CHAPTER IV

RESULTS AND DISCUSSION

4.1 Field experiment

The problem of cadmium contamination in cultivated soil and rice grain in Mae Sot district, Tak province, Thailand has been the interested environmental issue in the late five years. NRC-EHWM (2005) has zoned the areas in accordance with total cadmium concentration in soil into three ranges which include: < 3 mg Cd/kg, 3-20 mg Cd/kg and >20 mg Cd/kg. Those three difference areas was named here as Mae Ku, Mae Tao1 and Mae Tao2 for the concentration of <3, 3-20 and >20 mg Cd/kg areas, respectively. Many kinds of economic efficient non-edible crops have been introduced to cultivate in these areas to replace rice farming. However, sugarcane has been nominated to be the most appropriate plant because its destined application as a raw material for the ethanol production.

The field experiment aimed to investigate total cadmium and zinc in soils, the availability of cadmium and zinc in soils, uptake and accumulate in sugarcane cultivated in those areas of different in cadmium concentration. Soil and sugarcane samples were collected twice at the end of the second and the sixth months after the cultivation.

4.1.1 Physical and chemical properties of soils in the field experiment

Soil samples were collected from the area of Mae Ku, Mae Tao1 and Mae Tao 2 to determine initial properties of the soils. The physical and chemical properties of soils in the field experiment are presented in Table 4.1. Soil pH is the most important single soil property that controlling the soil reactions (Kabata-Pendias and Pendias, 2001). pH value of soils in Mae Ku, Mae Tao1 and Mae Tao2 area was equal to 7.35, 6.35 and 7.46, respectively. However, the soil in Mae Ku area seems to be slightly more acidic than the others. Phrammanee (1998) reported that soil pH with the range of 6.3-7.5 appropriate for sugarcane growth. Background cadmium and zinc in soil from those three areas were also determined. The results showed that they were 2.57, 16.66 and 174.51 mg Cd/kg and 35.12, 74.86 and 2,098.67 mg Zn/kg for Mae Ku, Mae Tao1 and Mae Tao2 area, respectively. This indicates that the concentration of zinc in those three areas is correlating well with cadmium concentration in soil. The different upper contamination levels of heavy metals in soils have been reported for different countries. For example 2, 3, 12, 20 mg/kg of cadmium and 200, 600, 720 and 2,800 mg Zn/kg, for Australia, Canada, the Netherlands and USA, respectively (USEPA, 1990; McBride, 1994; Alloway, 1995; Mc Laughlin and Singh, 1999) were reported. The texture of soil in Mae Ku, Mae Tao1 and Mae Tao2 areas was sandy loam, sandy clay loam and loam, respectively. As considered to the clay content of soil, the results demonstrated that clay content in Mae Tao1 and Mae Tao2 areas were also higher than the Mae Ku area. Adriano (2001) found that soil type and the mineralogy of the clay fraction may influence the sorption and the availability of metals in soils, higher sorption capacity is favored by fine-textured soils, or soils high in clay content.

Table 4.1 Physical and chemical properties of soils in the field experiment

Parameter	Analysis Values		
	Field Experiment (mg Cd/kg)		
	Mae Ku	Mae Tao1	Mae Tao2
	<3	3-20	>20
pH	7.35	6.35	7.46
Organic Matter (%)	1.48	1.31	2.52
Moisture content (%)	13.27	14.11	14.24
Total Nitrogen (%)	0.074	0.066	0.126
Total phosphorus (mg/kg)	415	342	439
Potassium (mg/kg)	63	80	78
Total cadmium (mg/kg soil)	2.57	16.66	174.51
Total zinc (mg/kg soil)	35.12	74.86	2,098.67
Sand (%)	55.60	51.20	42.80
Silt (%)	25.00	22.80	31.00
Clay (%)	19.40	26.00	26.20
Soil Texture	Sandy Loam	Sandy Clay Loam	Loam

4.1.2 Soil pH

After sample collection at the end of the second and the sixth months after the cultivation, pH values of collected soil from Mae Ku, Mae Tao1 and Mae Tao2 areas were measured. The results as illustrated in Table 4.2 showed that soil pH in all areas seem to be decrease slightly at the end of the sixth months after cultivation. This may have resulted from the heavy and regularity of rain during rainy season (July) which can decrease soil pH.

Campbell and Wansbrough (2005) described that rainfall also affects soil pH. Where soils are near neutral or alkaline, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} cations, known collectively as the exchangeable bases, balance most of the negative charges present on the surfaces of humus and the phyllosilicate clay minerals. As these exchangeable base cations are in dynamic equilibrium with the cations present in the bulk of the soil solution, it follows that they are also the dominant cations present in the soil solution. When more rain falls, it runs through the soil, removing water-soluble material. In particular, it removes the mobile Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} cations from soil solution and replaces them with H_3O^{+} (aq) and Al^{3+} (aq) ions. For this reason, soils formed under high rainfall conditions are more acidic than those formed under arid (dry) conditions.

Table 4.2 pH values of field experiment soil

Range of cadmium in soil (mg/kg)	pH	
	2 months	6 months
Mae Ku <3	7.45±0.03*	7.23±0.09
Mae Tao1 3-20	6.57±1.10	6.05±1.63
Mae Tao2 >20	7.53±0.07	7.26±0.05

*Mean ± Standard deviation (n = 3)

4.1.3 Total phosphorus in soils

Concentration of total phosphorus in soil samples collected from the area of Mae Ku, Mae Tao1 and Mae Tao2 both at the end of the second and the sixth months after sugarcane cultivation are presented in Figure 4.1. The results demonstrated that total phosphorus in soil seem to be decreased slightly at the end of the sixth months for all areas. The decrease of total phosphorus concentration in soil may be due to increasing crop uptake of phosphorus in the peak rate of sugarcane growth. This result indicated that further additions of fertilizer would be required in order to maintain high crop yields.

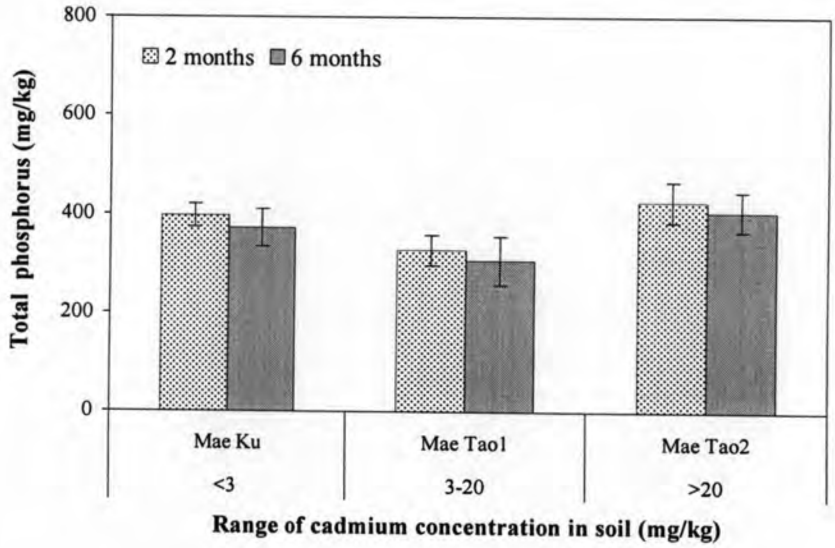

Figure 4.1 Concentration of total phosphorus in soils

4.1.4 Available phosphorus in soils

Figure 4.2 illustrates the concentration of available phosphorus in soil collected from Mae Ku, Mae Tao1 and Mae Tao2 area. The results show that available phosphorus in soil appeared to decrease slightly at the end of the sixth months after cultivation for all areas. Although a repeat application of the 16-16-8 NPK fertilizer was conducted in the fifth month after the sugarcane cultivation, the concentration of available phosphorus in those three areas was still decreasing.

However, the available phosphorus existing in soil of those three areas at the end of the sixth months was in the range of which being optimum for plant growth.

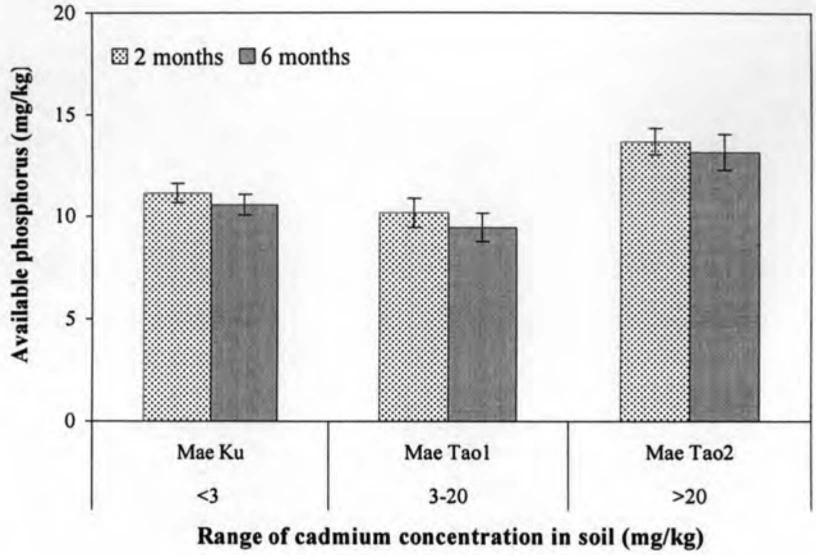

Figure 4.2 Concentration of available phosphorus in soils

4.1.5 Total cadmium and zinc in soils

Concentrations of total cadmium and zinc in soil were determined after sample collection in both the second and the sixth months after sugarcane was cultivated in Mae Ku, Mae Tao1 and Mae Tao2 area. As presented in Table 4.3, the results showed that concentrations of cadmium and zinc in all three areas of field experiment increased with the range of cadmium concentration in soil. However, there was no significant difference at $p < 0.05$ by ANOVA (Analysis of variance) between the area of Mae Ku and Mae Tao1. The highest concentration of total cadmium and zinc in soil were found in Mae Tao2 area (>20 mg Cd/kg). Moreover, the results also indicated that concentrations of both total cadmium and zinc in field experiment soils tended to decrease with increasing time as compared to the background cadmium and zinc concentration of each area.

