CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 General parameters of constructed wetland systems

In this study, five general parameters were measured every 10 days during 110 days experimental period were pH, temperature, conductivity, salinity, and suspended solid for using to explain the experimental condition.

1) pH

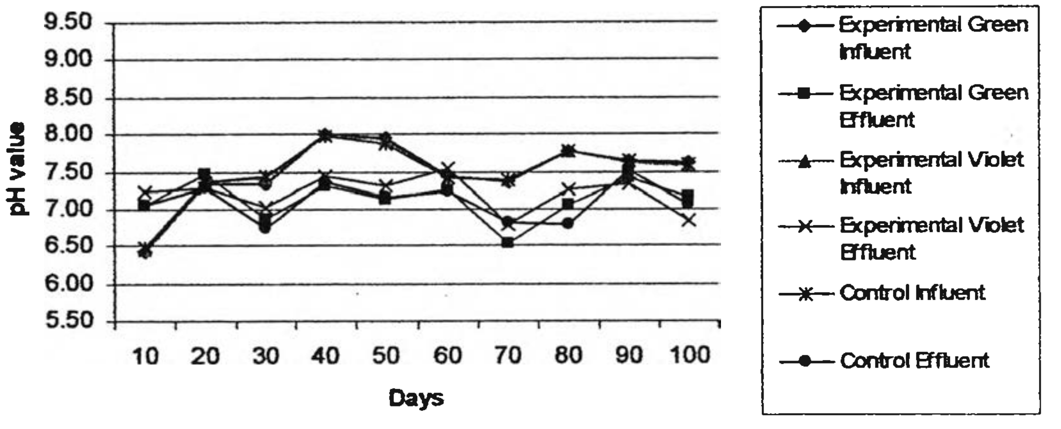
During the experimental period, pH of influent in experimental and control units which contained 0.15 m wastewater level was in the range of 6.43-8.00. The pH values of influent of 0.25 m and 0.35 m wastewater level ranged from 6.59-8.00 and 7.21-7.98, respectively. Effluent pH values of 0.15, 0.25, and 0.35m wastewater level in all experimental and control units were in the range of 6.53-7.55, 7.15-8.84, and 7.37-8.98, respectively.

The pH values of effluents were very slightly increased about 2.39% as shown trend of pH values in Figure 4-1.

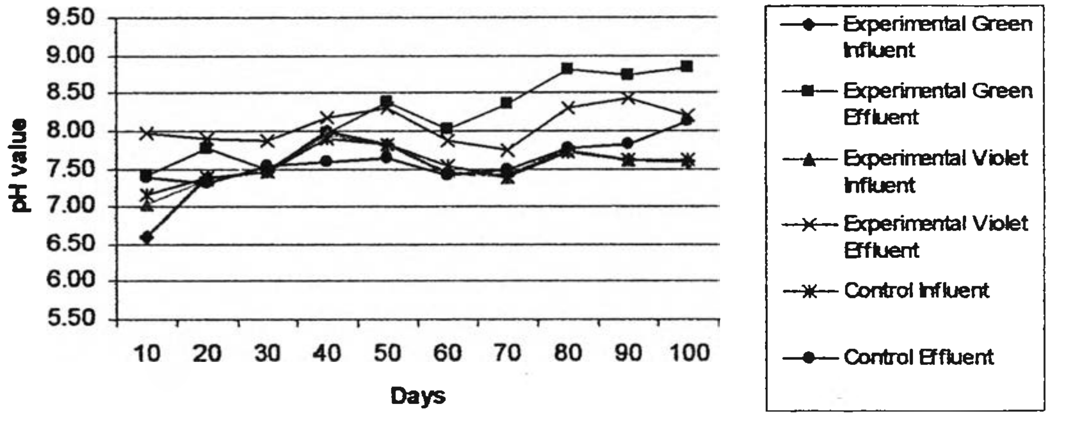
2) Temperature

Influent temperature of 0.15, 0.25, and 0.35 m wastewater level in all experimental and control units ranged from 28.5°C-40.1°C, 28.4°C-41.3°C, and 28.3°C-44.7°C, respectively, whereas effluent temperature of all experimental and control units were in the range of 27.2°C-37.5°C, 27.6°C-37.0°C, and 27.1°C-36.3°C at 0.15, 0.25, and 0.35 m wastewater level, respectively.

At 0.15 m wastewater level



At 0.25 m wastewater level



At 0.35 m wastewater level

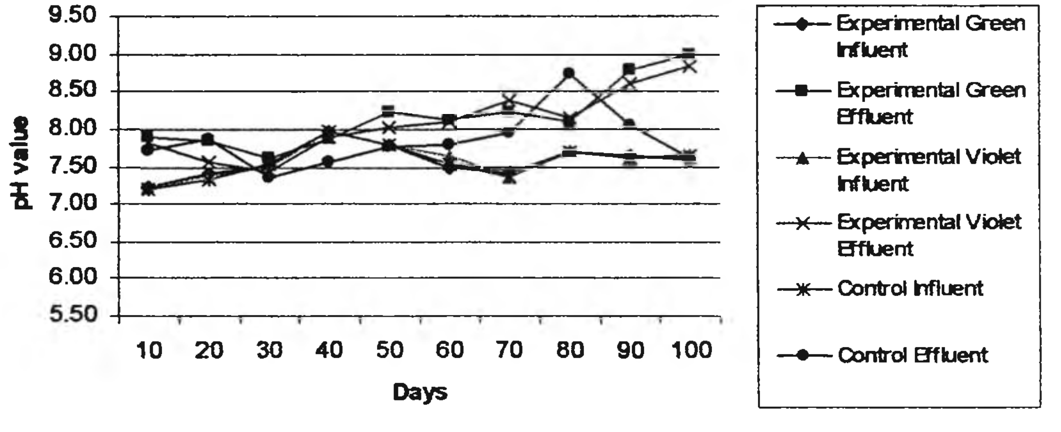


Figure 4-1 pH value of wastewater in constructed wetland systems (influent and effluent)

Figure 4-2 showed the trend of temperature in all units, temperature of effluents was slightly decreased about 10.07% but the noticeable point for this study was during day at 50, 60 and 70, temperature tended to increase higher than other day periods because of they were in April (see Table 3-2 in chapter 3 section 3.4.3 at pp.35) which was the hottest month in every years which conducted to very high evaporation

3) **Conductivity**

Influent conductivity of 0.15, 0.25, and 0.35 m wastewater level in all experimental and control units were in the range of 8.60-14.80, 6.45-14.80, and 5.37-15.00 µS/cm, respectively, while effluent conductivity of 0.15, 0.25, and 0.35 m wastewater level ranged from 8.73-20.60, 7.97-19.10, and 8.18-18.00 µS/cm, respectively.

Figure 4-3 expressed that conductivity of influent was rather stable along experimental period but conductivity in effluent tended to increase in day at 50, 60, and 70 in every wastewater level resulted from high evaporation. So ions were condensed in the pilot unit.

4) **Salinity**

Influent salinity of 0.15, 0.25, and 0.35 m wastewater level in all experimental and control units were in the range of 6.00-8.60, 6.00-8.50, and 6.00-8.70 ppt, respectively, whereas effluent salinity of 0.15, 0.25, and 0.35 m wastewater level ranged from 4.80-12.40, 4.30-11.40, and 5.20-10.60 ppt, respectively.

Trend of salinity was exactly the same as conductivity trend (see in Figure 4-4). Influent salinity was stable but effluent salinity was high at day 50, 60, and 70 in every wastewater level. This was resulted from high evaporation therefore salt ions were condensed in the pilot experiment.

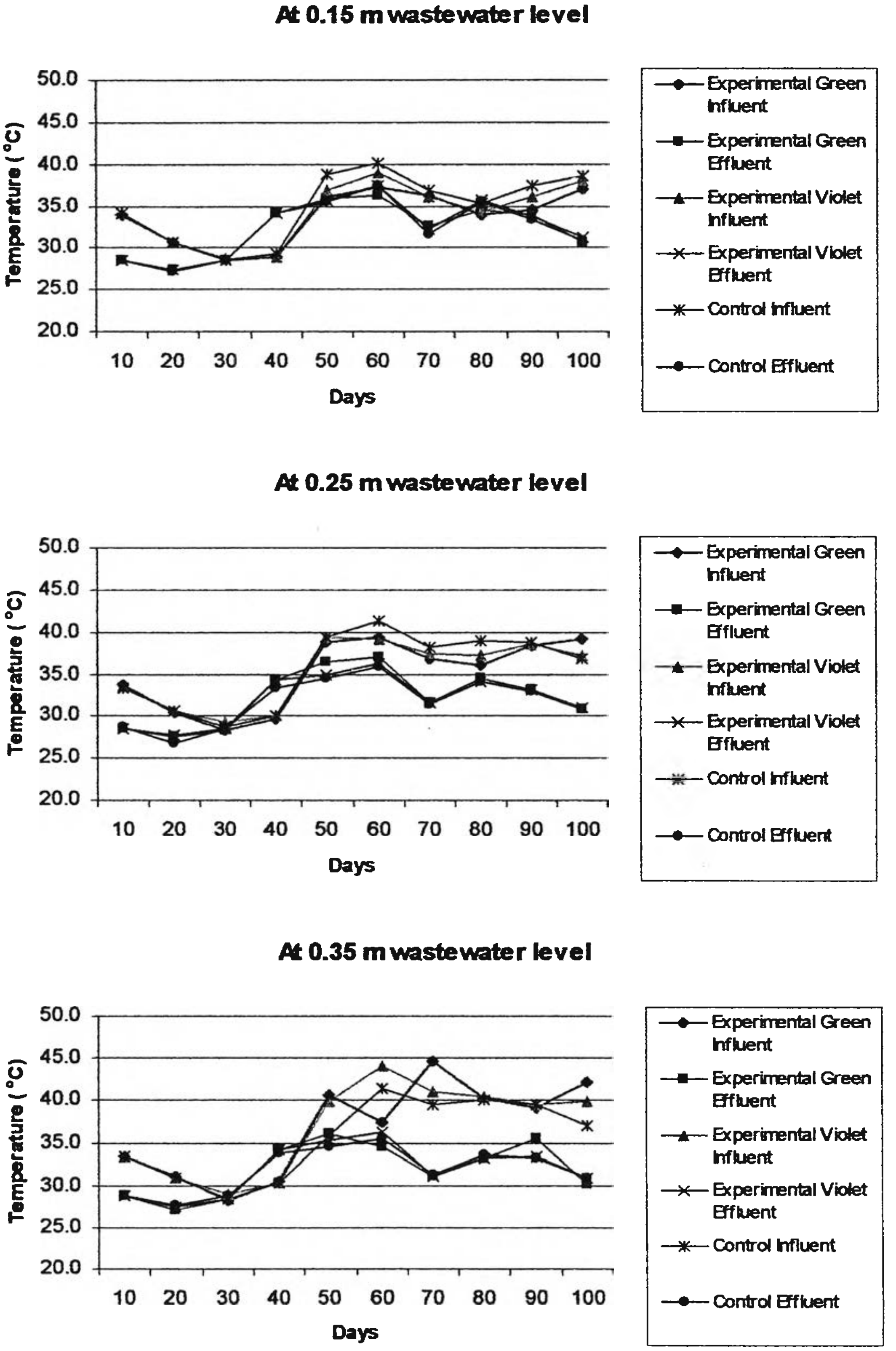


Figure 4-2 Temperature of wastewater in constructed wetland systems (influent and effluent)

