CHARPTER 4

Results and discussions

There are two parts of the results followed the objective of this study. First is water footprint of sugarcane cultivation in Mae Sot District. Second is heavy metal analysis especially Cd in two samples as sugarcane root and soil samples in both contaminated and control site which far from each other. Both of result will be useful for agriculture management.

4.1 Water footprint assessment

4.1.1 Data requirement for WF calculation

Climate data's outputs by CROPWAT 8.0 was importance to this part to find Green evapotranspiration (ET_{green}) which was necessary to calculate from this section. It was prepared from crop evapotranspiration (ET_c) and ET_c was prepared from reference evapotranspiration (ET_0) multiply by crop coefficiency (K_c). For this study ET_0 and ET_c received from the calculation by CROPWAT 8.0 similar with another studies (Holcomb, 2010; Lindholm, 2012; Kongboon and Sampattagul, 2012; Chooyok *et al*., 2013) and referred K_c from Royal Irrigation Department of Thailand (RID). Because this K_c data was more appropriate for Thailand than the average K_c by worldwide (Kongboon and Sampattagul, 2012; Chooyok *et al*., 2013).

First output table from CROPWAT 8.0 was average value of every parameter of each month to get the ET_0. The minimum temperature in cold season (November to February) was decreased while the maximum temperature was low in rainy season (June to October) (Figure 4.1). Humidity was increased since April and highest in August that caused by rainy season (Figure 4.2) (Allen *et al*., 1998).

Table 4.1 Climate data's output since October 2011 to September 2012 by CROPWAT 8.0.

Month	Min. Temp (°C)	Max. Temp (°C)	Humidity (%)	Wind (m/s)	Sun (hr)	Radiation ($MJ/m^2/day$)	ET_0 (mm/day)
October	22.3	32.5	81	4.5	9.1	21.1	4.96
November	19.2	33	72	4.8	8.6	18.6	5.26
December	16.6	31.5	69	5.6	8.1	17	5.25
January	16.9	33.1	66	4.4	6.8	16	5.33
February	18.1	35.5	60	4.6	4.7	14.5	6.18
March	20.5	36.9	58	5.4	3.3	13.8	6.99
April	23.6	37.1	63	6.4	1.4	11.7	6.79
May	24.4	34.2	76	5.6	1.3	11.7	4.75
June	23.9	31.2	84	5.9	3.5	14.9	4.04
July	23.3	30.8	85	5.3	6	18.7	4.36
August	22.7	29.7	88	4.8	8.3	22.1	4.42
September	23.5	32.6	83	3.6	8.8	22.2	4.98
Average	21.2	33.2	74	5.1	5.8	16.9	5.28

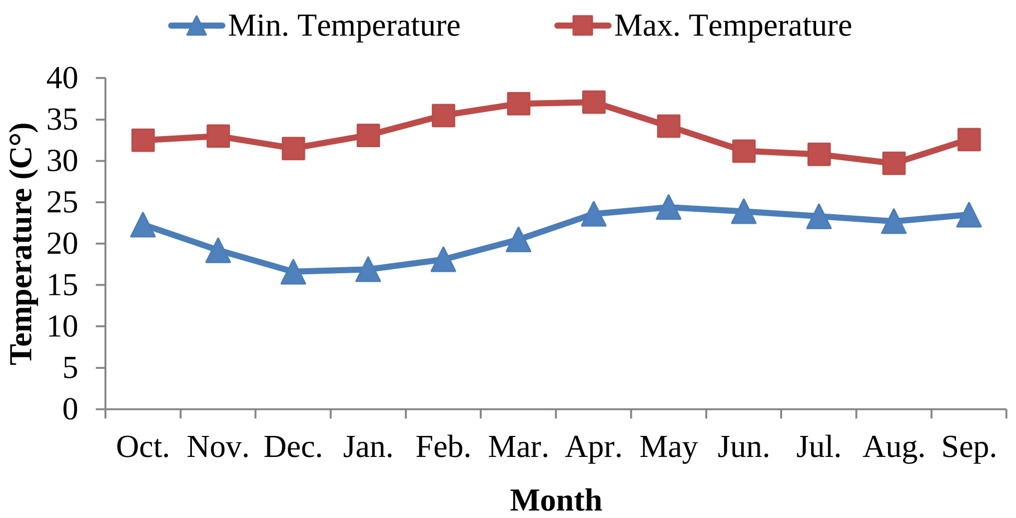

Figure 4.1 The minimum temperature and the maximum temperature during October 2011 to September 2012

The ET_0 was calculated following the Penman-Monteith formula that available in CROPWAT 8.0 program (Allen *et al.*, 1998; Holcomb, 2010; Linholm, 2012). For the results in February to April (hot season) have highest of ET_0 that related to the maximum. It can conclude that ET_0 was depended on season which agreed with Holcomb (2010) and Sun *et al*. (2012) study. According to Panomtaranichagul (2004) study, there are many factors effect to ET i.e. sunlight, temperature, humidity and wind. This study is expressed the correlation among various kind of parameter by Spearman's correlation coefficients (Table 4.2). Minimum temperature was significant positive correlation with both rainfall and P_{eff}. Whereas maximum temperature was significant negative correlation with humidity that agreed with Sun *et al*. (2013) which reported the reversion between high temperature and humidity. The correlation between humidity and ET_0 shows significant negative correlation (Figure 4.3, Table 4.2).

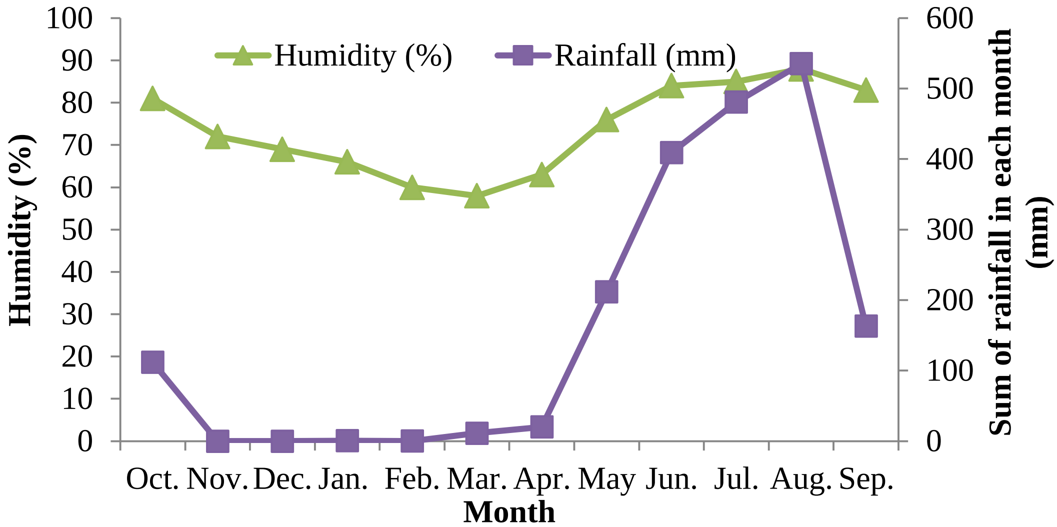

Figure 4.2 Relation between humidity and rainfall during October 2011 to September 2012

High temperature lead to loss humidity from land and atmosphere, therefore, losing humidity can ascribed by the correlation between maximum temperature and humidity could be diverse. These results follow Allen *et al*. (1998) study that reported the high humidity of the air will reduce the ET. Other effect to reduce ET is leaf covering by sugarcane and makes high humidity. Beside, in rainy season, ET were low that might affected by long leaf and high stem covering (stalk elongation phase). On the contrary, in dry season, ET_0 were high by temperature reason that mention above.