Table 4.3 Concentration of total cadmium and zinc in field experiment soil

Heavy metal	Range of cadmium in soil (mg/kg)	Time (months)	
		2	6
Cadmium	Mae Ku <3	2.3479[a]±0.4139*	2.2277[a]±0.4059
	Mae Tao1 3-20	15.7633[a]±3.5923	13.9811[a]±5.2300
	Mae Tao2 >20	161.0797[b]±64.5985	153.1281[b]±30.2802
Zinc	Mae Ku <3	33.3920[a]±5.2895	30.2922[a]±5.1435
	Mae Tao1 3-20	71.7075[a]±8.8469	65.7587[a]±9.3531
	Mae Tao2 >20	2,074.3209[b]±147.5279	2,048.7121[b]±111.9834

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.1.6 Available cadmium and zinc in soils

Availability or bioavailability is the proportion of total metals that are available for incorporation into biota or taken up by plant (John and Leventhal, 1995). Soil samples collected from three areas; Mae Ku, Mae Tao 1 and Mae Tao 2 at the end of the second and the sixth months after the cultivation were examined for the availability of cadmium and zinc by using DTPA extraction method. Table 4.4 represents the concentration of available cadmium and zinc in the field experiment soil. The results showed that the available cadmium and zinc in Mae Ku, Mae Tao 1 and Mae Tao 2 area were higher with the range of cadmium concentration in soils. However, statistical analysis by ANOVA indicated that there was no significant difference in the concentration of available cadmium and zinc in the soil collected from the areas of Mae Ku and Mae Tao1. It was interesting that the available cadmium and zinc existed in Mae Tao 2 areas was appeared to be higher than the other two areas. Thus, it should concern that the excessive accumulation could occur in sugarcane tissues in this area. Kabata-Pendias and Pendias (2001) stated that soluble forms of cadmium and zinc are readily available to plants and the uptake of cadmium and zinc has been reported to be linear with concentration in soil solution. Moreover, the results also indicated that the concentration of available cadmium and zinc in soil increased in the sixth months after sugarcane was cultivated in those three areas as compared to the second months. As mentioned above, at the end of the sixth months, pH of soil collected from all three areas tended to be decreased slightly. Adriano (2001) stated that decreasing of soil pH also influenced the increasing the availability of metals to taken up by plants. The decreasing of pH values of soil can be one of factors which affect the increase of available cadmium and zinc in the end of the six months. However, there are many factors that can affect the availability of metals in soil. Kabata-Pendias and Pendias (2001) stated that the concentrations of trace elements in soil solutions vary considerably among soils and with time. Great fluctuations can be observed under the influence of some factors such as microbial activities, waterlogged states, time, vegetation and heterogeneity of the solid soil phase.

Table 4.4 Concentration of available cadmium and zinc in field experiment soil

Heavy metal	Range of cadmium in soil (mg/kg)	Time (months)	
		2	6
Cadmium	Mae Ku <3	0.0553[a]±0.0175[*]	0.2473[a]±0.0251
	Mae Tao1 3-20	0.1886[a]±0.0647	0.3265[a]±0.0359
	Mae Tao2 >20	18.5211[b]±2.6226	27.5243[b]±1.2048
Zinc	Mae Ku <3	1.0795[a]±0.3881	1.9915[a]±0.3704
	Mae Tao1 3-20	3.2583[a]±1.0209	4.4882[a]±1.0665
	Mae Tao2 >20	154.7718[b]±41.7208	253.9158[b]±29.4367

[*]Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.1.7 Cadmium and zinc in sugarcane

The study of total cadmium and total zinc in sugarcane was separated into two parts: 1) cadmium and zinc accumulation in whole sugarcane and 2) concentration of cadmium and zinc in different parts of sugarcane reported in mg/ kg unit to compare the capacity of cadmium and zinc accumulation in each part of sugarcane.

1) Cadmium and zinc accumulated in whole sugarcane

The accumulation of cadmium and zinc in whole sugarcane body as presented in Figures 4.3 and 4.4 showed that both cadmium and zinc accumulation in sugarcane harvested at the end of the sixth months were higher as compared to the second months. The results from this study also indicated that the highest cadmium accumulation in sugarcane cultivated in those three cadmium contaminated areas occurred in the sixth months after the sugarcane cultivation and was equal to 0.4531, 1.1994 and 2.0145 mg Cd for the area of Mae Ku, Mae Tao 1 and Mae Tao 2, respectively. For the accumulation of zinc, at the end of the sixth months, whole sugarcane showed levels equal to 9.1171, 24.0089 and 73.5601 mg Zn for Mae Ku, Mae Tao 1 and Mae Tao 2 area, respectively (see Appendix E). Thus, it can be implied that metals uptake to sugarcane was mostly controlled by the total concentration in soil.

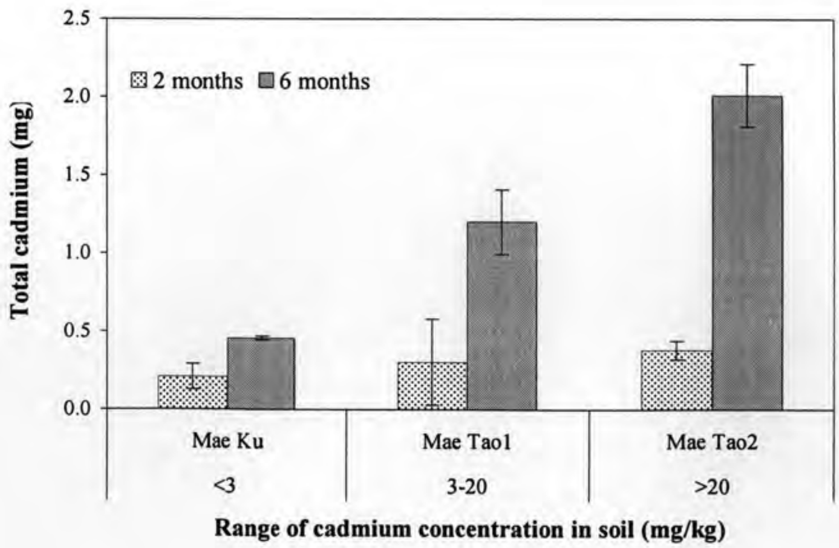

Figure 4.3 Cadmium accumulated in field experiment sugarcane

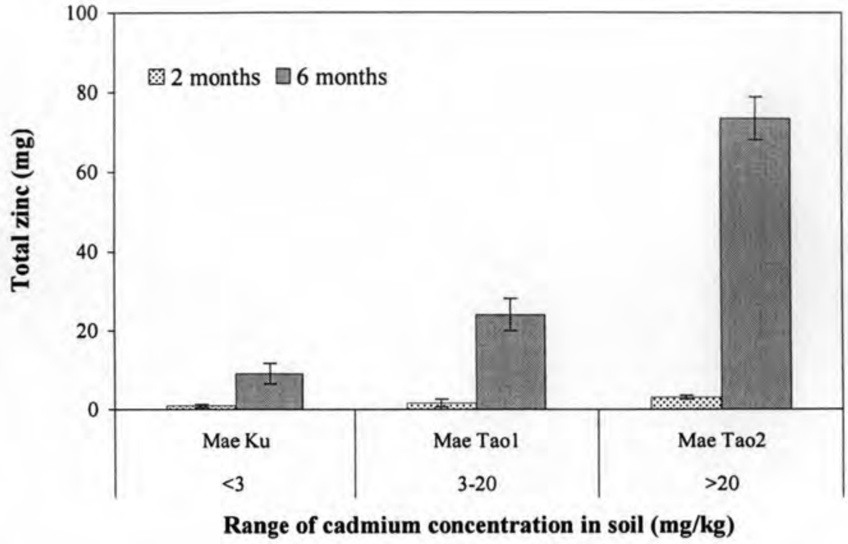

Figure 4.4 Zinc accumulated in field experiment sugarcane

Table 4.5 demonstrates the concentration of cadmium and zinc in sugarcane. The results showed that the concentration of cadmium and zinc in sugarcane cultivated in Mae Ku, Mae Tao1 and Mae Tao2 area were significantly higher ($p < 0.05$) with the higher range of cadmium concentration in soil of those three areas. The highest concentration of cadmium and zinc in the sugarcane was occurred in the sixth months of the Mae Tao2 area in which equal to 6.0584 mg Cd/kg and 221.5971 mg Zn/kg. It was noteworthy that sugarcane cultivated in the Mae Tao2 area contained quite high concentration of cadmium and zinc. Doyle (1998) reported that high levels of cadmium in soil can reduce plant growth.

