CHAPTER IV

RESULTS AND DISCUSSION

Physical and Chemical Parameters

pH

During the experimental period, pH of influent in constructed wetland systems that contained 0.15 m wastewater depth were in the range of 6.7-9.9. The pH values of influent of 0.30 m and 0.45 m wastewater depth in systems ranged from 6.5-10.4 and 6.5-10.9, respectively. Effluent pH values of 0.15 m, 0.30 m and 0.45 m wastewater depth in all constructed wetland systems were in the ranged of 7.0-10.1, 6.3-10.1 and 6.5-10.9, respectively.

pH of effluent also increased due to the presence of algal cells consuming CO_2 and bicarbonate, and producing hydroxyl ions. In no plant systems, effluent pH values were more increased to higher than in Eleocharis dulcis (spikerush) and Cyperus corymbosus (chufa) systems. These results agree with a previous study by Dan (1993) who found that plant growth created thick canopy of leaves and preventing sun light from reaching the water layer. Concurrently, plant uptook most nutrients present in aquatic environment. Therefore phytoplankton growth was later on inhibited.

Temperature

Constructed wetland systems with spikerush and chufa had lower ambient temperature than the system with no plant (Figure 4.1). The difference of water temperature among the systems with no plant was about 1-6 °C in the day time. There was some algal growth in no plant systems with 0.30 m and 0.45 m

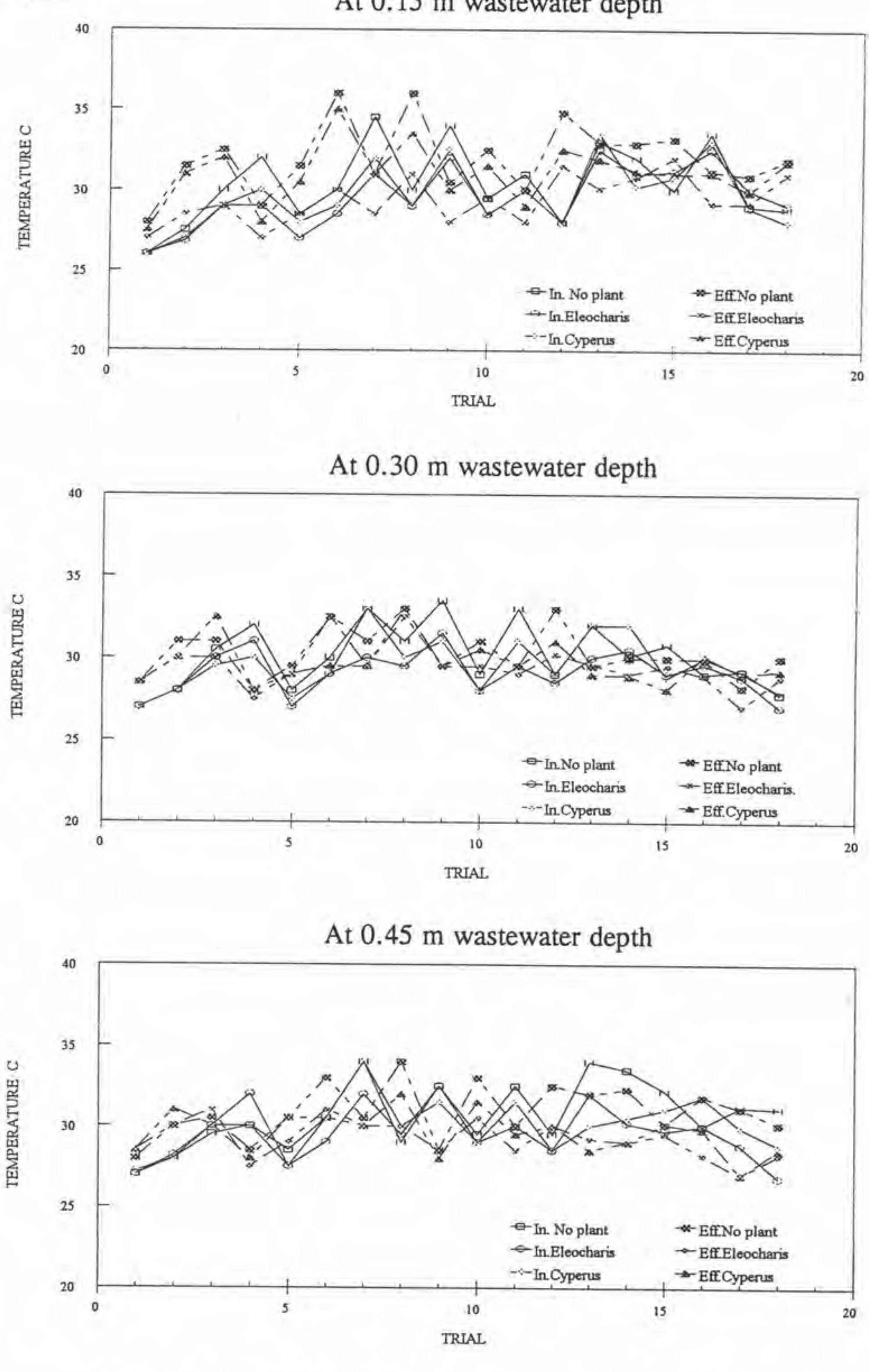

Figure 4.1 Temperature of influent and effluent wastewater in constructed wetland systems

wastewater depth, therefore the pH rose to above 9 during daytime (Appendix A : Table A-9).

Dissolved Oxygen (DO)

DO of influent and effluent in every constructed wetland systems varied as shown in Figure 4.2. In the three no plant systems with varied wastewater depths, average DO of the effluent were often lower than influent when compared to the constructed wetland systems with spikerush or chufa. Those DO of effluent were always higher than DO of influent. DO could be replenished largely by atmospheric reaeration, where oxygen is transported from the air into the water turbulence at the air-water interface, and by few photosynthesis organisms (such as algae and aquatic plants) convert CO_2 (or alkalinity of water) to organic matter with a consequent production of oxygen (Novotny and Olem, 1993).

Soil Texture

The average soil texture in every constructed wetland systems in this study were loamy sands and sands. Percentage of sand, silt and clay are shown in Table 4.1. Loamy sands were classed in the sandy soils category which were coarse-textured soils (10-15 % clay, 70-85 % sand and 85-100 % silt). In 0.15 m wastewater depth systems with spikerush and chufa contained gravel, stone, or other coarse fragments that are larger than the size of sand grains. As depicted in Table b-2, coarse sand has moderate surface area to support the biofilm (aerobic bacteria and associated animals/ plants/ fungi) which treat the sewage (Hiley, 1995).

The plants in these constructed wetland systems grew well probably due to the soil-type, loamy sands. In agreement with Chambers and McComb (1994), the present study found that sediment type also affected rhizome proliferation and the rate of increase in plant biomass. Plant survival, as measured by decreasing in a sand/clay mix and in clay. In addition, wetland plants grew well because of derivative fertile nutrient from wastewater.