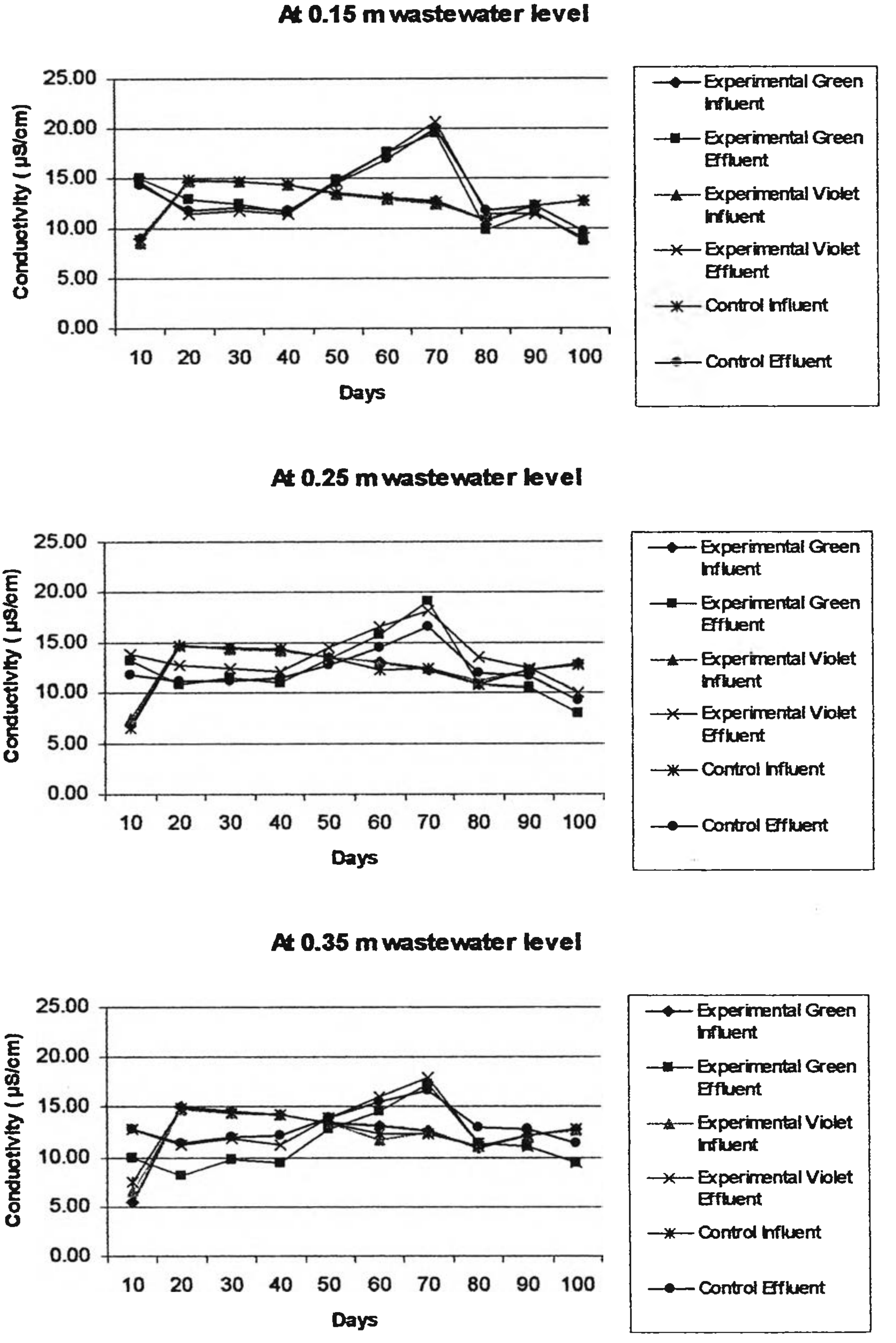
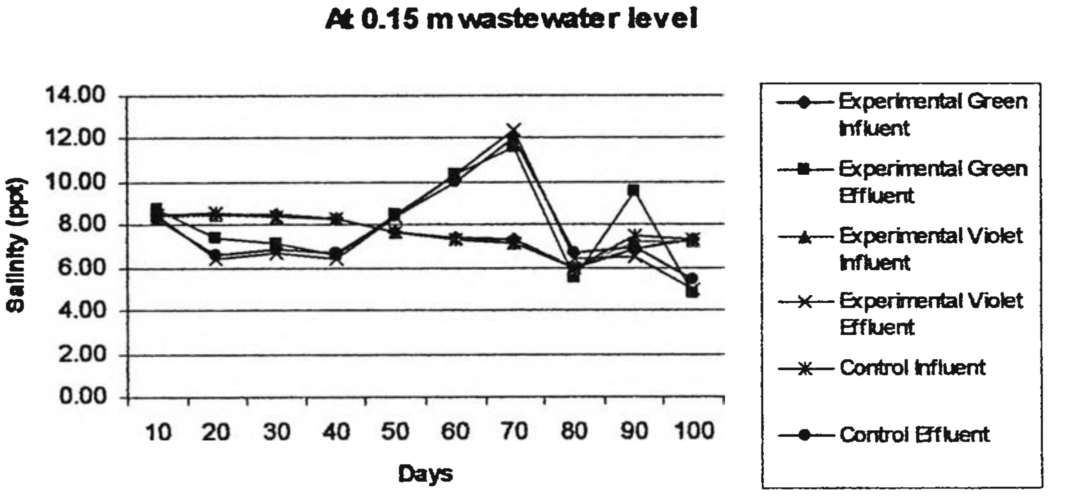
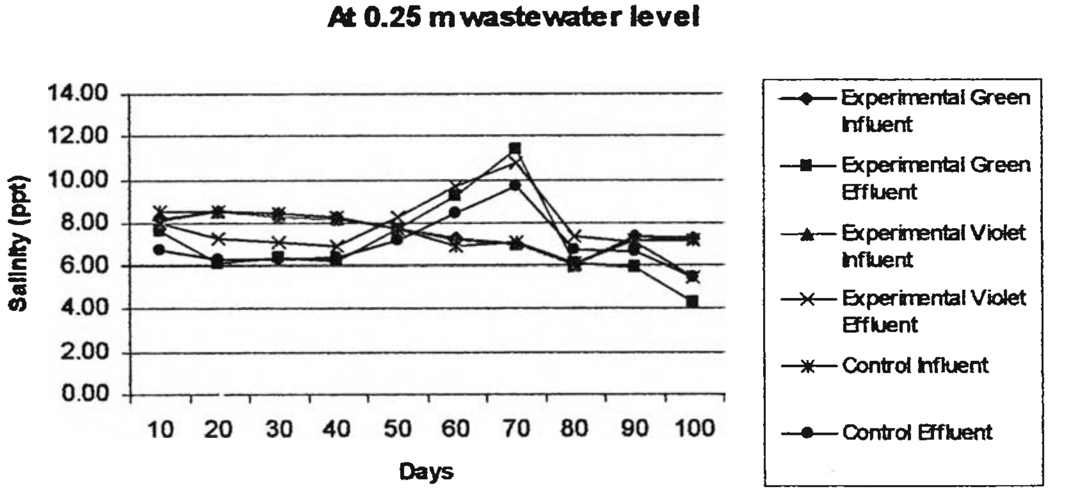


Figure 4-3 Conductivity of wastewater in constructed wetland systems (influent and effluent)





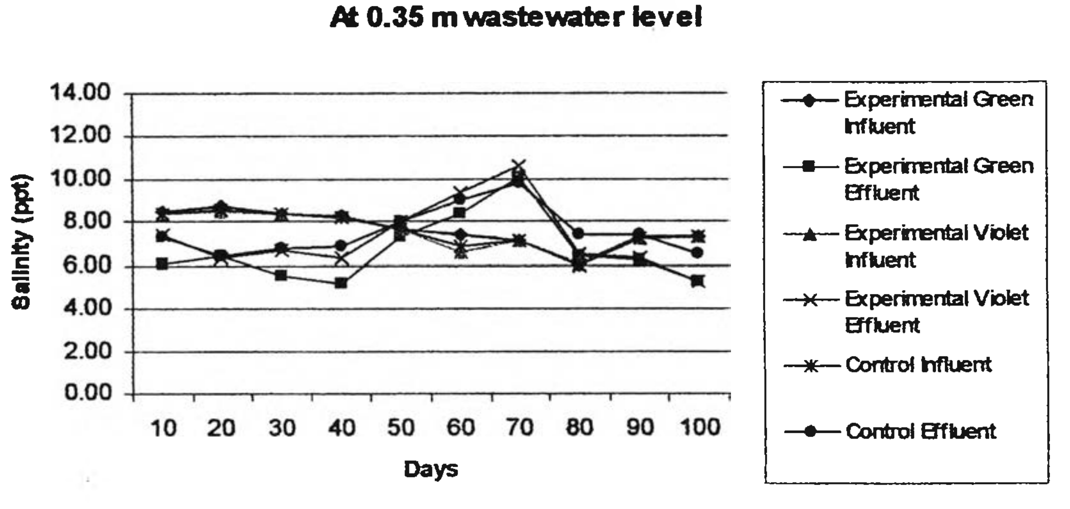


Figure 4-4 Salinity of wastewater in constructed wetland systems (influent and effluent)

5) Total suspended solid

Influent suspended solid of 0.15, 0.25 and 0.35 m wastewater level in all experimental and control units ranged from 16-96, 5-119, and 19-415 mg/l, respectively, whereas effluent suspended solid of 0.15, 0.25, and 0.35 m wastewater level were in the range of 2-49, 2-53, and 6-87 mg/l, respectively.

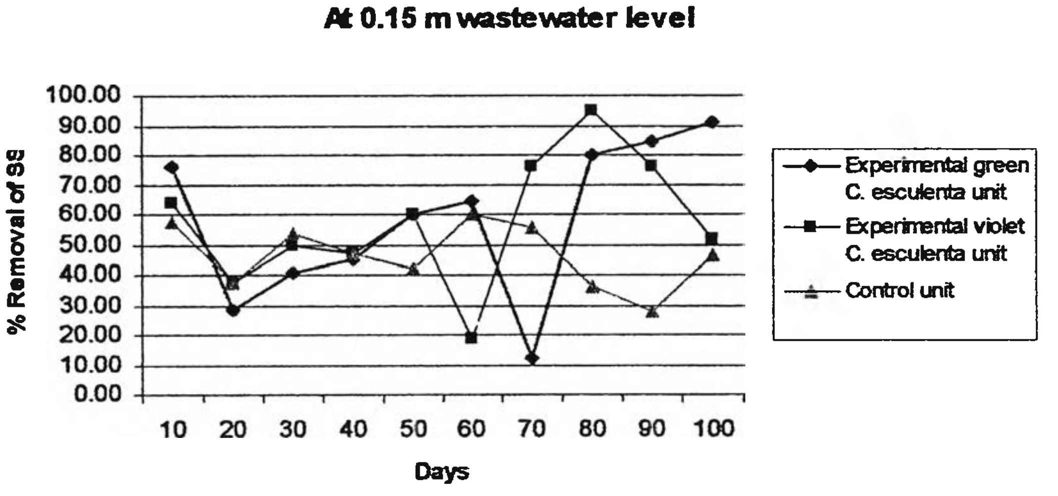
The average efficiency for suspended solid removal of experimental green unit at 0.15, 0.25, and 0.35 m wastewater level was 58.37%, 56.92%, and 63.73%, respectively and average suspended solid removal efficiency of violet *C. esculenta* unit at 0.15, 0.25, and 0.35 m wastewater level was 57.53%, 53.88%, and 54.80%, respectively .In control unit at 0.15, 0.25, and 0.35 m wastewater level, average TSS removal efficiency was 57.05%, 49.56, and 48.04%, respectively (Table 4-1).

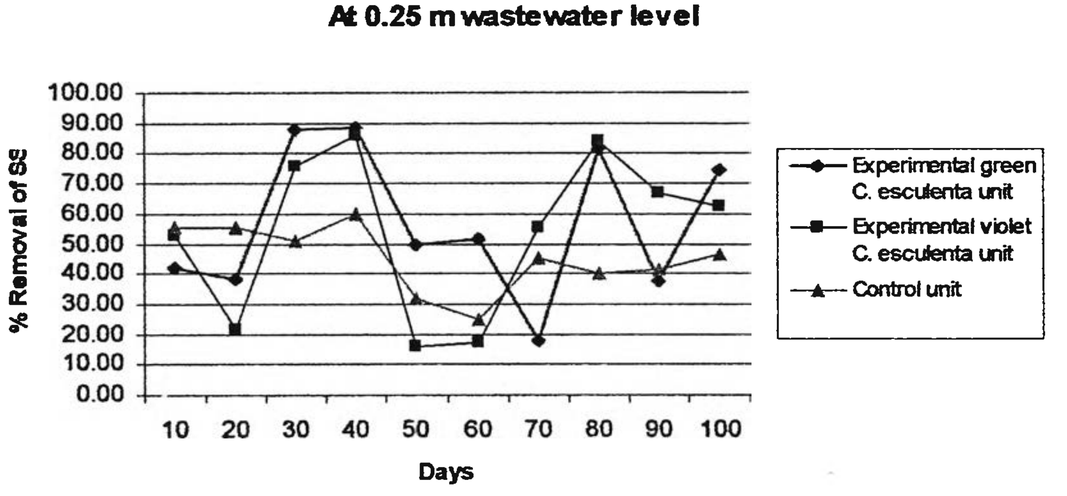
Figure 4-5 showed trend of %removal of suspended solid in every unit that tended to very fluctuate. This was resulted from natural characteristics of *Colocasia esculenta* (L.) Schott, which was their petioles and laminas, would be dropped when new stem was developed. This generated high amounts of suspended solid during system operation due to decomposition by microorganism activity. In contrast, %removal of all control units tended to stable at about 50-60 % because of there was no effect as mentioned.