For precipitation data, the summation of total rainfall was 1944.3 mm while the summation of total effective from rainfall (total P_{eff}) was 819.8 mm (Appendix B) from USDA SCS equation as widely use that performed by CROPWAT 8.0 (Smith,1998; Chapagain and Orr, 2009; Hess, 2010; Holcomb, 2010; Lindholm 2012). Moreover the precipitation was significant correlated with humidity as direct variation together (Figure 4.2 and Table 4.2).

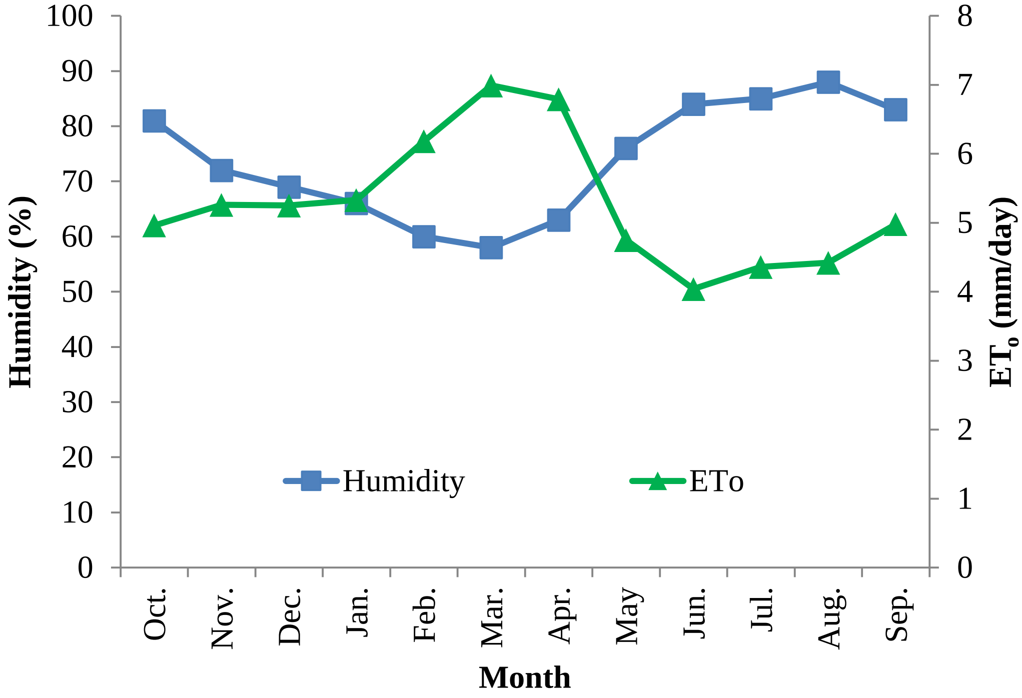

Figure 4.3 Correlations between Humidity and ET_0 during October 2011 to September 2012

Beside, correlation of K_c, precipitation and ET were performed by Spearman's correlation coefficients (Table 4.3). K_c was significant positive correlation with ET_c. Actually; K_c was variable and depended on age of plant (Figure 2.3) (Allen *et al*., 1998; Panomtaranichagul, 2004). In this study, obviously ET_c and K_c were correlated in the same trend (Figure 4.4 and Table 4.3) that agreed with the result of wheat grown in India by Hoekstra and Chapagain's (2004) worked. Therefore ET_c (in other word, ET_c was crop water requirement (CWR)) was variable by K_c (Hoekstra and Chapagain, 2004; Panomtaranichagul, 2004; Hoekstra *et al*., 2009; Hoekstra *et al*., 2011). In addition ET_c was significant negative correlation with P_{eff} that similar to ET_0 which was significant negative correlation with precipitation that mention above. On the other hand ET_{green} was significant positive correlation with P_{eff}. According to the equation for calculation ET_{green} that derived from the minimum of ET_c or P_{eff} (equation 7) that was shown how to select in Table 4.4. In this study most of ET_{green} carry out on P_{eff}.

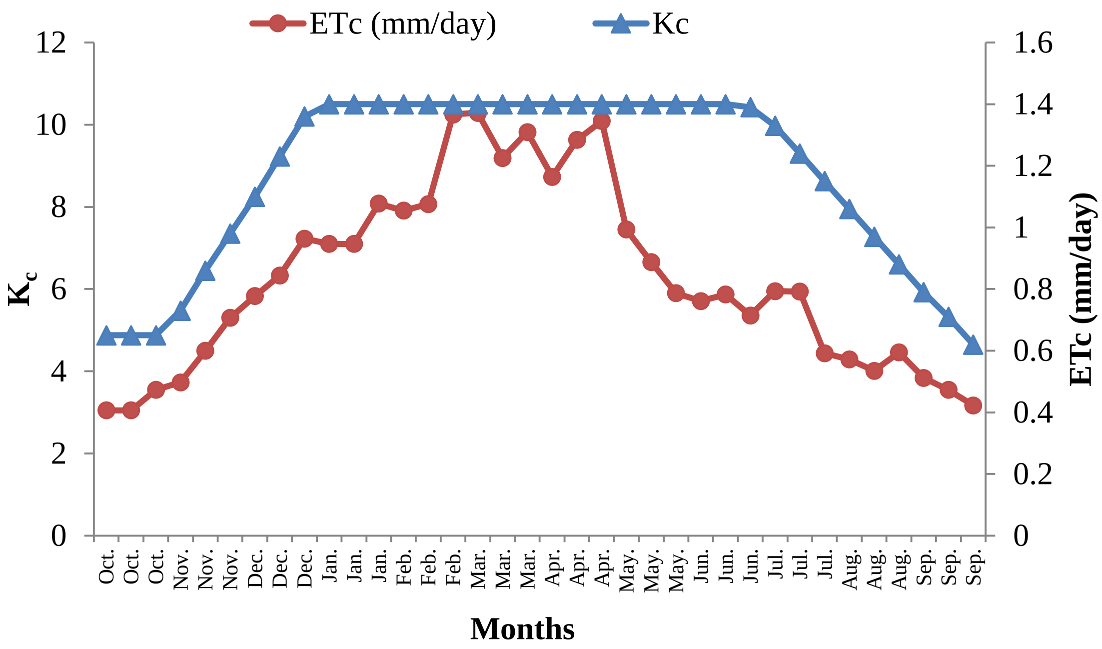

Figure 4.4 Correlations between K_c and ET_c during October 2011 to September 2012

Table 4.2 Correlations of climate parameters and precipitations

	Min. temp	Max. temp	Humidity	Wind	Sun	Radiation	ET_0	Rainfall	P_{eff}
Min. temp	1.000								
Max. temp	-0.042	1.000							
Humidity	0.462	-.874**	1.000						
Wind	0.400	0.116	-0.098	1.000					
Sun	-0.399	-0.517	0.392	-0.716**	1.000				
Radiation	-0.168	-0.732**	0.666*	-0.645*	0.907**	1.000			
ET_0	-0.490	0.839**	-0.930**	-0.070	-0.189	-0.445	1.000		
Rainfall	0.746**	-0.515	0.774**	0.105	-0.105	0.253	-0.739**	1.000	
P_{eff}	0.781**	-0.494	0.753**	0.155	-0.161	0.196	-0.760**	0.979**	1.000