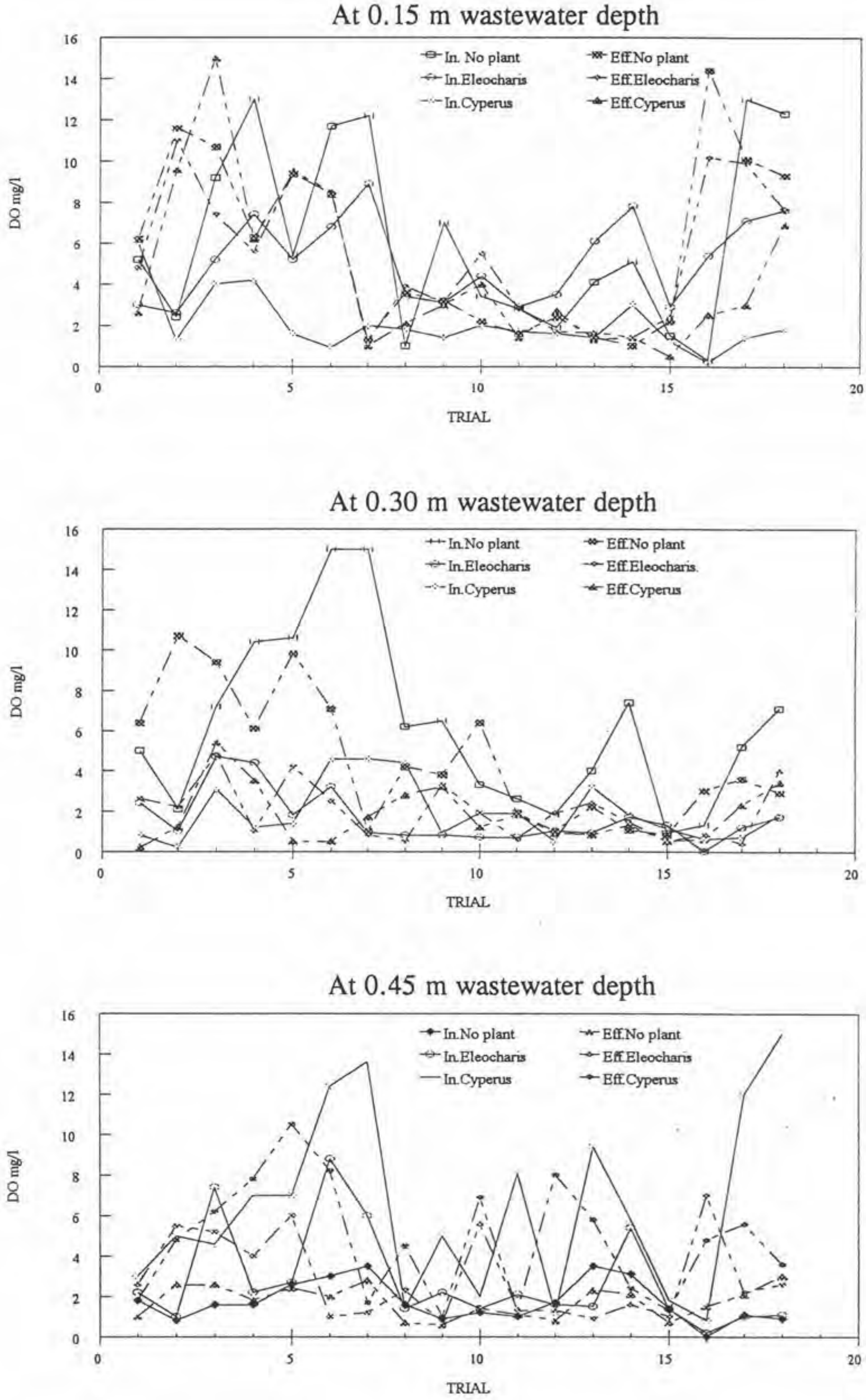

Figure 4.2 DO of influent and effluent in constructed wetland systems

Table 4.1 Soil texture

Wetland system	Sand (%)	Silt (%)	Clay (%)	Texture class
0.15 m Noplant	84.15	7.80	8.05	Loamy sand
0.15 m Eleocharis dulcis	82.51	10.02	7.47	Loamy sand
0.15 m Cyperus corymbosus	81.38	9.81	8.81	Loamy sand
0.30 m Noplant	84.69	9.02	6.29	Loamy sand
0.30 m Eleocharis dulcis	84.69	8.93	6.38	Loamy sand
0.30 m Cyperus corymbosus	83.03	10.59	6.38	Loamy sand
0.45 m Noplant	89.19	6.78	4.03	Sand
0.45 m Eleocharis dulcis	86.69	8.81	4.50	Loamy sand
0.45 m Cyperus corymbosus	88.60	8.11	3.29	Sand
0.15 m Eleocharis dulcis Cyperus corymbosus	87.60	7.78	4.62	Loamy sand
0.30 m Eleocharis dulcis Cyperus corymbosus	90.24	6.00	2.83	Sand
0.45 m Eleocharis dulcis Cyperus corymbosus	87.24	9.14	3.62	Sand

Plant Height

In these constructed wetland systems, plant height growth were measured to study plants growth in the differences of water depths, 0.15 m, 0.30 m and 0.45 m depth. Spikerush and chufa were lifted from the field nearby Sakol Nakorn Fisheries station and then replanted into the constructed wetland systems. As depicted in Table 4.2, average plants height were categoried by depths and plant types.

The plant height of spikerush in 0.15 m, 0.30 m and 0.45 m water depth were significantly difference. Spikerush in 0.45 m water depth were higher than those in 0.30 m and 0.15 m water depth, respectively (Table 4.3). Conversely, there were no significant differences between chufa height in the three water depths. As previous study have shown, this study confirmed that plant height in deep water always higher than in shallow water because they have to compete to reach for sunlight most. Furthermore, they grew and enlarged by spreading roots and rhizomes to surrounding area and increased their stems'height. Their density increased almost 100 % from the initial planting and increased following their life cycle. Spikerush grew and died by their life and the new stems shoot to success the old/died ones.

The plant stems filtered and reduced some particles in water. When they died, they acted as net that filtered some filthy. They reduced flow rate inflow and they could induce particles accumulated or precipitated in the systems. Moreover, died stems provided sites for filtration and adsorption of suspended solids and the growth of microbial communuties that sequester nutrients from the water column.

Plant height related to nutrients removal capacity in constructed wetlands. It is evidenced that plant has much efficiency for nutrients removal, thus plant's age and growth affected against the efficiency of constructed wetlands for nutrients removal.

Table 4.2 Average plants height (cm.) at three wastewater depths

Depth	0.15 m		0.30 m		0.45 m	
Trial	Eleocharis dulcis	Cyperus corymbosus	Eleocharis dulcis	Cyperus corymbosus	Eleocharis dulcis	Cyperus corymbosus
18/07/95	58.00	54.30	54.80	50.70	66.00	52.20
28/07/95	67.80	72.60	68.80	83.50	91.65	101.90
07/08/95	73.20	111.10	85.30	117.60	111.00	131.50
17/08/95	94.60	133.70	97.00	143.20	132.60	153.50
27/08/95	91.30	160.10	95.10	154.50	143.00	176.20
06/09/95	93.50	162.30	97.30	159.20	143.80	178.50
16/09/95	83.60	160.00	90.90	159.20	131.50	179.60
26/09/95	82.80	165.80	90.80	165.30	121.80	186.00
06/10/95	92.30	169.00	94.60	169.80	132.60	190.30
16/10/95	86.30	168.30	97.40	173.90	135.00	192.70

Table 4.3 Mean comparison tested by ANOVA (one-way) on plant height in various wastewater depths.

Wastewater depth (m.)	Species	
	Eleocharis dulcis	Cyperus corymbosus
0.15	82.34 ± 12.29^{a}	135.64 ± 42.35^{a}
0.30	87.20 ± 14.29^{a}	137.69 ± 41.18^{a}
0.45	120.90 ± 24.87^{b}	154.21 ± 46.19^{a}

Note : The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same column.

Wastewater Quality

BOD Removal

At 0.15 m Wastewater Depth

BOD of influent were in the range of 2.10-14.70 mg/l. BOD of effluent were ranged from 1.09-5.18 mg/l. Figure 4.3 illustrates that BOD of influent of no plant system at 0.15 m wastewater depth were fluctuated. In early trials, BOD of influent were low at 2.10-10.69 mg/l and the BOD of effluent were 1.09-5.18 mg/l. On the contrary,BOD of influent of the last trials were increased because there was heavy rain in the early trials and was less in the late trials. The average efficiency of this system for BOD removal was 54.59 %.

In constructed wetland system with spikerush, BOD of influent fluctuated in the range of 2.19-10.62 mg/l, BOD of effluent were 1.16-4.44 mg/l. Efficiencies of this system ranged from 22.22-77.29 % and its average efficiency was 62.68 %.

In constructed wetland system with chufa, BOD of influent and effluent were in the range of 2.61-14.70 and 1.40-4.77 mg/l, respectively. Its average efficiency was 59.56 %, while its efficiency ranged from 26.44-83.96 %.

Comparing of BOD removal of the three systems, it was found that the efficiency of no plant system was lower and rather fluctuated than the efficiencies of system with spikerush and with chufa. Average efficiencies of system with the chufa was best, the second was the system with spikesush and the lowest average efficiency was system with no plant. The reason for all of these was due to some physical factors and soil-biological factors that have partition for treating wastewater follow by distance and time in natural condition (self-purification). Wastewater in 0.15 m wastewater depth system derived the sunlight throughout the system and oxygen dissolved well into wastewater. So, organisms in soil and water could better degraded organic substance in wastewater. For system with plants, their efficiencies were better than system with no plant because plants tend to absorb some organic substances for their growth and plants helps wastewater to circulate well in the system.