From statistical analysis data, it was found that there was no significant difference at 95% confidence among wastewater level and unit type (Table 4-2). It might be resulted from dead plant which cause to decomposition and fermentation, suspended solid would be arise too much. The system could not treat immediately. Consequently, there were no differences between experimental units and control units in all cases.

Table 4-1 SS removal efficiency of constructed wetland systems (%)

Water Depths	0.15 m			0.25 m			0.35 m		
Units	Experimental		Control	Experimental		Control	Experimental		Control
	Green	Violet		Green	Violet		Green	Violet	
Days	*C. esculenta*	*C. esculenta*		*C. esculenta*	*C. esculenta*		*C. esculenta*	*C. esculenta*	
10	76.04	63.83	57.61	41.89	52.78	55.71	71.05	52.70	41.67
20	28.57	37.50	37.74	38.10	21.54	55.17	13.21	44.78	26.23
30	40.91	50.00	53.85	87.96	75.86	51.16	71.79	85.56	50.53
40	45.45	47.06	47.06	88.41	86.27	60.00	57.89	92.11	58.97
50	60.00	60.00	42.11	50.00	16.13	32.00	55.10	45.16	42.86
60	64.71	18.42	60.00	51.69	17.19	25.00	70.91	18.18	45.16
70	12.50	75.86	55.56	17.65	55.56	45.00	76.29	27.03	45.00
80	80.00	95.00	36.36	81.40	84.00	40.00	92.52	73.17	52.63
90	84.44	75.86	27.94	37.29	67.16	41.27	89.40	73.33	51.28
100	91.04	51.72	46.15	74.79	62.34	46.38	39.16	36.00	41.67
Average	**58.37**	**57.53**	**46.44**	**56.92**	**53.88**	**45.17**	**63.73**	**54.80**	**45.60**
Maximum	**91.04**	**95.00**	**60.00**	**88.41**	**86.27**	**60.00**	**92.52**	**92.11**	**58.97**
Minimum	**12.50**	**18.42**	**27.94**	**17.65**	**16.13**	**25.00**	**13.21**	**18.18**	**26.23**
SD	**25.89**	**21.74**	**10.46**	**24.62**	**26.89**	**11.01**	**23.76**	**25.13**	**8.81**





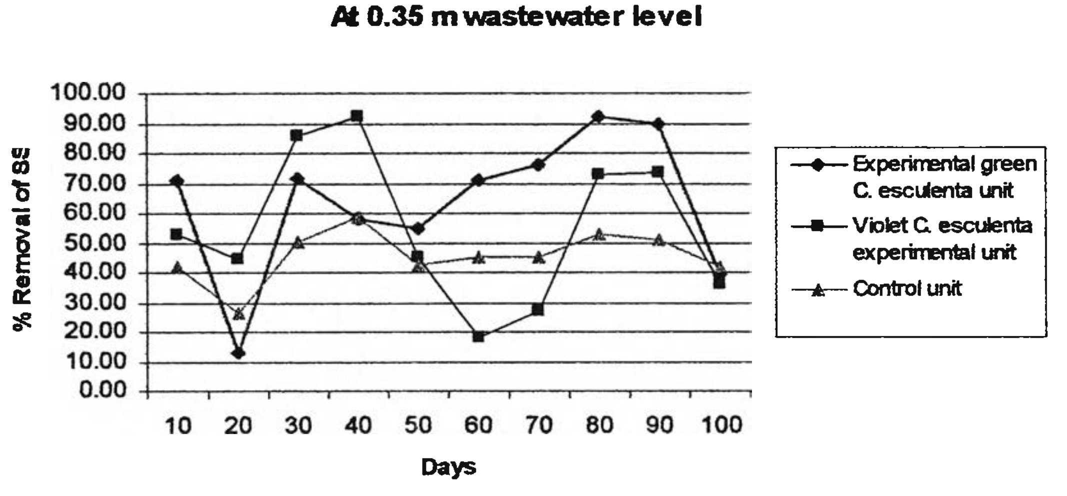


Figure 4-5 SS removal efficiency of constructed wetland systems

Table 4-2 Mean comparison tested by one-way ANOVA on SS removal efficiency (see Appendix C at pp.120-125)

Type of unit	Wastewater level		
	0.15 m	0.25 m	0.35 m
Experimental green *C. esculenta* unit	[a]64.18[a]	[a]69.67[a]	[a]67.18[a]
Experimental violet *C. esculenta* unit	[a]62.21[a]	[a]61.91[a]	[a]55.72[a]
Control unit	[a]55.24[a]	[a]57.45[a]	[a]50.45[a]

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same column for unit type comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same row for wastewater level comparison.

4.2 Chromium Removal efficiency of constructed wetland systems and optimal wastewater level for chromium removal from tannery post-treatment wastewater

Chromium removal efficiency

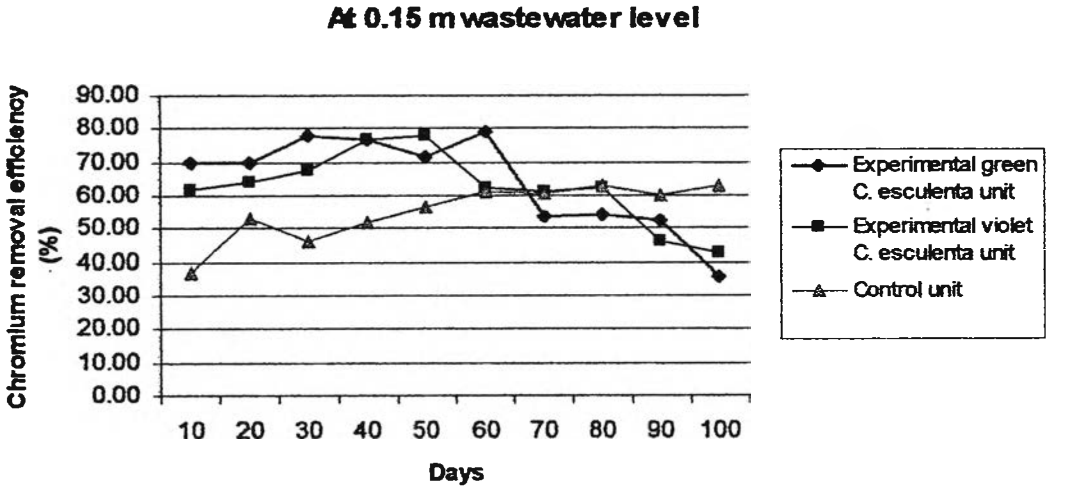
Chromium removal efficiency of constructed wetland systems was shown as a percentage of total chromium in unit per chromium concentration in the influent.

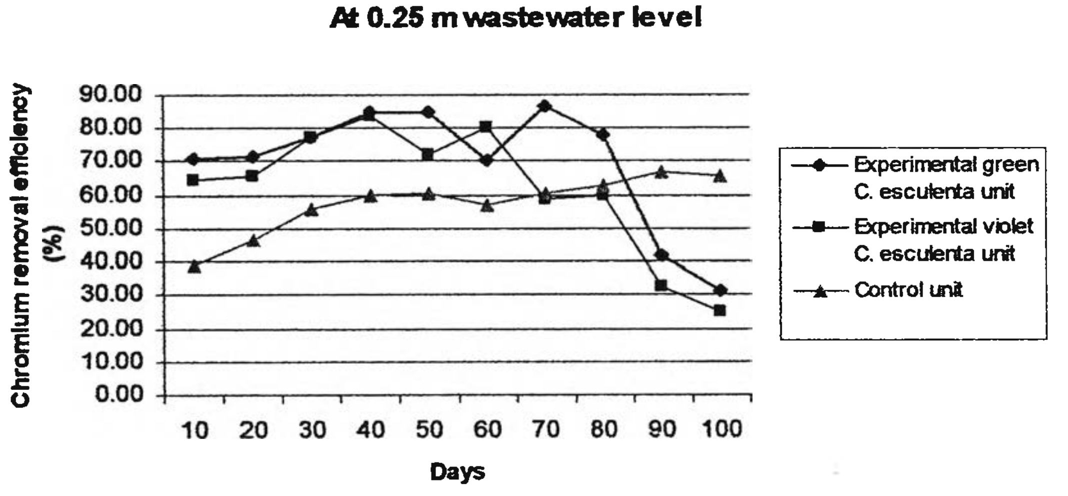
<u>At 0.15 m wastewater level</u>

Chromium removal efficiency of two experimental units (i.e. green and violet *C. esculenta*) of the constructed wetland system ranged from 35.90-79.17% and 42.50-77.78%. In the control unit was in the range of 36.67-63.16% (Table 4-3 and Figure 4-6). Nevertheless, there was no significant among the chromium removal efficiency of both experimental and control units at 95% confidence (Table 4-4).

Table 4-3 Chromium removal efficiency of constructed wetland systems (%)

Water Depths	0.15 m			0.25 m			0.35 m		
Units	Experimental		Control	Experimental		Control	Experimental		Control
	Green	Violet		Green	Violet		Green	Violet	
Days	*C. esculenta*	*C. esculenta*		*C. esculenta*	*C. esculenta*		*C. esculenta*	*C. esculenta*	
10	70.00	61.67	36.67	70.97	64.52	38.71	75.76	69.70	36.36
20	69.64	63.79	53.13	71.67	65.38	46.67	75.00	76.47	45.45
30	77.94	67.31	46.15	77.14	77.27	55.88	81.43	75.00	51.52
40	76.79	76.56	51.85	84.85	83.82	60.00	81.43	70.97	54.55
50	71.74	77.78	56.67	84.85	71.88	60.61	79.17	59.38	48.39
60	79.17	62.50	61.29	70.00	80.00	56.67	84.85	41.38	52.94
70	53.85	61.11	60.61	86.36	58.82	60.61	80.00	50.00	53.13
80	54.29	62.50	63.16	77.78	60.00	62.86	50.00	41.18	54.55
90	52.50	46.34	60.00	41.67	32.43	66.67	34.15	38.89	54.55
100	35.90	42.50	62.86	31.43	25.00	65.85	30.00	34.29	53.13
Average	**64.18**	**62.21**	**55.24**	**69.67**	**61.91**	**57.45**	**67.18**	**55.72**	**50.45**
Maximum	**79.17**	**77.78**	**63.16**	**86.36**	**83.82**	**66.67**	**84.85**	**76.47**	**54.55**
Minimum	**35.90**	**42.50**	**36.67**	**31.43**	**25.00**	**38.71**	**30.00**	**34.29**	**36.36**
SD	**14.28**	**11.15**	**8.53**	**18.60**	**19.45**	**8.70**	**20.90**	**16.45**	**5.77**





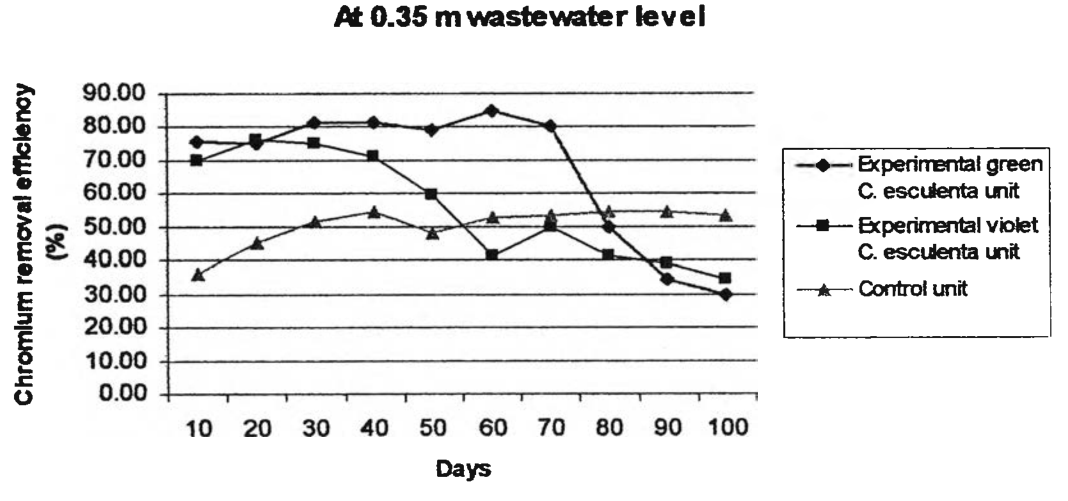


Figure 4-6 Chromium removal efficiency of constructed wetland systems

At 0.25 m wastewater level

Chromium removal efficiency of both experimental units which were green and violet *C. esculenta* of the constructed wetland system ranged from 31.43-86.36% and 25.00-83.82%. In the control unit was in the range of 38.71-66.67% (Table 4-3 and Figure 4-6). However, there was no significant among the chromium removal efficiency of both experimental and control units at 95% confidence (Table 4-4).

