CHAPTER IV

RESULTS AND DISCUSSIONS

The study consists of 8 farming procedure as the details mentioned in Table 3.1, Chapter 3. There were four procedures carried out for three replication and in each procedures were studied in comparison between with and without drainage (drained and flooded) during plantation period. So, there were twenty four experimental pots all together for this study.

4.1 Effect of flooding and drainage on redox potential and pH of soil solution

Drainage and flooding during plantation period is believed to be a major factor influence redox potential and pH of the soil solution in rhizosphere zone. According to treatment code assigned in Table 3.1, Rice grown in T1, T3, T5, and T7 pots were used the drainage technique while T2, T4, T6 and T8 were used flooding technique. The redox potential of soil solution was measured daily for 15 days for the first period of grain fill stage (75 to 90 days after transplanting). The measurement started from 3 days prior to the beginning of water drainage from pots. From the experiment showed that at the third day of redox measurement and water began to be drained, there were about 2 days, water level reduced until there was no flood on soil surface. Water was then added to the pots and the redox were continuous measured daily until the value was likely to be constant The redox potential were measured for all treatments at the same period from July 11, 2005 to July 23, 2005 as the result shown in Figure 4.1 and 4.2. This first period of measurement and sample collection is planned to be at grain-fill stage. However, since there was a technical problem from the location of greenhouse that affected from the shadow of a building, rice grain was not produced from our experimental pot. Therefore the period of sample collected was estimated from the time from grain fill stage that happens in real paddy field.

The drained techniques, which are T1, T3, T5, and T7, resulted in very high cadmium accumulation in rice plants. The rice plants cadmium concentration and the comparison of cadmium accumulation in rice plants between drainage and flooding technique is showed in Figure 4.3 and 4.4 respectively. From Figure 4.3 and 4.4, the drainage techniques result in higher cadmium accumulation in rice plant when compared with flooding techniques (T1 compared with T2, T3 compared with T4, T5 compared with T6, and T7 compared with T8). The results from nitric: perchloric digestion showed that the maximum plants cadmium concentrations from drainage technique were 2.0909 mg/kg and 3.4970 mg/kg for the first and the second period for stem and 0.4163 mg/kg and 4.8509 mg/kg for the first and the second period for leave, which were 3 to 20 times higher than that in flooding treatment. These results are showed that the hypothesis is true that the drained techniques will result in higher cadmium concentration than flooded technique.

The water drainage at the first sampling period caused the oxidizing condition in soil system, resulted in rapid increasing of redox potential of drainage treatments when compared with flooding treatments, which in reducing condition. Maeght et al., 2005 found that oxidizing condition caused the increasing of electron transfer, resulted in in creasing redox potential as showed in equation (1) and (2) as followed;

$$FeOOH + 3H^{+} + e^{-} \underset{Oxidation}{\overset{Reduction}{\rightleftharpoons}} Fe^{2+} + 2H_2O$$

$$MnO_2(s) + 4H^{+} + 2e^{-} \underset{Oxidation}{\overset{Reduction}{\rightleftharpoons}} Mn^{2+} + 2H_2O$$

For flooded condition soil becomes reducing condition the reactions go forward, results in proton consumption which causes a decrease of redox potential. On the other hand, for drained condition soil becomes oxidizing condition, the reactions go backward, results in electron generation, which causes an increase of redox potential. The redox potential comparison between drainage treatments and flooding treatments are showed in Figure 4.5. The higher redox potential cause the transformation of cadmium in soils to be in rice plants uptake able form (Simmons et al., 2003). Cadmium in the study soils mostly came from zinc mine activities, so the most common form of cadmium in the study soil is cadmium sulphide and cadmium carbonate (Alloway, 1990). Cadmium sulphide (CdS) is very stable and immobilize.

However, during the redox potential increased in the experiment, cadmium sulphide was transformed to be cadmium ion (Cd^{2+}) and sulfate (SO_4^{2-}) (Simmons et al., 2003). Cadmium ion is a bioavailable form that is the easiest to be uptake by the rice plants. This is the reason to explain that why the drained technique result in higher cadmium accumulation in rice plants. Actually, drainage the rice pots not only effected to soil redox potential but also pH in soil solution (Alloway, 1990). The change of pH effects to soluble cadmium concentration in soil solution (Simmons et al., 2003, Kashem et al., 2001a). Lower pH can cause the cadmium in soil become more soluble and increase its phyto-availability, consequently, this results in higher cadmium accumulation in rice plants (Chaney and Hornick, 1978, cited from Simmons et al., 2003). However, pH values in soil solution during the continuous collection for 15 days at the first sampling period (grain fill stage) did not show significantly change as much as found in redox potential value as measured in the same period. One of the reasons behind this phenomenon may be from a buffer condition in soil solution that is generated by carbon dioxide (CO_2) and carbonate (CO_3^-) in the soil as explained by H_2CO_3-HCO_3^- reaction (McBride, 1994, cited from Kashem et al., 2001a). Nonetheless, after water refilling in the drained pots for 4 days (7 days after starting the drainage), the difference in pH value between drainage and flooding technique was observed. The pH value from drainage treatment pots was a little lower than that from flooding treatment pots after water refilling for 6 days. The comparison of soil solution pH between drainage and flooding treatments are showed in Figure 4.5. According to soil redox potential values, soil solution pH, and cadmium concentration accumulated in plants, the experimental results showed that the drainage treatments, which had higher soil redox potential and lower pH than flooding treatments, resulted in higher cadmium accumulation in rice plants. For an example, T3, which was the lowest pH in soil solution and the second high of redox potential, produced the extremely high cadmium accumulation in rice plants when compared to T4. The results discussion above will be followed the theory and the hypothesis that drainage during grain fill stage will cause the higher soil redox potential and lower pH, which cause the extremely higher cadmium uptake to rice plants.

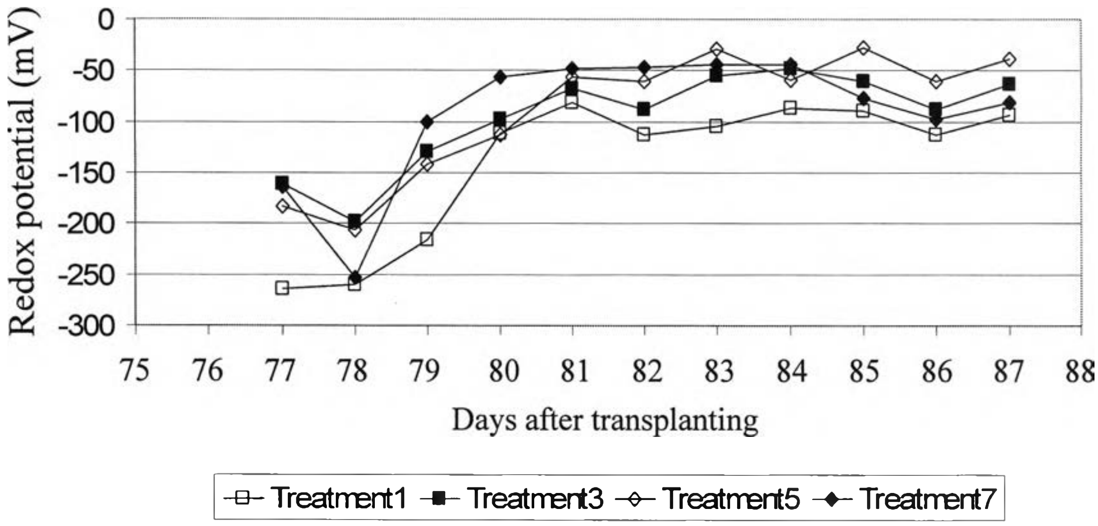


Figure 4.1: **Redox potential of drainage treatments at the first sampling period, continuous collection from July 11, 2005 to July 22, 2005.**

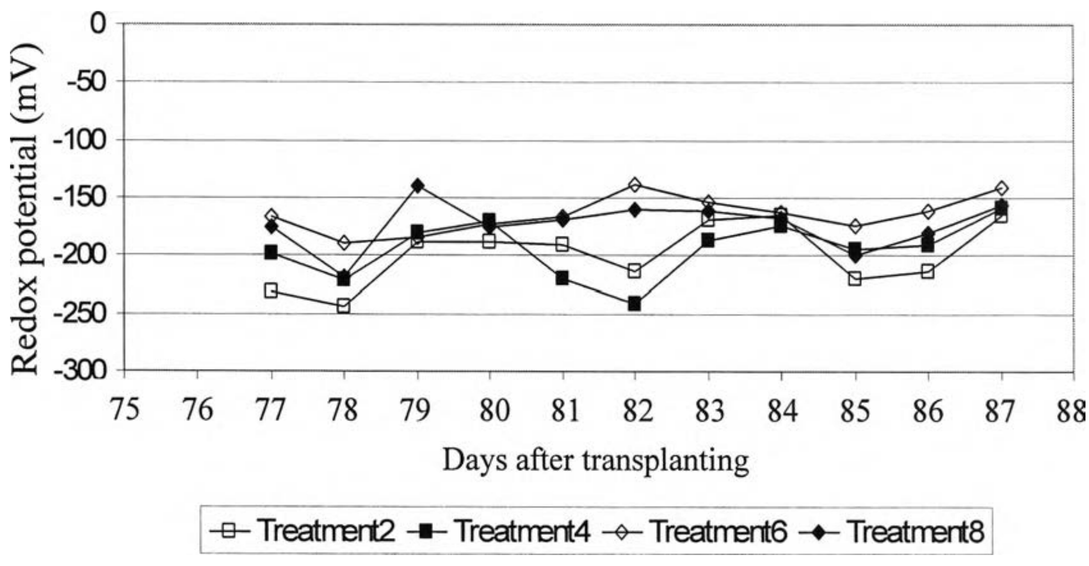


Figure 4.2: **Redox potential of flooding treatments at the first sampling period, continuous collection from July 11, 2005 to July 22, 2005.**

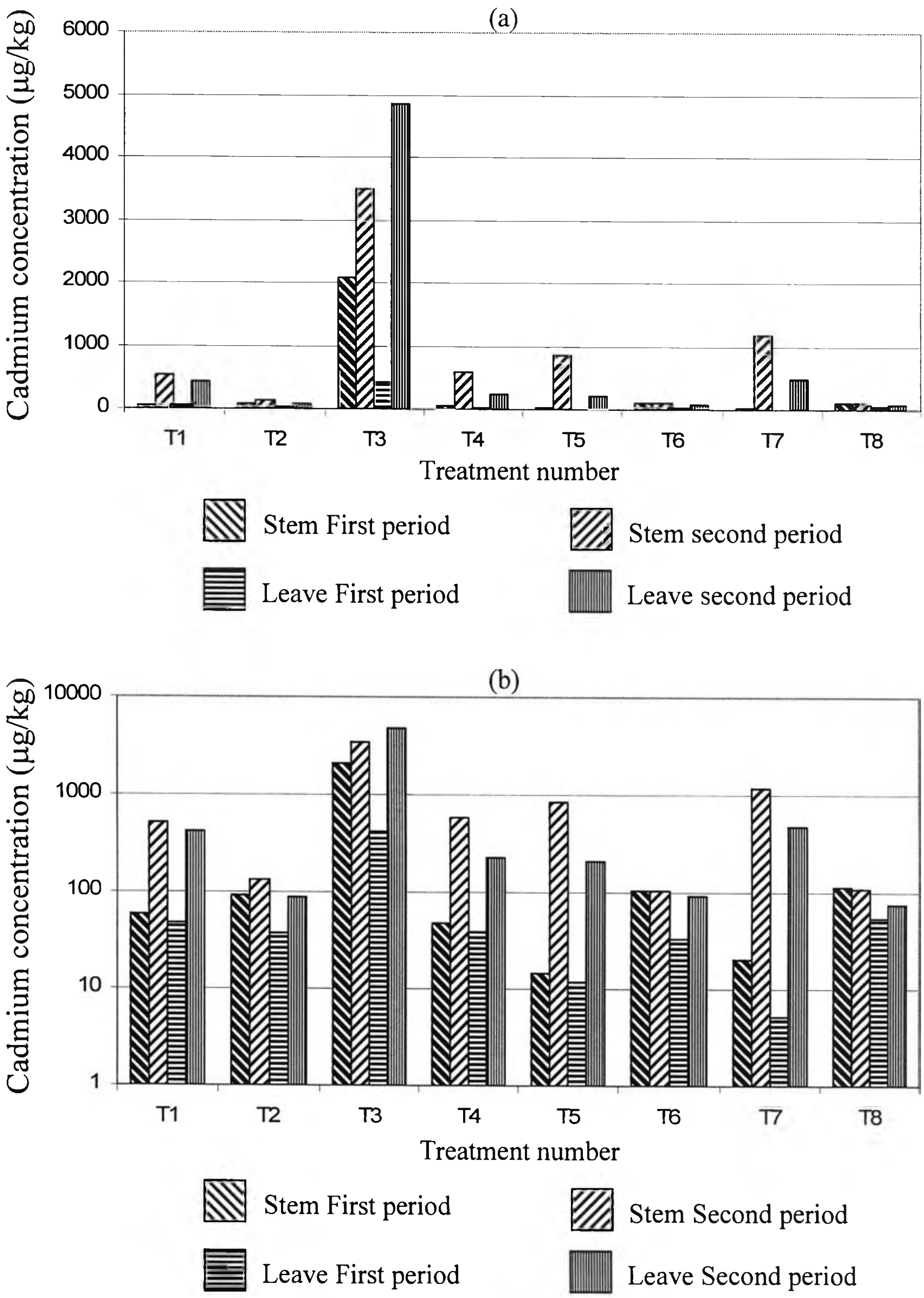
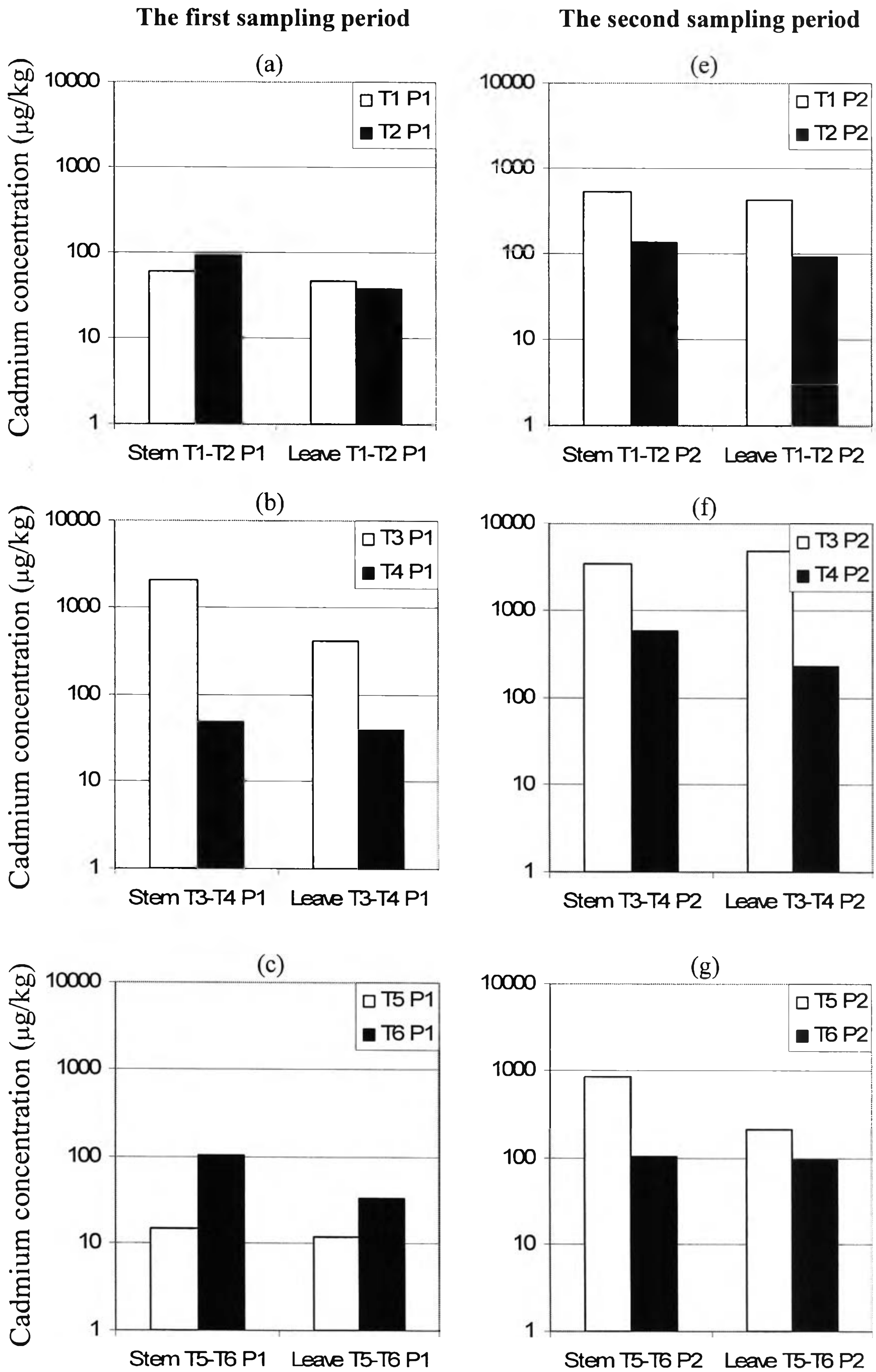
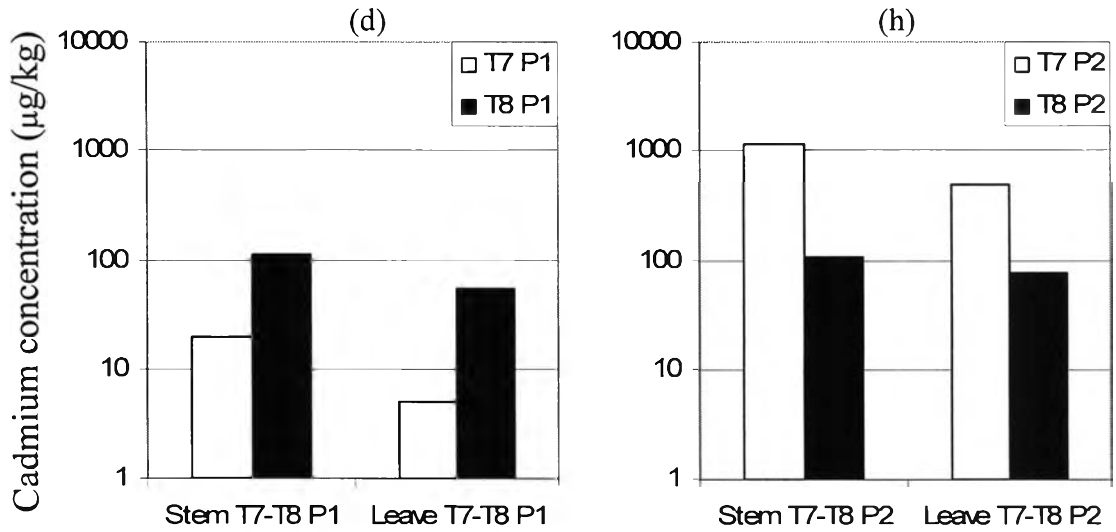