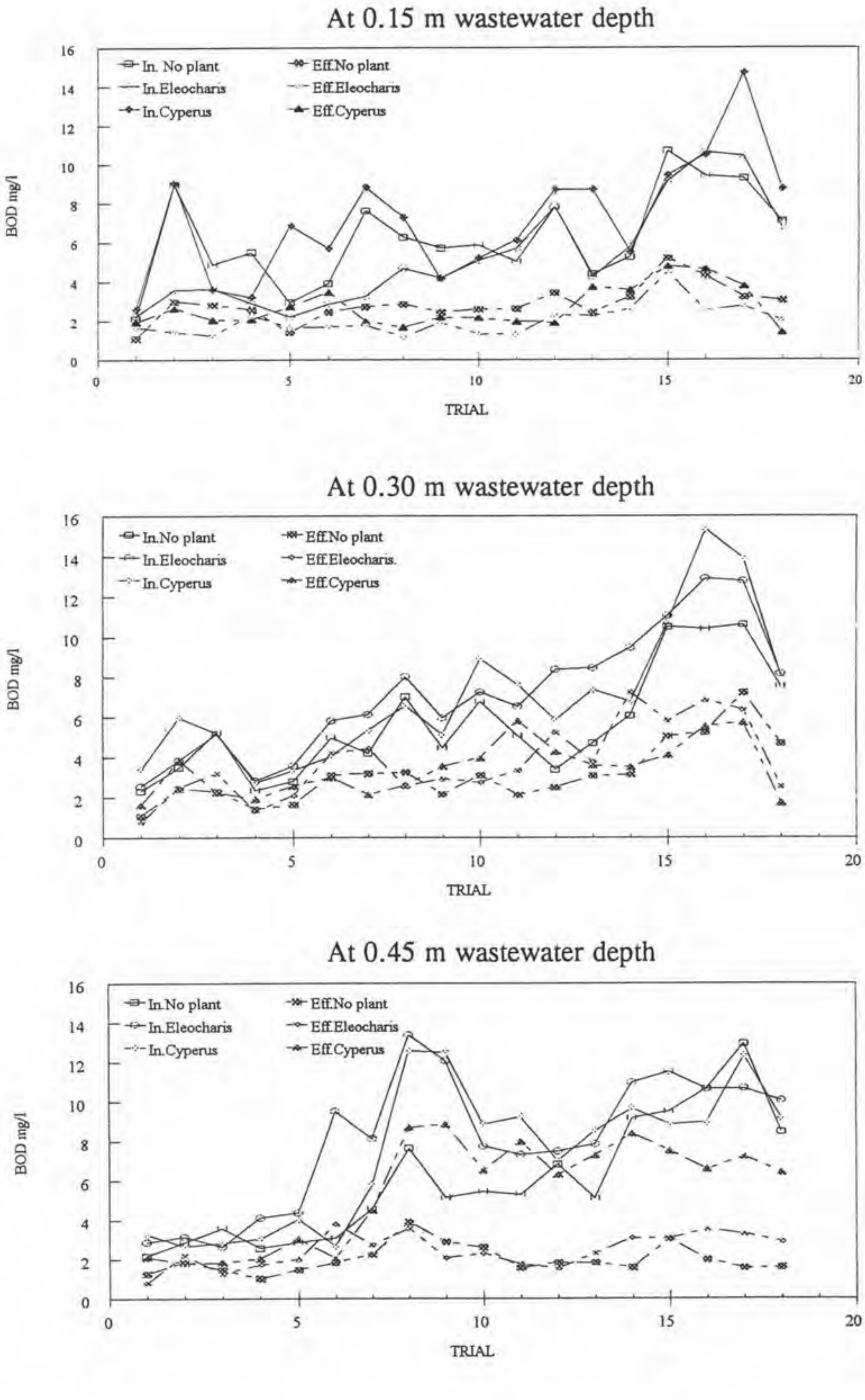

Figure 4.3 BOD of influent and effluent in constructed wetland systems

From the statistical analysis of the systems'efficiency at 0.15 m wastewater depth, there were no significant differences between system with spikerush, with chufa and with no plant. It was found that the efficiency of BOD removal of the system with no plant was the lowest. Plant selection for planting in constructed wetland systems, we could select one of two plant types or select no plant for reducing BOD value. Although, there were no significant differences between three systems, efficiency of them were more than 50 % and efficiency for system with spikerush was more than 60 %.

At 0.30 m Wastewater Depth

BOD of influent and effluent were in the range of 2.30-15.33 and 0.78-7.20 mg/l, respectively. Table 4.4 presents the efficiency of no plant system which ranged from 23.98-58.10 % and their average efficiency was 45.67 %. For spikerush system, its efficiencies for BOD removal were widely ranged from 23.70-69.20 % and the average efficiency was 49.04 %. In system with chufa, its efficiencies ranged from 23.19-78.81 % and average efficiency was 47.03 %. Comparing among the three systems at 0.30 m wastewater depth (Figure 4.4), the efficiency of system with spikerush was better than system with chufa or with no plant. The reason was due to spikerush has more stems and surface area for microorganism catchment than chufa.

There was no significant difference between the two plants and no plant system at 0.30 m wastewater depth (F.prob$>$0.05). So, we can select all plant types or no plant for wastewater treatment that give 40 % for BOD removal.

At 0.45m Wastewater Depth

BOD of influent and effluent were ranged from 2.17-13.38 mg/l and 0.78-8.86 mg/l, respectively. Table 4.4 depicts that the efficiency of no plant system were in the range of 10.26-41.19 % and average efficiency was 25.39 %. Efficiency of spikerush system ranged from 35.19-88.02 % and the average efficiency was 60.67 %. The efficiency of chufa system were in the range of 29.84-

Table 4.4 Efficiency of constructed wetland systems for BOD removal

Water Depth	0.15 m			0.30 m			0.45 m		
Trial	No plant	Eleocharis dulcis	Cyperus corymbosus	No plant	Eleocharis dulcis	Cyperus corymbosus	No plant	Eleocharis dulcis	Cyperus corymbosus
1	48.10	26.46	26.44	53.48	69.17	52.24	35.69	41.94	72.82
2	66.78	60.50	70.87	30.26	35.34	35.86	30.83	35.19	29.84
3	42.18	66.85	43.30	56.32	38.33	57.12	35.44	58.94	52.83
4	53.28	22.22	35.42	39.74	54.09	29.37	32.89	60.31	57.91
5	52.56	25.11	60.03	40.79	41.69	23.19	25.06	48.60	54.00
6	37.02	40.49	38.87	37.65	28.28	26.18	23.97	40.97	60.13
7	64.34	45.82	77.87	23.98	27.99	60.41	22.11	51.09	66.42
8	54.81	75.16	77.24	53.71	68.54	60.49	30.90	48.89	73.32
9	57.47	54.81	47.70	51.80	51.35	31.25	29.18	43.99	82.86
10	55.99	73.86	58.57	54.14	62.24	55.57	26.38	52.01	70.41
11	48.10	77.29	67.98	58.10	49.16	23.78	13.73	70.75	75.96
12	56.23	70.72	78.46	26.19	37.56	27.52	10.26	73.21	79.57
13	44.98	47.04	57.45	34.62	55.81	51.63	14.22	64.33	70.74
14	38.43	55.56	34.97	48.26	23.70	48.44	13.43	82.92	71.95
15	51.54	51.48	49.47	52.00	47.46	61.89	15.24	68.21	73.41
16	54.52	76.27	55.90	49.76	47.13	63.86	26.53	81.46	66.95
17	65.41	73.97	74.42	32.01	50.35	58.86	41.19	88.02	69.29
18	57.10	70.37	83.96	37.98	69.20	78.81	30.07	81.27	71.30
Average	54.59	62.68	59.56	45.67	49.04	47.03	25.39	60.67	68.82
SD	6.96	12.57	16.13	9.29	13.26	16.89	8.94	16.36	8.38

Table 4.5 Mean comparison tested by ANOVA (one-way) on efficiency of BOD removal by depths and plants

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	$^{a}54.59 \pm 6.96^{a}$	$^{b}45.67 \pm 9.29^{a}$	$^{c}25.40 \pm 8.94^{b}$	0.0000	0.15
Eleocharis dulcis	$^{a}60.33 \pm 15.35^{a}$	$^{b}49.04 \pm 13.26^{b}$	$^{a,b}60.67 \pm 16.36^{a,b}$	0.0175	0.15, 0.45
Cyperus corymbosus	$^{a}59.56 \pm 16.13^{a}$	$^{b}47.03 \pm 16.89^{b}$	$^{a}68.82 \pm 8.38^{a}$	0.0002	0.15, 0.45
F.prob	0.2048	0.7750	0.0000		
Suitable plant group	all 3 grs	all 3 grs	3,2		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

82.86 %, its average efficiency was 68.82 %. From data obtained, it is indicated that constructed wetland system with chufa had better efficiency than spikerush and no plant systems.

Average efficiency of constructed wetland system with no plant were significant difference from the system with spikerush and system with chufa at 95 % confidence (F.prob$<$0.05). Even though , there was no significant between the spikerush and chufa system. So according to this result, constructed wetland would have 60 % efficiency for BOD removal when they were planted with spikerush or chufa which had better efficiency than constructed wetland with no plant.

Figure 4.5 depicts the difference of efficiency for BOD removal of all nine, constructed wetland systems. It was found that the efficiency would decrease when wastewater depth was increased. In general, these results confirm that wastewater has self-purification process follow time and distance by nature in aerobic condition.

Plant Types

From data analysis for the efficiency for BOD removal of constructed wetland with no plant at the three wastewater depth, show that the efficiency of systems with 0.15 m and 0.30 m wastewater depth were better than system with 0.45 m wastewater depth significantly (F.prob$<$0.05). Moreover, it was found that the system with spikerush at 0.15 m wastewater depth had better efficiency than at 0.30 m wastewater depth significantly. The efficiency of system with chufa were significant difference between system at 0.45 m or 0.15 m and 0.30 m wastewater depth.

