S1	K 88-92	73.83	79.42	17.62	14.40
S2	LK 92-11	71.00	72.34	12.35	12.50
S3	Uthong 8	72.31	76.52	12.06	7.32
S4	Uthong 1	74.34	72.34	9.94	5.72
S5	Suphanburi 80	72.50	76.40	10.00	7.00
S6	LK 92-11	68.00	78.40	12.00	10.00
S7	LK 92-11	72.95	74.80	12.16	11.86
Mean		72.13	75.74	12.30	9.83
SE		2.12	2.76	2.56	3.25

Table 2.4 Fraction of dry mass in each sugarcane component

Sites	Sugarcane cultivars	Fraction of sugarcane biomass (in dry mass basis)			
		Cane stalks	Fresh leaves	Dry leaves	Dead leaves
S1	K 88-92	0.75	0.07	0.17	0.01
S2	LK 92-11	0.68	0.12	0.19	0.02
S3	Uthong 8	0.73	0.07	0.17	0.03
S4	Uthong 1	0.75	0.09	0.14	0.02
S5	Suphanburi 80	0.81	0.07	0.10	0.02
S6	LK 92-11	0.71	0.09	0.17	0.04
S7	LK 92-11	0.73	0.11	0.14	0.02
Mean		0.73	0.09	0.15	0.02
SE		0.03	0.01	0.02	0.00

To determine the sugarcane residue in Thailand, the residue-to-product ratio (RPR) associated with different farm management practices were investigated. The dry mass of sugarcane biomass and RPR values collected from field experiments are summarized in Table 2.5. It is observed that the RPR values ranged from 0.24 to 0.47 with a mean value of about 0.37. This is close to the RPR value of 0.35 reported for sugarcane in Thailand by Warcharapirak and Pattanakiat (2009). However, according to the literature, this ratio varies largely, in the range 0.1 to 0.5, possibly due to the variety of farming conditions and measurement techniques used (Koopmans and Koppenjan, 1997; Ravindranath et al. 2005; PCD, 2006, Prasertsan and Sajjakulnukit, 2006; Kishore, 2008; Kanokkanjana, 2010; and Sasaki, 2013). It is important to note that the variation in RPR used in this study was largely due to the variety of crop cultivars sampled, although climatic conditions and farming systems also contributed to RPR.

Table 2.5 The sugarcane residue-to-product ratio (RPR) in Thailand during harvesting periods in year 2012

Sites	Sugarcane cultivars	Cane yield ($kg\ m^{-2}$)	Sugarcane residue ($kg\ m^{-2}$)	RPR
S1	K 88-92	3.77	1.14	0.30
S2	LK 92-11	2.92	1.39	0.47
S3	Uthong 8	3.08	1.12	0.36
S4	Uthong 1	2.93	0.97	0.33
S5	Suphanburi 80	2.21	0.53	0.24
S6	LK 92-11	2.72	1.13	0.42
S7	LK 92-11	3.05	1.14	0.38
S8	K 88-92	1.83	0.68	0.37
S9	LK 92-11	2.20	0.94	0.44
S10	K 92-77	2.57	1.05	0.47
S11	K 88-92	2.13	0.58	0.27
S12	Suphanburi 80	2.12	0.50	0.24
S13	LK 92-11	2.22	1.05	0.47
Mean		2.60	0.94	0.37
SE		0.54	0.28	0.09

The quantity of sugarcane residue produced in Thailand in 2012 was evaluated using the RPR value of 0.37 as derived from the field survey and a sugarcane production of 98.40 million tons on a fresh mass basis (or 27.42 million tons on a dry mass basis) as reported by OAE (2012). The sugarcane biomass fuel in 2012 was estimated to amount to 10.15 million tonnes or about 0.79 kg m^{-2} (on dry mass basis), as presented in Table 2.6. This result is within the range of values reported by other research studies in Thailand, i.e. 0.47 and 1.72 kg m^{-2} (Warcharapirak and Pattanakiat, 2009; Yuttitham, 2009; and Kanokkanjana, 2010). It is also close to the default value given in the IPCC 2006 guidelines of 0.65 kg m^{-2} (IPCC, 2006).