Figure 4.3: **Rice plants cadmium concentration in each treatment and each plant parts at the first sampling period (grain fill stage) and the second sampling period (harvest period), (a) in normal scale, (b) in logarithmic scale.**


The first sampling period
The second sampling period
Cadmium concentration (µg/kg)
(a)
T1 P1
T2 P1
Stem T1-T2 P1
Leave T1-T2 P1
(b)
T3 P1
T4 P1
Stem T3-T4 P1
Leave T3-T4 P1
(c)
T5 P1
T6 P1
Stem T5-T6 P1
Leave T5-T6 P1
(e)
T1 P2
T2 P2
Stem T1-T2 P2
Leave T1-T2 P2
(f)
T3 P2
T4 P2
Stem T3-T4 P2
Leave T3-T4 P2
(g)
T5 P2
T6 P2
Stem T5-T6 P2
Leave T5-T6 P2
1
10
100
1000
10000



<u>Figure 4.4:</u> Rice plants cadmium concentration comparison between drainage technique and flooding technique;

(a) T1 and T 2 at the first sampling period (grain fill stage)

(b) T3 and T4 at the first sampling period (grain fill stage)

(c) T5 and T6 at the first sampling period (grain fill stage)

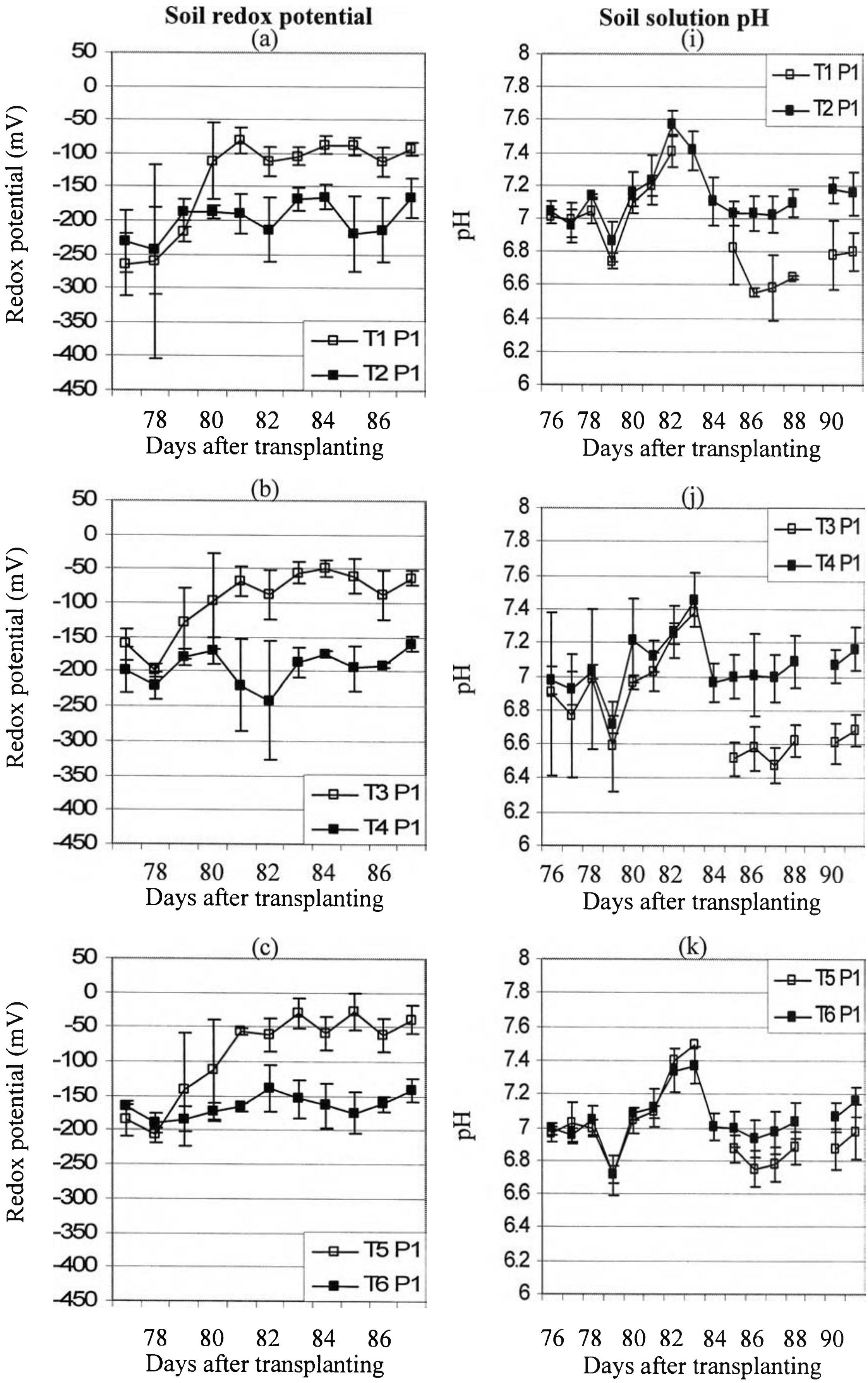
(d) T7 and T8 at the first sampling period (grain fill stage)

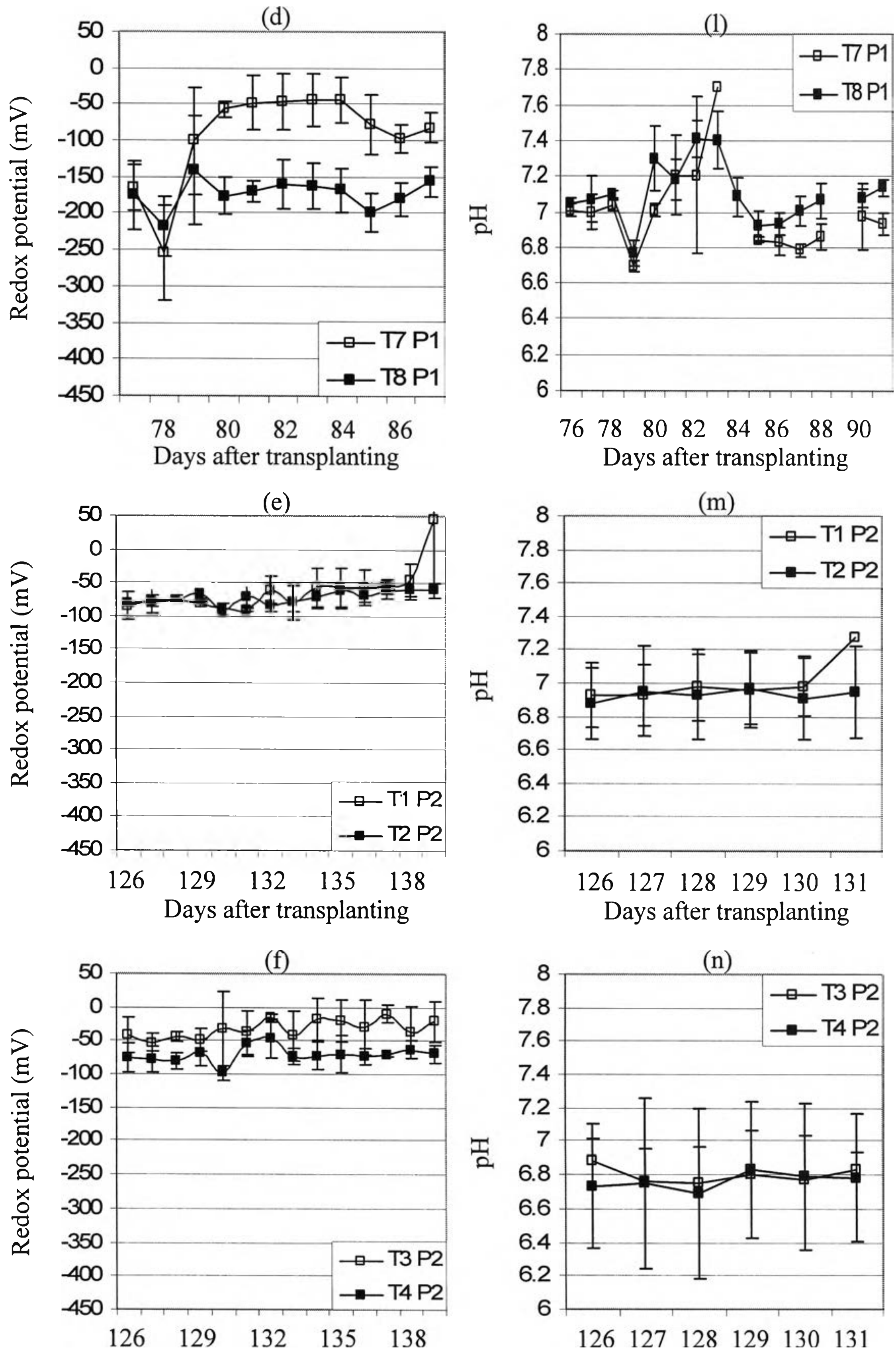
(e) T1 and T2 at the second sampling period (harvest period)

(f) T3 and T4 at the second sampling period (harvest period)

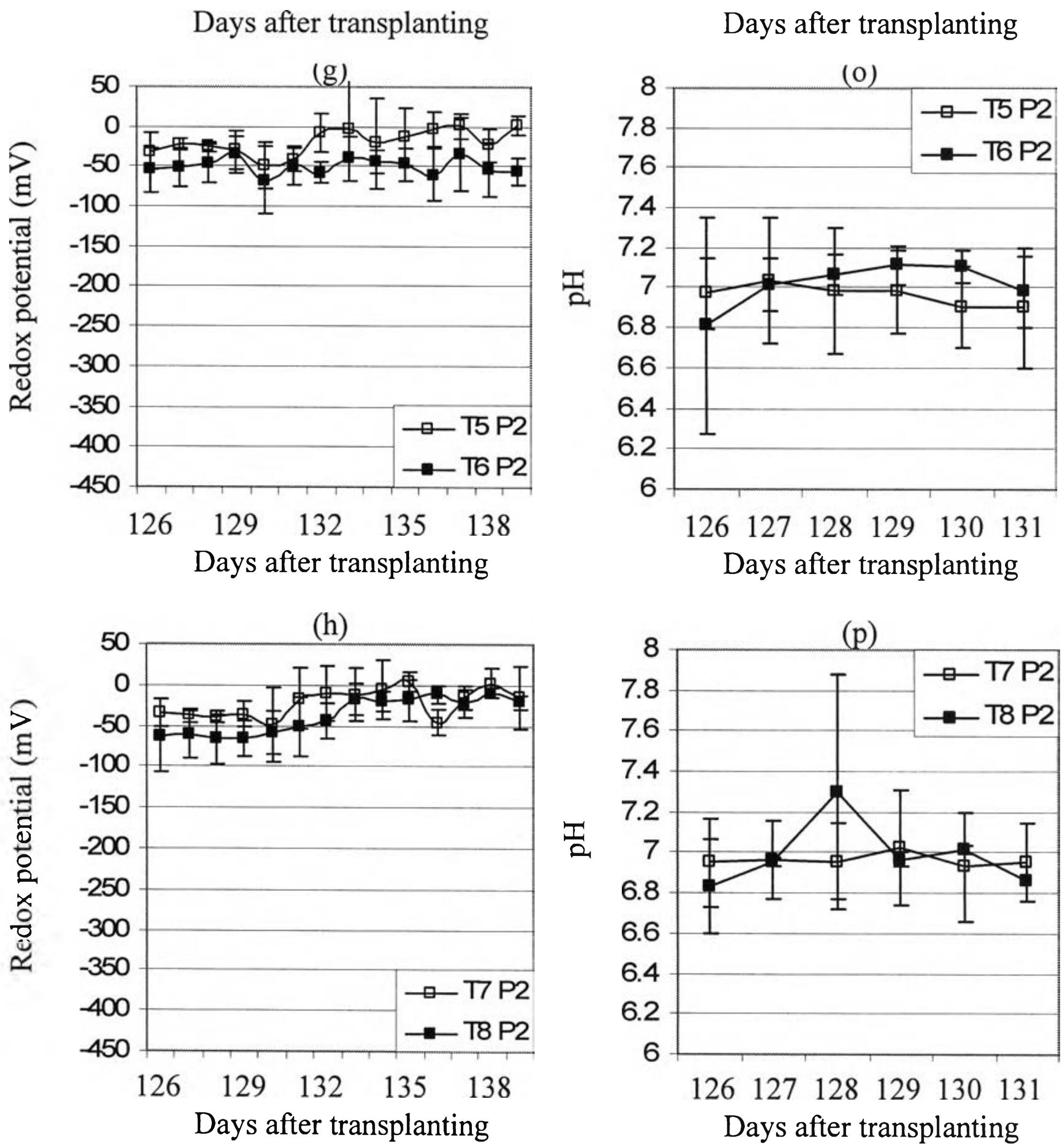
(g) T5 and T6 at the second sampling period (harvest period)