In this study, mean comparison tested by ANOVA on efficiency of BOD removal by depths and plant species were statistically differences. Systems with chufa at 0.45 m had the best efficiency and had better efficiency than the systems with no plant at 0.45 m and 0.30 m wastewater depth. In addition, there had significantly efficiency than system at 0.30 m wastewater depth with chufa or spikerush and every constructed wetland system had

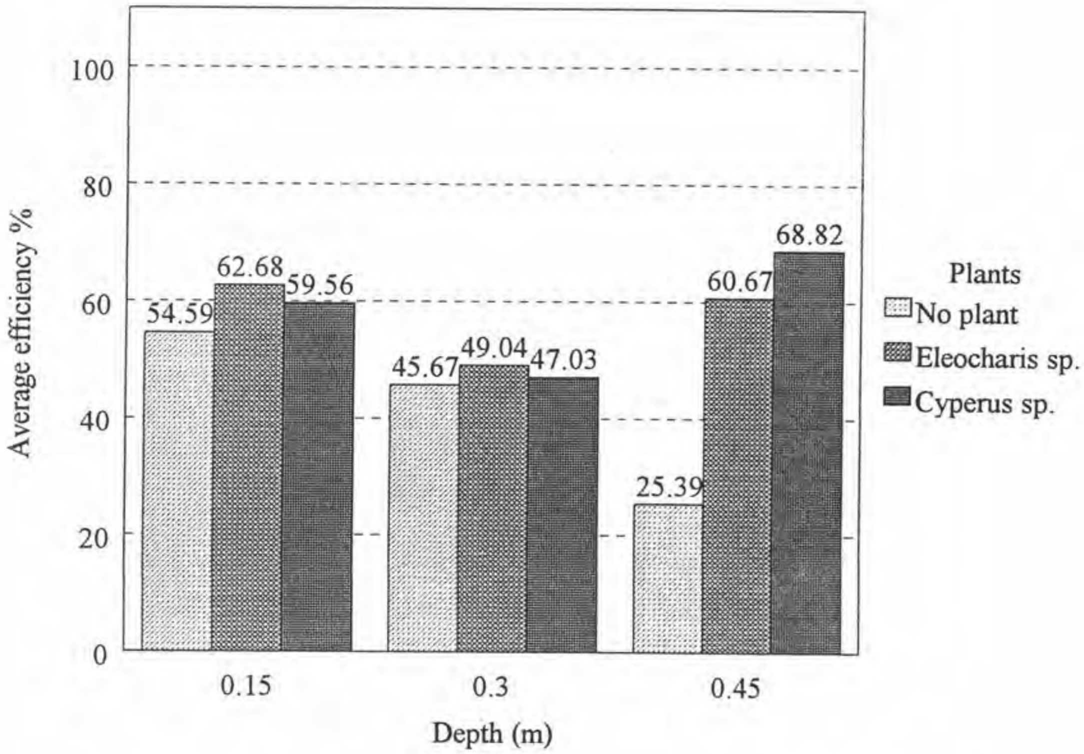

Figure 4.4 Average efficiency of plants for BOD removal at three wastewater depths

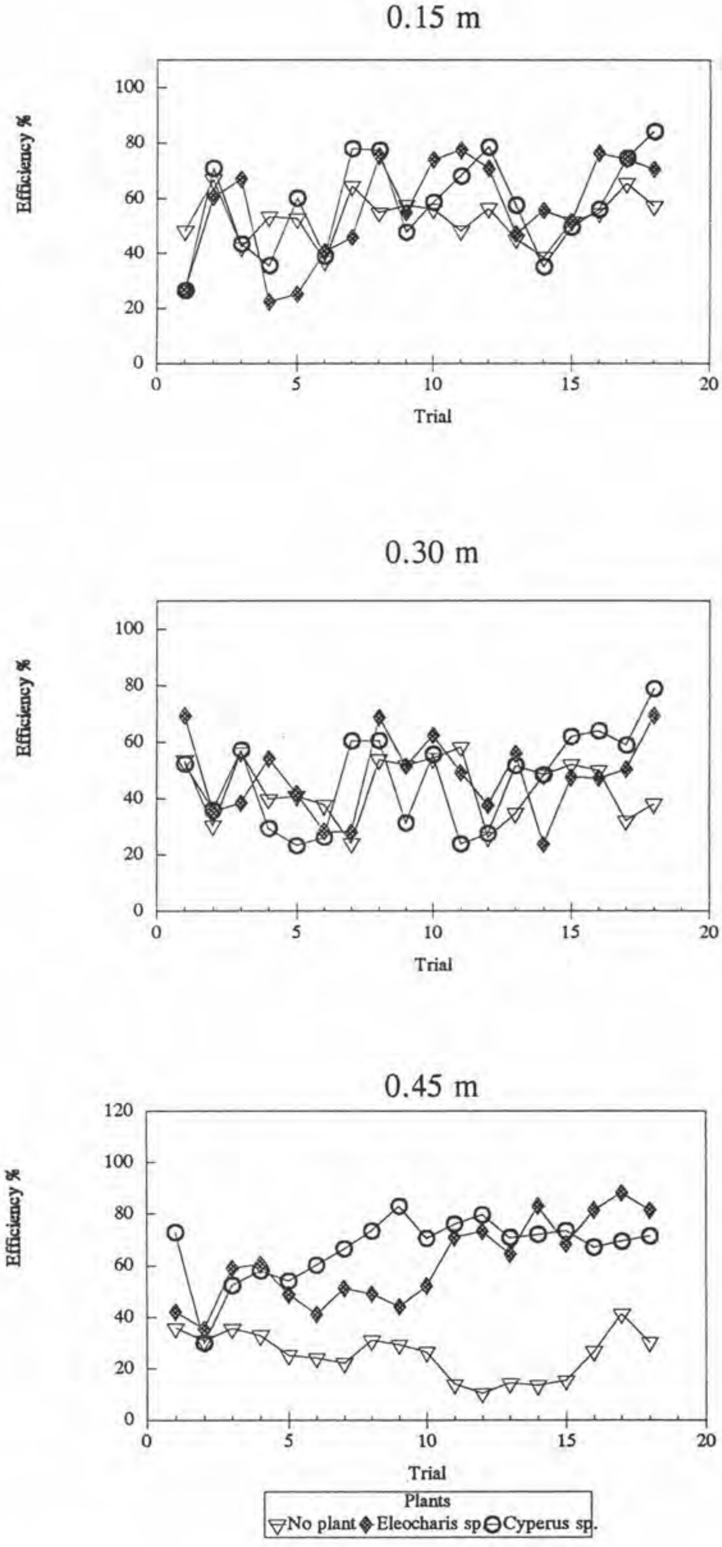

Figure 4.5 Efficiency of plants for BOD removal at three wastewater depths

significant difference between systems with no plant at 0.45 m wastewater depth.

Nutrient Removal

Orthophosphate Phosphorus Removal

At 0.15 m Wastewater Depth

The PO_4^{3-} of influent in constructed wetland system with no plant, with spikerush and with chufa were in the range of 0.096-1.790, 0.084-1.855 and 0.133-1.815 mg/l, respectively. PO_4^{3-} of effluent were ranged from 0.000-0.031, 0.000-0.143 and 0.000-0.173 mg/l, respectively.

From data obtained on the efficiency for PO_4^{3-} removal in all three constructed wetland systems, the system with spikerush have the highest average efficiency, the second was the system with no plant and the lowest was the system with chufa. On the other hand, there was no significant difference between the efficiency of the three constructed wetland systems that was shown in Table 4.6.

At 0.30 m Wastewater Depth

PO_4^{3-} of influent in constructed wetland systems with no plant were ranged from 0.030-1.630 mg/l. In systems with spikerush and with chufa were in the range of 0.154-2.580 and 0.104-1.650 mg/l, respectively. PO_4^{3-} of effluent in the system with no plant, with spikerush and with chufa were ranged from 0.000-0.087, 0.015-0.405 and 0.000-0.042 mg/l, respectively.

Average efficiency for PO_4^{3-} removal of system with no plant, with spikerush and with chufa were 89.98 %, 85.27 % and 96.90 %, respectively. In this study, it was found that there was significant difference between the system with chufa and the system with spikerush (F.prob=0.0013).

Table 4.6 Mean comparison tested by ANOVA (one-way) on efficiency of orthophosphate phosphorus removal by depths and plants.