Table 2.6 Summary of dry above-ground biomass in sugarcane areas in 2012

Regions	Harvested areas (ha)	Above-ground biomass (tonnes y^{-1})		
		Cane stalk	Sugarcane leaves[1]	Total
Northern	348,770	8,057,939	2,981,437	11,039,376
Northeast	518,395	10,370,229	3,836,985	14,207,214
Central	414,939	8,996,531	3,328,716	12,325,247
Whole Kingdom	**1,282,104**	**27,424,699**	**10,147,139**	**37,571,837**

Note: (1) Sugarcane leaves in this study was defined as sugarcane biomass fuel available for biomass burning.

As can be seen in Table 2.6, the dry mass of total biomass in sugarcane plantation systems in Thailand was estimated to be 37.57 million tonnes in 2012. The Northeast is the region where the largest amount of sugarcane biomass is accounted to be 38% of total biomass in Thailand, followed by the Central (33%) and the Northern (29%) regions. Total above-ground biomass in sugarcane cropping system in Thailand is in the range 19.08-34.64 tonnes ha^{-1}, with an average of 29.30 tonnes ha^{-1}.

Considering the below-ground biomass, the results show that the dry below-ground biomass in the 0-100 cm soil layer varied from 469.50 to 958.21 g m^{-2} and 636.19 g m^{-2} of the mean value. The dry mass of root biomass is about 55.26% of total below-ground biomass (Table 2.7). Typically, approximately 61.78% of root biomass was found in the 0-30 cm soil layer. Similarly, Smith et al. (2005) indicates that the root biomass above 30 cm is approximate 63%, in comparison to typical values of 70% for annual crops and 57% for grassland crops. Furthermore, our findings also agree with Blackburn (1984), who mentioned the root biomass in the top 20 cm could be up to 50% of total root dry mass and about 85% for the top 60 cm layer. This finding shows that the most sugarcane root is to found close to the surface, and declines with increasing soil depth.

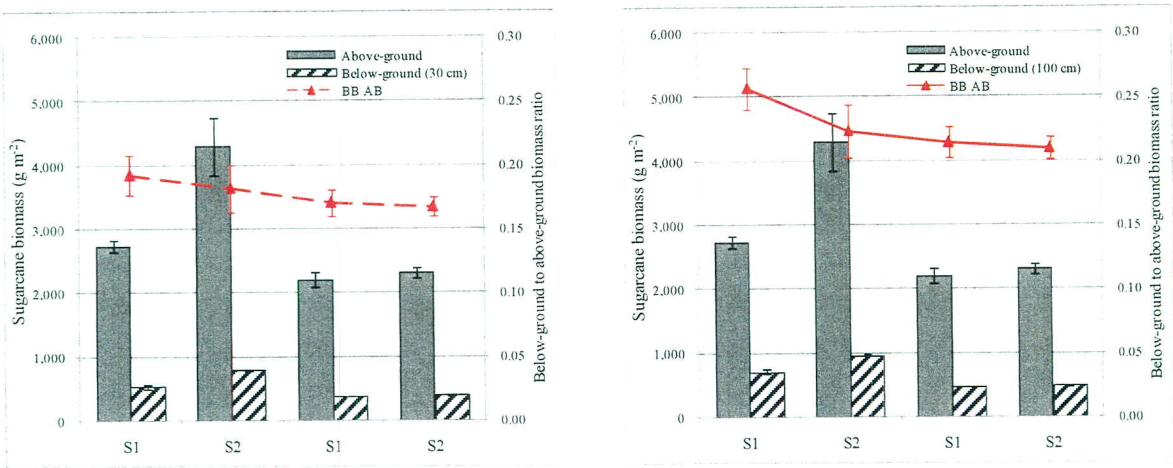
Table 2.7 Sugarcane biomass in the experimental sites

Sampling periods	Sites	Sugarcane cultivars	Dry matter of sugarcane biomass (g m^{-2})			
			Above-ground biomass	Below-ground biomass		
				Stool	Root	
					0-30 cm	30-100 cm
December, 2012	S1[(1)]	Suphanburi 80	2,721.84	283.31	239.75	174.96
December, 2013	S2[(2)]	LK 92-11	4,291.27	463.89	315.54	178.78
January, 2013	S1[(3)]	Khon Kaen 3	2,193.31	216.74	156.06	96.70
January, 2013	S2[(3)]	Khon Kaen 3	2,295.59	210.54	172.26	98.05
	Mean		2,875.50	293.62	220.91	137.12