(h) T7 and T8 at the second sampling period (harvest period)


Soil redox potential
Soil solution pH
(a)
Redox potential (mV)
T1 P1
T2 P1
Days after transplanting
(i)
pH
T1 P1
T2 P1
Days after transplanting
(b)
Redox potential (mV)
T3 P1
T4 P1
Days after transplanting
(j)
pH
T3 P1
T4 P1
Days after transplanting
(c)
Redox potential (mV)
T5 P1
T6 P1
Days after transplanting
(k)
pH
T5 P1
T6 P1
Days after transplanting



(d)
Redox potential (mV)
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
T7 P1
T8 P1
78 80 82 84 86
Days after transplanting
(l)
pH
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
6
T7 P1
T8 P1
76 78 80 82 84 86 88 90
Days after transplanting
(e)
Redox potential (mV)
T1 P2
T2 P2
126 129 132 135 138
Days after transplanting
(m)
pH
T1 P2
T2 P2
126 127 128 129 130 131
Days after transplanting
(f)
Redox potential (mV)
T3 P2
T4 P2
126 129 132 135 138
(n)
pH
T3 P2
T4 P2
126 127 128 129 130 131



<u>Figure 4.5:</u> The comparison of redox potential and pH in soil solution between drainage technique and flooding technique;

(a) T1 and T2 at the first sampling period (grain fill stage)

(b) T3 and T4 at the first sampling period (grain fill stage)

(c) T5 and T6 at the first sampling period (grain fill stage)

(d) T7 and T8 at the first sampling period (grain fill stage)

(e) T1 and T2 at the second sampling period (harvest)

(f) T3 and T4 at the second sampling period (harvest)

(g) T5 and T6 at the second sampling period (harvest)

(h) T7 and T8 at the second sampling period (harvest)

(i) T1 and T2 at the first sampling period (grain fill stage)

(j) T3 and T4 at the first sampling period (grain fill stage)

(k) T5 and T6 at the first sampling period (grain fill stage)

(l) T7 and T8 at the first sampling period (grain fill stage)

(m) T1 and T2 at the second sampling period (harvest)

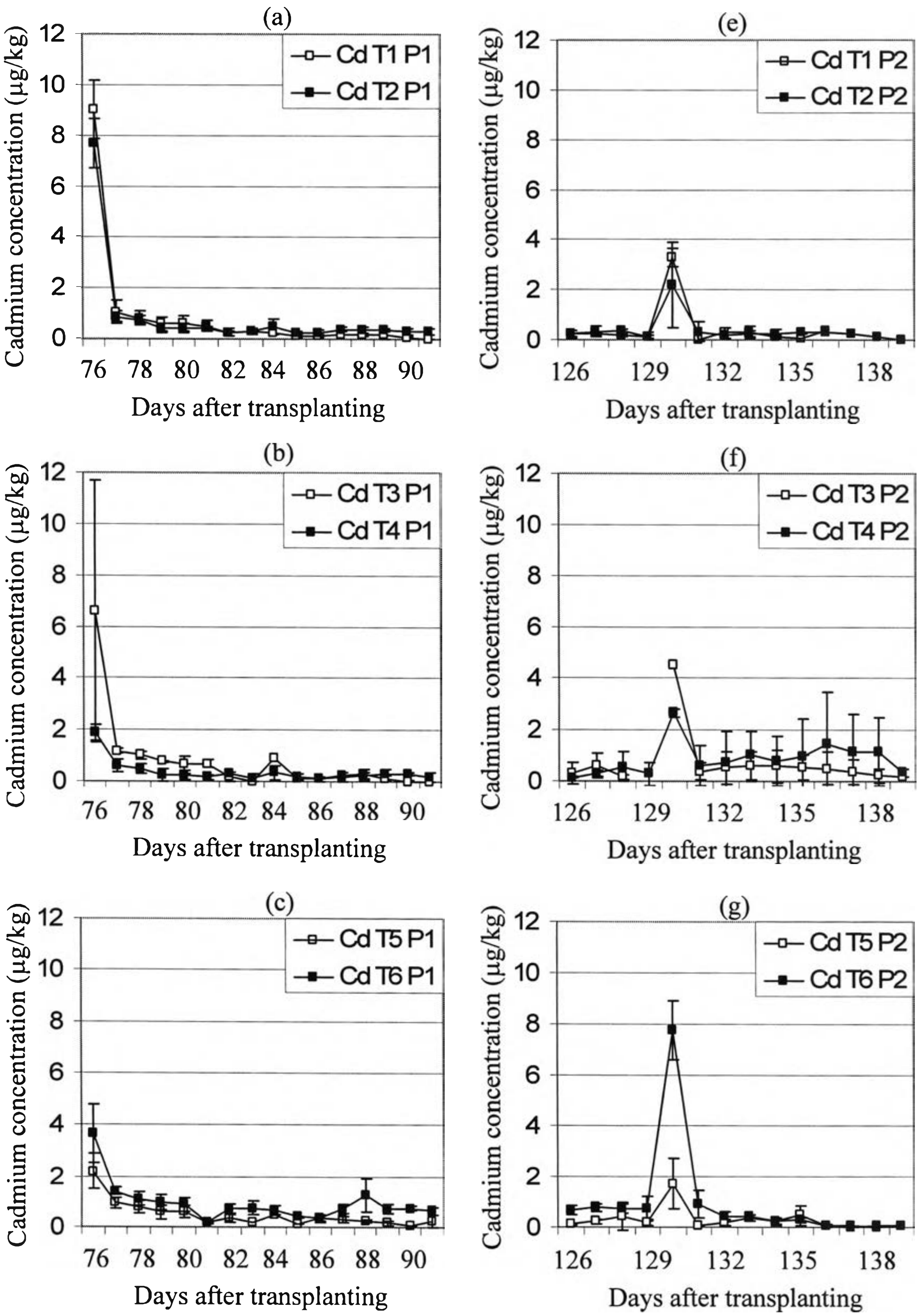
(n) T3 and T4 at the second sampling period (harvest)

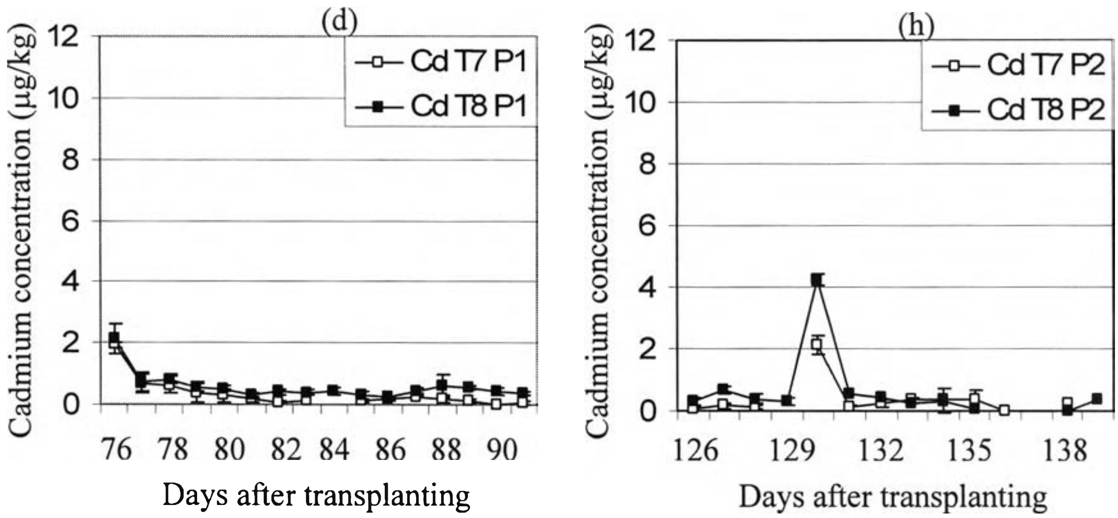
(o) T5 and T6 at the second sampling period (harvest)

(p) T7 and T8 at the second sampling period (harvest)

For cadmium concentration in soil solution, cadmium concentrations in all experimental pots were decreased continuously before starting the drainage. It is possible that cadmium concentration in soil solution was very low, thus after soil solution was transferred out of the root zone, bulk water from outside the rhizosphere zone replaced the transferred soil solution and cadmium took longer time than other metals to be transformed from other complex from soil to be soluble form in soil solution. So, the cadmium concentration was decreasing due to soil solution collection. After drainage, cadmium in soil solution continuous decrease and stable for flooding treatment, and continue decreasing for drainage treatment. And when compare cadmium in soil solution between drainage and flooding treatments, the results showed that drainage treatments had a cadmium concentration in soil solution lower than that in flooding treatments, which opposite from the redox and pH theory and also plants cadmium concentration. The comparison of cadmium concentration of soil solution between drainage and flooding treatment are showed in Figure 4.6. It is possible that the cadmium concentration in soil solution of flooding treatment came to stable. But for drainage treatments, when the pots were drained, root-exudates became more concentrate and play more effect to cadmium concentration in soil solution. It is possible that organic complex, caused by root-exudates, cannot be detected by analyzing instruments (Lin et al., 2003) or cadmium in metal organic complex can be uptake by rice plants easier, resulted in higher cadmium uptake to rice plants then lower cadmium concentration in soil solution. This results were followed the results of rice plants cadmium concentration, draining the pots caused cadmium to be more uptake by rice plants, resulted in extremely high cadmium concentration in rice plants from drainage treatments.

The first sampling period **The second sampling period**





<u>Figure 4.6:</u> Comparison of cadmium concentrations in soil solution between drainage technique and flooding technique;

(a) T1 and T2 at the first sampling period (grain fill stage)

(b) T3 and T4 at the first sampling period (grain fill stage)

(c) T5 and T6 at the first sampling period (grain fill stage)

(d) T7 and T8 at the first sampling period (grain fill stage)

(e) T1 and T2 at the second sampling period (harvest period)

(f) T3 and T4 at the second sampling period (harvest period)

(g) T5 and T6 at the second sampling period (harvest period)

(h) T7 and T8 at the second sampling period (harvest period)

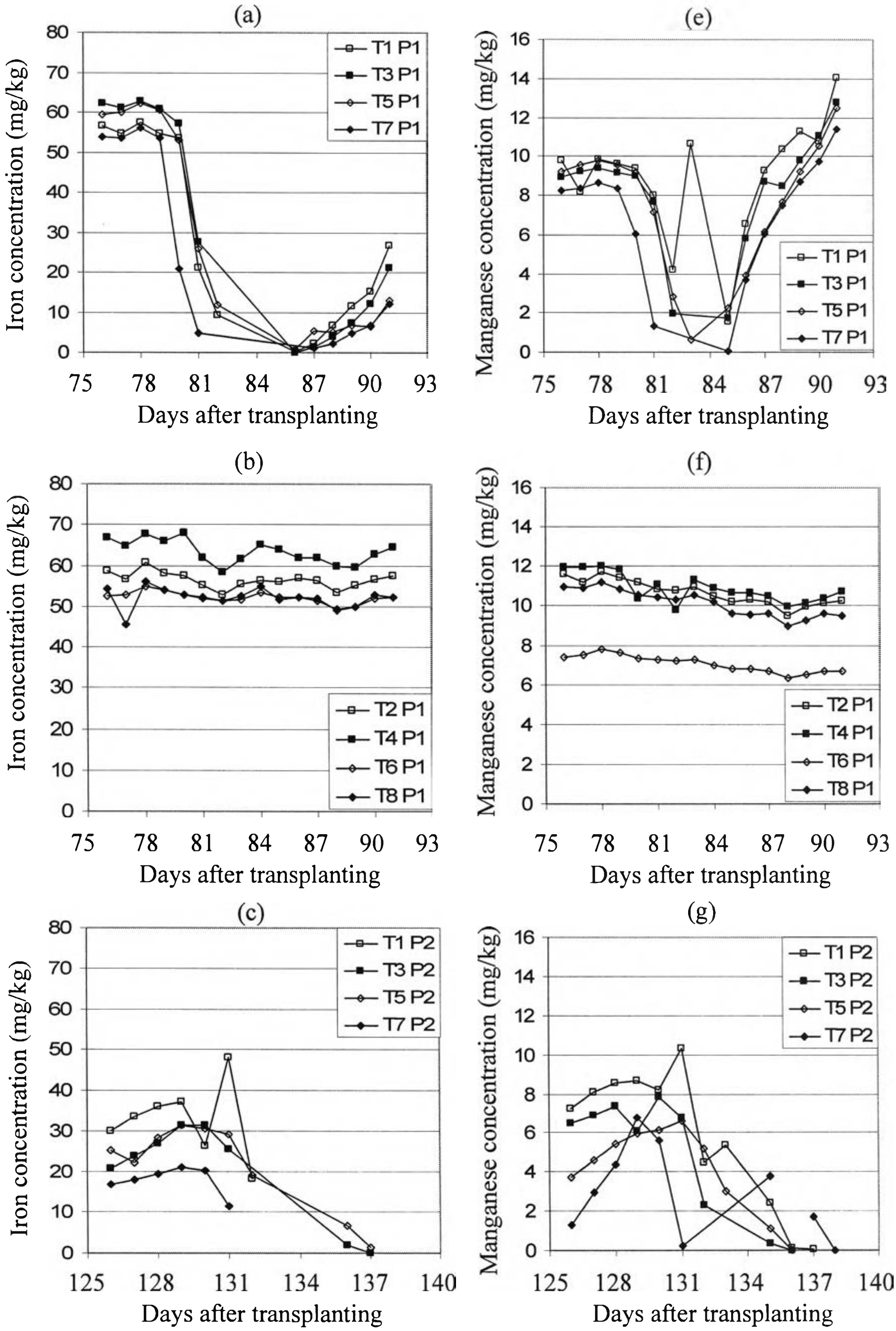
4.2 Effect of other metals in soil solution

In natural soil where several metals also exist in soil, the mechanism of transformation as well as the uptake by plant is very complex. Drainage technique in our study not only affected to cadmium but also to other metals released in soil solution, due to change of redox potential and pH (Alloway, 1990, Kashem et al., 2001a). In addition, the competition among the individual metal may be a factor for cadmium to be uptake (Liu et al., 2003). For this study, besides from cadmium, zinc, iron and manganese found in the studied soil were also analyzed for their concentrations in soil solution. The results of iron and manganese concentration in soil solution are shown in Figure 4.7.