At 0.35 m wastewater level

In experimental units of constructed wetland system with green and violet *C. esculenta*, chromium removal efficiencies were in the range of 30.00-84.85% and 34.29-76.47%. While chromium removal efficiency of control unit ranged from 36.36-54.55 % (Table 4-3 and Figure 4-6). In spite of that there was no significant among the chromium removal efficiency of both experimental and control units at 95% confidence (Table 4-4).

Table 4-4 Mean comparison between unit types tested by one-way ANOVA on chromium removal efficiency (see Appendix C at pp.126-128)

Type of unit	Wastewater level		
	0.15 m	0.25 m	0.35 m
Experimental green *C. esculenta* unit	64.18[a]	69.67[a]	67.18[a]
Experimental violet *C. esculenta* unit	62.21[a]	61.91[a]	55.72[a]
Control unit	55.24[a]	57.45[a]	50.45[a]

Note: The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column.

Optimal wastewater level for removing chromium

The statistics analytical results of chromium removal efficiency of all units in three wastewater level revealed that wastewater level had no effective on all system efficiencies, significantly as shown in Table 4-5 and Figure 4-7 at below.

Table 4-5 Mean comparison between wastewater levels tested by one-way ANOVA on chromium removal efficiency (see Appendix C at pp.129-131)

Wastewater level	Type of unit		
	Experimental green *C. esculenta* unit	Experimental violet *C. esculenta* unit	Control unit
0.15 m	64.18[a]	62.21[a]	55.24[a]
0.25 m	69.67[a]	61.91[a]	57.45[a]
0.35 m	67.18[a]	55.72[a]	50.45[a]

Note: The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column.

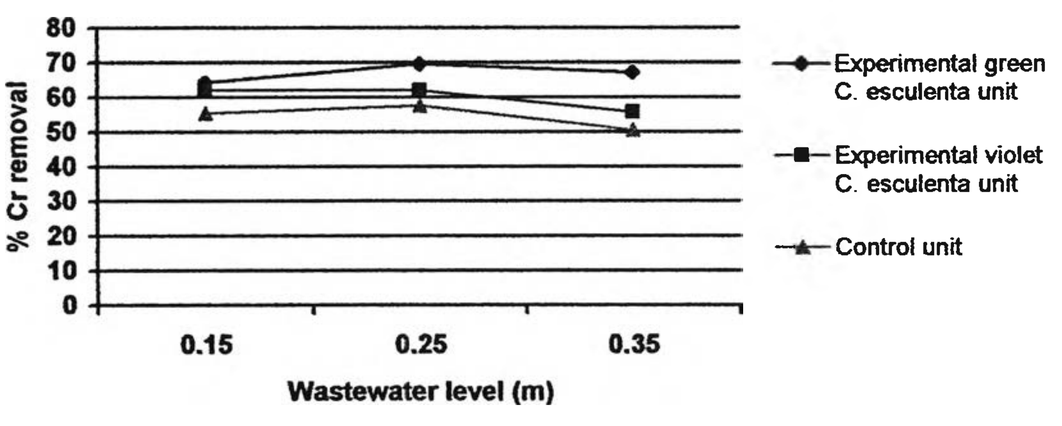


Figure 4-7 Average chromium removal efficiency of constructed wetland systems

4.3 Chromium accumulation in constructed wetland systems

Wetland soil beds property

In this study, three soil properties i.e. soil texture, soil pH, and cation exchange capacity (CEC) were measured before putting them into all constructed wetland units (as shown in Table 4-6 at below).

Table 4-6 Some properties of wetland soil beds in this study

Wetland soil property	Value
Soil texture	Sandy clay (50.96 : 7.14 : 41.90)
Soil pH	4.42
Cation exchange capacity (CEC) (cmol (+) kg^{-1})	15.00

Soil texture

From the analysis data, soil texture in this study was classed in sandy clay. Percentage of sand, silt, and clay were 50.96, 7.14, and 41.90%, respectively. The sediment type affected to rhizome proliferation and the rate of increase in plant biomass (Chambers and McComb, 1994 ref. in Kananidhinan, 1996).

Soil pH

Soil pH of wetland soil beds for this study was 4.42. At this condition, it was suitable for treating chromium in water because of the solubility of Cr (III) will decrease above pH 4 (Richard, 1991 ref. in Kananidhinan, 1996). So this property would increase efficiency of this system very well.

Cation exchange capacity (CEC)

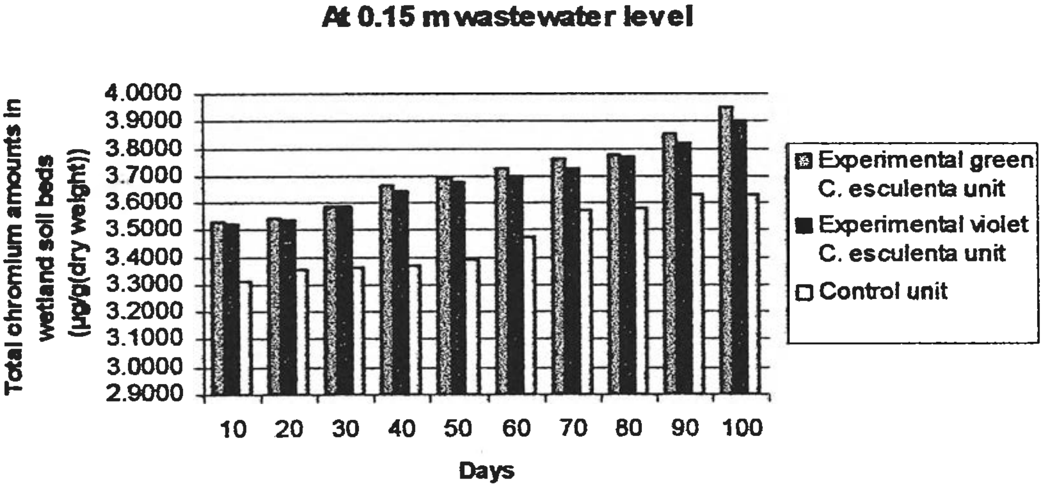
This value was the determination of adsorption reaction between soil particles and heavy metal ions. For this study, CEC of wetland soil bed was 15.00 cmol (+) kg^{-1} which tends to be moderately high (in range between 15-20 cmol (+) kg^{-1}) refer in Khieoruenrom (1990). Because of it related with soil texture that was sandy clay which had highly clay particle (41.90%). The clay particle was strong anion therefore it could trap chromium ion which was strong cation (Wilson, Schwarzer and Etonyeaku, 1986 ref. in Kananidhinan, 1996).

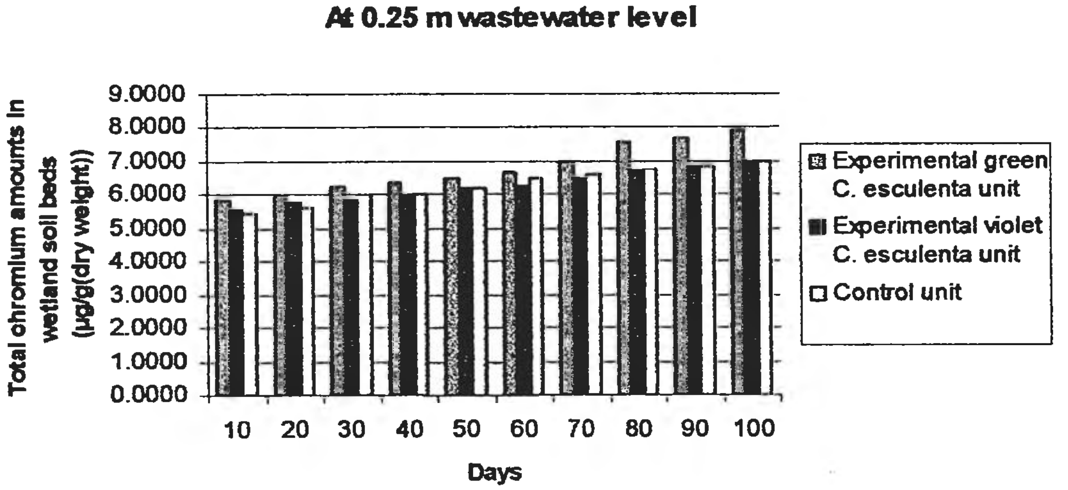
Chromium accumulation in wetland soil beds

Chromium accumulation in wetland soil beds was measured into milligram per gram of soil dry weight every 10 day along 100 days experimental period.

In experimental units of constructed wetland system with green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level, chromium accumulation were in the range of 3.5329-3.9478, 5.8467-7.9275, and 7.9978-11.9599 µg/g (dry weight), whereas chromium accumulation of experimental violet *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater ranged from 3.5217-3.8997, 5.5548-7.0035, and 7.4689-9.9856 µg/g (dry weight). For control unit, chromium accumulation at 0.15, 0.25, 0.35 m wastewater level diverged from 3.3145-3.6280, 5.4416-6.9939, and 7.2109-8.7045 µg/g (dry weight).

Figure 4-8 expressed trend of chromium accumulation in wetland soil beds in all experimental and control units. It was found that chromium accumulation in all units tended to higher along the experimental period time. Chromium accumulation in all experimental units was higher than all control units. This indicated that wetland plants in the system have impact on chromium precipitation process (heavy metals always could be complicated with dead plant materials and soil media (Reed et al., 1988)). Chromium amounts in each unit depended on chromium concentration which was remained in the unit which would show in the mass balance section.





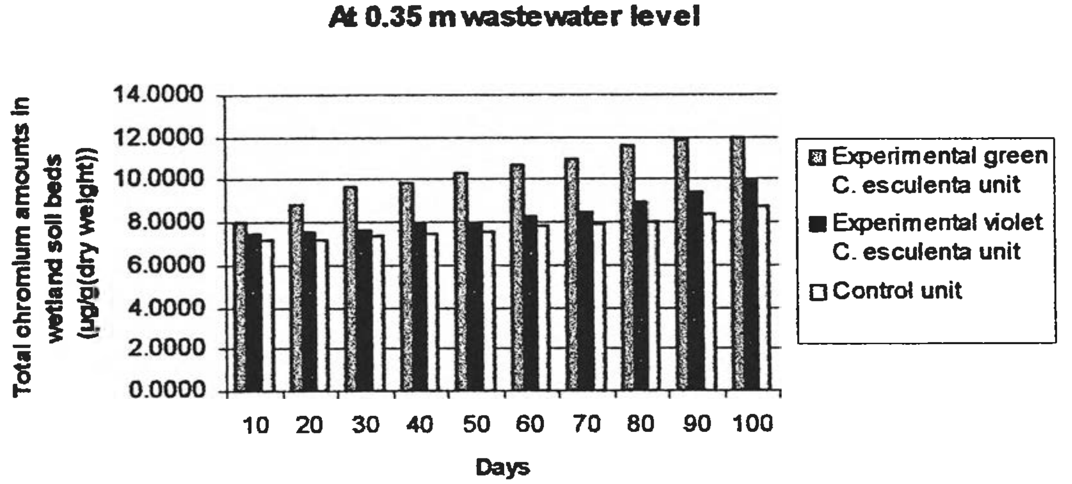


Figure 4-8 Total chromium accumulation in wetland soil beds of constructed wetland systems

Chromium accumulation in wetland plants

Chromium accumulation in wetland plant was measured into milligram per gram of plant dry weight every 10 day through 100 days experimental period.