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	$^{a}93.26 \pm 9.19^{a}$	$^{a,b}89.98 \pm 11.49^{a}$	$^{a}60.59 \pm 15.80^{b}$	0.0000	0.15, 0.30
Eleocharis dulcis	$^{a}90.28 \pm 9.63^{a}$	$^{b}85.27 \pm 9.64^{a,b}$	$^{b}80.87 \pm 13.36^{b}$	0.0479	0.15
Cyperus corymbosus	$^{a}96.55 \pm 6.44^{a}$	$^{a}96.90 \pm 4.63^{a}$	$^{c}95.41 \pm 3.71^{a}$	0.6622	0.15, 0.45
F.prob	0.1069	0.0013	0.0000		
Suitable plant group	all 3 grs	3, 1	3		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

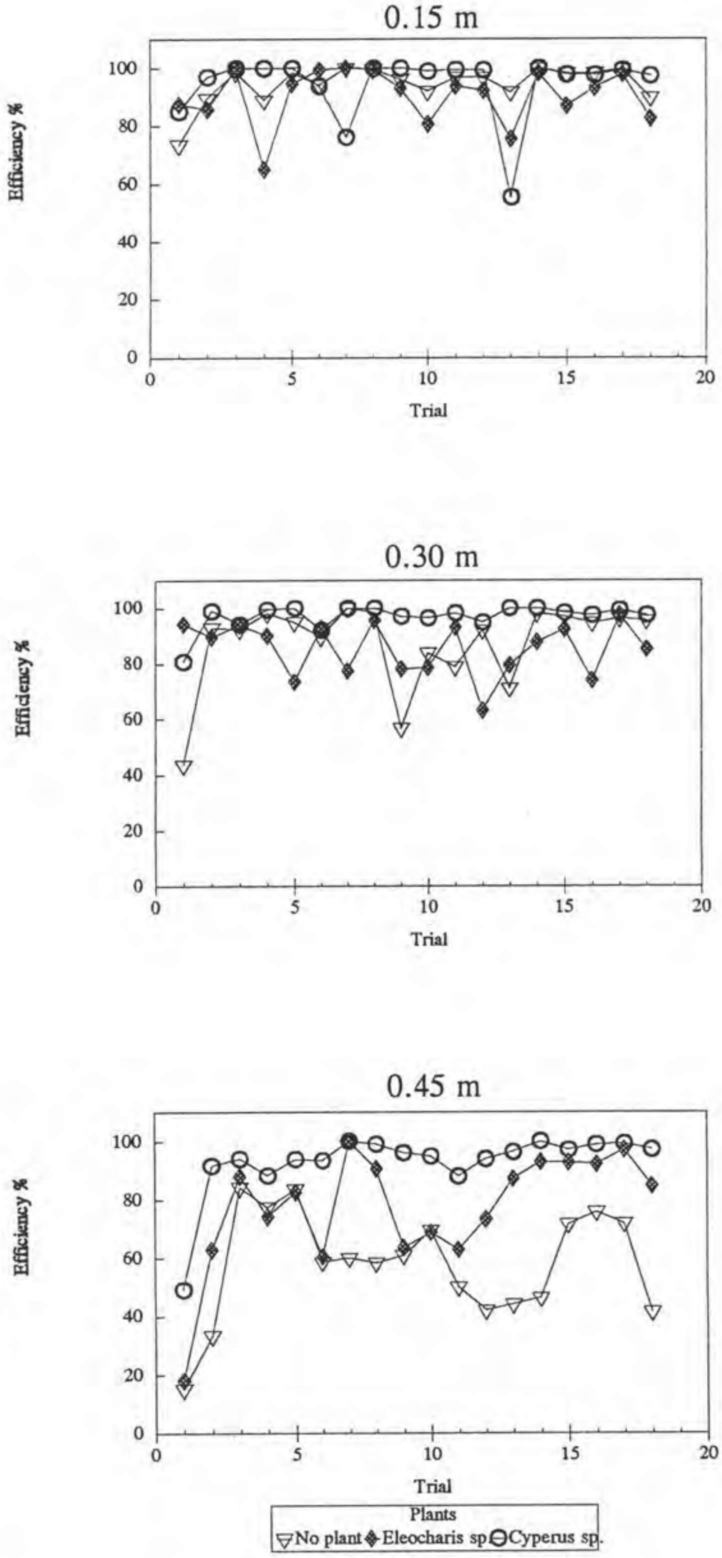

Figure 4.6 Efficiency of plants for orthophosphate phosphorus removal at three wastewater depths

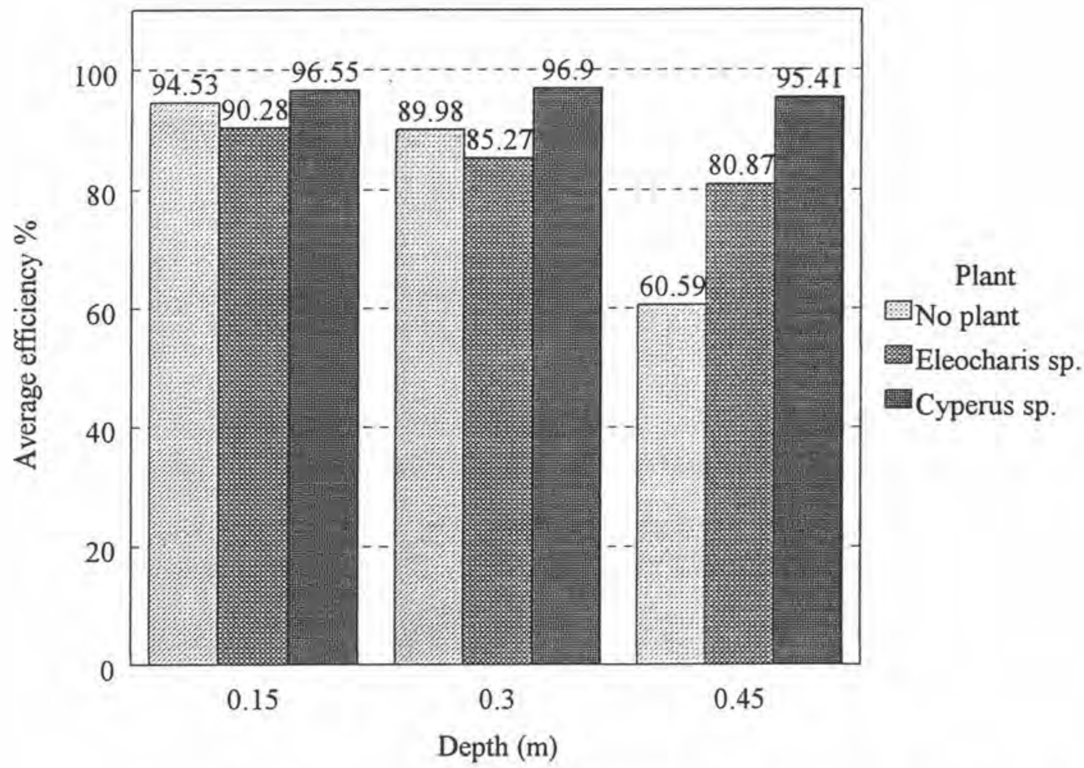

Figure 4.7 Average efficiency of plants for Orthophosphate Phosphorus removal at three wastewater depths.

At 0.45 m Wastewater Depth

PO_4^{3-} of influent were in the range of 0.060-1.313, 0.100-1.640 and 0.059-1.260 mg/l for constructed wetland systems with no plant, with spikerush and with chufa, respectively. PO_4^{3-} of effluent were ranged from 0.026-0.316, 0.000-0.100 and 0.000-0.030 for the three constructed wetland systems, respectively.

The average efficiency for PO_4^{3-} removal of the system with no plant was 60.59 %, these was 80.87 % for the system with spikerush and 95.41 % for the system with chufa. From statistical test, there was significantly difference between the efficiency of the system with chufa, and with spikerush or with no plant. In addition, there was significant difference between the efficiency of the system with spikerush and the system with no plant (Appendix C).

Plant Types

From data obtained on the efficiency statistical tested, the efficiency for PO_4^{3-} removal of the systems with no plant significantly difference from the system with 0.45 m or 0.30 m wastewater depth and the system with 0.15 m wastewater depth. In system with spikerush, there was significant difference between the system with 0.45 m and 0.15 m wastewater depths. However, in the systems with chufa, there was no significant difference between all three wastewater depths (Appendix C).

From the results of this study, it was found that the constructed wetland system with no plant has the best efficiency for PO_4^{3-} removal at 0.15 m wastewater depth, the second and the lpwest were the system at 0.30 m and 0.45 m wastewater depth, respectively. The reason was due to the efficiency of soil and soil-microorganisms for PO_4^{3-} absorption, and it was due to the difference of accumulated PO_4^{3-} in the difference wastewater depths. Moreover, these results are consistented with previous study in that these probably due to the greater availability of absorption sites on the gravel surface. Indeed, there was more accumulation PO_4^{3-} at 0.45 m wastewater depth than at 0.30 m and 0.15 m.

It is possible that these are due to the limited of wetland soil bed area for PO_4^{3-} absorption.

The present data confirmed that soil and its buffering capacity is the only barrier between surface contamination and pollutant desorption (Novotny and Olem, 1994). Wetland soil bed contains a thin layer of decaying organic debris with little soil and there is great densities of roots, soil microorganisms. There are importance in diffuse pollution. The soil layer is the place where the most of adsorption and biochemical degradation of pollutants takes place.

In system with spikerush increase of wastewater depth would have decreased the efficiency of pollutant removal. In addition, the systems with chufa at all three depths are almost similar or closed to each others, but these are better than the systems with no plant. The reasons for PO_4^{3-} reduction may be due to plant uptaking incorporated into sediments in P-organic matter or chemical precipitation (Rogers *et al*, 1985).

It was confirmed that in VSB planted with Baumea sp. and Cyperus sp. (similar to spikerush and chufa,respectively) were consistently better than no plant (Heritage,1995). Chufa has more efficiency for PO_4^{3-} removal from wastewater than spikerush. From data obtained that phosphorus in plants or soil may be orthophosphate and anion. Phosphate in formed of free anion phosphate would be absorped by plant through xylem and accumulated in cell plants. These may be due to chufa's stem are bigger than spikerush's stem, thus, chufa may have better efficiency for more PO_4^{3-} uptaking . Furthermore, according to the physiology and morphology chufa's stem tissue are taller, bigger and tighter tissue than spikerush's stem tissue, therefore they may have more PO_4^{3-} uptake capacity for their growth than spikerush. In other words, chufa's efficiency for PO_4^{3-} reduction is better than spikerush's.