The results showed that drainage caused the concentration of iron and manganese to decrease rapidly, while iron and manganese concentrations in soil solution from flooding treatment pots were rather steady. However, after the refilling all drained pots with water, iron and manganese were increased continuously. Lin et al. (2003) explained this event that may be from root-exudates, which rice plants release during drainage, changes some nutrients and elements to be organic complex form. Then after water refilling, reducing condition started to occur, metal-organic complex may transform back to soluble iron ion and manganese in soil solution. Drained the pots caused root-exudates became more concentrate and affected more to soil system, which resulted in decreasing soluble iron and manganese in soil solution and increasing iron and manganese in organic complex form. Another possible reason is that when the pots were drained, soluble iron and manganese in soil solution were also drained together with water. So, there was a very low amount of water left in the drained pots. However, the drainage water was not collected for iron and manganese determination, thus this expectation may not be confirmed.

The decrease of iron and manganese in soil solution during drainage period affected to cadmium uptake to rice plants. As mentioned before, iron and manganese can inhibit cadmium uptake by rice plants. The decreasing of iron and manganese in the drained pots caused the higher cadmium uptake to rice plants (Berglund et al., 1994, Chaney et al., 2001, cited in Simmons et al., 2003). The iron in soil solution in flooding treatment pots was quite steady in a range of 50 to 70 mg/kg (Figure 4.7b), once the pots were drained, iron concentrations in soil solution were decreased to the range from 0 to 5 mg/kg (see Figure 4.7a). Similar to iron, manganese showed the same trend with their concentrations in flooded pots were rather steady in the range of 7 to 12 mg/kg (Figure 4.7f), while manganese concentration in drained pots were decreased to the range of 0 to 2 mg/kg (Figure 4.7e). The results were followed the hypothesis that iron and manganese can inhibit cadmium uptake to rice plants. As showed in rice plants analysis results (Figures 4.3 and 4.4), the drained pots which a decrease of iron and manganese was occurred, shows cadmium accumulation in rice plants higher than those in the flooded pots. For zinc elements, zinc also plays important role in cadmium uptake inhibition. However, the results show that there was insignificant different for zinc concentration in soil solution between drainage and flooding treatment. So, it can be concluded that water drainage did not cause any effect to zinc concentration in soil solution. Zinc concentration in soil solution is showed in Figure 4.8.

Iron concentration in soil solution Manganese concentration in soil solution



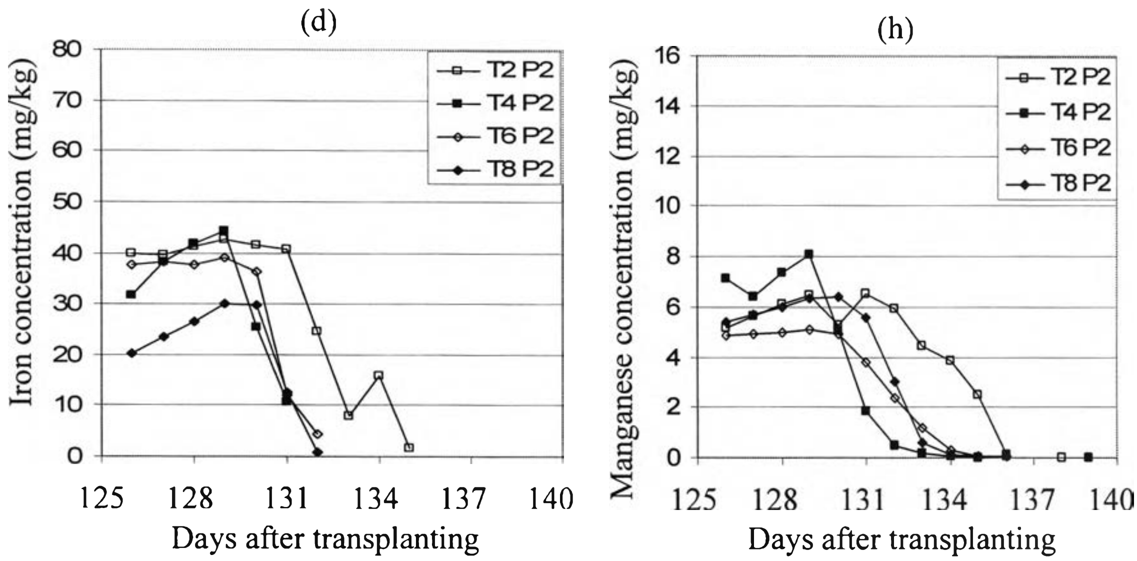


Figure 4.7: **Iron and manganese concentrations in soil solution of drainage technique and flooding technique;**

(a) at the first sampling period (grain fill stage)

(b) at the first sampling period (grain fill stage)

(c) at the second sampling period (harvest period)

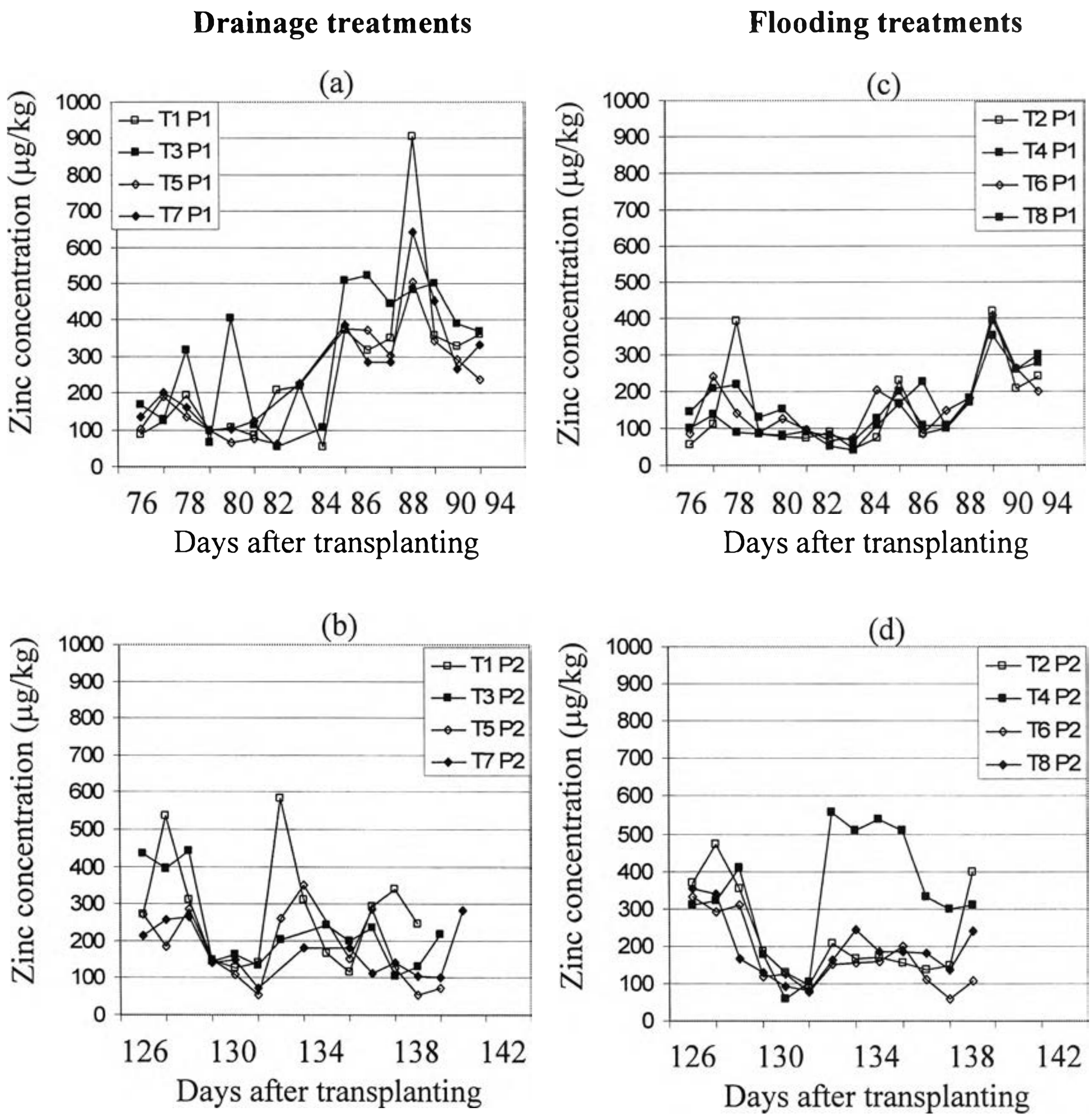
(d) at the second sampling period (harvest period)

(e) at the first sampling period (grain fill stage)

(f) at the first sampling period (grain fill stage)

(g) at the second sampling period (harvest period)

(h) at the second sampling period (harvest period)



<u>Figure 4.8:</u> Zinc concentrations in soil solution of drainage technique and flooding technique at different stage of platation;

(a) drainage treatment at first sampling period (grain fill stage)

(b) drainage treatment at second sampling period (harvest period)

(c) flooding treatment at first sampling period (grain fill stage)

(d) flooding treatment at second sampling period (harvest period)

4.3 Effect of rice straw adding in the studied soil

Rice straw adding was introduced to the study as it is considered as an organic matter which is expected to reduce cadmium uptake to rice plant. The treatments for rice straw adding were T3 and T4. While T3 followed the drainage practice that was carried out for T1; and T4 followed the practice for normal flooding as same as in T2. Figure 4.9 shows the cadmium concentrations in soil solution and cadmium accumulation in rice plants in comparison between T3 and T4 treatments.

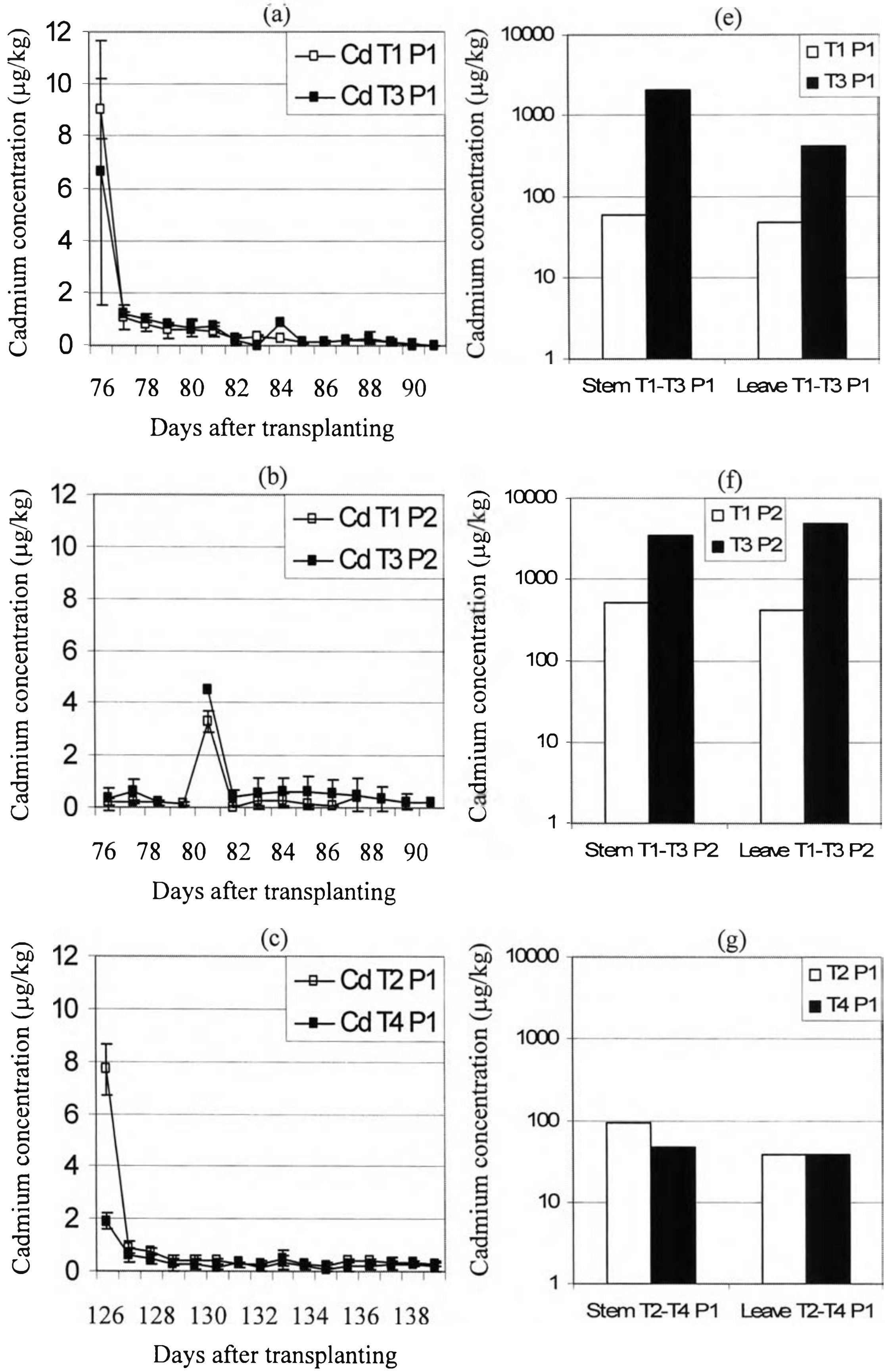
To investigate the effect of rice straw adding, the same planting techniques (T1 and T3) were compared. The cadmium accumulation in rice plants was found to be much higher for T3 up to 35 and 7 folds than for T1 at the first and the second periods in stem part, respectively. While in the leave part, cadmium accumulation in rice plants found to be 9 and 12 folds higher than those from T1 at the first and the second periods, respectively (see Figures 4.9e and 4.9f). For all cases of rice straw adding, cadmium accumulated in rice stems and leaves both in the first and the second period of plant collecting related to cadmium concentrations in soil solutions. The higher cadmium in soil solution, the higher cadmium uptake to plants is found. This confirms the previous study that found the same result.

Nonetheless, if we compared the result on cadmium uptake for same practice but with and without rice straw adding, (T1&T3 and T2&T4), the results do not obey our hypothesis that rice straw could inhibit cadmium uptake by rice plants as it is an organic matter which could play a role on changing cadmium in soils to be in organic-complex form which immobilize and insoluble form. To consider for the drainage practice, the results show that cadmium accumulate in leave and stems in both periods of collection were found much higher for rice straw adding treatment (T3) as shown in Figure 4.9e and 4.9f). In addition to higher concentration of cadmium in soil solution that was found higher for T3 as compared to T1 as mentioned earlier, pH of the soil solution in T3 was also found more acidic condition than in T1 (see Figures 4.10a and 4.10c). This may be the reason behind that rice straw adding for the oxidizing condition (drainage practice) lead to an increase acidic condition to the soil. It may be that during the drainage period with oxidizing condition, the digestion of rice straw by microbes are accelerated and produce more CO_2., subsequently, reduce pH of the soil. However, this need further study in more details for prove and identify the real reasons.

For the flooding procedure (T2 and T4), the result is even more complicated and different between the first and the second period of plant collecting. The result shows that at the first period, cadmium accumulation in stem was found higher for T2 with no rice straw adding while for the leave, cadmium accumulation was found indifferent for T2 and T4. From this result it seems that for reducing condition (flooding treatment), rice-straw adding may decrease cadmium uptake. However, for the total accumulation as can be seen from the second period collection, the cadmium uptake in T4 was found much higher both in stem and leave than those found in T2. This result contradicts to the study by Kasem and Singh (1001b) that found flooding treatment with organic matter adding reduce cadmium uptake. The study by Kasem and Singh (2001a), animal manure was used as an organic matter. In comparison between animal manure and rice-straw that used for this present study, rice straw has less organic matter but high in fiber than animal manure. In addition, nitrate (NO_3^-) is one of the components, which is believed to take part in reduction reaction after oxygen is consumed. But this may not be the case for rice straw since nitrate may be found at very low concentration in rice straw.