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed), n = 12

Table 4.3 Correlation of crop co-efficiency (K_c), ET_c, P_{eff} and the ET_{green} and precipitation

	K_c	ET_c	P_{eff}	ET_{green}
K_c	1.000			
ET_c	.886**	1.000		
P_{eff}	-0.174	-0.399*	1.000	
ET_{green}	-0.098	-0.337*	0.975**	1.000

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed), n = 36

Table 4.4 ET_{green} and results based on the CWR output from CROPWAT 8.0 since October 2011 to September 2012 (along growth season)

Month	Decade	Stage	K_c	ET_c (mm/day)	ET_c (mm/dec)	P_{eff} (mm/dec)	Irr. Req. (mm/dec)	ET_{green} (mm/dec)
Oct	1	Init	0.65	3.05	30.5	49	0	30.5
Oct	2	Init	0.65	3.05	30.5	26.2	4.3	26.2
Oct	3	Deve	0.65	3.55	39.1	2.2	36.9	2.2
Nov	1	Deve	0.73	3.73	37.3	0	37.3	0
Nov	2	Deve	0.86	4.5	45	0	45	0
Nov	3	Deve	0.98	5.3	53	0	53	0
Dec	1	Deve	1.1	5.83	58.3	0	58.3	0
Dec	2	Deve	1.23	6.33	63.3	0	63.3	0
Dec	3	Mid	1.36	7.23	79.5	0	79.5	0
Jan	1	Mid	1.4	7.1	71	0	71	0
Jan	2	Mid	1.4	7.1	71	0.6	70.4	0.6
Jan	3	Mid	1.4	8.08	88.9	0	88.9	0
Feb	1	Mid	1.4	7.91	79.1	0.2	78.9	0.2
Feb	2	Mid	1.4	8.07	80.7	0	80.7	0
Feb	3	Mid	1.4	10.25	82	0	82	0
Mar	1	Mid	1.4	10.29	102.9	7.2	95.7	7.2
Mar	2	Mid	1.4	9.19	91.9	0.5	91.4	0.5
Mar	3	Mid	1.4	9.82	108	3.2	104.9	3.2
Apr	1	Mid	1.4	8.73	87.3	13.9	73.4	13.9
Apr	2	Mid	1.4	9.63	96.3	0	96.3	0
Apr	3	Mid	1.4	10.09	100.9	5	95.9	5
May	1	Mid	1.4	7.45	74.5	57.1	17.4	57.1
May	2	Mid	1.4	6.66	66.6	15.8	50.8	15.8
May	3	Mid	1.4	5.9	64.9	32.5	32.4	32.5

Table 4.4 ET_{green} and results based on the CWR output from CROPWAT 8.0 since October 2011 to September 2012 (along growth season) (Cont.)

Month	Decade	Stage	K_c	ET_c (mm/day)	ET_c (mm/dec)	P_{eff} (mm/dec)	Irr. Req. (mm/dec)	ET_{green} (mm/dec)
Jun	1	Mid	1.4	5.71	57.1	53.1	4.1	53.1
Jun	2	Mid	1.4	5.87	58.7	52	6.7	52
Jun	3	Late	1.39	5.36	53.6	60.8	0	53.6
Jul	1	Late	1.33	5.95	59.5	48.7	10.9	48.7
Jul	2	Late	1.24	5.94	59.4	51.6	7.8	51.6
Jul	3	Late	1.15	4.44	48.8	72.1	0	48.8
Aug	1	Late	1.06	4.29	42.9	69.1	0	42.9
Aug	2	Late	0.97	4.01	40.1	63.8	0	40.1
Aug	3	Late	0.88	4.46	49	32.1	16.9	32.1
Sep	1	Late	0.79	3.84	38.4	52	0	38.4
Sep	2	Late	0.71	3.55	35.5	25	10.5	25
Sep	3	Late	0.62	3.17	31.7	26.2	5.6	26.2
Total over entire growing period					2,277.3	819.8	1,570	707.4

Both ET_0 and ET_c were few at the beginning of cultivation and rapidly increase since February to April (dry season). The sugarcane stem were high and long leafs covering land. After that, ET_0 and ET_c decreased rapidly in rainy season due to high humidity and effected from leaf covering (Allen *et al*., 1998; Panomtaranichagul, 2004).

For grey WF that required to the fertilizer application. The fertilization in Mae Sot was applied 3 time/growth season (Table 4.5). First time was the beginning of plantation because soil had high humidity from rainy season and farmers want to aid growth of sugarcane especially rooting. Second time was nutrient preparation for sugarcane to use along rainy season. Last time was used during rainy season for protect flowering of sugarcane that can cause of losing production.

Table 4.5 Average fertilizer application rate obtained by the interviews with farmers in Mae Sot (2011-2012)

Sugarcane	Formula of fertilizer	N	P_2O_5	K_2O
		(kg/ha)		
October-December	16-16-8	50	50	25
April-June	16-8-8	50	25	25
August-September	21-0-0	39.4	0	0
Total		139.4	75	50

In this study, grey WF was performed by nitrate nitrogen as pollutant in environment especially in southern hemisphere (Carpenter *et al*., 1998; Hoekstra *et al*., 2011; Liu *et al*., 2012). The different water standard will give a different grey WF. However, there are many studies, in which nitrate nitrogen is often used as the pollutant in calculation (Chapagain and Orr, 2009; Scholten, 2009; Holcomb, 2010; Hoekstra *et al*., 2011; Kongboon and Sampattagul, 2012; Herath *et al*., 2013). The fertilizers were spread to sugarcane fields 3 times a year and totally nitrogen used was 139.4 kg/ha/yr. For ambient water quality standards, the maximum acceptable concentration of PCD in Thailand (2013) for nitrate in surface water quality standards is 5 mg/L. In this study, the criterion of nitrate nitrogen of PCD was used.

4.1.2 Water footprint calculation

1) Green WF calculation

The ET_{green} under rain-fed (no irrigation) for 2011-2012 in Mae Sot District, Tak Province, Thailand, was 707.4 mm/growing period of sugarcane, and CWU_{green} was calculated using the equation (2) as 7,074 m^3/ha. Then, WF_{green} was 98 m^3/ton. Table 4.8 showed the green WFs obtained from many studies. Mekonnen and Hoekstra (2011) studied in three systems for sugarcane cultivation. One of them was rain-fed system, and the green WF was evidently bigger than this study. The other studies also showed large difference among green WFs. Hess's study (2010) only focused and reported on green WFA which depended on precipitation and ET. Their studies have offered the notion that the changes in land usage could be caused green WF changes. The most of cultivations of sugarcane in Mae Sot District is rain-fed system. Therefore, the green WF is mainly affected on total WF. Generally, the rain-fed crops are produced with green water greater than blue water (Wichelns, 2011). In the same way, green water is mainly usage to support agricultural ecosystems (Willaarts *et al*., 2012). Moreover, in Table 4.6 presented that green WF was highest which agreed with Kaenchan *et al.* (2013) and Ene *et al*. (2013. Uncertain of climatic condition was correlated with time and area (geography) that leads to effect green WF (Chahed *et al*., 2008; Chapagain and Orr, 2009; Mekonnen and Hoekstra, 2011). Particular the sugarcane cultivation of this study was rain-fed (no irrigation). Therefore, the green WF is changed due to climatic conditions and was a key of cultivation processing.