The results of the present study offer support for the notion that the direction of nutrient transportation in a plant is depended on many factors including plant structure, tissue requirements and availability and type of nutrients in the ambient solution.

Statistical testing by ANOVA of all 9 constructed wetland systems (by plant types and wastewater depth) indicated that the system with chufa at 0.30 m wastewater depth is the best for PO_4^{3-} removal. However, all constructed wetland systems have the efficiency for PO_4^{3-} removal over 60 %. The system with chufa at 0.15 m wastewater depth is one of the best ways for PO_4^{3-} removal and differ significantly with the chufa system at 0.45 m wastewater depth.

Ammonia Nitrogen Removal (NH_3-N) and Total Kjeldahl Nitrogen (TKN) Removal

<u>At 0.15 m Wastewater Depth</u>

NH_3-N of influent in constructed wetland system with no plant, with spikerush and with chufa were ranged from 0.56-7.28, 0.56-9.52 and 0.56-13.44 mg/l, and NH_3-N of effluent were 0.28-3.68, 0.00-2.24 and 0.00-1.68 mg/l, respectively.

Their average efficiency for NH_3-N removal of the system with no plant was 58.13 %. For the system with spikerush and with chufa, their average efficiency were 91.24 and 89.83 %, respectively. There was significantly difference between the systems with spikerush or with chufa and the system with no plant (F.prob$<$0.05).

TKN of influent in the system with no plant were in the range of 1.12-10.08 mg/l. The system with spikerush, TKN of influent were range from 1.12-11.76 mg/l and were in the range of 1.12-17.36 mg/l for the system with chufa. TKN of effluent in the system with no plant, with spikerush and with chufa were ranged from 0.28-6.72, 0.44-3.92 and 0.56-2.80 mg/l, respectively.

From data obtained by statistical analysis, there were significance differences betwen system with chufa or with spikerush and the system with no plant for the efficiency of TKN removal (F.prob$<$0.05). The best system for TKN removal was the system with chufa at 71.55 % of pollutant removal efficiency. The next system were the systems with spikerush and with no plant which their efficiencies were 65.23 and 52.68 %, respectively.

At 0.30 m Wastewater Depth

Constructed wetland system with no plant had NH_3-N of influent ranged from 0.28-11.76 mg/l and NH_3-N of effluent were 0.00-3.92 mg/l. NH_3-N of influent and effluent in the system with spikerush were ranged from 0.56-11.76 and 0.00-3.92 mg/l, respectively. And for the system with chufa, their NH_3-N of influent and effluent were 0.56-12.32 and 0.00-1.54 mg/l.

Their average efficiency for NH_3-N removal were 71.66 %, 72.69 and 85.42 % for constructed wetland systems with no plant, with spikerush and with chufa, respectively. There were no significant differences among the three plant types for NH_3-N removal at 95 % confidence interval.

The average TKN in the and effluent of the system with no plant were 0.84-12.88 and 0.56-5.32 mg/l. The system with spikerush, influent and effluent TKN were 1.12-14.56 and 0.28-5.62 mg/l. And TKN of influent and effluentin the system with chufa were 1.12-14.56 and 0.00-2.66 mg/l.

The average efficiency for TKN removal of the systems with no plant, with spikerush and with chufa were 35.28, 63.24 and 70.60 %, respectively. From data statistical analysis, there were significant difference between the systems with chufa or with spikerush and the system with no plant ($F.prob<0.05$).

At 0.45 m Wastewater Depth

NH_3-N of influent and effluent in the system with no plant were ranged from 0.56-10.64 and 0.00-1.68 mg/l. In the system with spikerush, NH_3-N of influent and effluent were 0.56-14.56 and 0.00-1.68 mg/l. And NH_3-N of influent and effluent in the system with chufa were 0.56-9.52 and 0.00-1.12 mg/l, respectively.

The average efficiency for NH_3-N removal of the system with no plant was 65.44 %. The best average efficiency for NH_3-N removal was the system with spikerush at 80.11 %, and the average efficiency of the system with chufa was 79.10 %. However, there was no significant difference among the three systems at 0.45 m wastewater depth.

TKN of influent and effluentin the system with no plant were 0.84-13.44 and 0.28-3.36 mg/l. In the system with spikerush, the TKN of influent and effluent were 0.56-16.80 and 0.00-2.80 mg/l. TKN of influent and effluent in the system with chufa were 0.56-16.80 and 0.00-2.24 mg/l.

The average efficiency for TKN removal of the systems with no plant was the lowest at 58.54 %, while the efficiency for the system with chufa was 69 %. The best average efficiency for TKN removal was the system with spikerush at 71.52 %. From data analysis among the three plant groups, it was found that plant type had no effective against the efficiency of TKN removal.

Plant Types

From data statistical analysis obtained, it was found that there was no significant difference between the efficiency for NH_3-N removal of the system with no plant at the three various wastewater depths. In other words, wastewater depth had no effective against NH_3-N removal of the constructed wetland system with no plant. For the spikerush system, it was found that the system at 0.15 m wastewater depth had better performance for NH_3-N removal but it was not different from the performance of the system at 0.45 m. Wastewater depth has no effective significantly against the efficiency for NH_3-N removal of the system with chufa at 95 % confidence interval.

Constructed wetland system with no plant at 0.45 m and 0.15 m wastewater depth had better performance for TKN removal than the system at 0.30 m wastewater depth significantly (F.prob=0.0001). There were no significant difference between the efficiency of the system with spikerush at any wastewater depths. In addition, there was no significant difference between the systems' performance at any wastewater depth.

For NH_3-N removal ANOVA analysis by plant types and wastewater depths, it is shown that plant types (chufa and spikerush) had significantly effective on NH_3-N removal. The efficiency of system with spikerush at 0.15 m wastewater depth was significant difference from the system at 0.30 m and 0.45 m water depth. Moreover, the performances for NH_3-N removal at 0.15 m and 0.30 m were better than the system with no plant at 0.15 m wastewater depth, significantly.

For data statistical testing by ANOVA by plant types and wastewater depths, it is found constructed wetland system with chufa at 0.15 m wastewater depth had the best performance for TKN removal and this was significant difference from the system with no plant at 0.30 m wastewater depth. The system with chufa at 0.30 m, at 0.45 m wastewater depth and system with spikerush at all three wastewater depths could reduce TKN values better than the system with no plant at 0.15 m wastewater depth significantly (Appendix C).

Ammonia nitrogen is a part of TKN removal. In Figure 4.8, it could be seen that the efficiency of NH_3-N removal and TKN removal of constructed wetland systems with plants were higher than constructed wetland with no plant. From previous studies, it was shown that there is increasingly an ammonium loss via sequential nitrification-denitrification process in the presence of wetland plants, and planted gravel bed wetlands which have generally shown to improve N removal compared to unplanted wetlands (Gersberg *et al.*,1986).

The aerobic environment of the no plant system was effective at both nitrifying NH_3-N and lowering nitrogen concentrations. The decrease in nitrogen concentration by the no plant FWS was probably the result of volatilization, denitrification and dilution (House *et al.*1994). Thereafter, Breen and Chick (1994), and Breen (1990) depicted that plant uptake was the major mechanism of N and P removal.

This finding is consistent with a previous study done by Zhu and Sikora (1991) that nitrification and adsorption by gravel were the most probable pathways for NH_3-N removal in the unplanted pots, and NH_3-N removal from water was probably due to sorption onto gravel.

Figure 4.8 depicts that in actual the average efficiency of TKN removal and NH_3-N removal of constructed wetland with no plant should increase in the same way with depths. The average efficiency at 0.30 m water depth was lower than expected, this might be caused by other environmental factors, and the present study differed from the previous experiments in the use of a different wastewater type. It was carried out outdoors under different climatic conditions such as increased temperatures and evapotranspiration rates, and additional rainfall.

These results agree with the research that the NH_4^+ reduction was varied, although NH_4^+ is the favourite source of N for plants and algae. The reduction observed could also be the result of the ability of some aquatic plants to translocate O_2 from the shoots to the roots and thereby establishing and oxidized rhizosphere (Vincent,1994).

Efficiency of constructed wetland with chufa for TKN and NH_3-N removal decerased when water depth increased. The reason may be that plant grow in shallow water has more capacity for nutrient uptake than plant grow in deep water. Consequently, these related to plant respiration and plant evaporation due to the high energy consumption.

Related study by Heritage *et al.*,(1995) in VFW with Cyperus involucratus and Baumea articulata showed resembled results to this present study (FWS), it was stated that Cyperus sp. were better than Baumea ps. and no plant for NH_3-N and TKN removal. Confirmed by the study, it is evident that the similar physiology and morphological plant between Cyperus corymbosus and Cyperus involucratus had better efficiency for TKN and NH_3-N than Eleocharis dulcis that resembled to Baumea articulata.