In experimental units of constructed wetland system with green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level, chromium accumulation were in the range of 0.4853-0.5735, 0.4919-0.5248, and 0.4888-0.5328 mg/g (dry weight) while chromium accumulation of experimental violet *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater ranged from 0.4797-0.5354, 0.4755-0.5236, and 0.4752-0.5514 mg/g (dry weight).

Figure 4-9 showed trend of chromium accumulation in wetland plant in every experimental units. The value of all units seemed to slightly decrease along the experimental period and died at last. At 0.15 m wastewater level, green *C. esculenta* died at day 70, whereas violet *C. esculenta* died at day 80. At 0.25 m wastewater level, green *C. esculenta* died at day 90, while violet *C. esculenta* died at day 70. At 0.35 m wastewater level, green *C. esculenta* died at day 80, whereas violet *C. esculenta* died at day 60. The cause of this possibly was "salt stress effect" as stated.

To compare chromium accumulation in wetland plant between both types of *C. esculenta,* the statistics analytical results revealed that there were not significant difference at 95% confidence between them and wastewater had no effective against all three wastewater levels (Table 4-7).

However, from chromium accumulation in plants data showed that *C. esculenta* could assimilate chromium in very high when compared with data in the past study: Polprasert, Dan and Thayalakumaran (1996) used FWS with *Typha* for chromium removing and found that *Typha* could assimilate chromium in the range of 0.015-0.219 mg/g (dry weight)

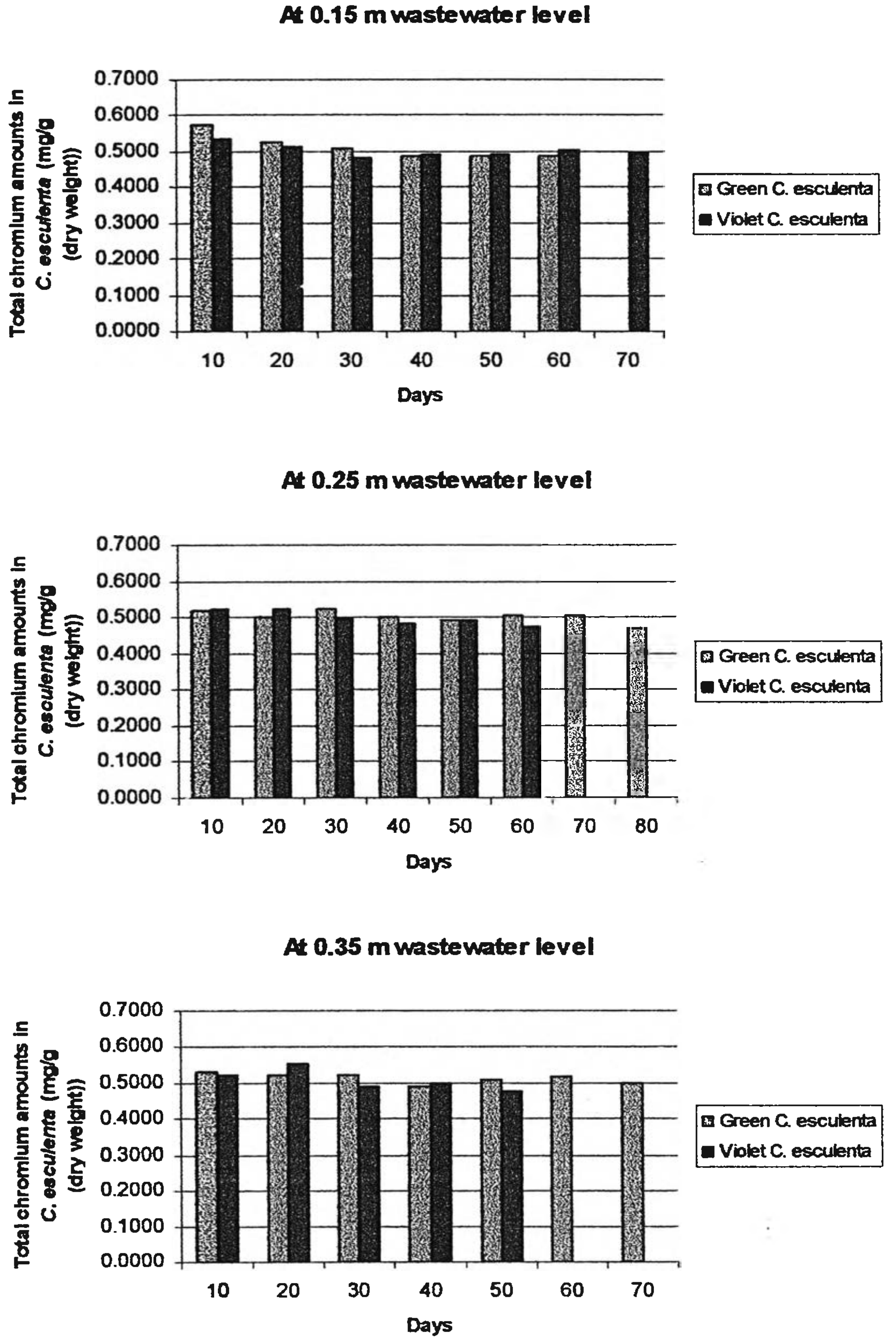


Figure 4-9 Total chromium accumulation in *Colocasia esculenta* (L.) Schott (green and violet)

Table 4-7 Mean comparison tested by one-way ANOVA and t-test on chromium accumulation in *Colocasia esculenta* (L.) Schott (see Appendix C at pp.132-134)

Type of *C. esculenta*	Wastewater level		
	0.15 m	0.25 m	0.35 m
Experimental green *C. esculenta*	$^{a}0.5105^{a}$	$^{a}0.5021^{a}$	$^{a}0.5129^{a}$
Experimental violet *C. esculenta*	$^{a}0.5006^{a}$	$^{a}0.4982^{a}$	$^{a}0.5070^{a}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same column for unit type comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same row for wastewater level comparison.

Mass balance

Mass balance was total chromium amount which was loaded in and out the system. The difference of both values was total chromium remained in the system or to be called chromium removal value. The chromium remained in the system were in two phase namely, wetland soil beds and wetland plant. For total chromium amount in influent and effluent could be calculated from chromium concentration (mg/l), flow rate (l/day), and hydraulic retention time (day) as shown in Table 4-8.

Table 4-9 showed that chromium amounts were accumulated in wetland soil beds much more than wetland plant in every wastewater level. Chromium accumulation in plant at all wastewater levels from mass balance data were higher than chromium amount data from laboratory analysis (as shown in Figure 4-10) because of many factors has occurred along operation run-time such as chromium was adsorbed by inner-concrete wall, the inconsistent of instrument especially, atomic absorption spectrophotometer and some error from chromium determination process in laboratory.

Table 4-8 Total chromium concentration in influent and effluent of constructed wetland systems (mg)

Water Depths	0.15 m.						0.25 m.						0.35 m.					
Units	Experimental Green		Experimental Violet		Control		Experimental Green		Experimental Violet		Control		Experimental Green		Experimental Violet		Control	
days	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
10	202.50	60.75	202.50	81.00	202.50	128.25	348.75	101.25	378.75	123.75	348.75	213.75	519.75	126.00	519.75	157.50	519.75	330.75
20	189.00	60.75	195.75	74.25	216.00	101.25	337.50	101.25	292.50	101.25	337.50	180.00	535.50	101.25	535.50	126.00	519.75	283.50
30	229.50	54.00	175.50	60.75	175.50	94.50	393.75	90.00	371.25	90.00	382.50	168.75	551.25	110.25	504.00	126.00	519.75	252.00
40	189.00	47.25	216.00	54.00	182.25	87.75	371.25	56.25	382.50	67.50	337.50	135.00	551.25	110.25	488.25	141.75	519.75	236.25
50	155.25	47.25	182.25	40.50	202.50	87.75	371.25	56.25	360.00	101.25	371.25	146.25	378.00	78.75	504.00	204.75	488.25	252.00
60	162.00	33.75	162.00	60.75	209.25	81.00	337.50	101.25	337.50	67.50	337.50	146.25	519.75	78.75	456.75	267.75	535.50	252.00
70	263.25	121.50	243.00	94.50	222.75	87.75	371.25	56.25	382.50	157.50	371.25	146.25	630.00	90.00	535.50	267.75	504.00	236.25
80	236.25	108.00	270.00	101.25	256.50	94.50	303.75	67.50	393.25	157.50	393.75	146.25	378.00	189.00	535.50	315.00	519.75	236.25
90	270.00	128.25	276.75	148.50	236.50	94.50	405.00	236.25	416.25	281.25	472.50	157.50	645.75	425.25	567.00	346.50	519.75	236.25
100	263.25	168.75	270.00	155.25	236.50	87.75	393.75	270.00	405.00	303.75	461.25	157.50	630.00	441.00	551.25	362.25	504.00	236.25
Average	216.00	83.03	219.38	87.08	214.03	94.50	363.38	113.63	371.95	145.13	381.38	159.75	533.93	175.05	519.75	231.53	515.03	255.15
Remain	132.98		132.30		119.53		249.75		226.83		221.63		358.88		288.23		259.88	
Maximum	270.00	168.75	276.75	155.25	256.50	128.25	405.00	270.00	416.25	303.75	472.50	213.75	645.75	441.00	567.00	362.25	535.50	330.75
Minimum	155.25	33.75	162.00	40.50	175.50	81.00	303.75	56.25	292.50	67.50	337.50	135.00	378.00	78.75	456.75	126.00	488.25	236.25
SD	42.45	45.12	42.72	38.77	25.11	13.12	31.40	76.38	35.62	83.93	49.31	22.99	94.63	139.66	32.36	92.15	12.97	30.43

Table 4-9 Average total chromium of constructed wetland systems

Wastewater level	Type of unit	Chromium amount (mg)			
		System	Soil beds (%)	Remain (%)	Net (%)
0.15 m	Experimental green *C. esculenta*	132.98	110.41 (83.03)	22.57 (16.97)	4.41 (3.32)
	Experimental violet *C. esculenta*	132.30	109.80 (82.99)	22.50 (17.01)	4.45 (3.36)
	Control	119.53	103.21 (86.35)	16.32 (13.65)	0
0.25 m	Experimental green *C. esculenta*	249.75	201.95 (80.86)	47.80 (19.14)	9.22 (3.69)
	Experimental violet *C. esculenta*	226.82	186.41 (82.18)	40.41 (17.82)	5.38 (2.37)
	Control	221.63	187.39 (84.55)	34.24 (15.45)	0
0.35 m	Experimental green *C. esculenta*	358.88	309.21 (86.16)	49.67 (13.84)	10.01 (2.79)
	Experimental violet *C. esculenta*	288.22	248.90 (86.36)	39.32 (13.64)	7.46 (2.59)
	Control	259.88	231.15 (88.95)	28.73 (11.05)	0

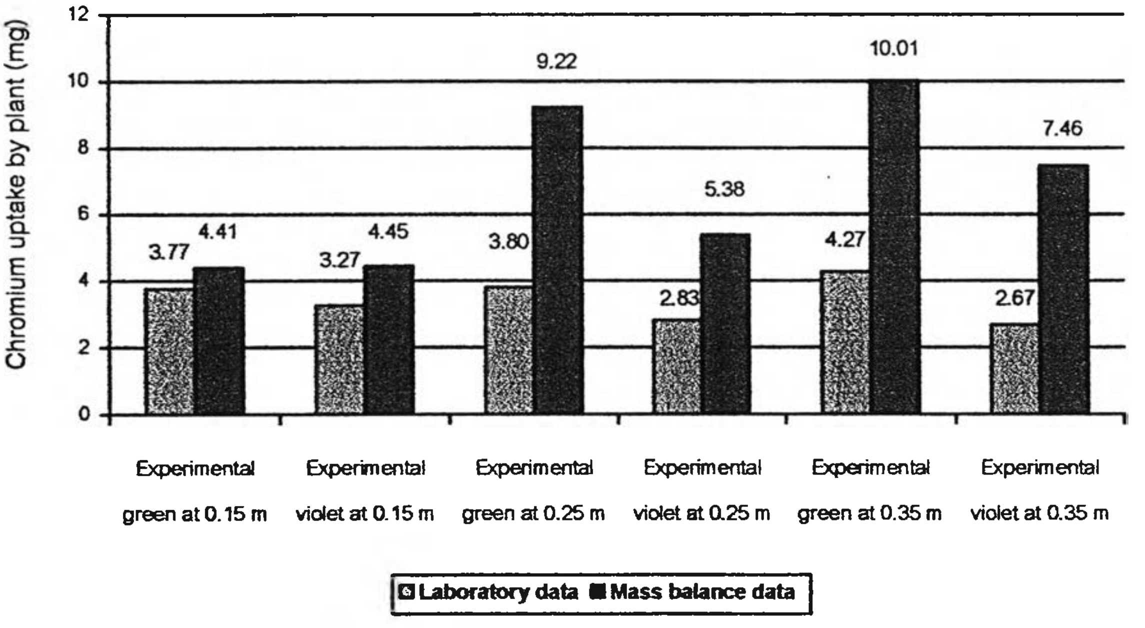


Figure 4-10 Comparing chromium accumulation in wetland plant between laboratory data and mass balance data

4.4 Chromium accumulation in various parts of *Colocasia esculenta* (L.) Schott

In this study, all plants were divided into four parts, namely lamina, petiole, corm, and root for chromium determination analysis. The amount of chromium was determined into milligram per gram dry weight (mg/g (dry weight)).