Table 4.5 Concentration of total cadmium and zinc in sugarcane

Heavy metal	Range of cadmium in soil (mg/kg)	Concentration of Cd and Zn (mg/kg)	
		2 months	6 months
Cadmium	Mae Ku <3	3.5639[a]±0.7109*	2.1489[a]±0.4604
	Mae Tao1 3-20	4.3209[a]±1.4059	3.6665[b]±0.1772
	Mae Tao2 >20	7.7281[b]±1.8721	6.0584[c]±0.3944
Zinc	Mae Ku <3	15.9206[a]±2.7176	42.5469[a]±12.1326
	Mae Tao1 3-20	25.9237[a]±5.8844	73.5377[b]±7.0764
	Mae Tao2 >20	63.7718[b]±11.6317	221.5971[c]±15.8080

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

2) Concentration of cadmium and zinc in different parts of sugarcane

2.1) Cadmium

Figure 4.5 illustrates the concentration of cadmium accumulated in the different parts of sugarcane at the end of the second months after sugarcanes were cultivated in Mae Ku, Mae Tao1 and Mae Tao2 area. The results indicated that in the areas of Mae Tao2, cadmium appeared to be mostly accumulated in the roots followed by bagasses, underground stems and leaves, respectively. This trend was different from the sugarcane cultivated in the areas of Mae Ku and Mae Tao1, possibly due to higher in the concentration of cadmium contaminated in this area. At the end of the sixth months, the results showed the same trend in all three areas (Mae Ku, Mae Tao1 and Mae Tao2 areas) with cadmium accumulation in sugarcane in the following sequence roots > underground stems > bagasses >leaves > juice (Figure 4.6). The highest concentration occurring in root equal to 5.4219, 6.8809 and 28.3526 mg/kg for Mae Ku, Mae Tao 1 and Mae Tao 2, respectively (see Appendix E). This can be concluded that cadmium accumulated and remained in roots rather than translocated to the aboveground portions. This result conformed to Kabata-Pendias and Pendias (2001) who noted that a great proportion of cadmium is known to accumulate in root tissues of plants. Cieśliński et al. (1996) indicated that the cadmium distribution in strawberries, grown in soil with 60 ppm cadmium and neutral pH, was higher in roots rather than in leaves and fruits. Moreover, a similar trend was also reported by Chen et al. (2006) that roots of wheat appears to be the part where most cadmium accumulated followed by haulm, chaff and grain, respectively.

At present, the sugarcane juice from the study site is intended to be used as a raw material for the ethanol production. Determination of cadmium in sugarcane juice showed that sugarcane cultivated in the Mae Tao 2 area appears to be significantly ($P < 0.05$) higher (0.0858 mg Cd/kg) in cadmium concentration when compared to the others two areas (0.0152 and 0.0182 mg Cd/kg for Mae Ku and Mae Tao1, respectively) (Appendix D). However, there are still no reports so far on the threshold amount of cadmium in sugarcane juice which can cause toxic repercussion used when being as a raw material in the ethanol production process.

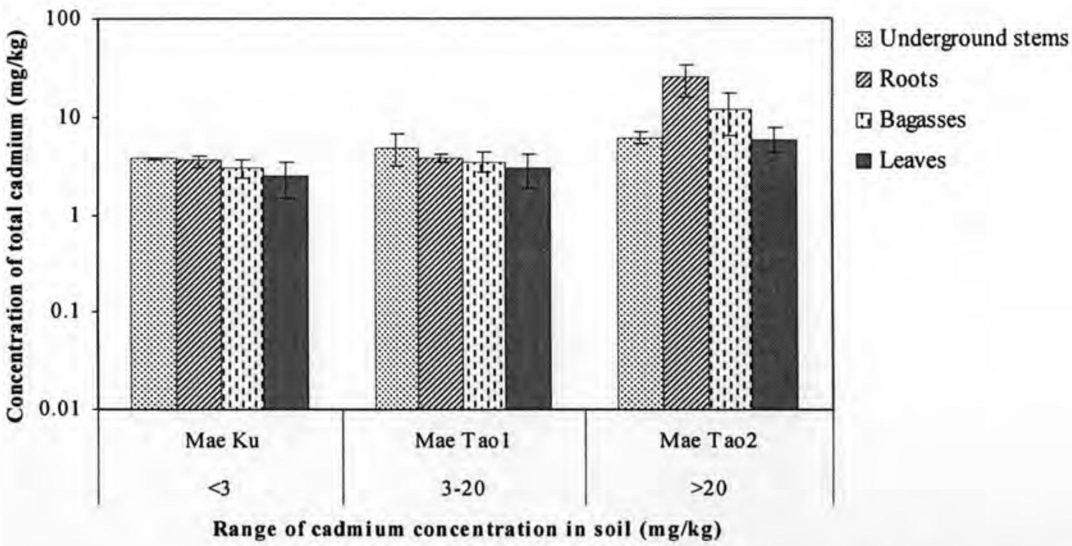

Figure 4.5 Concentration of cadmium in different parts of sugarcane at the end of the second months after cultivation

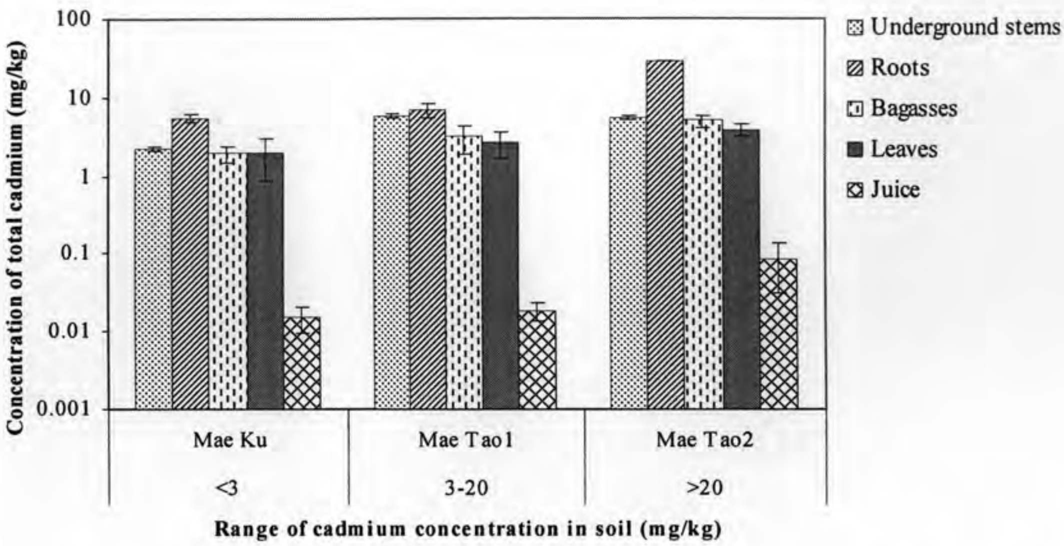

Figure 4.6 Concentration of cadmium in different parts of sugarcane at the end of the sixth months after cultivation

2.2) Zinc

The capacity of the different parts of sugarcane to accumulated zinc is presented in Figure 4.7. At the end of the second months, the results showed that concentration of zinc accumulated in sugarcane was appeared to be mostly in sugarcane roots followed by bagasses, underground stems and leaves, respectively. At the end of the sixth months, the results indicated that the most zinc accumulation part belongs to roots followed by bagasses, leaves, underground stems and juice, respectively (Figure 4.8). The accumulation of zinc at the end of the sixth months tended to translocate into the higher parts of sugarcane (leaves). Many investigators have stated that zinc-efficient genotypes have been generalized to typically contain higher concentration in young leaf blades, indicating a better transport and utilization of zinc (Graham and Rengel, 1993; Khan et al., 1998). The results also showed that the accumulation of zinc in roots occurred to be the highest in Mae Tao 2 area at the end of the sixth months after the sugarcane was cultivated and equaled to 478.9821 mg Zn/kg (Appendix E). Kabata-Pendias and Pendias (2001) stated that roots often contain much more zinc than do tops, particularly if plants are grown in zinc-rich soil. For the concentration of zinc in sugarcane juice, the results showed that zinc in sugarcane juice was equal to 3.6033, 3.7900 and 6.6517 mg Zn/kg for Mae Ku, Mae

Tao 1 and Mae Tao 2 areas, respectively (Appendix E). However, the accumulation of zinc in sugarcane juice was not a major concerned because it appears to be one of the micronutrients which are necessary for plant growth and normally present.

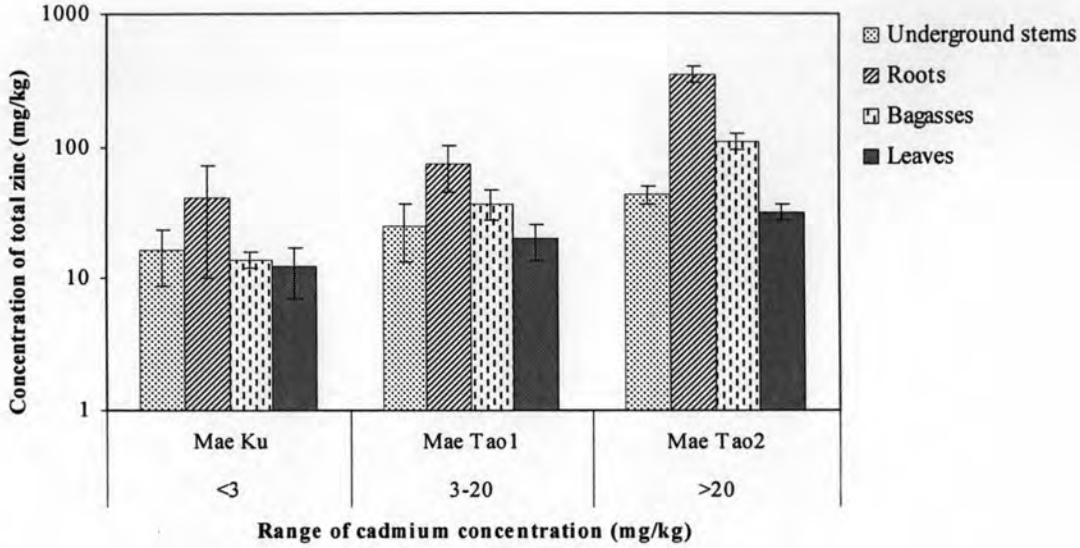

Figure 4.7 Concentration of zinc in different parts of sugarcane at the end of the second months after cultivation