Apparent reduction of NH_3-N by some plant species (especially Cyperus and Baumea) support the measurements of high TKN removal by planted systems, but they do not distinguish between the two processes of plant uptake and nitrification/denitrification.

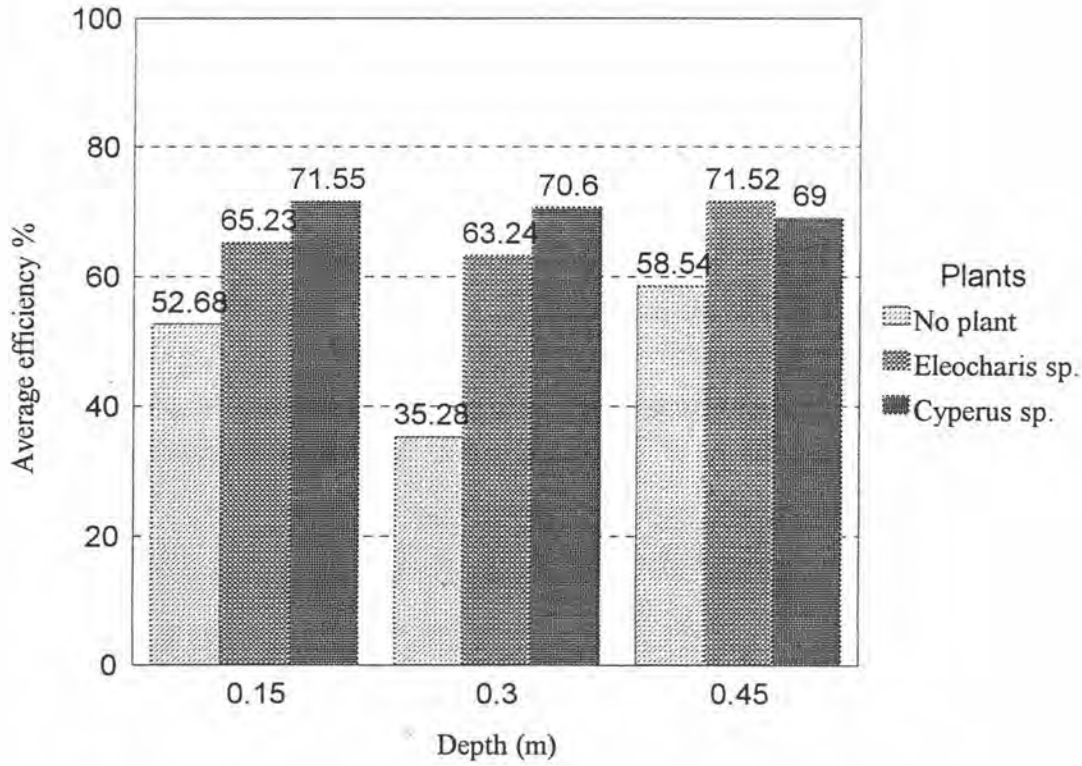

Figure 4.8 Average efficiency of plants for TKN removal at three wastewater depths

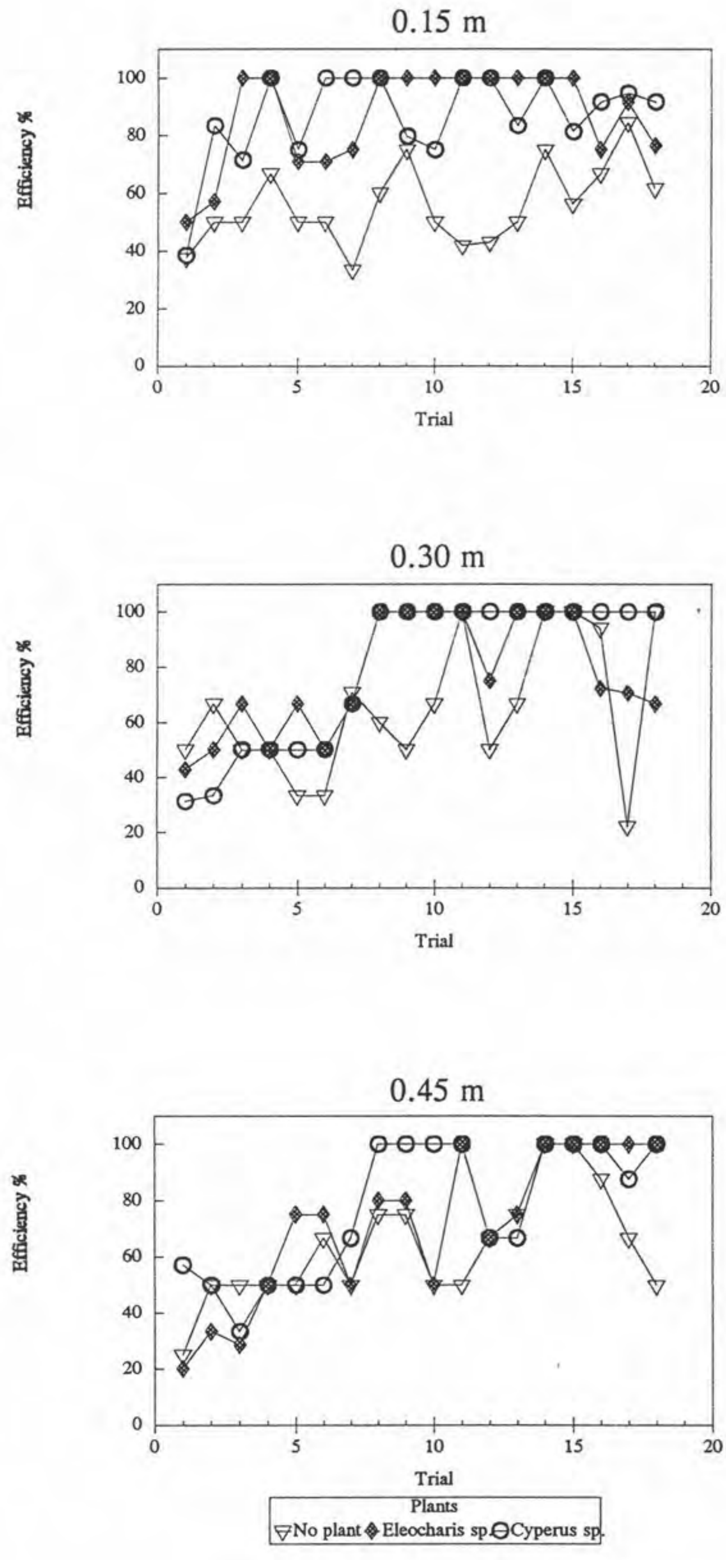

Figure 4.9 Efficiency of plants for ammonia nitrogen removal at three wastewater depths

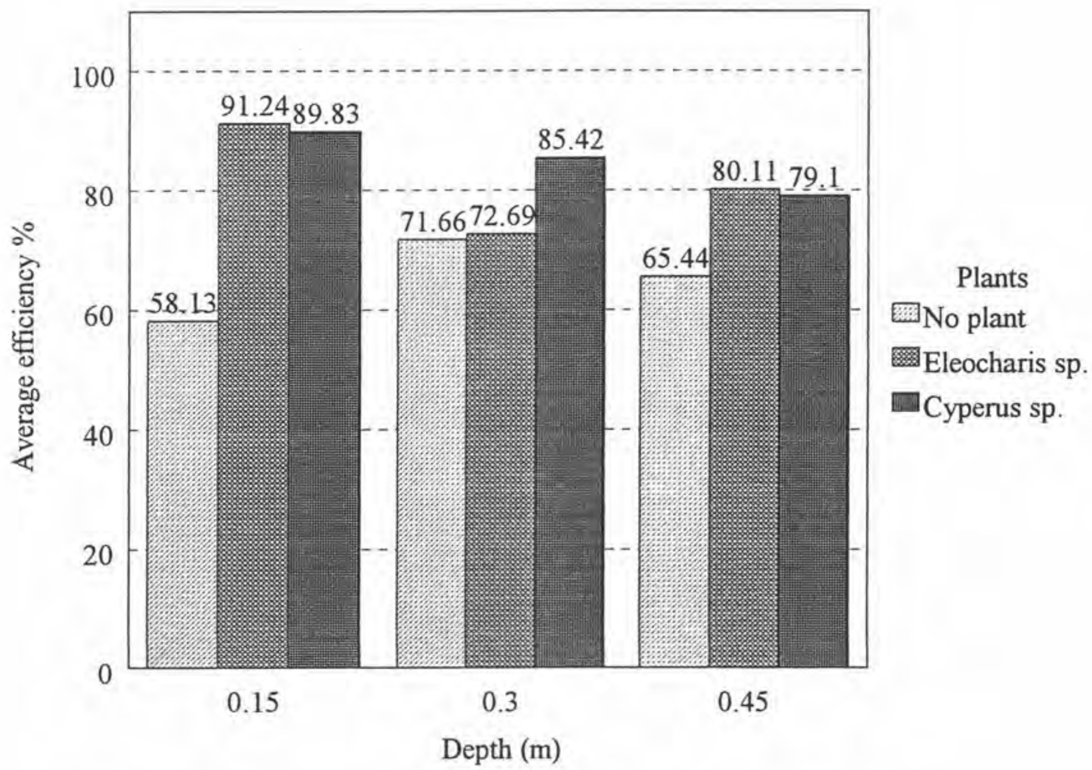

Figure 4.10 Average efficiency of plants for Ammonia Nitrogen removal at three wastewater depths