However, the result for pH of soil solution was found to be corresponding to cadmium uptake to the plant that in higher acidic condition, cadmium found higher accumulated in rice plant. In addition, there is a study reveals that for some organic matters can produce cadmium organic complex by root-exudates and then transform to cadmium uptake able form (Liu et al., 2003). Our results for T3 and T4 treatment may be the case. In conclusion, rice straw may not be applicable for a decrease of cadmium uptake in rice planting. Further studies are needed to be explored for different type of organic matter to be added to planting practice and research is also need to carry out for explain their mechanism.

Soil solution cadmium concentration **Rice plants cadmium concentration**



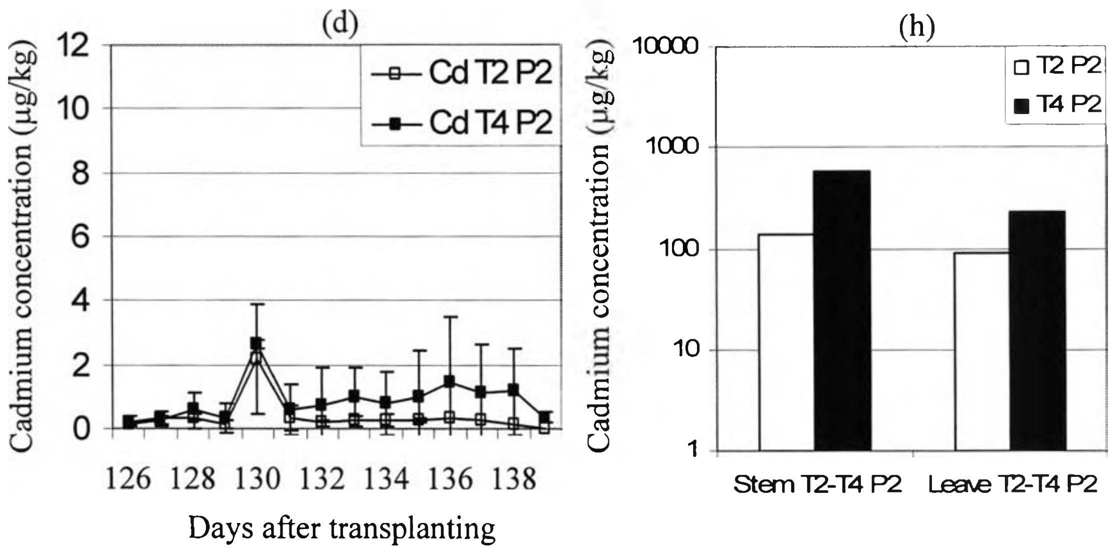


Figure 4.9: The plots of soluble cadmium in soil solution and cadmium concentration in rice plants with the comparison between normal practice (T1 and T2) and rice straw addition technique (T3 and T4);

(a) Soluble cadmium in soil solution of T1 and T3 at the first sampling period

(b) Soluble cadmium in soil solution of T1 and T3 at the second sampling period

(c) Soluble cadmium in soil solution of T2 and T4 at the first sampling period

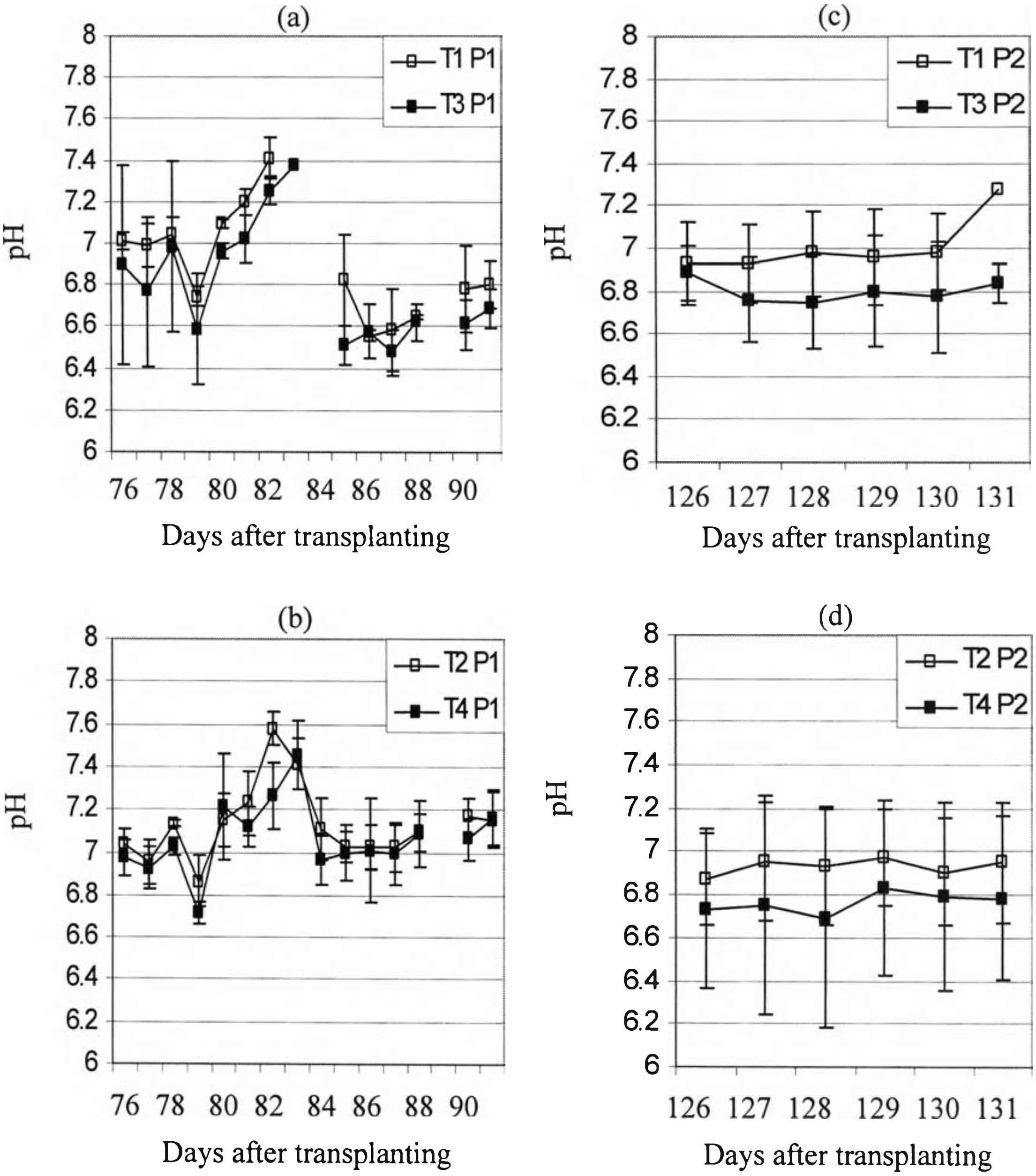
(d) Soluble cadmium in soil solution of T2 and T4 at the second sampling period

(e) Cadmium concentration in rice plants of T1 and T3 at the first sampling period

(f) Cadmium concentration in rice plants of T1 and T3 at the second sampling period

(g) Cadmium concentration in rice plants of T2 and T4 at the first sampling period

(h) Cadmium concentration in rice plants of T2 and T4 at the second sampling period



<u>Figure 4.10:</u> The pH of soil solution comparison between rice straw adding technique (T3 and T4) and normal practice (T1 and T2) at the first and the second sampling periods;

(a) T3 and T1 at the first sampling period

(b) T4 and T2 at the first sampling period

(c) T3 and T1 at the second sampling period

(d) T4 and T2 at the second sampling period

4.4 Effect of liming agent (calcium oxide) adding in the studied soil

Acidic condition in soil is well recognized that is the condition suitable for most metals to be in soluble form and leads to be easy to be uptake by plant. Therefore, liming agent adding technique was applied in order to reduce acidic condition in soil. The T5 and T6 were the experimental pots with calcium oxide adding and followed the drainage and flooding practice respectively. In the same manner, the pairs of comparison are between the same practice and drainage practice with lime adding or without lime adding which then will be T1 vs. T5 and T2 vs. T6.

Figure 4.11 shows the plots of cadmium in soil solution and cadmium accumulated in plants in comparison between T1 vs. T5 and T2 vs. T6. From the results, cadmium concentrations in soil solution related to cadmium uptake in all cases. However, when compare T5 (drainage with liming agent addition) with T1 (normal drainage), the result showed that calcium oxide adding could not reduce cadmium uptake by rice plants. On the other hand, it found that cadmium accumulation in rice plants of the pots with lime was higher than the one without lime especially, for the stem parts (see Figure 4.11f).

For T2 and T6, the cadmium uptake to rice plant were not much different as shown in Figure 4.11f and 4.11h, however, the result shows different direction with the drainage treatment. To explain what happened in these experimental pots, pH values are needed to be considered. Figure 4.12 shows the plot of pH at the two periods of measurements. For drainage practice (T1 and T5), liming agent did not seem to make soil solution to be basic. However, for the flooding practice, liming agent slightly increased pH of the system.

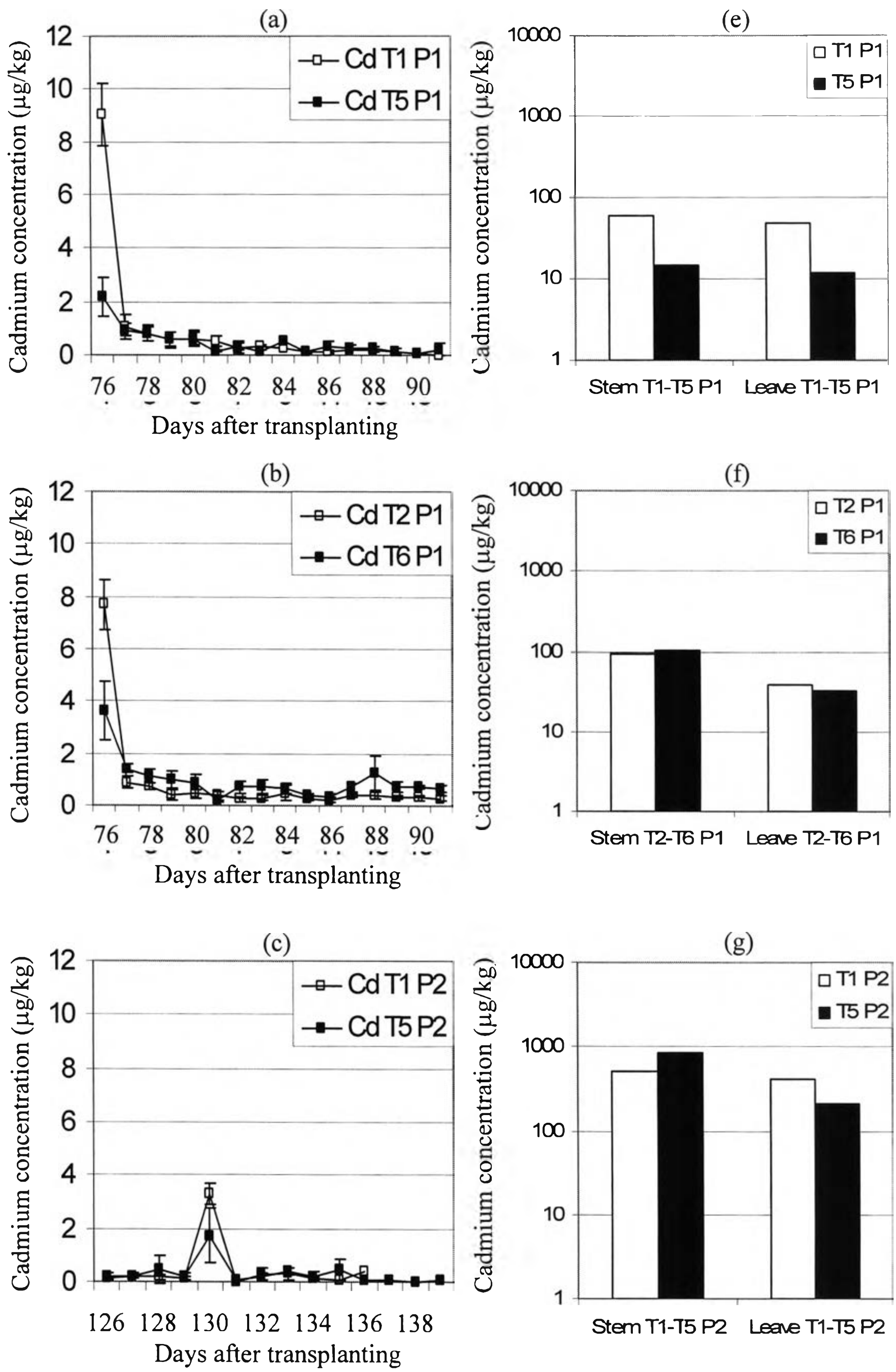
Since the systems of experimental pots were very complicated, single parameters may not be enough to explain what happens. Therefore, interaction among other metals in soils is needed to take into account. Interesting that from iron and manganese concentration in soil solution results (Figure 4.13) obviously showed much lower iron and manganese concentration for the case of calcium oxide adding (T5) as compared to T1 (Figures 4.13a and 4.13c for iron, and 4.13e and 4.13g for manganese). Thus, it may be possible that calcium oxide, which was used as liming agent in the experiment, transformed iron and manganese to be in insoluble form instead of cadmium. And iron and manganese play important role on available cadmium, because iron and manganese in oxide form bind with cadmium, which is insoluble and immobilize (Liu et al., 2003; Kashem et al., 2001a). So, when there was lower iron and manganese in soil system, rice plants, by root-exudates, can transformed cadmium in soil system to be in soluble form easier, resulted in higher cadmium concentration in soil solution.

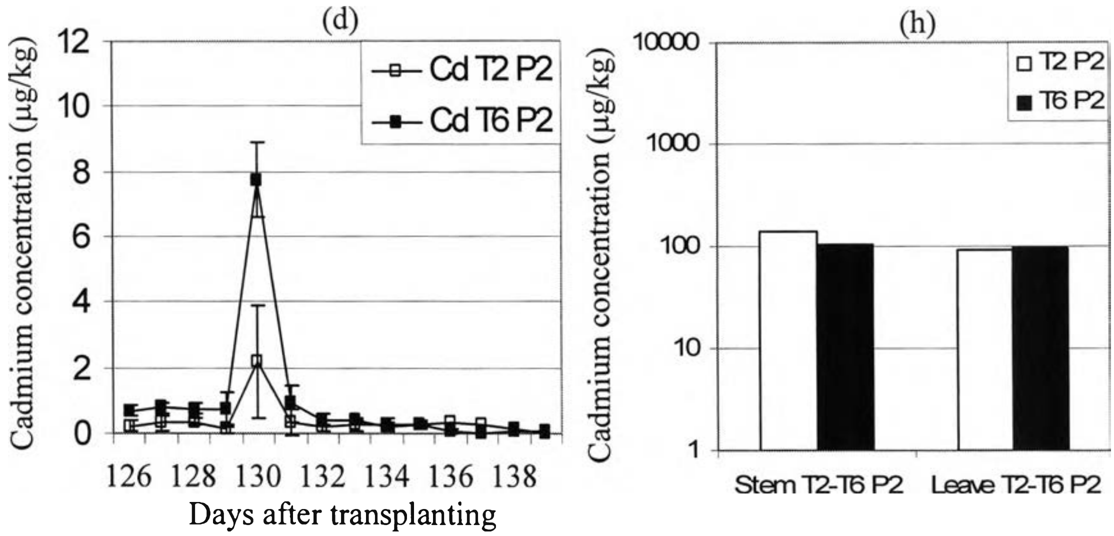
However, for the first sampling period, cadmium accumulation in rice plants form liming agent addition technique was lower than normal practices. It is possible that calcium oxide can inhibit cadmium uptake to rice plants at the first duration of rice age. For the long term effect, the acidity of root-exudates and the lack of iron and manganese may lead to the changing of cadmium to available form to be uptake to rice plants. So, cadmium accumulation in rice plants from liming agent addition technique was lower than normal practices at the first sampling period and higher at the second sampling period.