2) Blue WF calculation

The blue WF was zero due to ET_{blue} equal zero because there were no irrigation in Mae Sot District (Table 4.6). This result conformed too many studied which reported blue WF as low number or zero if the cultivation without irrigation (Chapagain and Orr, 2009; Scholten, 2009; Deurer *et al*., 2010; Holcomb, 2010; Ene *et al*., 2012; Lindholm, 2012; Zeng *et al*., 2012). Actually if rainfall becomes very low, the farmers have to use the irrigation for the sufficient moisture of normal plant growth (Hoekstra *et al*., 2011). Moreover, because of uncertain climate, MSCE Company has a plan to set up irrigation system, in which the company makes ponds to collect water and sends water using pipe to sugarcane fields near the company but not now. Chapagain and Orr (2009) had predicted that temperature will cause high and low precipitation. This situation leads to decreasing of productivity and increasing of WF because plant was still high water requirement (high ET). Moreover, from Marta *et al*. (2012) study WF was affected by climate variability that mainly came from through the effect of climate on the crop cycle. The total WF decreased over time but an increase of the blue component was found due to the change in precipitation patterns and to the rise of temperature. In consequence, it is possible to set up irrigation system in Mae Sot in the future. If the irrigation system is succeeded in Mae Sot District, the blue WF will be properly changed.

Table 4.6 Overview of all major green and blue components of the WF

Plant	ET_{green} (mm/dec)	ET_{blue} (mm/dec)	CWU_{green} (m^3/ha)	CWU_{blue} (m^3/ha)	Yield (ton/ha)	WF (m^3/ton)	
						Green	Blue
Sugar cane	707.4	0	7,074	0	72.31*	98	0

* Sugarcane's yield for 2011-2012 only

3) Grey WF Calculation

Then, the grey WF was calculated as 5 m^3/ton as shown in Table 4.7. Normally for sugarcane cultivation, the fertilizer especially nitrate nitrogen is necessary. In this study, the highest grey WF was obtained compared with other studies (Table 4.8), because the data collection might be different from other studies. That is, the fertilizer data was collected from the interviews with farmers and the MSCE Company staffs directly by interviewing.

Table 4.7 Data and calculation of the grey water component for sugarcane in Mae Sot District, Tak Province in 2011-2012

Plant	N (kg/ha)	N leaching fraction	Surface water quality standards in Thailand by PCD (mg/L)	Yield (ton/ha)	Grey WF (m^3/ton)
Sugarcane	139.4	0.10	5	72.31*	38

* Sugarcane's yield for 2011-2012 only

Table 4.8 Average WFs of sugarcane cultivation in global scale and Thailand

Source	Study site	Period	Farming system	Yield (ton/ha)	Sugarcane (m^3/ton)			
					Green WF	Blue WF	Grey WF	Total WF
A	Global average	1996-2005	Rain-fed	58.70	164	0	13	176
			Irrigated	71.17	120	104	14	238
			Global	64.96	139	57	13	210
B	Thailand	2009	Global	56.40	152	132	18	301
C	Thailand	2008-2010	Global	69.08	95	87	25	202
D	Mae Sot Tak, Thailand*	2011-2012	Rain-fed	72.31**	98	0	38	136

Note: Given are mean values for various WF of different studies: A = Mekonnen and Hoekstra (2011), B = Scholten (2009), C = Kongboon and Sampattagul (2012) and D = this study, *this study, **Sugarcane's yield was collected from October 2011 to September 2012 only

For WF in Thailand, Scholten (2009), Kongboon and Sampattagul (2012) reported grey WF, but those data were the secondary data only. Furthermore the criteria of nitrate nitrogen of EPA (2005) were also used by them. The maximum acceptable concentration of EPA for nitrate in drinking water quality standard is 10 mg/L. According to the WF assessment manual (2011) recommend, that if there is no ambient water quality standards available and the water body in that area is suitable for drinking, one can decide to use drinking water standards from EPA (Hoekstra *et al*., 2011). To use different ambient water quality standards as C_{max} in grey WF equation lead to different grey WF (Linholm, 2010). Because the ambient water quality standards of Thailand were used, grey WF was different with other studies.

4.1.3 Total of WF of sugarcane in Mae Sot District, Tak Province, Thailand

As Kaenchan *et al.* (2013) pointed high yields was not necessary to get high WF. It depends on many factors i.e. soil quality or technology. The advantage in Mae Sot District is an efficiency to produce the highest yield while total WF is the lowest (Table 4.8), although there is no irrigation in this area. The sugarcane as yields in Mae Sot was highest and lowest total WF as well. It seems that sugar cane cultivation in Mae Sot was efficiency water usage.

The rain-fed system has no cost for sugarcane cultivation while the irrigation system needs installation and management cost. According to Aldaya *et al*. (2010), Hoekstra *et al.* (2011) reported green WF generally has a lower cost than blue water. Therefore, it will be better to use of rainfall only if possible. That means increasing yields per drop of rainwater will reduce the demand for blue water in agricultural production process (Chapagain and Hoekstra, 2011).

As previously mentioned, the WF of sugarcane is mainly determined by climate conditions, application of irrigation, rate of chemical fertilizer application and crop yield. The challenge of this total WF result was green WF as major of water use. Therefore adding sugarcane is one solution to increase crop yields. Moreover, new technology to help increasing and better quality yields per year should be used and making sugarcane yields higher. However, this adding should be concerned about nitrogen in this area which will cause of high grey WF. As the climatic condition is uncertainly predictable in the future, the farmer should study irrigation system to prepare for the sugarcane cultivation plan in arid condition.

By the way, according to Kaenchan *et al*. (2013) water volume in Thailand was fluctuated every year. Therefore, climatic condition will be changed over times and definitely was impact on WF. One point that should be awareness in this study is calculation of WF for growing period October 2011 to September 2012 because WF is not constant. Therefore, this study will be useful for farmer or policy maker who take care of sugarcane in this area at that time.

4.2 Determination of heavy metals and elements in soil and sugarcane root samples

4.2.1 Method validation for analysis of heavy metals and trace elements

1) Analysis of certified reference for analysis of heavy metals and trace element.

Three replications of certified reference materials (CRMs); pepperbush NIES 1 and clay soil RTC 051 were used to test the method efficiency i.e. precision and accuracy.

a. Use of Pepperbush NIES 1

Pepperbush (*Clethra barbinervis*) was used as CRM in this work. Certificated values of 8 elements (Ba, Ca, Cd, Cu, Fe, Mn, Mg and Zn) and 1 element as reference value (Cr) were matched in this study. Recoveries of elements analyzed from CRM are shown in Table 4.9. Good recoveries (81 to 98%) were obtained. These values were within acceptable range referred to association of analytical chemistry (AOAC).

b. Clay soil RTC 051

This SRM was analyzed for 8 elements. The results are shown in Table 4.10. Good recoveries (102 to 118%) were obtained.