Note: The biomass sampling was done in the sites where planted (1) the 2nd ratoon crop; (2) the 4th ratoon crop; (3) the plant crop under drought condition

The results showed that the ratios of below-ground to above-ground biomass (BAR) for sugarcane cropping ranged from 0.21 to 0.26 for the top 100 cm, with a mean value of 0.23. At 30 cm depth, the mean value of BAR was 0.18 ± 0.01 (Figure 2.3). Similarly, Herrera (1999) stated the dry matter of root was approximately 15% of total sugarcane biomass. Also, it was observed that there was no significant difference in the ratio of below-ground to above-ground biomass (BAR) among the experimental sites. While, the highest dry mass of below-ground was found in the 4th ratoon crop area, followed by the 2nd ratoon and the plant crop, respectively. The sugarcane crop class can actually affect the amount of below-ground biomass, however this effect is not effected in the BAR, as shown in Figure 2.3. That confirmed estimating the below-ground biomass by deriving from the aboveground biomass could be used.

Based on Equation 2.6, the mean value of the BAR ratios obtained from Figure 2.3 were used to calculate the total above-ground biomass. The annual below-ground sugarcane biomass for the 0-100 cm was estimated to amount to 3.76 million tons for stool and 4.88 million tons for sugarcane root, adding up to a total below-ground biomass of 8.64 million tonnes. For 30 cm soil depth, total below-ground biomass was about 6.77 million tonnes including 3.76 million tons of stool and 6.77 million tonnes of sugarcane root, as summarized in Table 2.8.



(a) (b)

Figure 2.3 The ratio of below-ground to above-ground biomass in sugarcane areas at soil depths of (a) 0-30 cm and (b) 0-100 cm. The bar indicates the standard errors about the mean.

Table 2.8 Dry mass of below-ground biomass in sugarcane cropping systems in Thailand in year 2012

Regions	Below-ground biomass (tonnes y^{-1})				
	Stool	Root[1]		Total [1]	
		0-30 cm	30-100 cm	0-30 cm	0-100 cm
Northern	1,103,938	883,150	551,969	1,987,088	2,539,057
Northeast	1,420,721	1,136,577	710,361	2,557,299	3,267,659
Central	1,232,525	986,020	616,262	2,218,544	2,834,807
Whole Kingdom	**3,757,184**	**3,005,747**	**1,878,592**	**6,762,931**	**8,641,523**

Note: [1] dry matter of below-ground biomass under different soil depth

Regarding the total biomass in sugarcane areas, the finding shows that the annual amount of sugarcane biomass in Thailand in 2012 was 46.21 million tonnes (on dry mass basis) with an average of 36.05 tonnes ha^{-1} y^{-1} based on the total below-ground biomass at the 0-100 cm soil depth. In case of total below-ground biomass of the top 30 cm depth, total sugarcane biomass was estimated to be 44.33 million tones with mean value of 34.58 tonnes ha^{-1} y^{-1}, as reported in Table 2.9. In addition, by classifying per province, it is observed that the first top five of sugarcane biomass production areas are: (1)

Kanchanaburi, (2) Nakhon Sawan, (3) Nakhon Ratchasima, (4) Khon Kaen, and (5) Suphanburi. The spatial distribution of sugarcane biomass is shown in Figure 2.4 and Appendix A.

Table 2.9 Dry mass of sugarcane biomass in Thailand in cropping season of year 2012

Regions	Sugarcane biomass (tonnes y^{-1})				
	Above-ground biomass	Below-ground biomass [(1)]		Total biomass [(2)]	
		0-30 cm	0-100 cm	0-30 cm	0-100 cm
Northern	11,039,376	1,987,088	2,539,057	13,026,464	13,578,433
Northeast	14,207,214	2,557,299	3,267,659	16,764,512	17,474,873
Central	12,325,247	2,218,544	2,834,807	14,543,792	15,160,054
Whole Kingdom	**37,571,837**	**6,762,931**	**8,641,523**	**44,334,768**	**46,213,360**