For pH in soil solution, though there was an adding of liming agent in T5 and T6, the pH in soil solution from T1 and T2 was not much different from T5 and T6. The pH in soil solution of liming agent technique (T5 and T6) and normal practices (T1 and T2) is shown in Figure 4.12. So, liming agent adding was not effectively increasing pH in soil system, because the acidity of root-exudates, which rice plants produced every day, dynamically decrease pH in soil system. Thus, pH in soil solution of liming agent adding technique was not the major parameter to affect on cadmium uptake to rice plants. From the T5 results, cadmium accumulation in stem part was more than those in leave part. Salt et al. (2002) showed that cadmium in rice plants xylem mostly bound with oxygen and nitrogen ligands. It is possible that CaO adding increase oxygen in rice plants, resulted in higher cadmium in oxygen ligand form. So, cadmium was accumulated in stem part higher than in leave part.

For T6 (flooding with liming agent adding) compared with T2 (normal flooding) it is not significantly different of cadmium accumulation in rice plants between these 2 farming practices. The possible explanation is normal drainage technique can provide the minimum cadmium accumulation in rice plants. So, addition of liming agent was not providing any significant different level of cadmium accumulation in rice plants for flooding technique.

Soil solution cadmium concentration **Rice plants cadmium concentration**





<u>Figure 4.11:</u> The plots of soluble cadmium in soil solution and cadmium concentration in rice plants in comparison between normal practice (T1 and T2) and liming agent addition technique (T5 and T6);

(a) Soluble cadmium in soil solution of T1 and T5 at the first sampling period

(b) Soluble cadmium in soil solution of T1 and T5 at the second sampling period

(c) Soluble cadmium in soil solution of T2 and T6 at the first sampling period

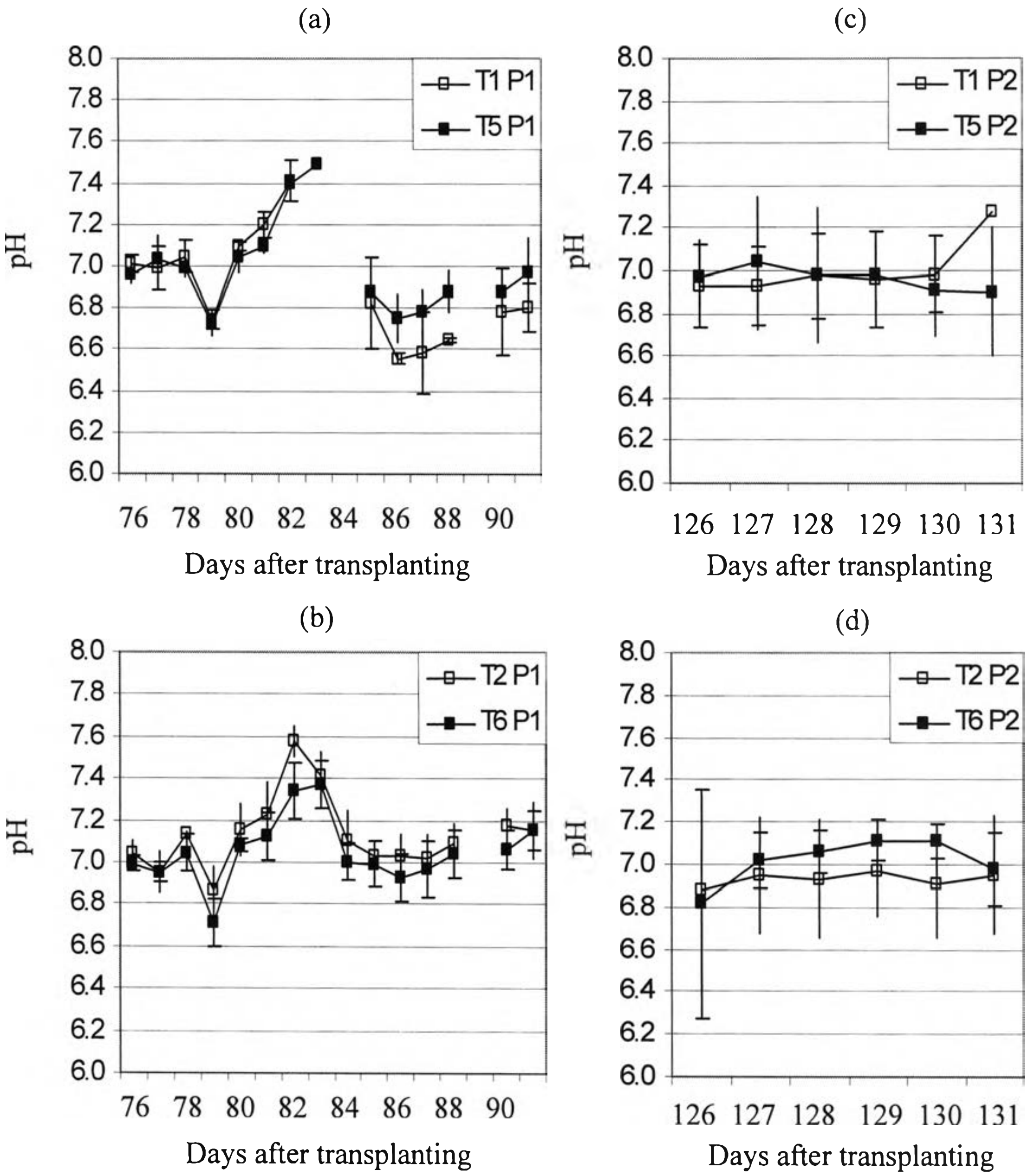
(d) Soluble cadmium in soil solution of T2 and T6 at the second sampling period

(e) Rice plants cadmium concentration of T1 and T5 at the first sampling period

(f) Rice plants cadmium concentration of T1 and T5 at the second sampling period

(g) Rice plants cadmium concentration of T2 and T6 at the first sampling period

(h) Rice plants cadmium concentration of T2 and T6 at the second sampling period



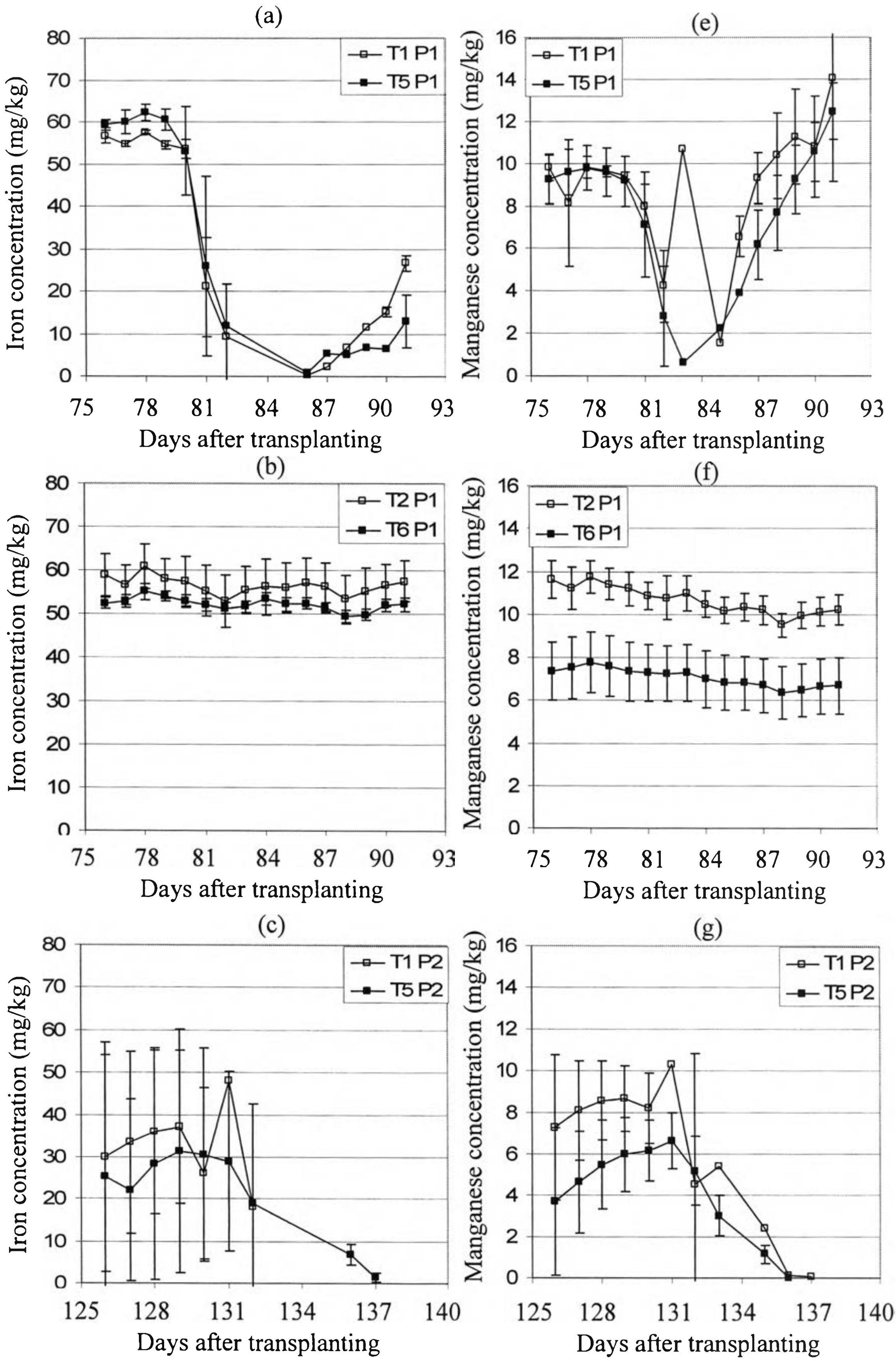
<u>Figure 4.12:</u> The pH of soil solution comparison between rice straw addition technique (T5 and T6) and normal practice (T1 and T2) at the first and the second sampling period;

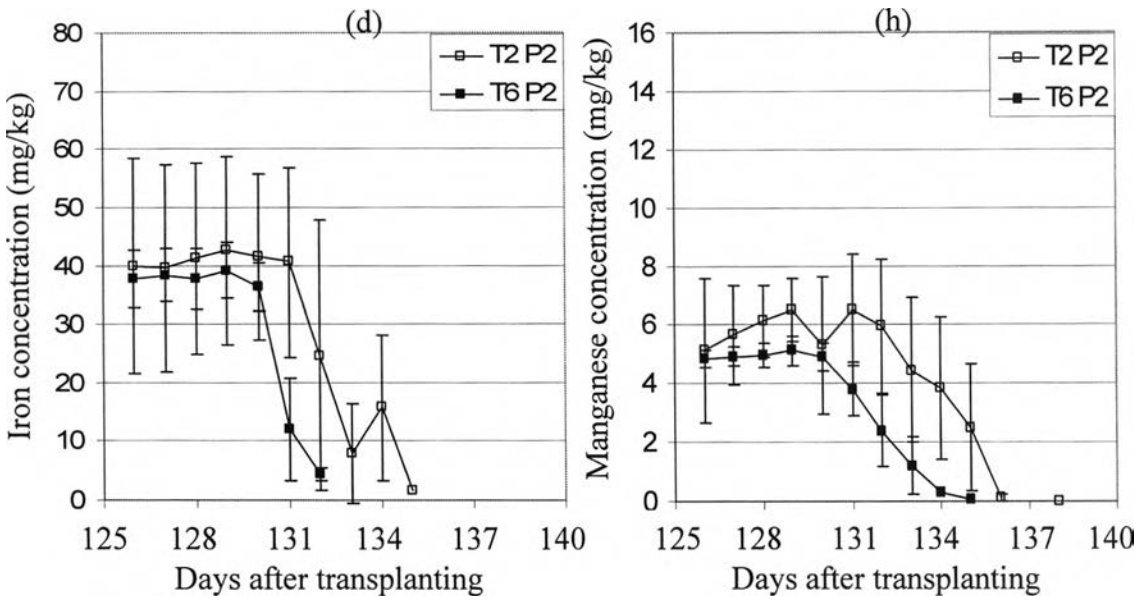
(a) T5 and T1 at the first sampling period

(b) T6 and T2 at the first sampling period

(c) T5 and T1 at the second sampling period

(d) T6 and T2 at the second sampling period


(a)
(b)
(c)
(e)
(f)
(g)
Iron concentration (mg/kg)
Manganese concentration (mg/kg)
Days after transplanting
T1 P1
T5 P1
T2 P1
T6 P1
T1 P2
T5 P2



<u>Figure 4.13:</u> The iron and manganese concentrations in soil solution comparison between liming agent addition technique (T5 and T6) and normal practice (T1 and T2) at first and second sampling period;

(a) T5 and T1 at first sampling period

(b) T6 and T2 at first sampling period

(c) T5 and T1 at second sampling period

(d) T6 and T2 at second sampling period

(e) T5 and T1 at first sampling period

(f) T6 and T2 at first sampling period

(g) T5 and T1 at second sampling period

(h) T6 and T2 at second sampling period

4.5 Effect of rice straw and liming agent adding in the studied soil

The treatments, which both rice straw and liming agent addition, are T7 (drainage with rice straw and liming agent adding) with T1 (normal drainage practice), To compare the cadmium uptake on plants between T1 and T7, the result showed that drainage with rice straw adding together along with liming agent provided a higher cadmium concentration in rice plant than those found in normal drainage technique. Figure 4.14 shows the comparison of cadmium concentration in rice plants of T7 and T8 with T1 and T2. . The result found to be similar to be in the case of lime adding that the treatment did not reduce cadmium uptake to rice plant.

This may be explained that because rice straw transformed cadmium in soil to be in metal organic complex form. Subsequently, rice plants released root-exudates, which transformed metal organic complex to be in another metal organic complex, which uptake able by rice plants. But cadmium accumulation in rice plants, which planted in rice straw and liming agent adding soils (treatment7), was not as high as in rice plants which planted in rice straw adding only (T3). This is may be because liming agent transformed cadmium that had been transformed by rice straw before to be in less soluble and less phyto-availability. So, this means the two effects occurred in one treatment (T7) subsequently.

However the results from rice plants cadmium accumulation comparison between both rice straw and liming agent adding technique and only rice straw adding technique showed that the adding of liming agent inhibit the cadmium transformation by rice straw. Though the adding of liming agent decrease the iron and manganese concentration in soil solution, resulted in higher cadmium uptake to rice plants as same as liming agent adding technique, it changed the condition in soil system to be not suitable for rice straw to produced cadmium organic complex, which can be transformed by root-exudates to be in soluble form. Consequently, the cadmium accumulation in rice plants from both rice straw and liming agent addition technique was not high as rice straw adding technique.