2) Standard calibration curves of metal and elements

The calibration curve of each element was examined at 0.0025, 0.005, 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5, 10 and 20 ppm. Linear equations and values of variation coefficient (R^2) obtained from the standard curves are shown in Figure 4.5 and Table 4.11. The R^2 value of linear plots ranged from 0.9998 to 1.0000. The equation curves were used for calculated the concentrations of elements contained in samples

Table 4.9 Recovery of elements obtained from pepperbush NIES 1

Element	Certified value (mg/kg)	Measured value (n = 5) ± SD	% Recovery
Ba	165 ± 10	162 ± 3	98
Ca	13,800 ± 700	12,800 ± 283	92
Cd	6.7 ± 0.5	5.8 ± 0.2	86
Cr	1.3*	1.1 ± 0.5	88
Cu	12 ± 1	11 ± 0	90
Fe	205 ± 17	166 ± 6	81
Mg	4,080 ± 200	3,470 ± 78	85
Mn	2,030 ± 170	1,890 ± 41	93
Zn	340 ± 20	310± 7	91

*Reference value was presented by NIES 1

Table 4.10 Recoveries of elements obtained from Clay soil RTC 051

Element	Certified value (mg/kg)	Measured value (n = 3) ± SD	% Recovery
Ca	1,220	1,440 ± 373	118
Cd	42.2	43.0 ± 3.7	102
Cr	246	256 ± 22	104
Cu	58.5	61.4 ± 4.4	105
Fe	4,520	5,070 ± 489	112
Mg	925	1,060 ± 91	115
Mn	757	822 ± 68	109
Zn	44	51 ± 0	116

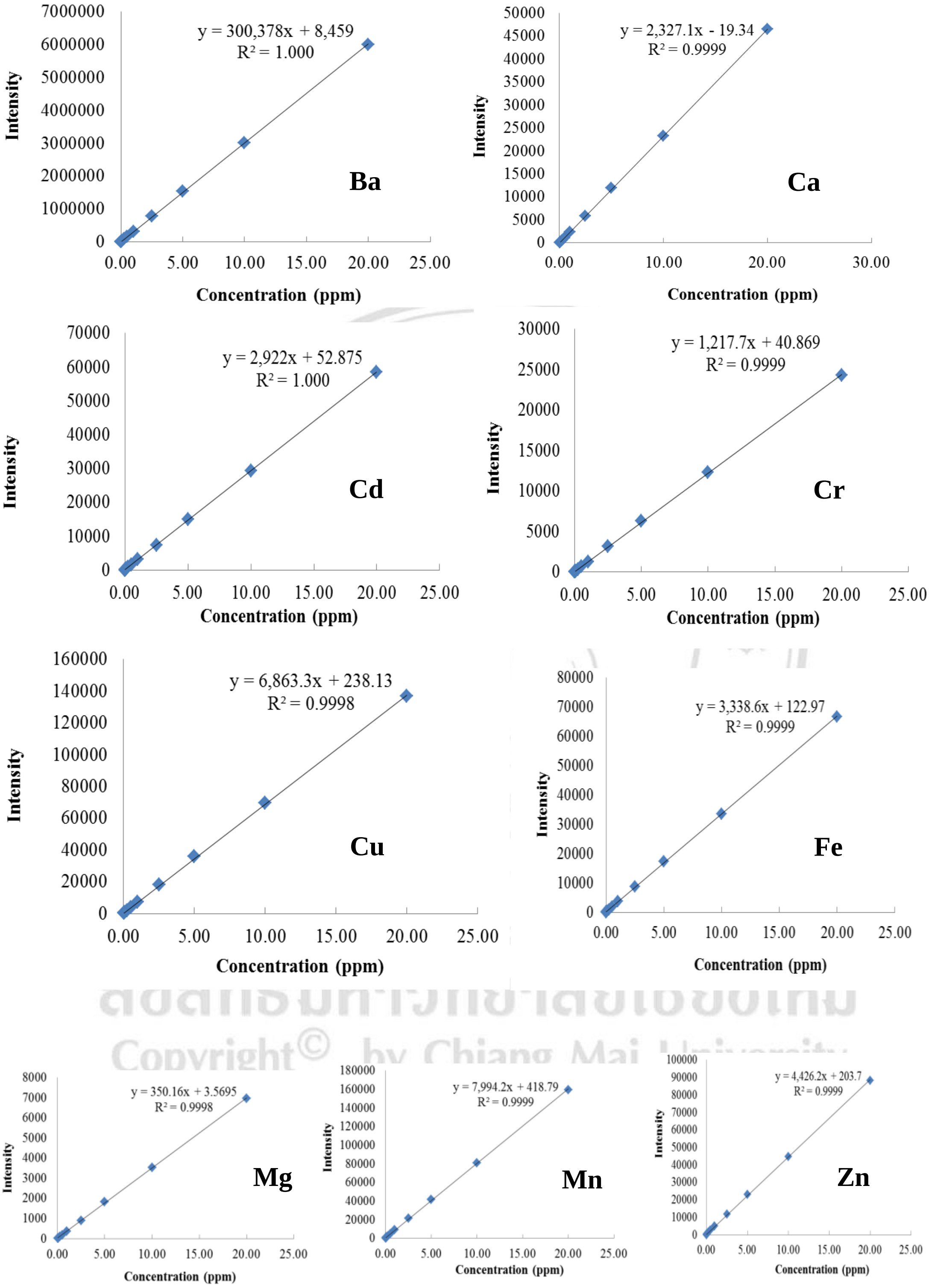

Figure 4.5 Standard calibration curves of heavy metal and elements

Table 4.11 Calibration equation and variation coefficient of elements

Elements	Wavelength (nm)	Linear equation	Variation coefficient (R^2)
Ba	455	y = 300,378x + 8,459	1.0000
Ca	315	y = 2,327.1x - 19.34	0.9999
Cd	214	y= 2,922x + 52.875	1.0000
Cr	357	y = 1,217.7x + 40.869	0.9999
Cu	324	y = 6,863.3x + 283.13	0.9998
Fe	238	y = 3,338.6x + 122.97	0.9999
Mg	279	y = 350.16x + 3.5695	0.9998
Mn	260	y = 7,994.2x + 418.79	0.9999
Zn	213	y = 4426.2x + 203.7	0.9999

4.2.2 Concentrations of heavy metals and trace elements in soil and sugarcane root samples

The samples were collected in August 2011 (wet season) and February 2012 (dry season). Contaminated site was in Ban Mae Tao Mai, Mae Sot District near zinc mine. Control site was in Ban Mae Kued, Mae Sot District. These two areas were approximately 20 kms far from each other.

The compositions of elements in sugarcane root and soil samples are shown in Figures 4.6-4.7. The dominant elements were Fe, Ca and Mg both of samples. For soil samples, the result was similar to Yaroshevsky (2005) study that reported the major of compositions of elements in the Earth’s crust which are Fe, Ca and Mg. Although Cd has few amounts, it existed and higher than Cu and Cr.

The concentrations of elements in sugarcane root and soil samples are shown in Appendix D. Mae Sot District is contaminated area by Cd (Simmons, 2005). This study focuses mainly on Cd. Cd in soil between contaminated site and control site was significantly different in both months (Table 4.12). However, soil in contaminated site was not significant between August 2011 and February 2012, it showed Cd had equally spread around area (Table 4.13). It might be soil properties and environment around this area which supported Cd accumulation and still stable.