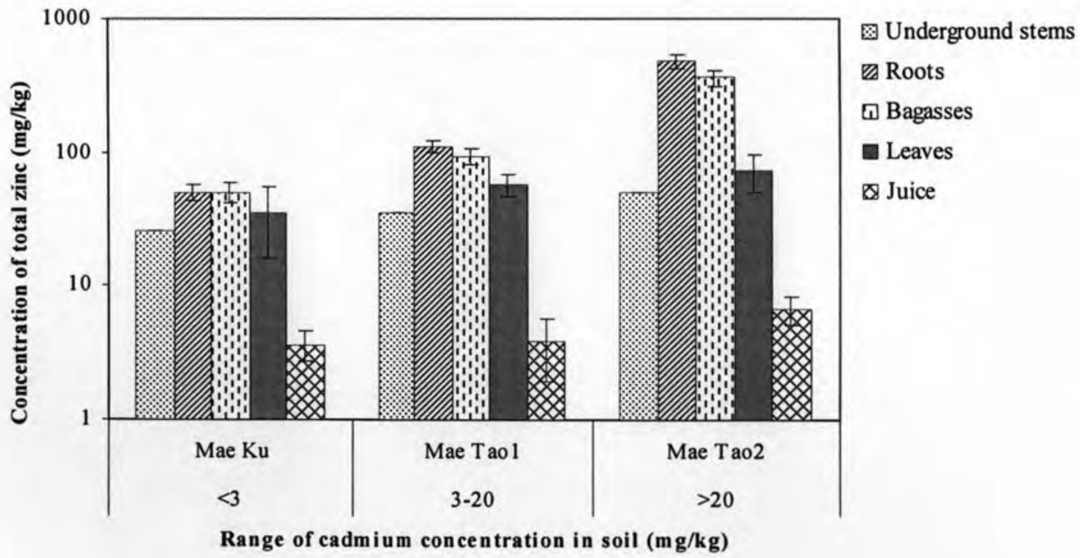

Figure 4.8 Concentration of zinc in different parts of sugarcane at the end of the sixth months after cultivation

4.2 Pot experiment

Sugarcane is widely cultivated in Mae Sot area. It also requires fairly large amounts of phosphorus to promote their growth. Farmers in Mae Sot area always apply phosphorus in the form of 16-16-8 NPK fertilizer to their sugarcane cultivated fields to improve the sugarcane growth. Many investigators reported that phosphorus can affect the availability of cadmium and zinc in soil and the ability of plants to uptake these metals (Saeed and Fox, 1979; Xie and McKenzie, 1989; Tu et al., 2000). Also, the possible negative effects of fertilizer application to agricultural soils have been reported. In USA, Minnesota Department of Agriculture, Pesticide and Fertilizer Management (2002-2006) reported high level contamination of heavy metals in various types of fertilizers. The results showed that the level of cadmium contained in fertilizers ranged from less than 0.4 to 47 mg/kg. To see the effect of applying 16-16-8 NPK fertilizer on the accumulation of cadmium and zinc in soil, the soil which was zoned in the range of <3 mg Cd/kg was selected to be used in the pot experiment.

The pot experiment aimed to determine the effect of phosphorus in 16-16-8 NPK fertilizer on total cadmium, total zinc, total phosphorus and available phosphorus in soil when applying different rates of fertilizer. In addition, the available cadmium and zinc and the accumulation of both metals in sugarcane were investigated. The soil used in the pot experiment was collected from cadmium contaminated areas in Mae Ku sub-district, Tak province with the range of cadmium concentration < 3 mg/kg was treated with the different rates of 16-16-8 NPK fertilizer (0, 50, 100 and 200 kg fertilizer/rai). The method for sugarcane cultivation in the pot experiment emulated the method used in the real sites in Mae Sot area. Soil and sugarcane samples were collected at the end of the second and the sixth months after cultivation.

4.2.1 Physical and chemical properties of soil used in the pot experiment

The soil used in pot experiment was analyzed for initial properties. Basic physical and chemical properties of soil used in the pot experiment are presented in Table 4.6. The results showed that the soil contained background concentrations of total cadmium and total zinc equal to 2.57 and 28.00 mg/kg, respectively. Although the pot experiment soil was collected from the lowest range of cadmium contaminated zone in Mae Sot areas (<3 mg Cd/kg), it appear to be higher in cadmium and zinc concentration when compared to general topsoils in Thailand. Zarcinas et al. (2004) reported the investigation levels for metals in soils of Thailand. Their study found that the concentration ranges (minimum up to 95th percentile) for all Thailand topsoils sampled contained cadmium in the range of 0.01–0.17 mg/kg and zinc in the range of 0.10–71.0 mg/kg. For the analysis of soil texture, the result indicated that the texture of soil used in the pot experiment appears to be a sandy loam with low clay content (9.60 %).

Table 4.6 Physical and chemical properties of soil used in the pot experiment

Parameter	Analysis Values
pH	7.17
Organic Matter (%)	1.01
Moisture content (%)	8.89
Total Nitrogen (%)	0.050
Total phosphorus (mg/kg)	356
Potassium (mg/kg)	48
Total cadmium (mg/kg soil)	2.57
Total zinc (mg/kg soil)	28.00
Sand (%)	79.40
Silt (%)	11.00
Clay (%)	9.60
Soil Texture	Sandy Loam

*Mean ± Standard deviation (n = 3)

4.2.2 Fertilizer analysis

The fertilizer used in this study was a granular commercial fertilizer 16-16-8 NPK formulation. Farmers in Mae Sot areas generally use this kind of fertilizer to promote their sugarcane production. This fertilizer may possibly have a substantial amount of cadmium as an ingredient. Properties of the fertilizer were determined and the results are presented in Table 4.7. The results illustrate that pH value of the fertilizer appears to be slightly alkaline. The fertilizer was found to contained cadmium and zinc equal to 0.6518 and 81.5259 mg/kg fertilizer, respectively. However, the cadmium content in this fertilizer is quite low as compared to others studies. Williams and David (1973) reported that the range of cadmium concentration of several Australian commercial fertilizer was 18 to 91 ppm, whereas Swedish fertilizers were shown to contain <0.1 to 30 ppm cadmium (Stenström and Vahter, 1974).

Table 4.7 Properties of a granular 16-16-8 NPK fertilizer used in the study

Properties	Values
pH	7.75±0.02*
Total cadmium (mg/kg fertilizer)	0.6518±0.0185
Total zinc (mg/kg fertilizer)	81.5259±1.7063

*Mean ± Standard deviation (n = 3)

4.2.3 Effect of fertilizer application rates on soil pH

Soil pH plays a major role in the uptake of micronutrients and heavy metals, because element mobility increases with the acidification of the soil. In addition, different forms and rates of phosphorus fertilization may change the original soil pH, thus affecting the availability of various elements and their transport to the crop (Osztoics et al., 2005). After harvesting both at the end of the second and the sixth months after sugarcane was cultivated, soil samples were collected and pH values of soils were measured. Table 4.8 showes the results of different rates of fertilizer application on soil pH. The results indicated that soil pH was significantly increased

(P<0.05) with increase in fertilizer application rates. Levi-Minzi and Petruzzelli (1984) reported the increasing of pH values when diammonium phosphate (DAP) was applied to soil.

Table 4.8 Effect of fertilizer application rates on soil pH

Fertilizer application rate (kg/rai)	pH	
	2 months	6months
0	$7.20^{a}\pm0.02^{*}$	$7.04^{a}\pm0.02$
50	$7.31^{b}\pm0.03$	$7.14^{b}\pm0.02$
100	$7.38^{c}\pm0.02$	$7.23^{c}\pm0.04$
200	$7.50^{d}\pm0.03$	$7.32^{d}\pm0.02$

[*]Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.2.4 Effect of fertilizer application rates on dry matter yield of sugarcane

Dry matter yield of sugarcane grown in the pot experiment was measured to determine the growth after 16-16-8 NPK fertilizer was applied to the soil. After harvesting, sugarcane samples were allowed to air-dry for 72 hour and then oven-dried at 105° C for 24-48 hour to constant weight. The results as presented in Table 4.9 showed that dry matter yield of sugarcane was increased significantly ($P < 0.05$) with increasing of fertilizer application rate. However, there was no significant difference between the rate of 50 kg/rai and 100 kg/rai at the end of the sixth months after cultivation. This study also found that the highest dry matter yield of sugarcane occurred at the rate of applying 200 kg fertilizer/rai in which equal to 27.14 and 199.87 g/pot for the second and the sixth months, respectively (Appendix E). This can be concluded that increasing rate of 16-16-8 NPK fertilizer application can promote higher dry matter yield of sugarcane. The conformable result was reported by Chien et al.(2003) who indicated a strong PK effect on rice grain yield. In that work, rice grain yield increased from 1.2 g/pot with the control pot (no P and K) to the average value of 23.6 g/pot with PK fertilizers. Many studies reported that in a soil deficient in available phosphorus, the application of phosphorus to the soil will increase the plant growth and produce higher yield (Mortvedt, 1987; Chien and Menon, 1994). Accordance result was reported by Bokhtiar and Sakurai (2003). Their finding in improving sugarcane yield through increasing phosphorus revealed that higher phosphorus application rate significantly increased cane and sugar yield by about 31% over yields obtained under present soil phosphorus fertility. Application of phosphorus fertilizer promotes root growth, stimulates tillering, influences millable cane growth and thereby sugarcane yield per hectares (Pannu et al., 1985). Besides yield, adequate phosphorus nutrition is conductive of higher sugar accumulation in cane tissues. Kumar and Verma (1999) observed that application of 50 kg P_2O_5/ha and above increased cane yield significantly over control (37.2 to 56.4 t/ha). Panwar et al. (1999) indicated that application of phosphorus increased significantly the dry matter yield of cowpea and mungbean and also found a beneficial effect of phosphorus in counteracting the adverse effect of cadmium may be attributed to the decrease solubility of cadmium in soil.