Note: [(1)] dry matter of below-ground biomass at different soil depth

[(2)] Sum of the above-ground and the below-ground biomass at different soil depths

2.2.2 Carbon storage in sugarcane biomass in Thailand

Results from ultimate analysis are reported in Table 2.10. High content of carbon are found in cane stalks with a mean value of 44.37%, which is quite similar to the values presented in the literature indicating a range of 44.1% to 44.9% (Jorapur, 1997; Garivait, 2006 Demirbas, 2010). Based on weighted average method, the carbon content in sugarcane residue including fresh leaves, dry leaves and dead leaves varied from 41.70% to 46.40%, or about 43.33% in average. This finding also agrees with previous studies reporting the carbon content in sugarcane leaves of about 39.8% to 45.24% (Jorapur, 1997; Yutthitham, 2009).

The annual estimates of carbon storage in sugarcane biomass in Thailand for the cropping season of year 2012 were calculated using Equation (2.7). The results are reported in Table 2.10 and Appendix B, it found that, in year 2012, approximately 20,104 tonnes of carbon was storage in sugarcane biomass; 16,526 tonne C for the above-ground biomass and 3,578 tonne C for the below-ground biomass in the 100 cm soil depth. The finding shows more than 80% of total carbon was found in the above-ground biomass which is consumed large amount of sugarcane biomass. The spatial distribution of carbon storage in sugarcane biomass in Thailand is presented in Figure 2.4. Considering the total carbon storage in below-ground biomass for the top 30 cm soil surface, the total carbon storage was about 19,350 tonnes C, as presented in Table 2.11.

Table 2.10 Carbon content in sugarcane biomass in Thailand

Sugarcane partitioning	Carbon content (%)		
	Min	Max	Mean
Cane stalks	43.41 ± 0.19	46.74 ± 0.13	44.37 ± 0.49
Fresh leaves	42.46 ± 0.09	45.44 ± 0.22	43.65 ± 0.43
Dry leaves	41.13 ± 0.23	44.53 ± 0.16	42.70 ± 0.47
Dead leaves	41.32 ± 0.21	42.99 ± 0.02	42.13 ± 0.22
Stool	42.29 ± 0.79	43.59 ± 0.17	43.07 ± 0.15
Root	39.20 ± 0.21	41.41 ± 0.17	40.11 ± 0.06

Table 2.11 Carbon storage in sugarcane biomass in Thailand

Regions	Carbon storage in sugarcane biomass (tonnes C y^{-1})				
	Above-ground biomass	Below-ground biomass		Total biomass	
		0-30 cm	0-100 cm	0-30 cm	0-100 cm
Northern	4,856	830	1,051	5,686	5,907
Northeast	6,249	1,068	1,353	7,317	7,602
Central	5,421	926	1,174	6,348	6,595
Whole Kingdom	16,526	2,824	3,578	19,350	20,104

2.3 Summary of findings

Sugarcane biomass was investigated for Thailand based on a field survey covering different sugarcane farm management systems and weather conditions. The average RPR value for sugarcane was estimated to be 0.37 and the annual above-ground biomass produced to amount to 37.57 million tons in year 2012. For the below-ground biomass, the result shows the ratios of below-ground biomass to above-ground biomass (BAR) were estimated to be 0.23 for the 0-100 cm soil depth and 0.18 for the 0-100 cm.

Total below-ground biomass is about 8.64 million tons for the 0-100 cm and 6.76 million tons for the 0-30 cm. The dry matter of total sugarcane biomass, which is equal to the sum of above-ground biomass and below-ground biomass, was 46.21 million tons with the average value of 36.05 tonnes ha^{-1} based on the below-ground biomass in the 0-100 cm. For the below-ground biomass at 0-30 cm depth, the total sugarcane biomass was 44.33 million tones with a mean value of 34.58 tonnes ha^{-1} y^{-1}.

In order to determine carbon storage in sugarcane biomass, the ultimate analysis was done to measure the carbon content in the partitioning of the sugarcane plants. The carbon content varied in the different parts of sugarcane plants, ranged from 40% to 44%. The carbon storage in sugarcane biomass was calculated to be 20 tonnes (15.68 kg C ha^{-1}) and 19 tonnes (15.09 kg C ha^{-1}) considering the below-ground biomass in the 0-100 cm and in the 0-30 cm, respectively. These results are an important scientific data to improve the current state of knowledge of the GHG balance under the sugarcane plantation system in Thailand.