Table 4.12 Cd concentrations of heavy metal and trace element in soil samples

Month	Cd concentration (mg/kg)					
	Contaminated site			Control site		
	$\bar{X}$ ± SD	min	max	$\bar{X}$ ± SD	min	max
Aug.	9.3^{a} ± 5.3	5.5	15.3	2.5^{b} ± 0.2	2.3	2.6
Feb.	11.3^{a} ± 4.2	7.7	15.9	2.8^{b} ± 0.3	2.5	3.1

However, Cd concentration in soil of control site between August 2011 and February 2012 were significantly different (Table 4.13). It might cause from seasonal reason (ATSDR, 2012; Rahman *et al*., 2012; Buaka *et al*., 2013). According to Buaka *et al*. (2013) presented that Cd concentration in cassava field which was affected by pollution problem. Their result showed that Cd in soil in dry season was higher than wet season because of evaporation that lead to increasing of Cd concentration. Some studies (Marzieh *et al*., 2010; Kim *et al*., 2012; Rahman *et al*., 2012) reported that heavy metal in soil in wet season was low because no run-off processing. In addition other effect for increasing Cd concentration in soil is from long-term using of fertilizer application as phosphorus fertilizers (Page *et al*., 1987; Lambert *et al*., 2007; Wu *et al*., 2012).

Table 4.13 Comparison the concentration of Cd in soil between sites each month

Sites	Months	Cd concentration (mg/kg)		
		$\bar{X}$ ± SD	min	max
Contaminated site	August 2011	9.3^{a} ± 5.3	5.5	15.3
	February 2012	11.3^{a} ± 4.2	7.7	15.9
Control site	August 2011	2.5^{a} ± 0.2	2.3	2.6
	February 2012	2.8^{b} ± 0.3	2.5	3.1

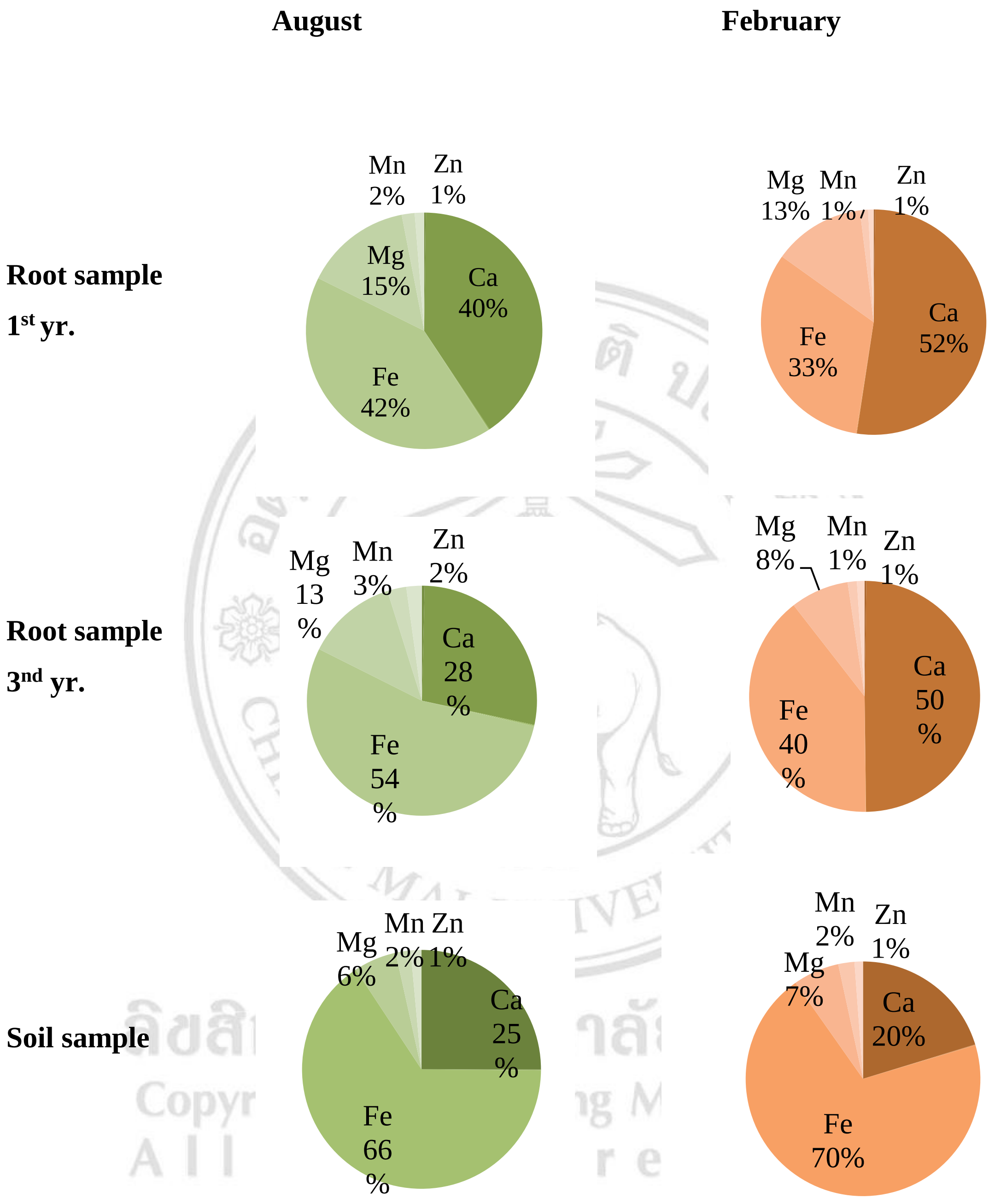

Figure 4.6 Ratio of heavy metals and trace elements absorbed by sugarcane root of contaminated site and soil in contaminated site in August 2011 and February 2012