Table 4.9 Effect of fertilizer application rates on dry weight of sugarcane

Fertilizer application rate (kg/rai)	Dry matter yield (g/pot)	
	2 months	6months
0	$20.70^{a}\pm2.07^{*}$	$119.20^{a}\pm8.32$
50	$24.54^{ab}\pm2.46$	$177.17^{b}\pm6.64$
100	$25.87^{ab}\pm4.99$	$184.03^{b}\pm9.45$
200	$27.14^{b}\pm3.04$	$199.87^{c}\pm1.76$

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.2.5 Effect of fertilizer application rate on total phosphorus in soil

As considered to the effect of fertilizer application rates on total phosphorus in soil, the results showed that the concentration of total phosphorus in soils tended to increase with increasing fertilizer application rate in both the second and the sixth months after sugarcane was cultivated (Table 4.10). However, the statistical analysis by ANOVA (Analysis of Variance) indicated that there was no significant difference at $P < 0.05$ with increasing of application rate at the end of the second months. The data also indicated that percent phosphorus uptake by sugarcane increased with increasing of fertilizer application rate as compared to the background total phosphorus in soil (356 mg P/kg). Phosphorus is an essential element which stimulates root and shoot growth, promoting vigorous seedling and advancing maturity. The period of 2 to 6 months is the period of the peak rate of sugarcane growth (Miller and Gilbert, 2006). Thus, this may be attributed to the decreasing of concentration of total phosphorus in soil. This corroborates the results showed in dry matter yield that phosphorus was utilized for increasing the sugarcane growth. A supporting result was reported by Panwar et al. (1999) that increasing phosphorus application rate resulted in increasing of phosphorus uptake by cowpea and mungbean.

Table 4.10 Effect of fertilizer application rates on total phosphorus in soil

Fertilizer application rates (kg/rai)	2 months		6 months	
	TP (mg/kg)	% P uptake**	TP (mg/kg)	% P uptake
0	309.3513±17.1674*	13.10	258.3242^{a}±14.9963	27.44
50	316.9715±19.1022	13.57	269.5287^{ab}±15.3902	29.51
100	324.3619±18.9632	14.11	282.0741^{ab}±18.6633	31.22
200	340.5000±16.7618	14.81	306.8402^{b}±19.6213	34.72

*Mean ± Standard deviation (n = 3)

** See Appendix C

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.2.6 Effect of fertilizer application rates on available phosphorus in soil

The concentration of available phosphorus in pot experiment soil was determined after sugarcane samples were harvested at the end of the second and the sixth months. As presented in Table 4.11, the statistical analysis by ANOVA showed that concentration of available phosphorus in soil increased significantly ($P<0.05$) at all rates of fertilizer application for both the second and the sixth months after the cultivation. This may be the result from phosphorus in fertilizers being initially quite soluble and available for plant uptake. Havlin et al. (1999) stated that water-soluble phosphorus applied to soil readily dissolves and increases the concentration of soil solution phosphorus. However, the results showed the decreasing of available phosphorus in the pot experiment soil at the end of the sixth months such that it was lower than at the second months. This held even with repeat application of fertilizer was conducted in the fifth months. From this result, it can be concluded that repeat application of fertilizer is necessary for plant uptake and use for their growth especially in the first six months after sugarcane was cultivated. Busman et al. (1998) stated that a growing crop would quickly deplete the phosphorus in the soluble phosphorus if it was not being continuously replenished. Crops generally need more phosphorus than is normally dissolved in the soil solution for optimal growth; therefore this phosphorus pool must be replenished many times during the growing season. Although the available phosphorus was lower at the end of the sixth months, the result obtained from this study showed that the concentration of available phosphorus was not lower than the value in which appropriate for plant growth. Mallarino and Sawyer (2000) stated that available phosphorus in soil in the range of 11-14 mg P/kg is optimum for plant growth.

Table 4.11 Effect of fertilizer application rates on available phosphorus in soil

Fertilizer application rate (kg/rai)	Available phosphorus (mg P/kg)	
	2 months	6months
0	$12.3207^{a}\pm0.3840^{*}$	$8.9101^{a}\pm0.8952$
50	$14.9035^{b}\pm0.8950$	$13.5253^{b}\pm0.5752$
100	$19.9059^{c}\pm0.7105$	$17.3795^{c}\pm1.1193$
200	$26.5502^{d}\pm0.9879$	$24.9571^{d}\pm0.5154$

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.2.7 Effect of fertilizer application rates on total cadmium and zinc in soil

The results shown in Table 4.12 represent the effect of fertilizer application rates on the concentration of total cadmium and zinc in pot experiment soil after sugarcanes were harvested in the second and the sixth months. The results from statistical analysis by ANOVA (Analysis of variance) showed that there was no significant difference at $p < 0.05$ for cadmium and zinc in all rates of fertilizer application (Appendix D). Moreover, the results demonstrated that concentration of total cadmium in both the second and the sixth months seemed to be increased with increasing fertilizer application rates. However, it showed that the concentration of total cadmium in soil did not exceeded the initial soil cadmium concentration (2.57 mg Cd/kg). In contrast, total zinc soil tended to decrease with increasing of fertilizer application rate. This may be due to the fact that zinc in which is an essential elements was preferentially taken up by plant than toxic element cadmium. Both total cadmium and zinc in soil tended to decrease with increasing time as compared to background cadmium and zinc contained in soil (2.57 mg Cd/kg and 28.00 mg Zn/kg). Although the fertilizer application rate reached 200 kg fertilizer/rai, the present study was clearly demonstrated that there was no effect on the accumulation of cadmium and zinc in soil resulting from fertilizer application. Thus, it can be assumed that the amounts of cadmium and zinc uptake by sugarcane were much greater than the amount added by the fertilizer.

Table 4.12 Effect of fertilizer application rates on total cadmium and zinc in soil

Heavy metal	Fertilizer application rate (kg/rai)	Total Cd and Zn (mg/kg)	
		2 months	6 months
Cadmium	0	2.5628±0.1967*	2.5456±0.1700
	50	2.5630±0.1812	2.5467±0.1019
	100	2.5631±0.1056	2.5474±0.1534
	200	2.5638±0.1106	2.5505±0.1296
Zinc	0	27.9785±0.8885	27.8531±1.3003
	50	27.9831±0.6246	27.8484±1.4573
	100	27.9942±0.7461	27.8406±1.0227
	200	27.9993±0.6088	27.8386±0.8762

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

4.2.8 Effect of fertilizer application rates on available cadmium and zinc in soil

After sample collection at the end of the second and the sixth months after cultivation, soil samples were examined for the available cadmium and zinc by using the DTPA extraction method. Table 4.13 demonstrates the effect of fertilizer application rates on available cadmium and zinc in soil. The results showed that increasing of fertilizer application rate can resulte in significantly decreased ($P < 0.05$) available cadmium and zinc in soil. The lowest available cadmium was equal to 0.0793 and 0.1492 mg/kg and available zinc equal to 0.9696 and 1.0600 mg/kg in the second and the sixth months after sugarcane cultivation, respectively. This evidence occurred when 200 kg fertilizer/rai was applied to soil. This study clearly demonstrated that available zinc in soil was lowered due to increasing fertilizer application rate. However, the lowest concentration of available zinc was not below the considered critical value of 0.50 mg/kg by DTPA extraction for zinc deficiency (Whitney, 2000). Therefore, this can be assured that applying the 16-16-8 NPK fertilizer at the rate of 200 kg/rai would not induced zinc deficiency for plant uptake.

Table 4.13 Effect of fertilizer application rates on available cadmium and zinc in soil

Heavy metal	Fertilizer application rate (kg/rai)	Available Cd and Zn (mg/kg)	
		2 months	6 months
Cadmium	0	0.1647[a]±0.0083[*]	0.2625[a]±0.0140
	50	0.1193[b]±0.0076	0.2113[b]±0.0173
	100	0.1033[b]±0.0142	0.1853[b]±0.0171
	200	0.0793[c]±0.0133	0.1492[c]±0.0189
Zinc	0	1.5520[a]±0.1045	1.6358[a]±0.0896
	50	1.1080[b]±0.0610	1.1950[b]±0.1016
	100	0.9795[bc]±0.0241	1.1243[b]±0.0873
	200	0.9696[c]±0.0581	1.0600[b]±0.0380

[*]Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

Correlation curves were plotted between fertilizer application rates and concentration of available cadmium and zinc in soil as illustrated in Figures 4.9 and 4.10. The results showed negative correlation with $r^2 = 0.9327$ and $r^2 = 0.6700$ for cadmium and zinc at the end of the sixth months, respectively. The decreasing of available cadmium and zinc in soil may be the result from increased soil pH as affected by the increasing fertilizer application rate. From a review of literature, fertilizer can alter soil properties such as pH or directly react with heavy metal ions in soil. All these effects could result in changes in the forms of metals and induced ions absorb in soil. In general, the solubility and phytoavailability of metals are inversely related to soil pH. Levi-Minzi and Petruzzelli (1984) stated that when diammonium phosphate (DAP) was applied to soil, it can increase the pH value from 6.4 (original soil) to 7.7 which affect decreased solubility of cadmium in soil. This is consistent with Adriano (2001) who reported that at soil pH above 7.0, the bioavailability of zinc is substantially reduced. Chang et al. (1982) also found that uptake by barley of sludge-borne zinc was much lower from a soil whose pH was 7.8 than from the other two soils (pH 7.1 and 6.0). Moreover, a similar trend was reported by Lagerwerff

(1971) that increasing pH decreased the uptake of radish plants grown on cadmium-contaminated soils due to a decrease in mobility of cadmium in the soil.