1) Chromium accumulation in various parts of green *C. esculenta*

Chromium accumulation in lamina, petiole, corm, and root of green *C. esculenta* in all experimental units at every wastewater level (0.15, 0.25 and 0.35 m) were in the range of 0.0750-0.0870, 0.0575-0.0655, 0.1050-0.1290, and 0.2150-0.3120 mg/g (dry weight), respectively.

Figure 4-11 showed trend of chromium accumulation in all parts of green *C. esculenta* in each experimental unit during experimental period. Chromium accumulations of all parts of plant in every wastewater level were likely steady until plant dead occurred and seemed to the part that could accumulate chromium at most was root which was tested by statistical analysis method to confirm this result.

The statistical analysis results revealed that among four parts of green *C. esculenta* in all experimental units at every wastewater level, chromium accumulation in root was the most and the next were corm, lamina and petiole, respectively and there were no significant difference of chromium accumulation between all wastewater levels in each part of plant (see Table 4-10).

Table 4-10 Mean comparison tested by one-way ANOVA on chromium accumulation in parts of *Colocasia esculenta* (L.) Schott (green) (see Appendix C at pp.135-145)

Parts of green *C. esculenta*	Wastewater level		
	0.15 m	0.25 m	0.35 m
Lamina	$^{a}0.0796^{a}$	$^{a}0.0805^{b}$	$^{a}0.0829^{b}$
Petiole	$^{a}0.0607^{a}$	$^{a}0.0619^{a}$	$^{a}0.0609^{a}$
Corm	$^{a}0.1131^{c}$	$^{a}0.1228^{c}$	$^{a}0.1137^{c}$
Root	$^{a}0.2575^{d}$	$^{a}0.2469^{d}$	$^{a}0.2554^{d}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same row for water level comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column for part of plant comparison.

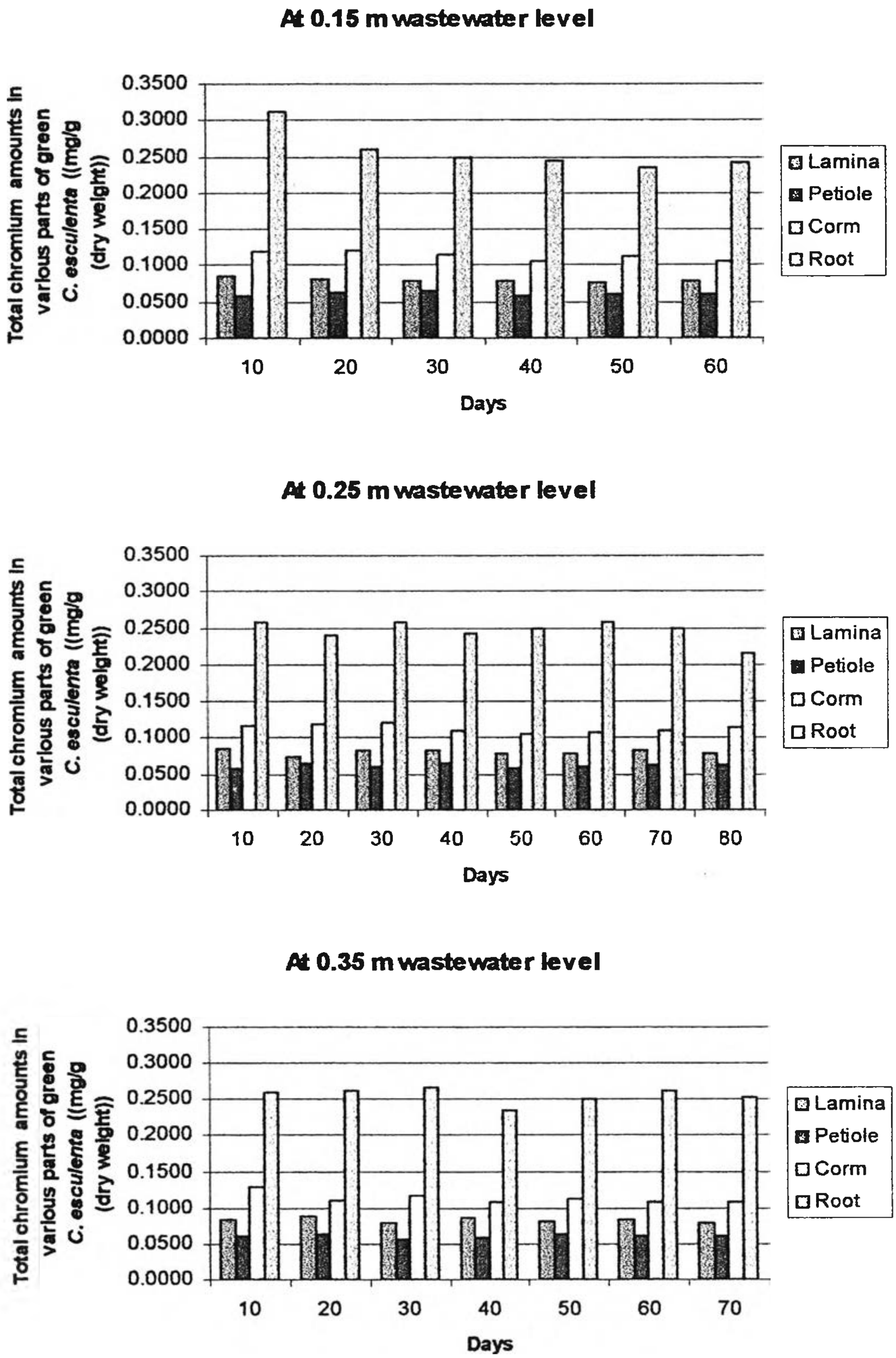


Figure 4-11 Total chromium accumulation in various parts of *Colocasia esculenta* (L.) Schott (green)

From the statistical analysis results, it was found that root was the best tissue for chromium accumulation. These results were expected because of the close contact between the roots' surface and the toxic compound which were same as the past research of Polprasert, Dan and Thayalakumaran (1996) in the topic "Application of constructed wetlands to treat some toxic wastewaters under tropical conditions".

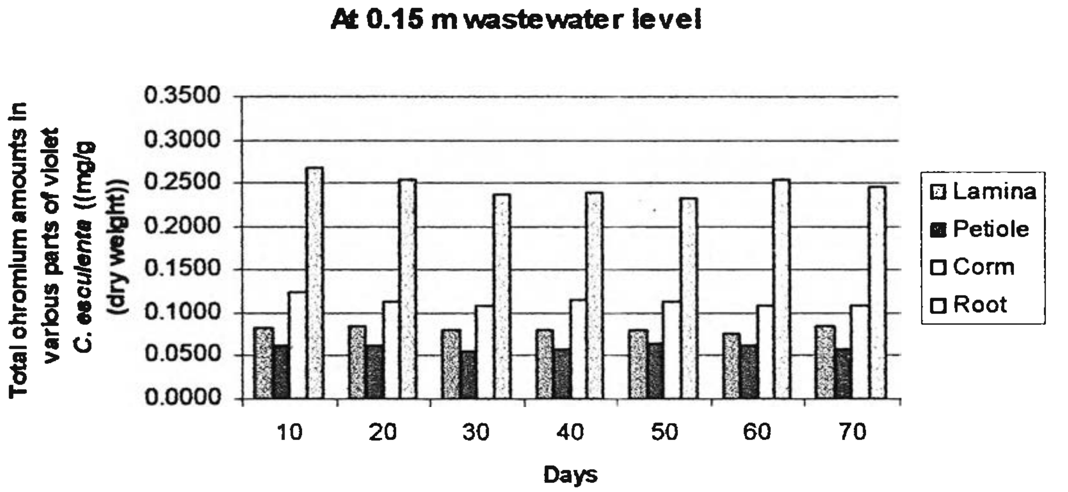
At 0.15 m wastewater level, average chromium amount in root was more than lamina, petiole and corm into percentage 52.77, 61.85 and 38.96%, respectively. At 0.25 m wastewater level, chromium amount in root was more than lamina, petiole and corm 50.82, 59.91 and 33.57%, respectively. At 0.35 m wastewater level, chromium amount in root was more than lamina, petiole and corm 50.99, 61.49 and 38.39%, respectively.

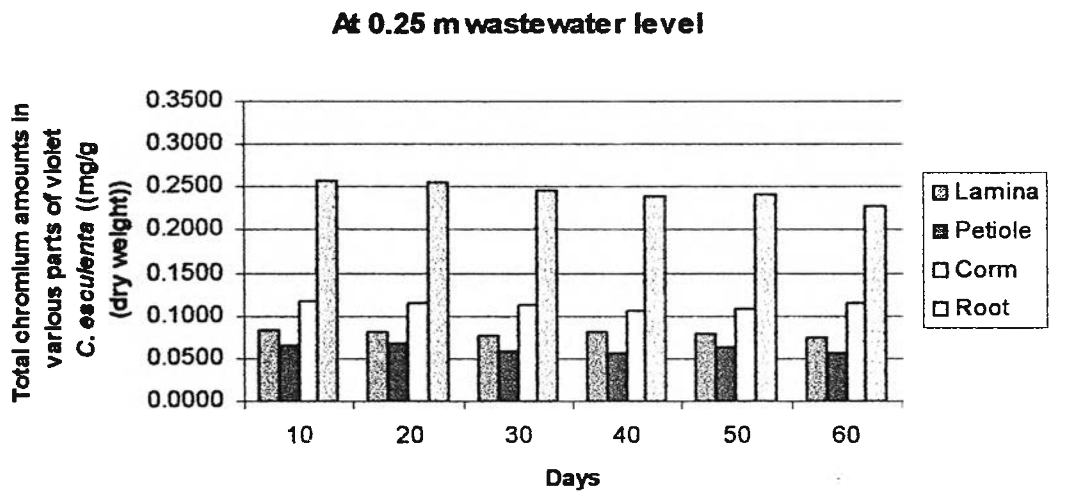
2) Chromium accumulation in various parts of violet *C. esculenta*

Chromium accumulation in lamina, petiole, corm, and root of violet *C. esculenta* in all experimental units at every wastewater level (0.15, 0.25 and 0.35 m) ranged from 0.0740-0.0843, 0.0555-0.0678, 0.1020-0.1300, and 0.2270-0.2880 mg/g (dry weight), respectively.

Figure 4-12 showed trend of chromium accumulation in all parts of violet *C. esculenta* in each experimental unit during experimental period. The trend was same as green *C. esculenta* that was chromium accumulations of all parts of plant in every wastewater level were likely constant until plant dead occurred and appeared to part that could accumulate chromium at most was root which was tested by statistical analysis method to confirm this result.

The statistics analytical results revealed that among four parts of violet *C. esculenta* in all experimental units at every wastewater level, chromium accumulation in root was the most and the next were corm, lamina and petiole, respectively and there were no significant difference of chromium accumulation between all wastewater levels in each part of plant (see Table 4-11).