For cadmium concentration in soil solution, there was no significantly different between cadmium concentration in soil solution from both rice straw and liming agent adding technique (T7 and T8) and normal practices (T1 and T2). Figure

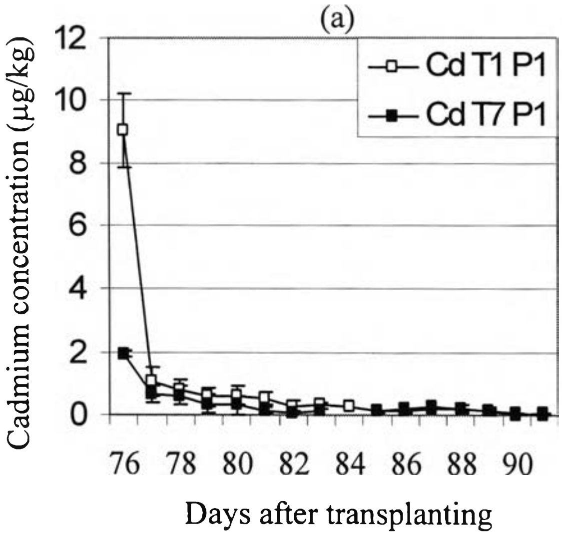
4.14 shows the comparison of cadmium concentration in soil solution between both rice straw and liming agent adding (T7 and T8) and normal practices (T1 and T2).

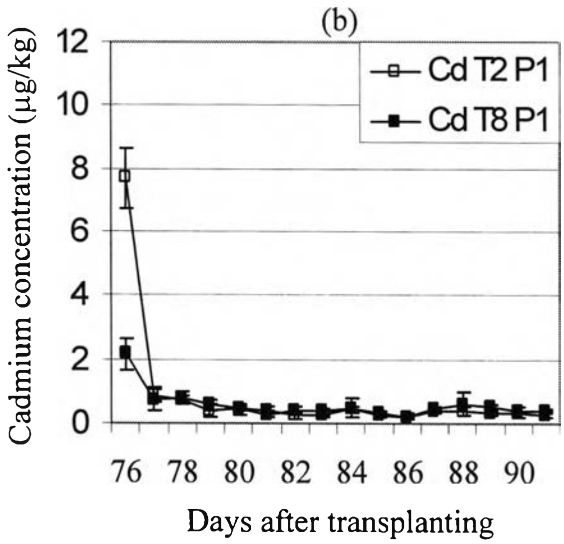
For pH in soil solution, both rice straw and lime adding technique (T7 and T8) produced pH value insignificantly different from normal practices (T1 and T2) and liming agent adding (T5 and T6), however all of 3 techniques generated higher pH as compared to rice straw adding technique. The pH in soil solution comparison between each technique is shown in Figure 4.15. It is possible that liming agent inhibited the activities of microorganism in soil system, resulted in decreasing the CO_2 production. Thus, when compared with rice straw addition technique, the pH of both rice straw and liming agent adding not low as rice straw adding technique.

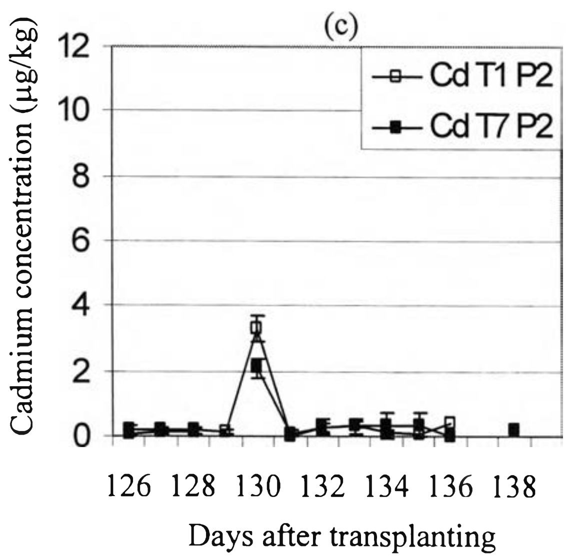
For T8 (flooding with rice straw and liming adding) compared with T2 (normal flooding), there is insignificantly different of cadmium accumulation in rice plants between these 2 farming treatments. The possible explanation is that the normal drainage technique can provide the minimum cadmium accumulation in rice plants. Therefore, adding of both rice straw and liming agent showed less affect on cadmium accumulation in rice plants..

Cadmium concentration in soil solution comparison between each treatment, separated by drainage and flooding technique, is shown in Figure 4.16. And cadmium concentration in plants comparison between each treatment, separated by drainage and flooding technique, is shown in Figure 4.17.

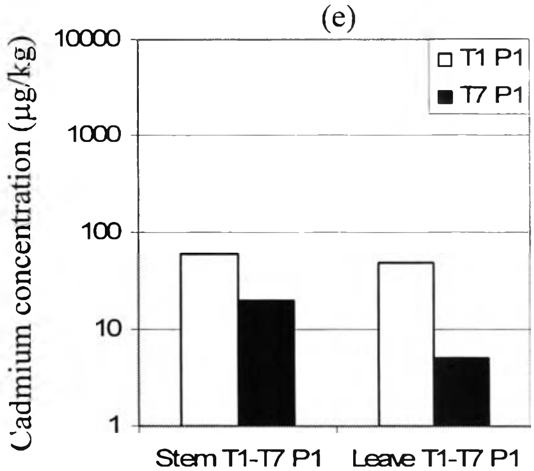
Cd concentration in soil solution

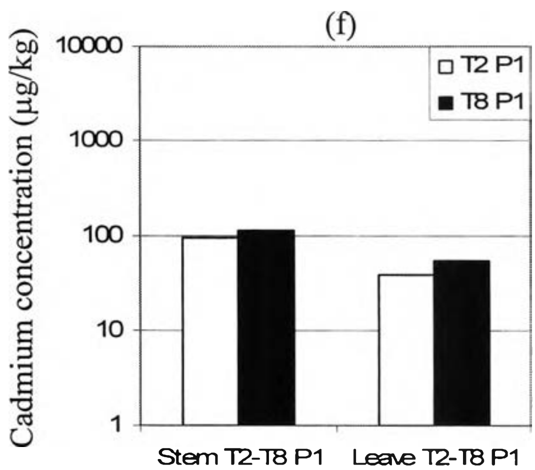


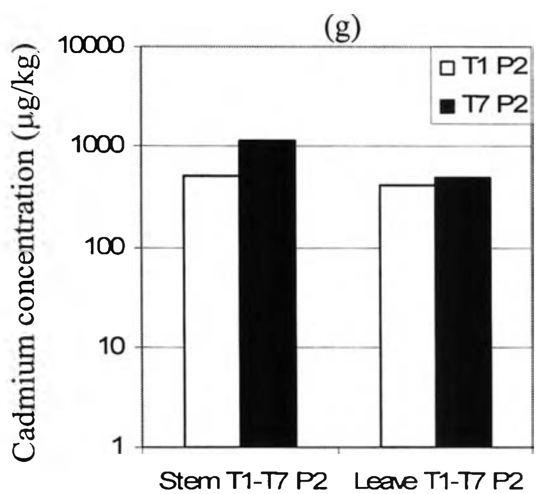


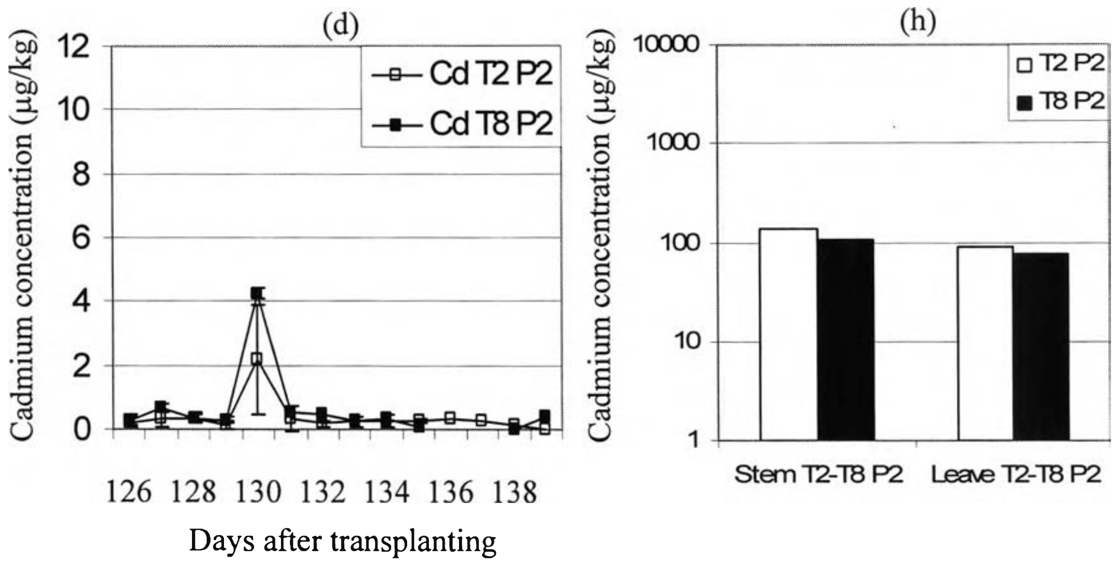


Cd concentration in plants









<u>Figure 4.14:</u> The relation between soluble cadmium in soil solution and cadmium concentration in rice plants with the comparison between normal practice (T1 and T2) and both rice straw and liming agent addition technique (T7 and T8);

(a) Soluble cadmium in soil solution of T1 and T7 at the first sampling period

(b) Cadmium concentration in rice plants of T1 and T7 at the first sampling period

(c) Soluble cadmium in soil solution of T1 and T7 at the second sampling period

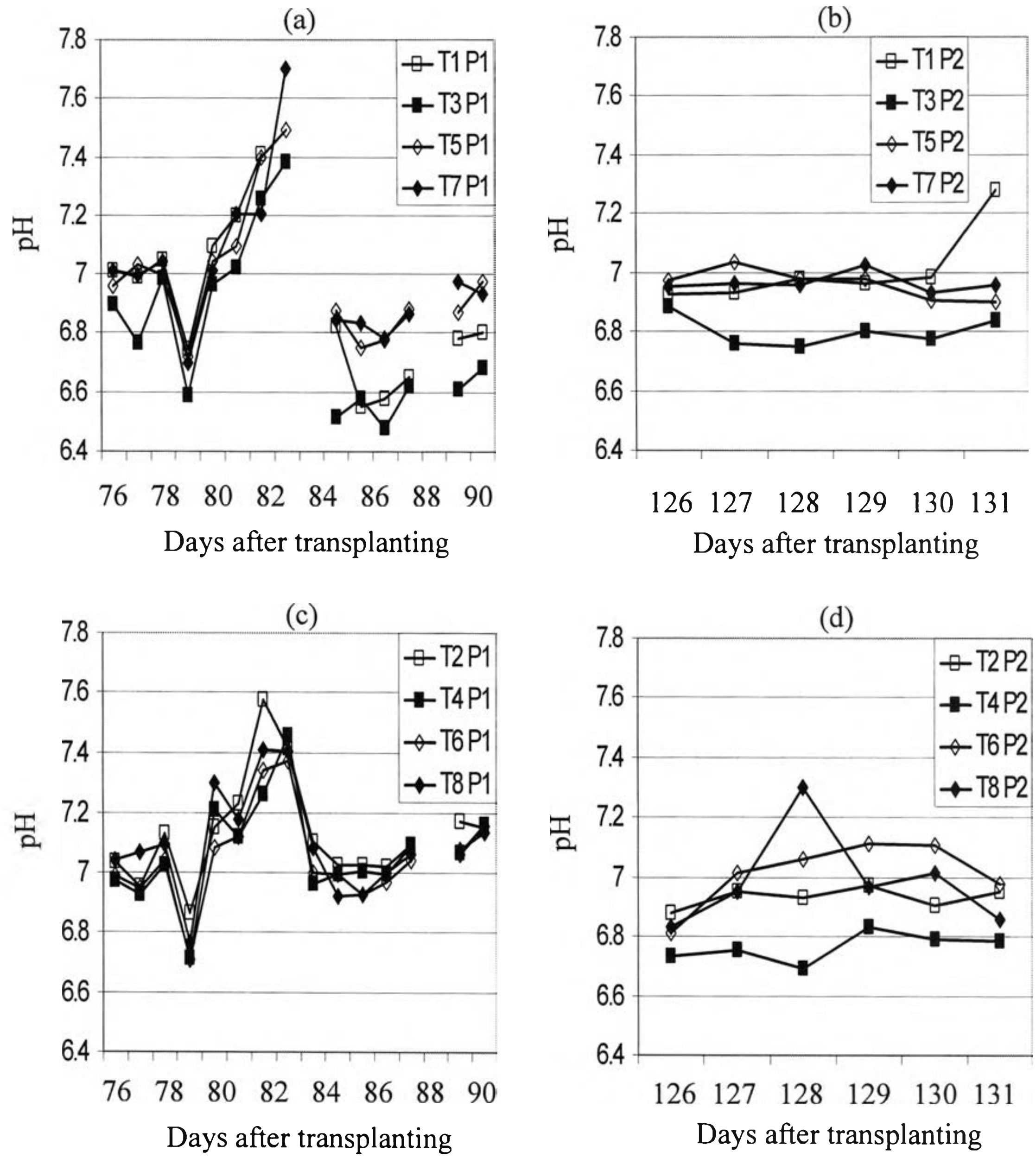
(d) Cadmium concentration in rice plants of T1 and T7 at the second sampling period

(e) Soluble cadmium in soil solution of T2 and T8 at the first sampling period

(f) Cadmium concentration in rice plants of T2 and T8 at the first sampling period

(g) Soluble cadmium in soil solution of T2 and T8 at the second sampling period

(h) Cadmium concentration in rice plants of T2 and T8 at the second sampling period



<u>Figure 4.15:</u> The comparison of soil solution pH between normal practice (T1 and T2), rice straw addition technique (T3 and T4), liming agent addition technique (T5 and T6), and both rice straw and liming addition technique (T7 and T8);