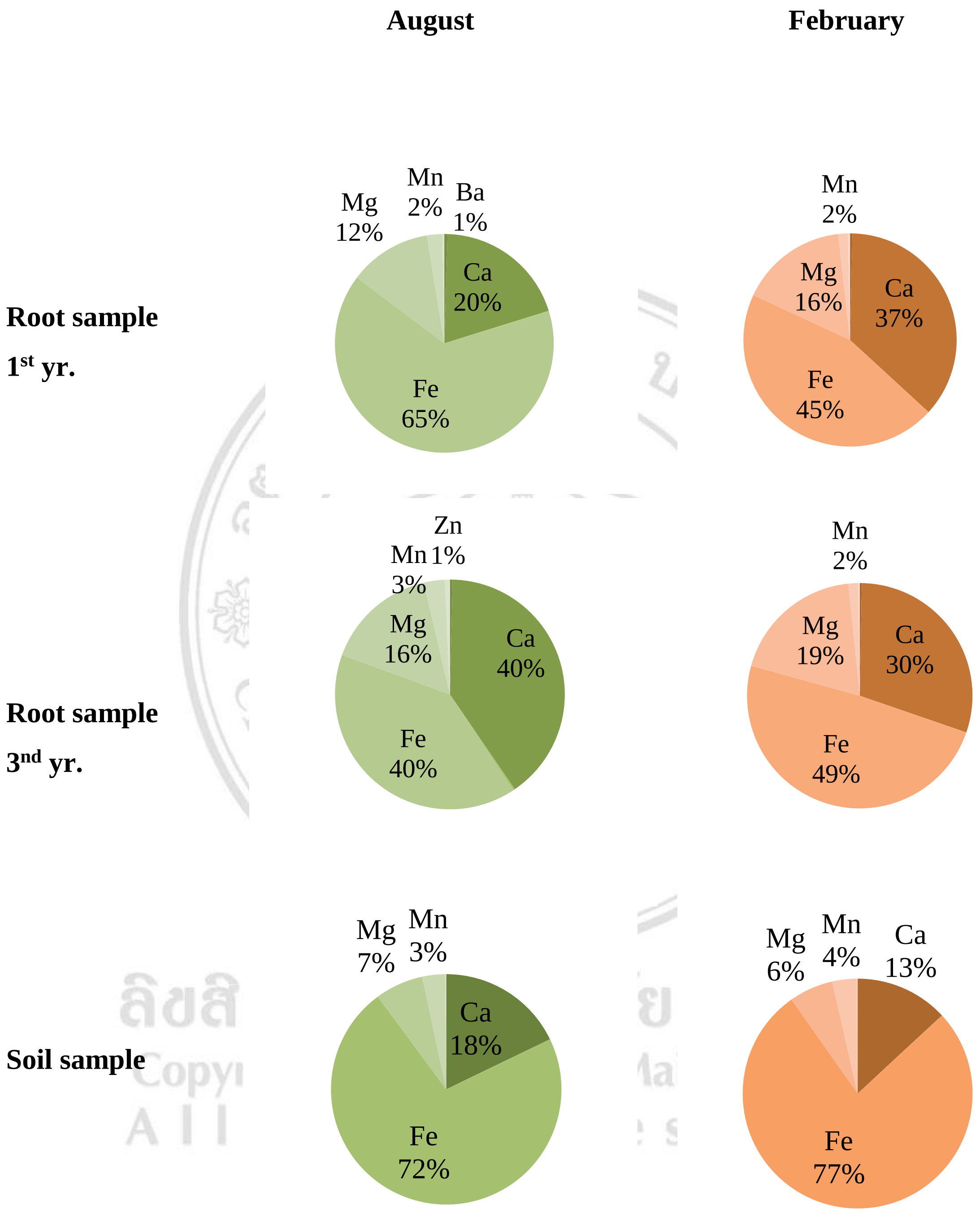

Figure 4.7 Ratio of heavy metals and trace elements absorbed by sugarcane root of control site and soil in control site in August 2011 and February 2012

High Cd contamination is found in contaminated area by nonferrous metal mining and smelting (Alloway and Steinnes 1999). Even though the area is far from mining, there is contaminated by Cd deposition in the environment (Muntau and Baudo 1992; IARC 1993). According to Hasselbach *et al*. (2005) described Cd deposition in the environment, that those areas as far as 12 kms north of the haul road may be affected by mining emission depositions. In this study the contaminated site located on Ban Mae Tao Mai which nearby Mae Tao Stream. According to Simmons *et al*. (2005) reported plant (rice) which cultivated closes to Mae Tao Stream is contained Cd concentration. Moreover, they reported 85% rice fields in Mae Sot District were exceeded the European Union (EU) Maximum Permissible (MP) level of 3.0 mg/kg for agricultural soils (EEC, 1986). Furthermore, Maneewong (2005) reported that high concentration of Cd and Zn in Mae Tao Stream has been regularly discharged runoff with sediment from Doi Pha Daeng where zinc mine placed on. Their results showed Cd concentration of sediment in Mae Tao Stream was 66.19 mg/kg and can conclude that zinc mining lead to Cd. Therefore Cd in soil in Mae Tao Mai might come from Mae Tao Stream, atmosphere fallout and fertilizer application. However Cd in control site might from fertilizer application.

Distinctly, Cd and Zn concentration in contaminated site were higher than control site while other elements in control site were rather higher than those in contaminated site during both months (Table 4.14). The strong association of Cd and Zn may have been derived from anthropogenic sources (Rahman *et al*. 2012). It agreed to the correlation between Cd-Zn in soil in both study sites that were positive correlation (Appendix C) and this results was in line with Nan *et al*. (2002) and Akkajit and Tongcumpou (2010).

Table 4.14 Comparison the concentration in soil between contaminated site and control site of heavy metal and trace element in August 2011 and February 2012

Elements	Average concentration (mg/kg)			
	August		February	
	Contaminated site	Control site	Contaminated site	Control site
Ca	5,990	8,100	4,960	5,670
Cd	9.3	2.5	11.3	2.8
Cr	14.3	38.2	12.4	34.2
Cu	9.4	21.2	7.1	17.3
Fe	15,700	32,700	17,100	33,400
Mg	1,390	3,080	1,560	2,680
Mn	485	1,450	545	1,490
Zn	347	73	285	59

In part of sugarcane root concentration analysis, Cd and Zn concentrations in contaminated site were higher than control site (Table 4.15 and 4.16). Apart from Ca, Cd and Zn, the elemental content of the first year sugar cane root was lower than that of the control site.

The heavy metal concentration in plant is always correlated with soil (Alina, 2011). According to Alloway (1995), Adriano (2001) and Sritumpawa (2007) reported that heavy metal accumulation in plant is depended on heavy metal concentration in soil. Therefore, due to the difference Cd concentration in soil could make the difference Cd concentration in root of sugarcane in this study.

Table 4.15 Comparison the concentration each age of sugarcane root between contaminated site and control site of heavy metal and element in August 2011

Elements	Average concentration (mg/kg)			
	Contaminated site (1st yr.)	Control site (1st yr.)	Contaminated site (3nd yr.)	Control site (3nd yr.)
Ba	16.5	53.8	29.4	21.7
Ca	2,960	2,250	2,190	2,280
Cd	6.7	ND	6.2	ND
Cr	2	6.8	2.3	2.2
Cu	4.2	4.9	8.6	11.8
Fe	3,040	7,420	4,210	3,390
Mg	1,070	1,390	997	897
Mn	129	259	209	168
Zn	94	33	171	40

Table 4.16 Comparison the concentration each age of sugarcane root between contaminated site and control site of heavy metal and element in February 2012

Elements	Average concentration (mg/kg)			
	Contaminated site (1st yr.)	Control site (1st yr.)	Contaminated site (3nd yr.)	Control site (3nd yr.)
Ba	22	22.3	25	20.8
Ca	5,430	2,260	5,210	2,120
Cd	4.2	ND	2	ND
Cr	2.4	2.6	2.5	2.2
Cu	4.6	2.8	6.2	3.4
Fe	3,370	2,790	4,160	3,460
Mg	1,370	1,010	859	1,350
Mn	121	91.9	135	100
Zn	82	19	113	15

Cd and some metals were occurred in plant because of the effect from anthropogenic activity (Olajire and Ayodele, 2003). This study showed that concentrations of Cd and Zn in soil and root samples collected from Cd contaminated site were higher than control site, because of nearby pollution source (Olajire and Ayodele (2003) (Table 4.14 to 4.16). According to Wallace *et al.* (1980), high Cd accumulation in plants' root is occurred jointly with high Zn level. Papoyan *et al*. (2007) observed high Zn concentrations in *Thlaspi caerulescens* (Cd and Zn hyper-accumulation plant) increased Cd tolerance and Cd levels of a plant. These results agreed with the correlation analysis in this study, in which Cd- Zn correlation was significant (Appendix C). The results were well agreed with Bailey, 1997, Nan *et al*., 2002, Zeng *et al.*, 2008 and Alina, 2011.