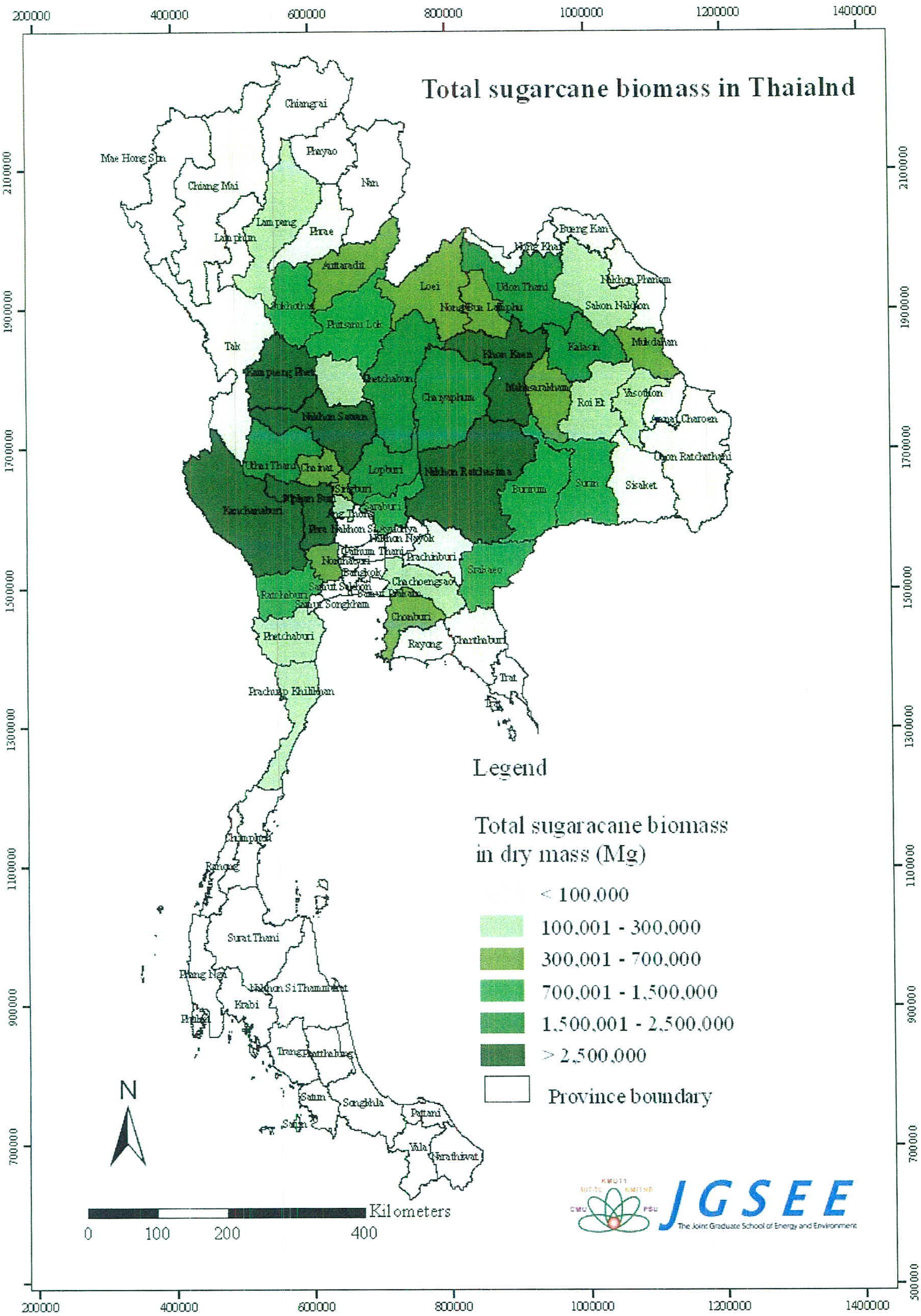


Figure 2.4 Spatial distribution of total biomass (considering total below-ground biomass at 0-100 cm soil depth) in sugarcane cultivation areas in Thailand in the cropping season of year 2012