In addition, increasing of available phosphorus through the fertilizer application also influences the availability of cadmium and zinc in the soil. Many investigators have reported that soluble phosphate fertilizer could provide an abundance of available phosphorus and increase the efficiency of metal-phosphate mineral formation (Ma et al., 1993; Berti and Cunningham, 1997; Hettiarachchi et al., 1997; Cooper et al., 1998). A similar result was reported by Street et al. (1978) in that the reduction in the availability of cadmium could be related to high phosphorus availability, which depresses cadmium uptake by plants. Moreover, available phosphorus induced the formation of heavy metal phosphate precipitates (Cotter-Howells and Capron, 1996). Therefore, metal-phosphate minerals were shown to control metal solubility in soil suspension when soluble phosphorus was added (Santillian-Medrano and Jurinak, 1975). The corroborated results were reported by a number of studies that the addition of soluble phosphate compounds decreased the bioavailability and mobility of cadmium, which has been attributed to the decrease in the solubility of cadmium in soils (Hettiarachchi et al., 2000; Pearson, 2000; McGowen, et al., 2001).

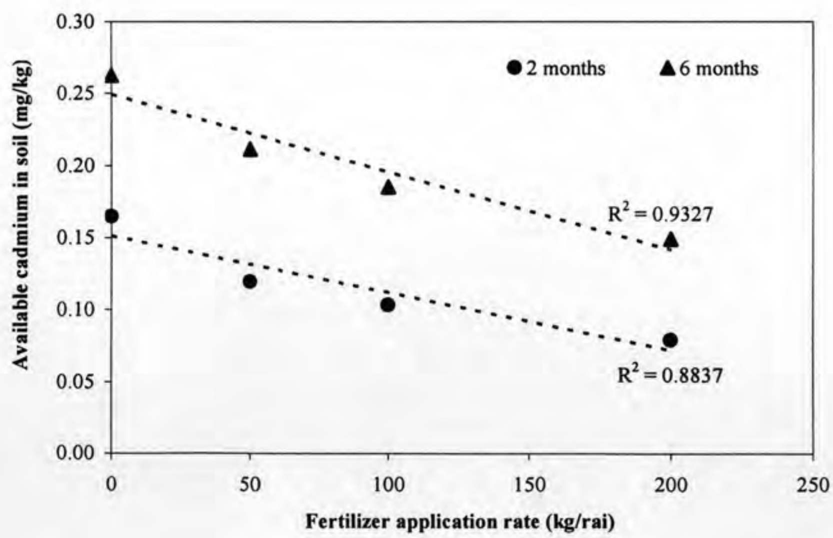

Figure 4.9 Effect of fertilizer application rates on available cadmium in soil

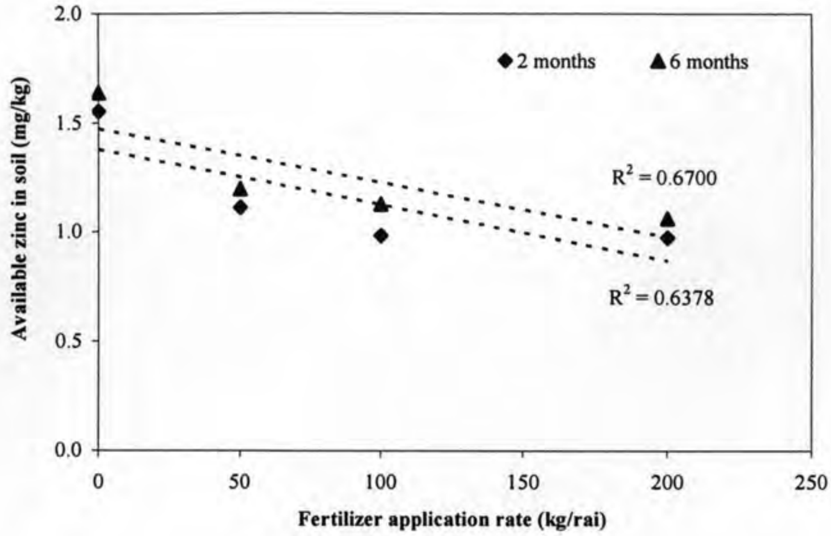

Figure 4.10 Effect of fertilizer application rates on available zinc in soil

4.2.9 Effect of fertilizer application rates on cadmium and zinc in sugarcane

The study of total cadmium and total zinc in sugarcane was separated into two parts: 1) cadmium and zinc accumulation in whole sugarcane and 2) concentration of cadmium and zinc in different parts of sugarcane reported in mg/ kg to compare the amount of cadmium and zinc accumulated in each part of sugarcane.

1) Cadmium and zinc in whole sugarcane

Sugarcane samples (underground stems, roots, bagasses and leaves) were analyzed by microwave digestion technique in order to determined total cadmium and zinc contents in sugarcane tissue. Total cadmium and zinc in the sugarcane juice was analyzed by tri-acid digestion (HNO_3: H_2SO_4: $HClO_4$). Table 4.14 presents the effect of fertilizer application rates on the concentration of cadmium and zinc in sugarcane. The statistical analysis by ANOVA showed that cadmium and zinc in sugarcane tended to significantly decrease ($P < 0.05$) with increasing fertilizer application rates. The results also indicated that the lowest concentration of both cadmium and zinc in sugarcane occurred when fertilizer was applied to soil at the rate of 200 kg/rai. Zinc is one of the macronutrients necessary for plants growth. Although applying fertilizer at the rate of 200 kg/rai can induce the lowest concentration of zinc in sugarcane tissue, the result in this study clearly demonstrated that it did not induced zinc deficiency in sugarcane. Kabata-Pendias and Pendias (2001) stated that the deficiency content of zinc in plants has been established at 10 to 20 ppm dry weight. This value, however, may vary considerably because zinc deficiency reflects both the requirements of each genotype and effects of the interactions of zinc with other elements within the plant tissues.

Table 4.14 Effect of fertilizer application rates on cadmium and zinc in sugarcane

Heavy metal	Fertilizer application rate (kg/rai)	Concentration of Cd and Zn (mg/kg)	
		2 months	6 months
Cadmium	0	$7.8727^{a}\pm0.3144^{*}$	$4.2797^{a}\pm0.1640$
	50	$6.6500^{b}\pm0.3527$	$2.7921^{b}\pm0.1416$
	100	$6.2437^{b}\pm0.1627$	$2.6060^{b}\pm0.0598$
	200	$4.9551^{c}\pm0.4166$	$2.0007^{c}\pm0.0341$
Zinc	0	$14.2736^{a}\pm0.7320$	$24.6097^{a}\pm0.3648$
	50	$12.7279^{ab}\pm0.8879$	$21.0995^{b}\pm1.4009$
	100	$12.4060^{ab}\pm1.0953$	$20.8023^{b}\pm0.4379$
	200	$11.9069^{b}\pm0.4310$	$20.2599^{b}\pm1.2043$

*Mean ± Standard deviation (n = 3)

Note: Numbers followed by the same letter within each column are not significantly different at $p < 0.05$ by Duncan's multiple range tests (Appendix D).

1.1) Cadmium

The correlation curve as presented below shows the negative correlation between fertilizer application rate and concentration of cadmium in sugarcane (Figure 4.11) and also for cadmium accumulated in sugarcane, in terms of mass, presented in Figure 4.12. Kashem and Singh (2002) stated that the uptake of trace metals by plants is closely related to the concentration of those elements in the soil solution. Therefore, decreasing available cadmium as affected by fertilizer application rates also caused decreases in cadmium uptake by sugarcane. Moreover, the dilution effect from the influence of phosphorus in increasing sugarcane dry matter yield during the peak rate of sugarcane growth (2-6 months) (Miller and Gilbert, 2006) was also considered. The conformable result was concluded by Williams and David (1977) in that addition of phosphorus to the soils led to the decrease in cadmium content of plant because of the increase in plant yield. Moreover, they also stated that the concentration of available soil phosphorus may affect the cadmium content of plants mainly through the effect of phosphorus supply on plant growth and vigor. A consistent result was reported by Prochnow et al. (2001) that application of high rates of bioavailable phosphorus tended to reduced plant cadmium concentration mainly due to the dilution effect. This means that the increasing rate of 16-16-8 NPK fertilizer applications to the soil can induced lower cadmium concentration in the sugarcane.

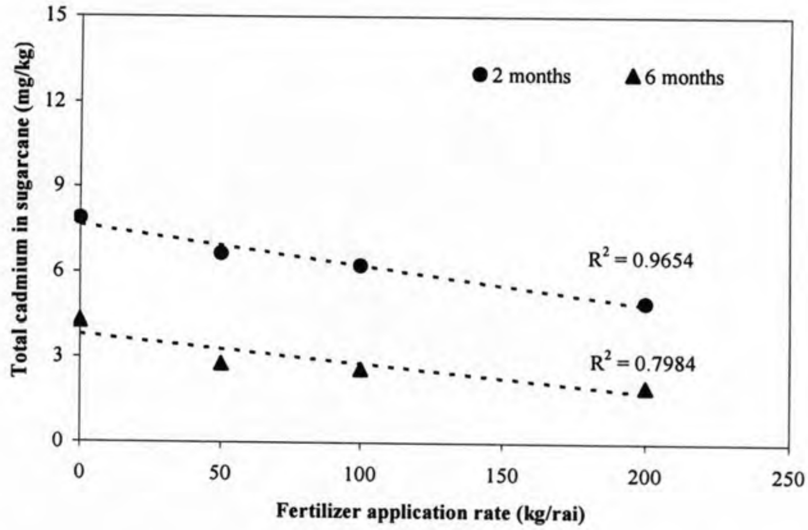

Figure 4.11 Effect of fertilizer application rates on concentration of total cadmium in sugarcane