In contaminated site, Cd and Zn concentration in root were high because soil-to-plant transfers high coefficients and poor sorption in the soil (Kloke *et al*., 1984). Therefore, it is high possibility to increase Cd concentration in root if the sugarcane cultivation was in Cd and Zn contaminated site.

Considering seasonal effect, there was no significantly different in both age and no correlation between Cd concentration in roots and soil sample of 1 and 3^{rd} yr. crops neither in August 2011 nor in February 2012 (Table 4.17). Therefore their concentrations were average and presented together (Figure 4.8). However, Zn was significantly different in both age and old sugarcane had Zn accumulation higher than young sugarcane.

Table 4.17 Comparison the average concentration of Cd and Zn concentrations in sugarcane root in first and third year sugarcane

Elements	Samples	Months	Concentration (mg/kg)					
			1 yr			3 yr		
			$\bar{X} \pm SD$	min	max	$\bar{X} \pm SD$	min	max
Cd	Mae Tao Mai	Aug.	$6.7^{a} \pm 0.9$	5.8	7.5	$6.2^{a} \pm 5.9$	2.4	13
		Feb.	$4.2^{a} \pm 3.0$	2.0	7.6	$2.0^{a} \pm 1.1$	1.1	3.3
	Mae Kued	Aug.	ND	ND	ND	ND	ND	ND
		Feb.	ND	ND	ND	ND	ND	ND
Zn	Mae Tao Mai	Aug.	$94^{a} \pm 20$	72	113	$171^{b} \pm 91$	109	275
		Feb.	$82^{a} \pm 41$	45	126	$113^{a} \pm 39$	77	155
	Mae Kued	Aug.	$33^{a} \pm 7$	25	40	$40^{b} \pm 9$	30	46
		Feb.	$19^{a} \pm 17$	7	39	$15^{b} \pm 8$	7	24

Table 4.18 Comparison the average concentration of Cd and Zn concentrations in sugarcane root in August 2011 and February 2012.

Elements	Samples	Months	Concentration (mg/kg)					
			Aug.			Feb.		
			$\bar{X} \pm SD$	min	max	$\bar{X} \pm SD$	min	max
Cd	Mae Tao Mai	1st yr.	$6.7^{a} \pm 0.9$	5.8	7.5	$4.2^{b} \pm 3.0$	2.0	7.6
		3nd yr.	$6.2^{a} \pm 5.9$	2.4	13	$2.0^{b} \pm 1.1$	1.1	3.3
	Mae Kued	1st yr.	ND	ND	ND	ND	ND	ND
		3nd yr.	ND	ND	ND	ND	ND	ND
Zn	Mae Tao Mai	1st yr.	$94^{a} \pm 20$	72	113	$82^{b} \pm 41$	45	126
		3nd yr.	$171^{a} \pm 91$	109	275	$113^{b} \pm 39$	77	155
	Mae Kued	1st yr.	$33^{a} \pm 7$	25	40	$19^{b} \pm 17$	7	39
		3nd yr.	$40^{a} \pm 9$	30	46	$15^{b} \pm 8$	7	24

ND = not detected

The average Cd concentrations in root samples collected from Cd contaminated site was 6.6 mg/kg in August 2011 (6months old) and 3.3 mg/kg in February 2012 (12 months old) (Figure 4.8). Cd concentration in root samples was lowest in February because sugarcane was at its maturation and ripening phase (Figure 4.8). In addition Zn concentration had the same trend with Cd (Table 4.18). This phenomenon was described by dilution effect as slower uptake than increase in biomass (Rains, 1971; Brekken and Steinnes, 2004). The 6 months old of sugarcane plantation (August sample) was during stalk elongation phase or grand growth phases that expand its biomass. Thus the highest of Cd concentration in root was in August 2011.

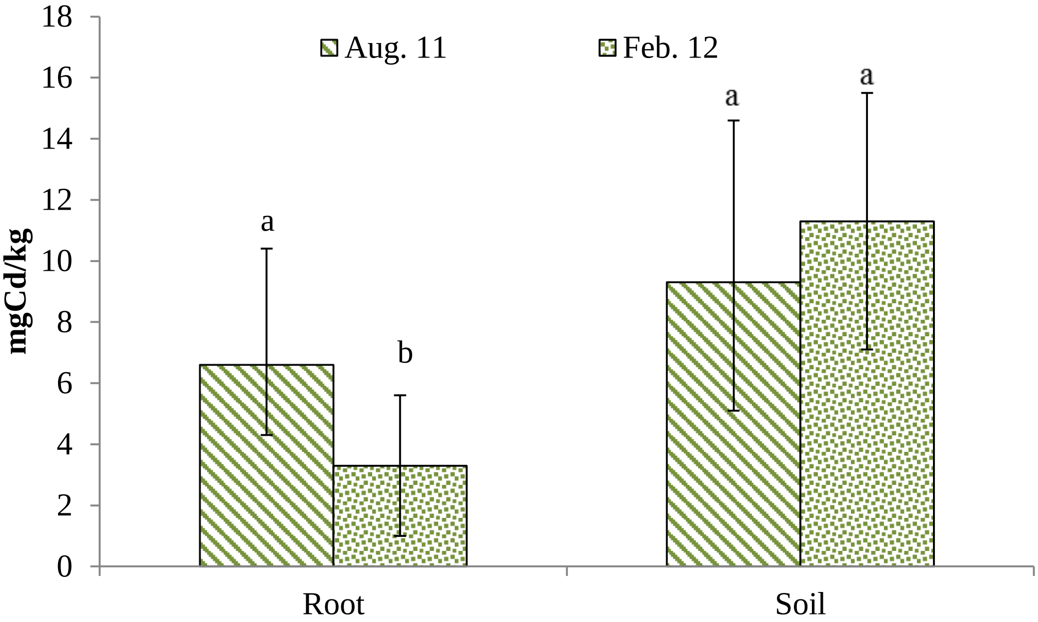

Figure 4.8 Cd concentrations in contaminated site of sugarcane root and soil samples collected in August 2011 and February 2012

After that, the efficiency of sugarcane e.g. growth rate will be decreased by aging effect toward harvesting in 12 months as February 2012 that was in line with Sritumpawa (2007) study. They collected sugarcane root from study site in Mae Sot District which the Cd concentration were 3-20 mg/kg. Their results showed roots of sugarcane were 3.9, 6.9 and 5.0 mgCd/kg when ages of sugarcane were 3, 6 and 9 months. These results showed similar trend with this study as decreasing of Cd concentration as sugarcane was elder.

For phytoremediation title, actually sugarcane offers the potential to be a phytoremediation species (Sereno *et al*., 2007). They presented ability of sugarcane shoot was able to tolerate up to 451 mgCd/kg after 33 days in nutrient solution containing 500 µM doses of Cd without symptoms of toxicity. Although in this study Cd accumulation of roots was lower than other studies, low Cd accumulation ability of sugarcane was still useful. According to Xueli *et al*. (2012) presented that sugarcane was selected to plant in low level of heavy metal in contaminated area. Although sugarcane had low ability to accumulate but they was high tolerance and provide high yields. Use of sugarcane for phytoremediation and Cd fixation by sugarcane root after harvesting are possible. However, more in depth studies are needed and the results are expected to be useful for local community. At the same time, it will become the solution and plantation to produce ethanol from sugarcane at the same time. This is forwards to resource assessment as sustainable and phytoremediation by agriculture.