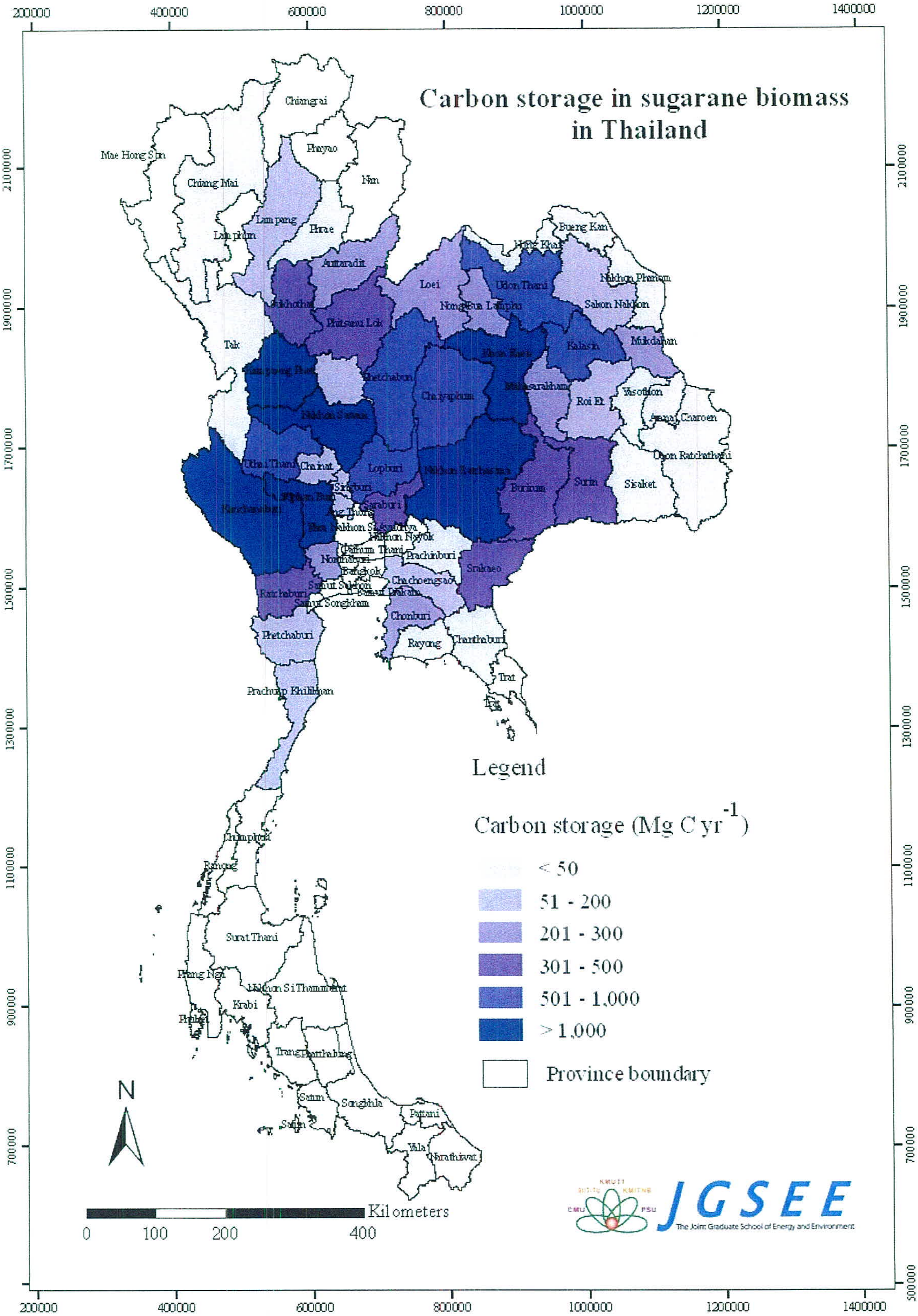


Figure 2.5 Spatial distribution of total carbon storage (considering total below-ground biomass at 0-100 cm soil depth) in sugarcane biomass in Thailand