(a) T1, T3, T5, and T7 at the first sampling period

(b) T1, T3, T5, and T7 at the second sampling period

(c) T2, T4, T6, and T8 at the first sampling period

(d) T2, T4, T6, and T8 at the second sampling period

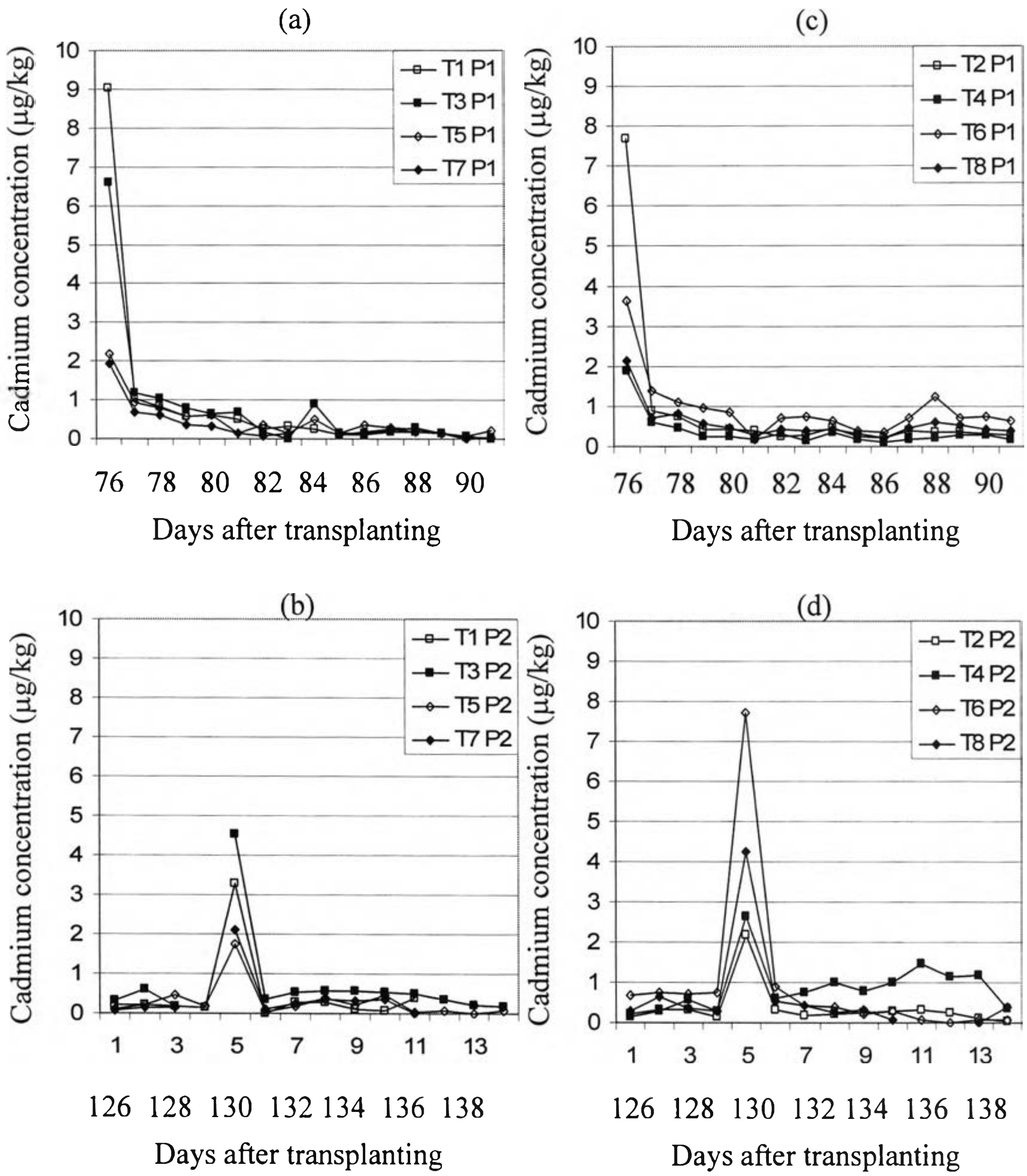


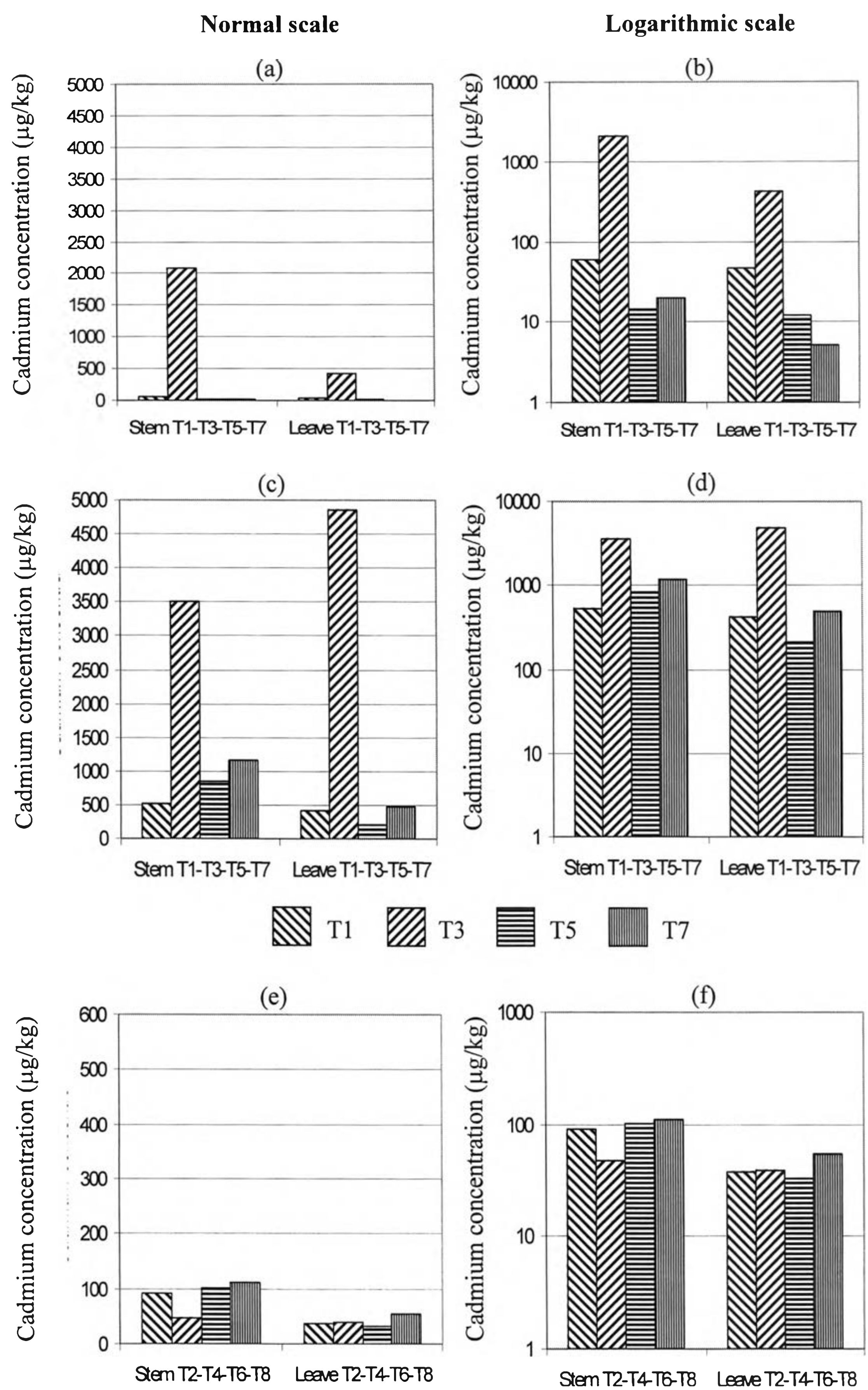
Figure 4.16: The comparison of cadmium concentrations in soil solution between normal practice (T1 and T2), rice straw addition technique (T3 and T4), liming agent addition technique (T5 and T6), and both rice straw and liming addition technique (T7 and T8);

(a) T1, T3, T5, and T7 at the first sampling period

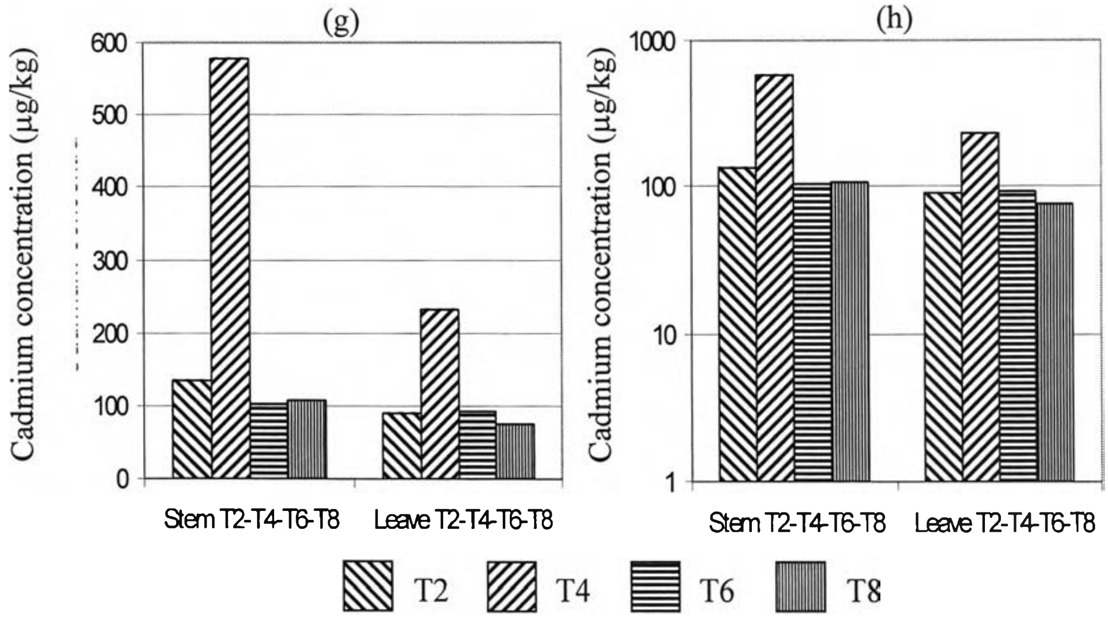
(b) T1, T3, T5, and T7 at the second sampling period

(c) T2, T4, T6, and T8 at the first sampling period

(d) T2, T4, T6, and T8 at the second sampling period



Normal scale
Logarithmic scale
(a)
(b)
(c)
(d)
(e)
(f)
Cadmium concentration (µg/kg)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
600
1
10
100
1000
10000
Stem T1-T3-T5-T7
Leave T1-T3-T5-T7
Stem T2-T4-T6-T8
Leave T2-T4-T6-T8
T1
T3
T5
T7



<u>Figure 4.17:</u> The comparison cadmium concentrations in rice plants between normal practice (T1 and T2), rice straw addition technique (T3 and T4), liming agent addition technique (T5 and T6), and both rice straw and liming addition technique (T7 and T8);

(a) T1, T3, T5, and T7 at the first sampling period in normal scale

(b) T1, T3, T5, and T7 at the first sampling period in logarithmic scale

(c) T1, T3, T5, and T7 at the second sampling period in normal scale

(d) T1, T3, T5, and T7 at the second sampling period in logarithmic scale

(e) T2, T4, T6, and T8 at the first sampling period in normal scale

(f) T2, T4, T6, and T8 at the first sampling period in logarithmic scale

(g) T2, T4, T6, and T8 at the second sampling period in normal scale

(h) T2, T4, T6, and T8 at the second sampling period in logarithmic scale

4.6 Correlation of cadmium in soil and cadmium accumulation in rice plants

In addition to analysis of cadmium in soil solution and in rice plant, wet soil samples were also analyzed by using calcium chloride extraction in order to predict bioavialable form of cadmium. The soil samples were collected for two periods as same time as plant samples collection for all treatments. Figure 4.18 shows the plot between the cadmium concentration in wet soil and in plant at the two period of samples collection for all treatments. The plot from Figure 4.18 illustrates that there is the samples points for all data are scatter and seems to be no correlation between soil cadmium concentration and cadmium accumulation in rice plants. It is possible that the form of cadmium in soil in the sampling position was different from the cadmium in rhizosphere zone. Lin et al., 2003 revealed that the form of cadmium in vary distance from the rhizosphere are different. So, the higher extractable cadmium concentration in soil may not show significantly correlation to the cadmium concentration in rice plants.

Table 4.1: Cadmium concentrations in wet soil from calcium chloride extraction and in rice plant at the two periods of samples collection

Treatment	First period			Second period		
	Cd conc.(µg/kg)			Cd conc. .(µg/kg)		
	Soil	leave	stem	Soil	leave	stem
T1	930	47	59	395	421	522
T2	652	38	92	577	90	135
T3	1,188	416	2,091	248	4851	3497
T4	1,111	39	47	904	232	579
T5	172	12	14	106	213	846
T6	172	33	103	79	93	103
T7	523	5	20	281	485	1161
T8	227	54	112	124	76	107

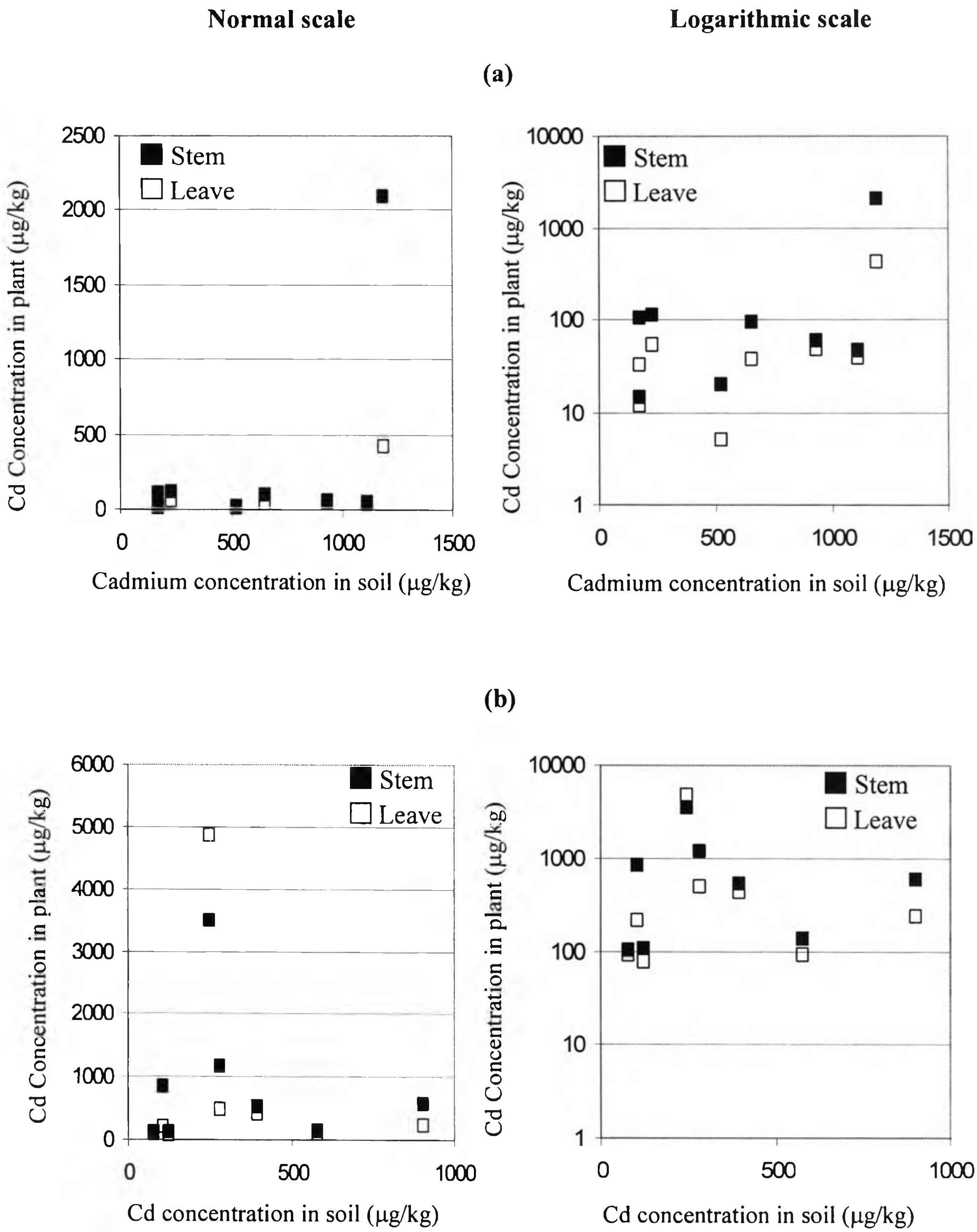


Figure 4.18: The correlation of cadmium concentration in soil by calcium chloride extraction and rice plants of all treatments; (a) first period and (b) second period