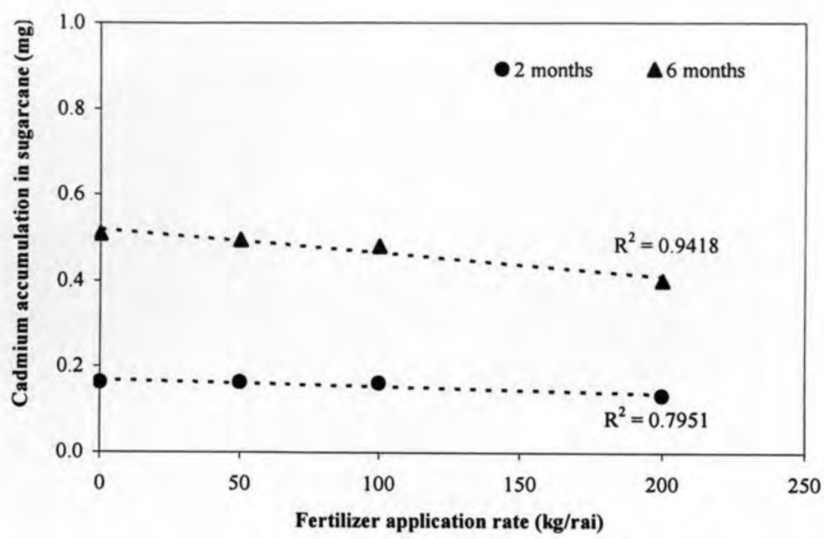

Figure 4.12 Effect of fertilizer application rates on cadmium accumulated in sugarcane

1.2) Zinc

As presented in Figure 4.13, the result showed a negative correlation between fertilizer application rate and the concentration of zinc in sugarcane. This can be indicating that increasing fertilizer application rate also induced the decrease of zinc concentration in sugarcane. Many researchers stated that high levels of phosphate fertilization are known to reduce zinc concentration in plant tissues (Lindsay, 1972; Racz and Haluschak, 1974; Morghan, 1984; Loneragan and Webb, 1993). In contrast, the results shown in Figure 4.14 present the positive correlation between fertilizer application rate and zinc accumulation in sugarcane in term of mass. Due to zinc being an important micronutrient. It is a preferred uptake metal for plants. Besides phosphorus increasing sugarcane dry matter yield during the peak rate of sugarcane growth (2-6 months), it also induced increasing zinc uptake by sugarcane for utilization in the normal lifecycle.

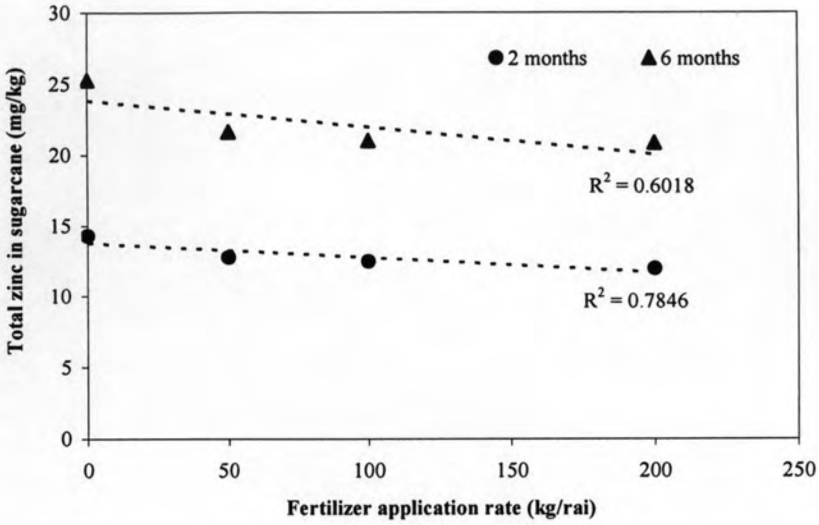

Figure 4.13 Effect of fertilizer application rates on concentration of total zinc in sugarcane

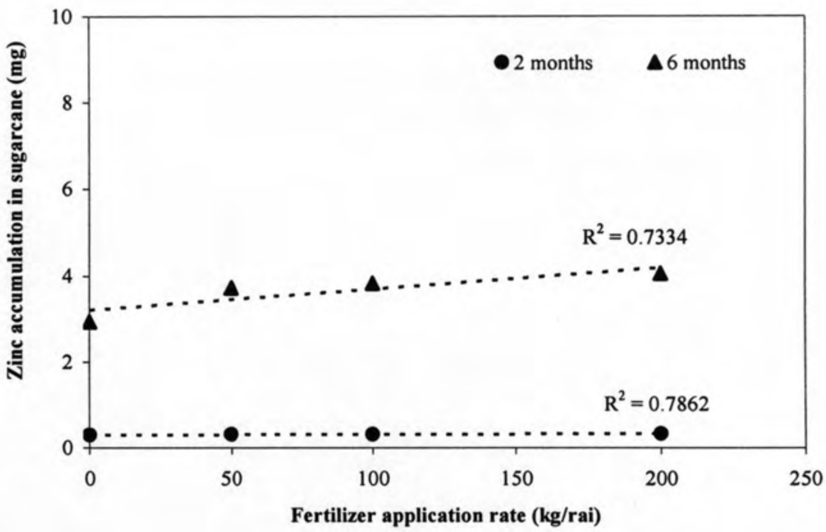

Figure 4.14 Effect of fertilizer application rates on zinc accumulated in sugarcane

2) Concentration of cadmium and zinc in different parts of sugarcane

2.1) Cadmium

The concentration of cadmium in different parts of sugarcane is illustrated in Figure 4.15. The results show that the most accumulation take place in the roots followed by underground stems, bagasses and leaves, respectively. However, sample collection at the end of the second months did not include sugarcane juice analysis because of low production due to immaturity of sugarcane. At the end of the sixth months after the cultivation, the results showed the same trend as the second months. The concentration of cadmium in different parts of sugarcane appear to be highest in roots followed by underground stems > bagasses > leaves > sugarcane juice (Figure 4.16). The results also found that the highest concentration in which occurring in root was equal to 5.7416, 4.0411, 3.5889 and 2.4627 mg Cd/kg for applying 16-16-8 NPK fertilizer at the rate of 0 (control group), 50, 100 and 200 kg/rai, respectively (Appendix E). A supporting result was reported by Segura-Muñoz et al. (2006) that the metal concentrations (Cd, Cr, Cu, Hg, Mn, Pb and Zn) detected in sugarcane (*Saccharum* spp.) leaves were significantly lower than those in roots. Confirmation on the similar trend, Azimi et al. (2006) reported that cadmium accumulated mostly in root and a smaller amount is mobilized through upper parts of beans. MacLean (1976) showed that cadmium was present in higher concentrations in root than other organs of oats, soya bean, timothy grass etc. Moreover, the influence of phosphorus on the translocation of cadmium in plant was reported by Williams and David (1976). They stated that high available phosphorus interfered with cadmium translocation from roots to aboveground plant parts.

For the concentration of cadmium in sugarcane juice, the results showed that the concentration of cadmium in sugarcane juice was significantly ($p < 0.05$) decreased by ANOVA (see Appendix D) when increasing rates of fertilizer were applied to soils. However, there was no significant difference between applying the fertilizer at the rate of 100 and 200 kg fertilizer/rai. The concentrations of cadmium in juice were equal to 0.0161, 0.0111, 0.0071 and 0.0060 mg/kg for the rate of 0, 50, 100 and 200 kg/rai, respectively.

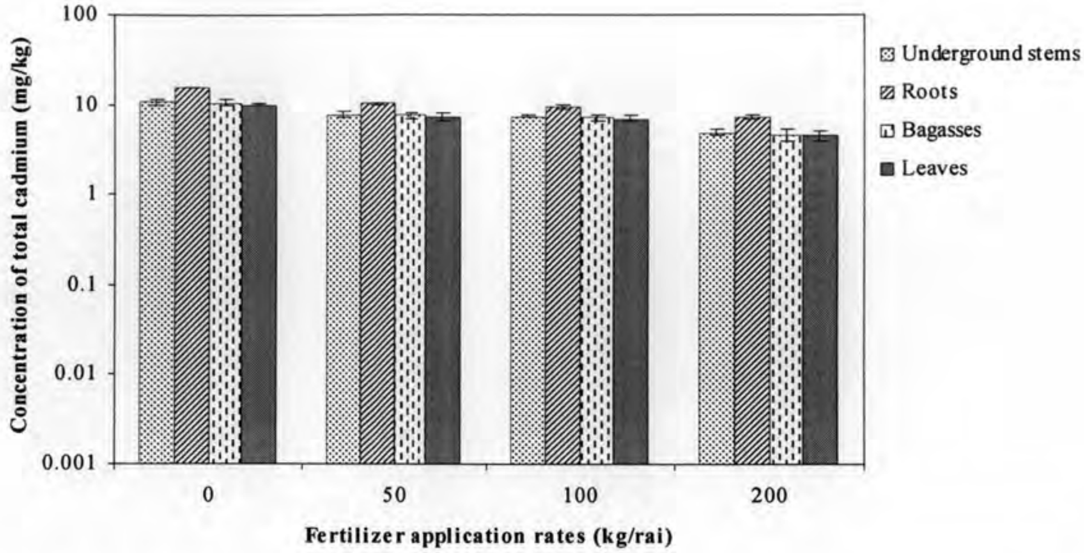

Figure 4.15 Concentration of total cadmium in different parts of sugarcane in the second months after cultivation in pot experiment