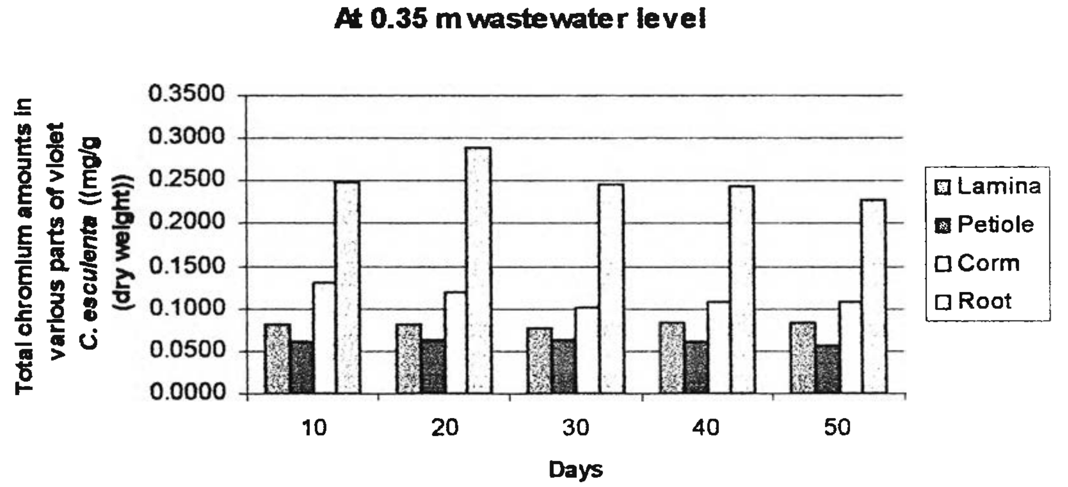


Figure 4-12 Total chromium accumulation in various parts of *Colocasia esculenta* (L.) Schott (violet)

Table 4-11 Mean comparison tested by one-way ANOVA on chromium accumulation in parts of *Colocasia esculenta* (L.) Schott (violet) (see Appendix C at pp.135-145)

Parts of violet *C. esculenta*	Wastewater level		
	0.15 m	0.25 m	0.35 m
Lamina	$^{a}0.0806^{b}$	$^{a}0.0793^{b}$	$^{a}0.0813^{a}$
Petiole	$^{a}0.0600^{a}$	$^{a}0.0613^{a}$	$^{a}0.0608^{a}$
Corm	$^{a}0.1129^{c}$	$^{a}0.1127^{c}$	$^{a}0.1138^{c}$
Root	$^{a}0.2471^{d}$	$^{a}0.2450^{d}$	$^{a}0.2512^{d}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same row for water level comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column for plant type comparison.

In the same way of green *C. esculenta* results, root of violet *C. esculenta* was the best tissue for chromium accumulation with the same reason that was the close contact between the roots' surface and the toxic compound.

At 0.15 m wastewater level, average chromium amount in root was more than lamina, petiole and corm into percentage 50.81, 60.92 and 37.28%, respectively. At 0.25 m wastewater level, chromium amount in root was more than lamina, petiole and corm 51.09, 59.97 and 36.99%, respectively. At 0.35 m wastewater level, chromium amount in root was more than lamina, petiole and corm 51.09, 61.03 and 37.64%, respectively.

4.5 The growth rate of *Colocasia esculenta* (L.) Schott in constructed wetland systems

During experimental period, the growth rate of *Colocasia esculenta* (L.) Schott was recorded into fresh weight, dry weight and length of petioles. In grove production, the petiole of experimental green *C. esculenta* could be developed and spouted out from its corm as well at 0.25 m wastewater level, whereas experimental violet *C. esculenta* could grow well in 0.15 m wastewater level unit.

To compare with plant-observed units, it was found that plant-observed green *C. esculenta* could be developed and spouted out from its corm as well at 0.35 m wastewater level, while plant-observed violet *C. esculenta* could grow well at 0.15 m wastewater level.

Fresh weight

For fresh weight of both plants, all parts of *C. esculenta* consisting of lamina, petiole, corm, and root were consecutively weighted in total through the experimental periods into gram (g).

Concerning on experimental green and violet *C. esculenta*, total fresh weight of plants growing under all wastewater level conditions tended to decrease through out the experimental period and died at last. These were quite opposite to trend of plant in all plant-observed units which increased continually as shown in Figure 4-13. Particularly, plant-observed green *C. esculenta* could grow very well in this condition.

However, total fresh weight of green *C. esculenta* in experimental units at 0.15, 0.25, and 0.35 m wastewater level ranged from 96.4898-238.6072, 48.0778-186.8760, and 110.6910-235.2233 g., respectively, whereas violet *C. esculenta* in experimental units at 0.15, 0.25, and 0.35 m wastewater level were in the range of 90.9146-150.3991, 88.1365-165.0164, and 60.2844-184.8613 g., respectively.

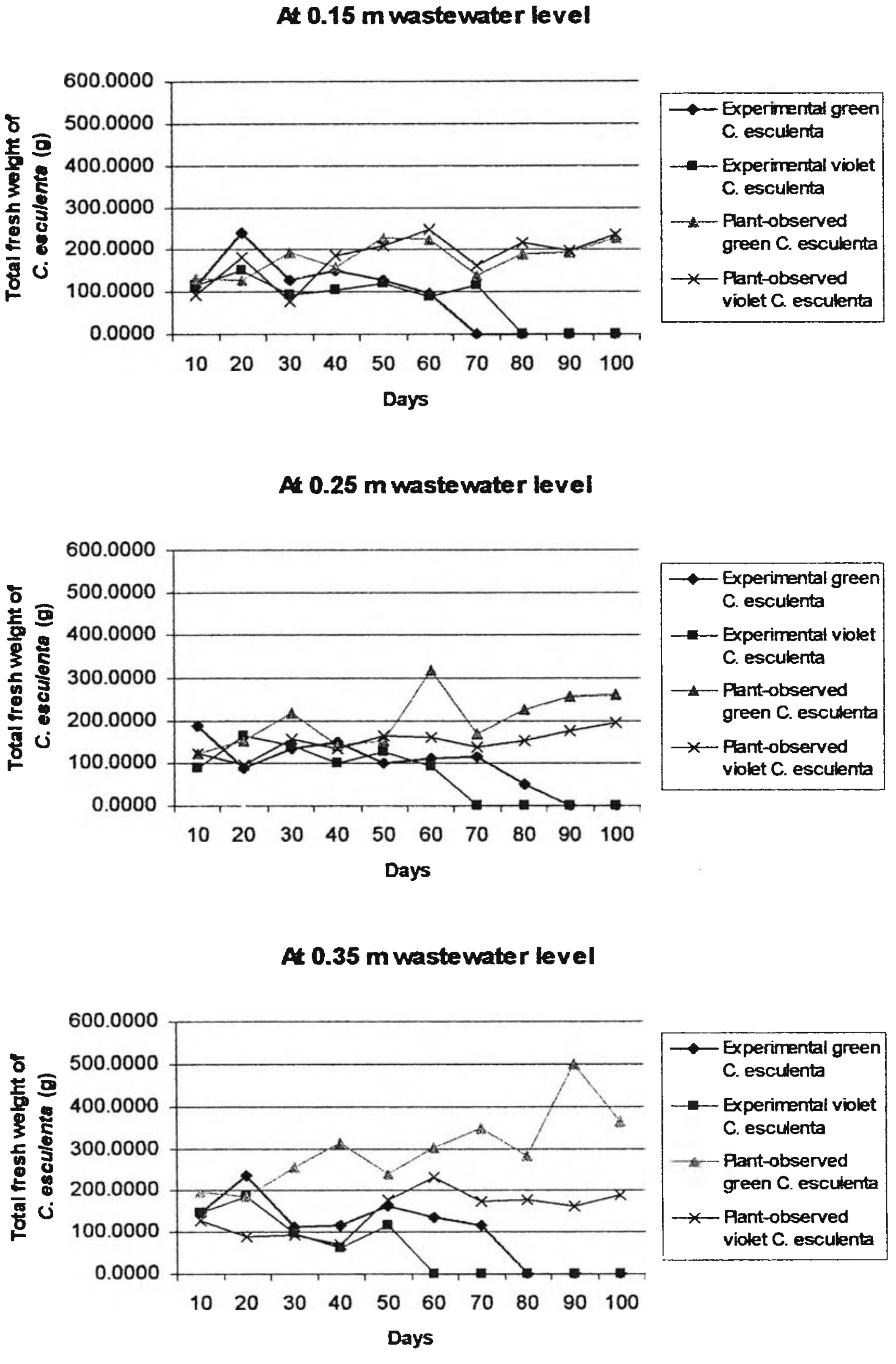


Figure 4-13 Total fresh weight of *C. esculenta* in constructed wetland systems

Total fresh weight of plant-observed green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level ranged from 128.9809-228.2297, 121.3547-317.9952, and 187.0122-497.7211 g., respectively. While total fresh weight of violet *C. esculenta* in plant-observed units at 0.15, 0.25, and 0.35 m wastewater level were in the range of 77.0098-248.9191, 94.8632-195.1125, and 68.4829-233.0513 g., respectively.

The statistics analytical results revealed that water level had no significantly effected on total fresh weight. On the contrary, plant type has effected significantly on total fresh weight between experimental and plant-observed types (Table 4-12).

Table 4-12 Mean comparison tested by one-way ANOVA on total fresh weight of *Colocasia esculenta* (L.) Schott in constructed wetland systems (g) (see Appendix C at pp.146-153)

Types		Water level		
		0.15 m	0.25 m	0.35 m
Experimental	green *C. esculenta*	$^{a}84.9581^{a}$	$^{a}92.8074^{a,b}$	$^{a}102.6066^{a}$
	violet *C. esculenta*	$^{a}79.3074^{a}$	$^{a}71.3201^{a}$	$^{a}60.5041^{a}$
Plant-observed	green *C. esculenta*	$^{a}181.4569^{b}$	$^{a}201.7136^{c}$	$^{b}298.2636^{b}$
	violet *C. esculenta*	$^{a}180.9990^{b}$	$^{a}149.3428^{b,c}$	$^{a}149.6970^{a}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same row for water level comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column for plant type comparison.

All experimental *C. esculenta* died before finishing system operation possibly because of the phenomenon as call "salt stress effect" which is defined "high salt concentrations in the rhizosphere generate stress through water deficits and ion-toxicity" (Hopkins, 1995). Salt ions were generated from hide preservative process and passed into the constructed wetland system through the influent.