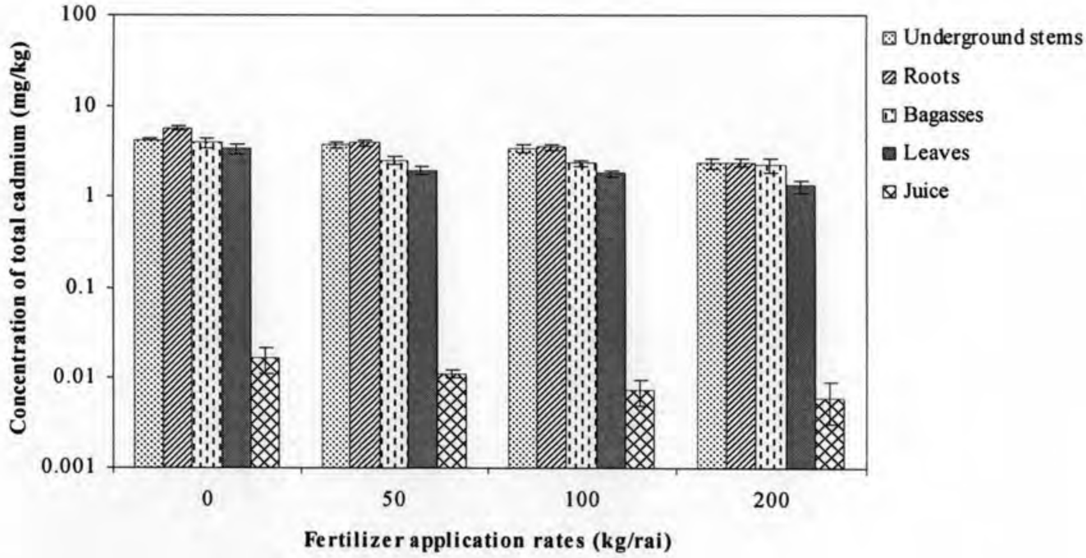

Figure 4.16 Concentration of total cadmium in different parts of sugarcane in the sixth months after cultivation in pot experiment

2.2) Zinc

As illustrated in Figure 4.17, the results showed that the accumulation of zinc in different sugarcane parts of sugarcane at the end of the second months after the cultivation appears to be highest in roots followed by bagasses, underground stems and leaves, respectively. At the end of the sixth months, zinc accumulation was mostly accumulated in roots followed by bagasses> leaves > underground stems> juice (Figure 4.18). Zinc appeared to be better translocated to upper parts of plant. This may be the reason from the fact that zinc is micronutrient that essential for plant growth therefore it may be needed to translocate and distribute to all part of plant more readily. The results also indicated the lowest concentration occurred when applying fertilizer at the rate of 200 kg/rai for both the second months and the sixth months. For the sixth months, concentration of zinc in different parts was equal to 30.5857, 26.1195, 9.9376, 8.5126 and 1.3486mg Zn/kg for roots, bagasses, leaves, underground stems and juice, respectively (see Appendix E).

For zinc in sugarcane juice, the statistical analysis also indicated that increasing the fertilizer application rates were tended to decrease zinc in the sugarcane juice although there was no significant difference at $P < 0.05$ by ANOVA (see Appendix D). Concentrations of zinc in juice were equal to 1.7419, 1.4086, 1.3780 and 1.3486 mg/kg for fertilizer applied at the rate of 0, 50, 100 and 200 kg/rai, respectively. However, high accumulation of zinc in sugarcane juice was not to be of concerned because zinc is appeared to be the microelement in which necessary for plant growth. From the results of cadmium and zinc in different parts of sugarcane, it can be concluded that increasing rate of fertilizer application can reduce the concentration of cadmium and zinc in all parts of sugarcane.

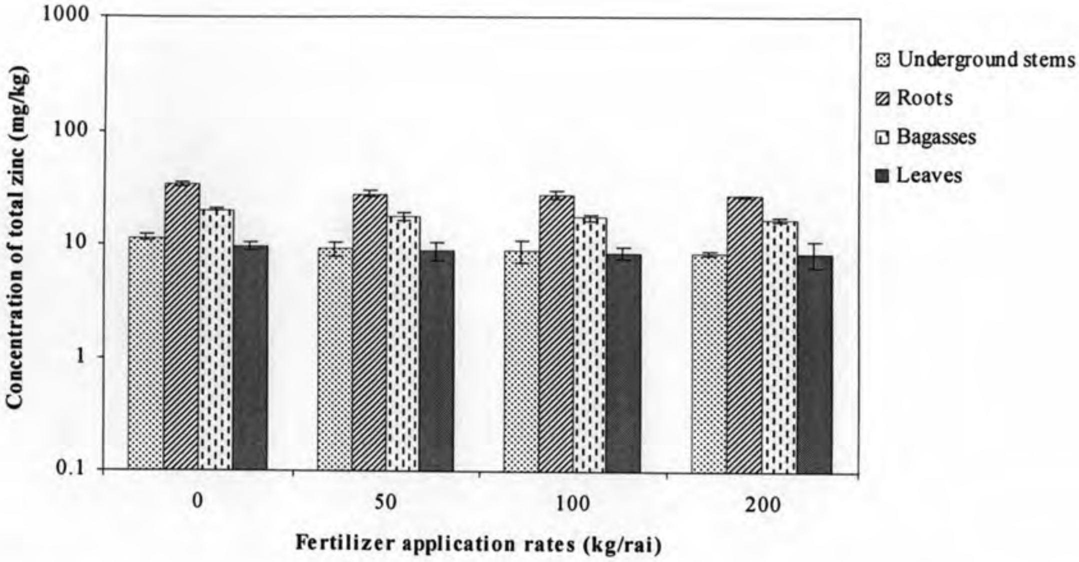

Figure 4.17 Concentration of total zinc in different parts of sugarcane in the second months after cultivation in pot experiment

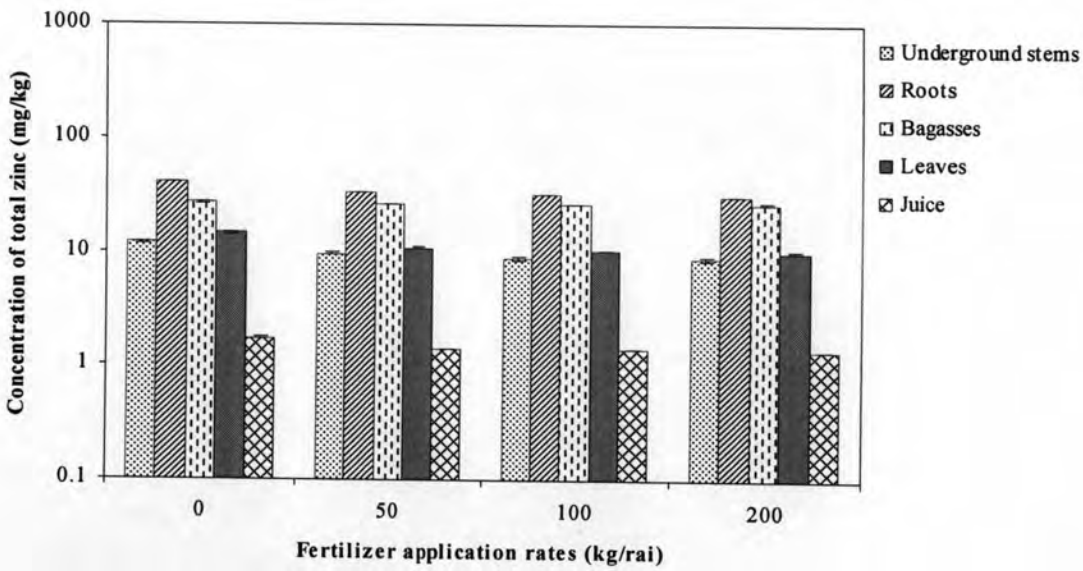

Figure 4.18 Concentration of total zinc in different parts of sugarcane in the sixth months after cultivation in pot experiment

4.3 Application of using NPK fertilizer for contaminated area in Mae Sot district, Tak province

Presently, farmers in Mae Sot district, Tak province generally apply phosphorus nutrient to the soil to enhance their sugarcane yield. A granular commercial fertilizer 16-16-8 NPK formulation is used at the single rate of 50 kg fertilizer/ rai. Improper use of fertilizer can cause the negative effect such as the accumulation of heavy metals in the agricultural soils.

To determine the effect of applying different rates of fertilizer, the pot experiment was conducted. The results from the pot experiment showed that concentration of total phosphorus and available phosphorus in soil tend to be decreased in all rate of fertilizer application (50, 100 and 200 kg/rai) at the end of the sixth month although repeat application of the fertilizer was conducted at the same rate in the fifth month after sugarcane was cultivated. This may be due to the increase of phosphorus utilization in the peak rate of sugarcane growth (2-6 months). Phosphorus is known as the one of the micronutrients necessary for plants growth. Adequate Phosphorus availability for plants generally stimulates root and shoot growth, promotes vigorous seedling growth and advances maturity. Dry matter yield of sugarcane also increases with increasing of fertilizer application rates. However, there was no significant difference at $P < 0.05$ between applying 16-16-8 NPK fertilizer at the rate of 50 and 100 kg/ rai. In this present study, the highest dry matter yield was obtained when the rate of 200 kg/ rai was applied. This corroborates the results in the decreasing of total phosphorus and available phosphorus in soil. For the accumulation of cadmium and zinc in soil as affected by increasing of fertilizer application rate, the results showed that there was no accumulation of cadmium and zinc in soil although the rate of applying fertilizer reached to 200 kg/ rai. Moreover, the results also indicated that increasing fertilizer application rates also affected in the decrease of available cadmium and zinc in soil and hence decreased cadmium and zinc concentration in whole sugarcane. In this study, the lowest available cadmium and zinc in soil and the concentration of both metals in sugarcane occurred when the rate of 200 kg fertilizer/ rai was applied.

The results from this present study can be used as a guideline for the fertilizer management in cadmium contaminated sugarcane cultivated field in Mae Sot district, Tak province. For the areas which contained cadmium concentration in soil in the range of > 20 mg Cd/ kg (Mae Tao2), applying of 16-16-8 NPK fertilizer at the rate of 200 kg/ rai is recommended because of its possible in induced lower available cadmium and zinc in soil and hence lower accumulation of both metals in sugarcane. However, there are many factors that should be considered. For example the cost of fertilizer, sugarcane dry matter yield obtained with increasing fertilizer application rate and price of sugarcane yield (Baht/ ton) must all be considered in determining the final selection.