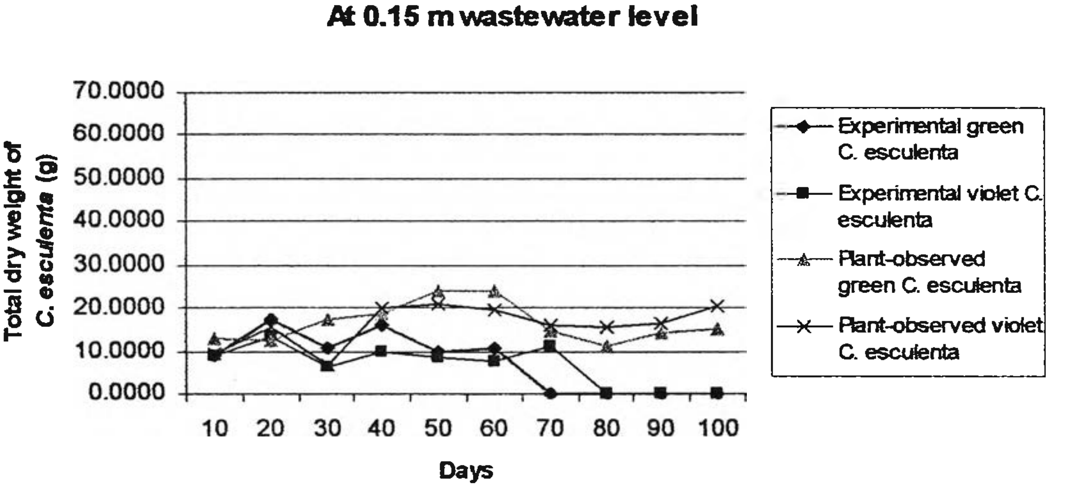
Dry weight

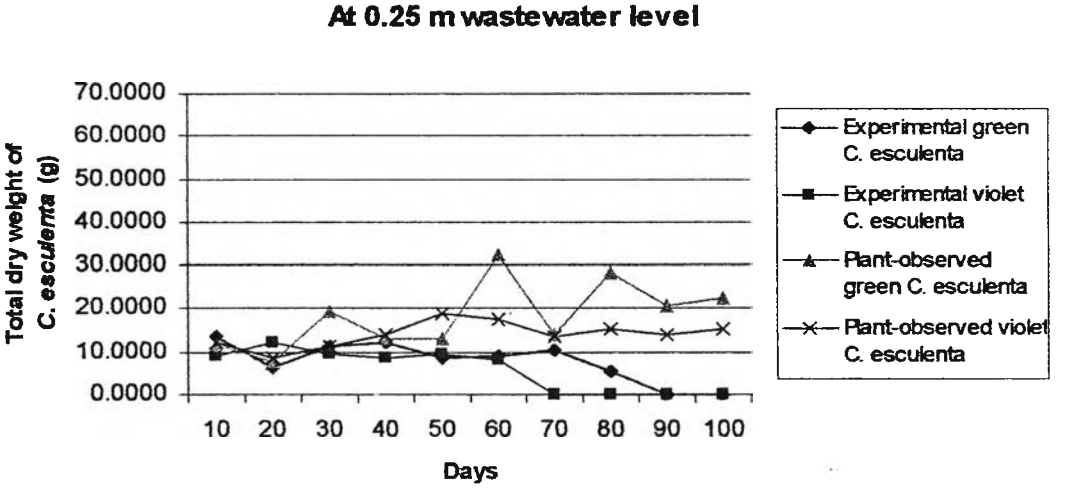
For dry weight of both plants, all parts of *C. esculenta* consisting of lamina, petiole, corm, and root were consecutively weighted in total through the experimental periods into gram (g).

Consider to experimental green and violet *C. esculenta*, total dry weight of plant growing under all wastewater level tended to decrease along the experimental period and died at last. In contrast, total dry weight of both *C. esculenta* in plant-observed units tended to perpetually increase; especially, plant-observed green *C. esculenta* at 0.35 m wastewater level could grow very well in this condition (Figure 4-14).

Total dry weight of experimental green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level diverged from 8.8518-17.5618, 5.4509-13.4084, and 9.1087-17.0874 g., respectively. While total dry weight of experimental violet *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level ranged from 6.3249-13.4118, 8.1554-12.2571, and 5.0011-16.9066 g., respectively.

Total dry weight of plant-observed green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level diverged from 11.1564-23.9807, 7.6551-32.1613, and 17.9116-59.6233 g., respectively, whereas total dry weight of plant-observed violet *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level ranged from 6.5755-20.8048, 6.7126-18.9094, and 7.6552-22.7230 g., respectively.





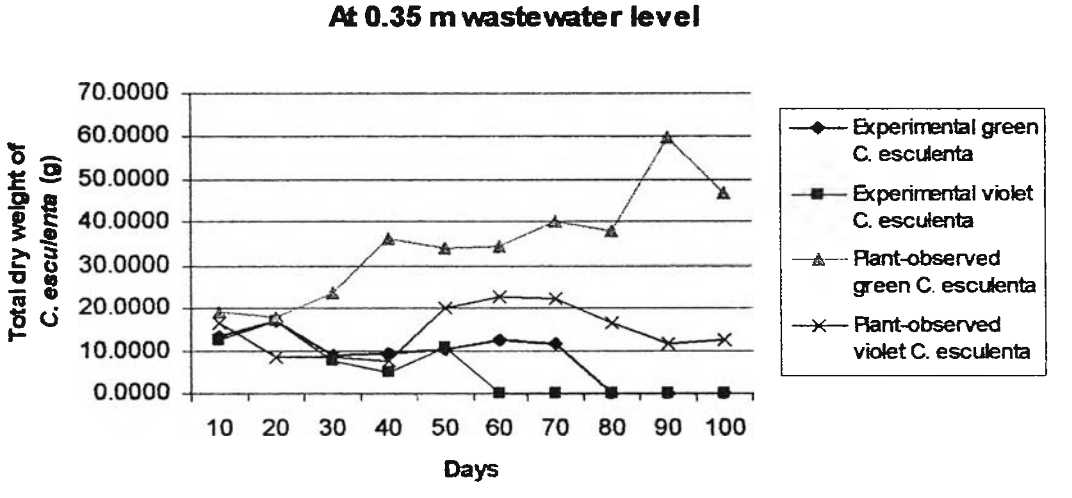


Figure 4-14 Total dry weight of *C. esculenta* in constructed wetland systems

The statistical analysis revealed that water level had no significantly effected on total dry weight as same as total fresh weight. In contrast, plant type had effected significantly on total dry weight between experimental and plant-observed types (see in Table 4-13).

Table 4-13 Mean comparison tested by one-way ANOVA on total dry weight of *Colocasia esculenta* (L.) Schott in constructed wetland systems (see Appendix C at pp.154-161)

Types		Water level		
		0.15 m	0.25 m	0.35 m
Experimental	green *C. esculenta*	$^{a}7.3849^{a}$	$^{a}7.5702^{a,b}$	$^{a}8.3175^{a}$
	violet *C. esculenta*	$^{a}6.5357^{a}$	$^{a}5.6831^{a}$	$^{a}5.2568^{a}$
Plant-observed	green *C. esculenta*	$^{a}16.4352^{b}$	$^{a}18.1839^{c}$	$^{b}34.9304^{b}$
	violet *C. esculenta*	$^{a}16.0928^{b}$	$^{a}14.0029^{b,c}$	$^{a}14.7323^{a}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same row for water level comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column for plant type comparison.

In the same way of total fresh weight results, all experimental *C. esculenta* died before finishing process possibly due to the same phenomenon was called “salt stress effect”. Salt ions were generated from hide preservative process and to be passed into the constructed wetland system through the influent.

Length of petioles

Length of petioles of both plants was consecutively measured in total through out the experimental periods into centimeter (cm).

Concerning on experimental green and violet *C. esculenta*, length of both petioles at all wastewater level tended to decrease along the experimental period and plants were died at last. On the contrary, length of both *C. esculenta* in plant-observed units tended to stable along the period time (as shown in Figure 4-15). This could be explained that *C. esculenta* would drop its petioles during growing up process by nature. Then, length of its petioles would not be changed much.

Length of petioles of experimental green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level diverged from 46.15-52.85, 31.00-52.40, and 31.00-76.20 cm, respectively. While length of petioles of experimental violet at 0.15, 0.25, and 0.35 m wastewater level ranged from 26.00-54.63, 43.45-60.03, and 53.35-70.98 cm, respectively.

Length of petioles of plant-observed green *C. esculenta* at 0.15, 0.25, and 0.35 m wastewater level diverged from 48.97-76.85, 50.20-72.60, and 58.94-77.80 cm, respectively. Whereas length of petioles of experimental violet at 0.15, 0.25, and 0.35 m wastewater level ranged from 47.59-64.50, 51.25-70.95, and 52.32-96.43 cm, respectively.

The statistical analysis revealed that water level had not significantly effected on length of petioles. On the other hand, plant type had effected significantly on length of petioles between experimental and plant-observed types (see in Table 4-14).

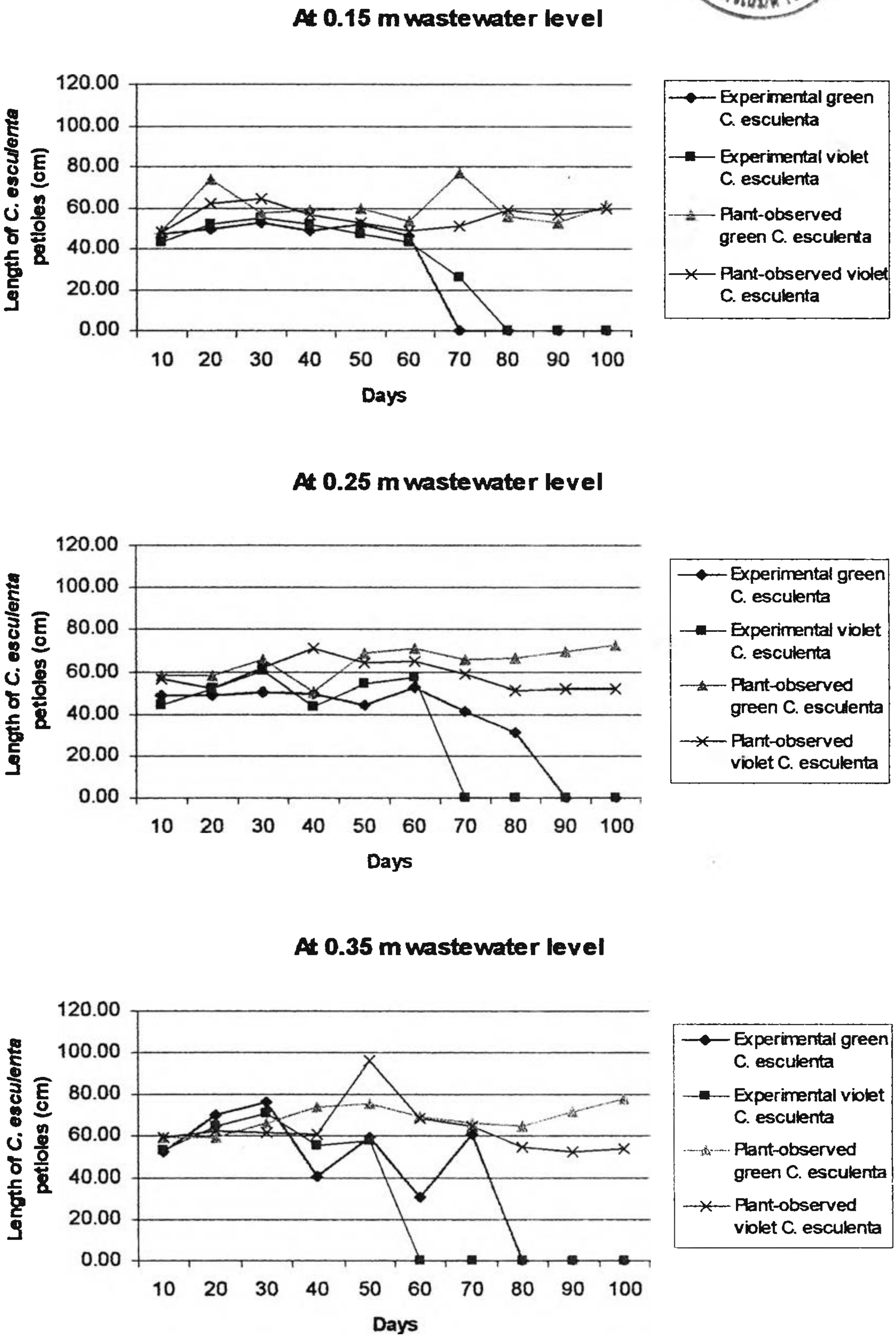


Figure 4-15 Length of *C. esculenta* petioles in constructed wetland systems

Table 4-14 Mean comparison tested by one-way ANOVA on length of petioles of *Colocasia esculenta* (L.) Schott in constructed wetland systems (see Appendix C at pp.162-169)

Types		Water level		
		0.15 m	0.25 m	0.35 m
Experimental	green *C. esculenta*	${}^{a}29.6210^{a}$	${}^{a}36.6160^{a,b}$	${}^{a}38.9410^{a,b}$
	violet *C. esculenta*	${}^{a}31.7070^{a}$	${}^{a}31.1380^{a}$	${}^{a}30.1990^{a}$
Plant-observed	green *C. esculenta*	${}^{a}59.9170^{b}$	${}^{a}64.5780^{c}$	${}^{a}68.3000^{b}$
	violet *C. esculenta*	${}^{a}55.7520^{b}$	${}^{a}58.3860^{b,c}$	${}^{a}63.3440^{b}$

Note: The same alphabet on the left corner means that there is not significant difference at 95% confidence interval within the same row for water level comparison.

The same alphabet on the right corner means that there is not significant difference at 95% confidence interval within the same column for plant type comparison.

All experimental *C. esculenta* died before finished operation period possibly because of the phenomenon “salt stress effect” too. Salt ions were generated from hide preservative process and passed into the constructed wetland system through the influent.