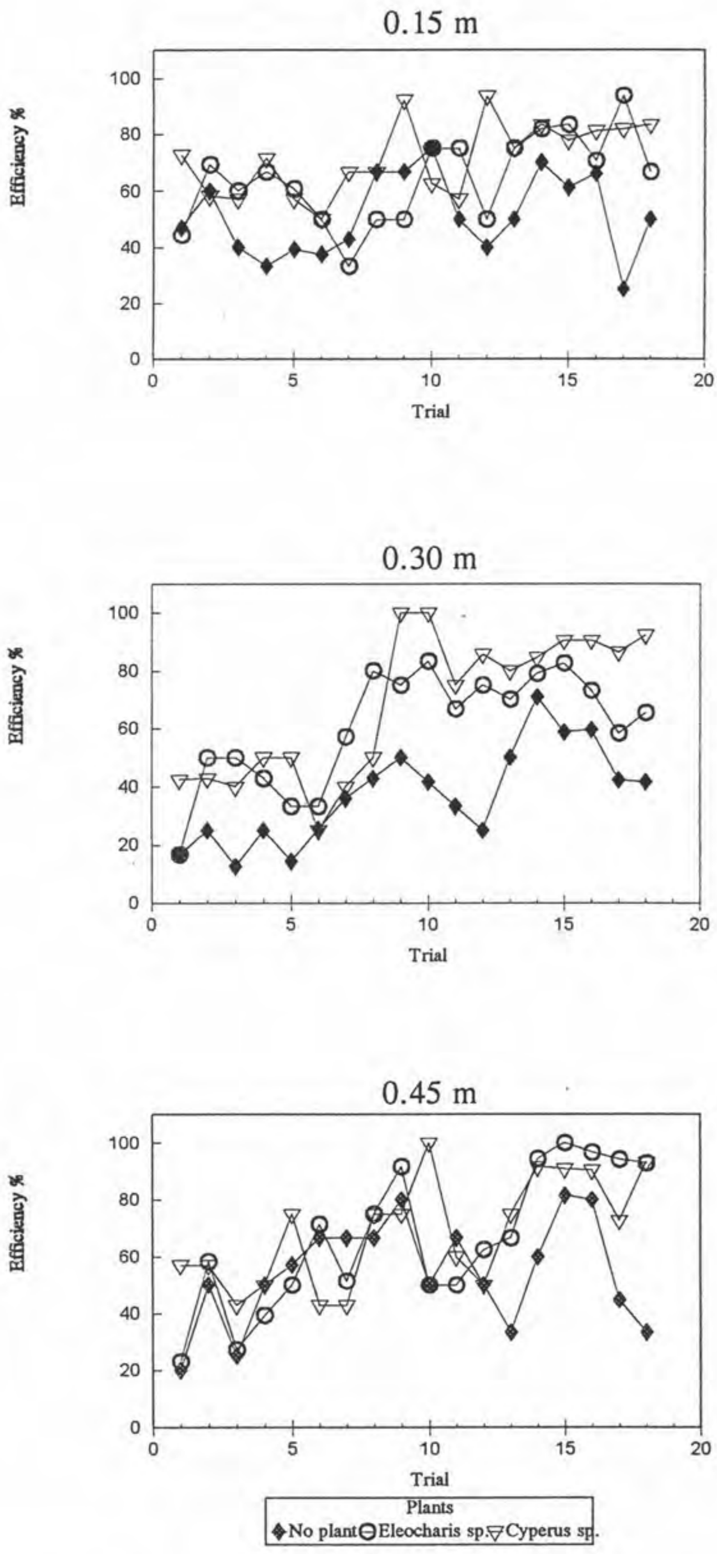

Figure 4.11 Efficiency of plants for TKN removal at three wastewater depths

Table 4.7 Mean comparison tested by ANOVA (one-way) on efficiency of ammonia nitrogen by depth by depths and plants.

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	$^{a}58.13 \pm 12.45^{a}$	$^{a}71.66 \pm 21.17^{a}$	$^{a}65.44 \pm 17.79^{a}$	0.1072	0.15, 0.30, 0.45
Eleocharis dulcis	$^{b}91.24 \pm 12.51^{a}$	$^{a}72.35 \pm 20.05^{b}$	$^{a}80.11 \pm 19.55^{a,b}$	0.0128	0.15
Cyperus corymbosus	$^{b}89.83 \pm 10.59^{a}$	$^{a}85.42 \pm 22.67^{a}$	$^{a}82.04 \pm 21.42^{a}$	0.4904	0.15, 0.30, 0.45
F.prob	0.0000	0.1299	0.0359		
Suitable plant group	2, 3	all 3 grs	all 3 grs		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

Table 4.8 Mean comparison tested by ANOVA (one-way) on efficiency of TKN removal by depths and plants.

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	$^{a}52.66 \pm 13.14^{a}$	$^{a}35.29 \pm 14.76^{b}$	$^{a}58.54 \pm 15.22^{a}$	0.0001	0.15, 0.45
Eleocharis dulcis	$^{b}64.28 \pm 12.47^{a}$	$^{b}63.24 \pm 16.50^{a}$	$^{a}71.53 \pm 20.76^{a}$	0.3233	0.15, 0.30, 0.45
Cyperus corymbosus	$^{b}71.55 \pm 12.90^{a}$	$^{b}70.60 \pm 23.02^{a}$	$^{a}69.00 \pm 19.25^{a}$	0.9185	0.15, 0.30, 0.45
F.prob	0.0003	0.0000	0.1206		
Suitable plant group	3, 2	3, 2	all 3 grs		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

TSS Removal

At 0.15 m Wastewater Depth

TSS of influent in the system with no plant were ranged from 22-108 mg/l. In the system with spikerush TSS of influent were in the range of 8-75 mg/l and of system with chufa were ranged from 30-178 mg/l. TSS of effluent in the system with no plant, spikerush and chufa were in the range of 6-77, 2-36 and 2-77 mg/l, respectively.

Average efficiency for TSS removal of all 3 systems were 66.56, 58.44 and 84.39 %, respectively. It was found that the best system was the system with chufa, and there was significant difference between the system with chufa and the system with spikerush or with no plant (F.prob=0.0018).

At 0.30 m Wastewater Depth

TSS of influent in the system with no plant, with spikerush and with chufa were 8-145, 20-136 and 8-240 mg/l, respectively. TSS of effluent in the system with no plant , spikerush and chufa were ranged from 2-25, 4-56 and 5-60 mg/l, respectively.

For the average efficiency for TSS removal, it was found that the system with no plant had the best average efficiency for TSS removal at 68.35 %. The system with spikerush had better average efficiency (59.37%) than the system with chufa (57.53%). Nevertheless, there was no significant difference among the efficiency for TSS removal of the system with no plant, spikerush and chufa at 95 % confidence.

At 0.45 m Wastewater Depth

In the constructed wetland system with no plant, TSS of influent and effluent were ranged from 14-85 and 4-52 mg/l. TSS of in fluent and effluent in the spikerush system were in the range of 8-135 and 0-12 mg/l and TSS of influent and effluent in the system with chufa were ranged from 8-95 and 0-18 mg/l.

The best system for TSS removal was the system with chufa at 73.21 % efficiency. The moderate and lowest systems for TSS removal were system with no plant (58.88 %) and system with chufa (57.58 %). However, there was no significant difference for TSS removal among all 3 systems (F.prob > 0.05).

Plant Types

From statistical data analysis of TSS removal of the system with no plant at three wastewater depths, it was found that wastewater depths had no effective against the efficiency for TSS removal of the system with no plant, significantly. The efficiency for TSS removal of system with spikerush was similar to the system with no plant. Contrast to those, in the system with chufa the efficiency for TSS removal were significant difference with in this system at 0.15 m or at 0.45 m and at 0.30 m wastewater depth.

Statistical analysis (ANOVA) of the efficiency for TSS removal by plant types and wastewater depths, it was found that there was significant interaction between plant types and wastewater depths. The system with chufa at 0.15 m wastewater depth had better efficiency for TSS removal than the system with chufa at 0.30 m wastewater depth, significantly. All constructed wetland systems had efficiency for TSS removal over 50 %, particularly the three systems at 0.15 m wastewater depth, system with no plant at 0.30 m wastewater depth and system with chufa at 0.45 m wastewater depth had efficiency for TSS removal over 60 %.

Figure 4.12 showed that no large differences in efficiency of spikerush at various water depths was observed. TSS of effluent in the system with chufa has consistently negative relation with water depth. Not only in shallow (0.15 m) that chufa was the best performance, but also deeper (0.45 m).

It is evidenced that constructed wetland system with plant better than no plant. Consequently, these results offer support for the notion that TSS in outflows from the no plant control system were consistently higher than from planted

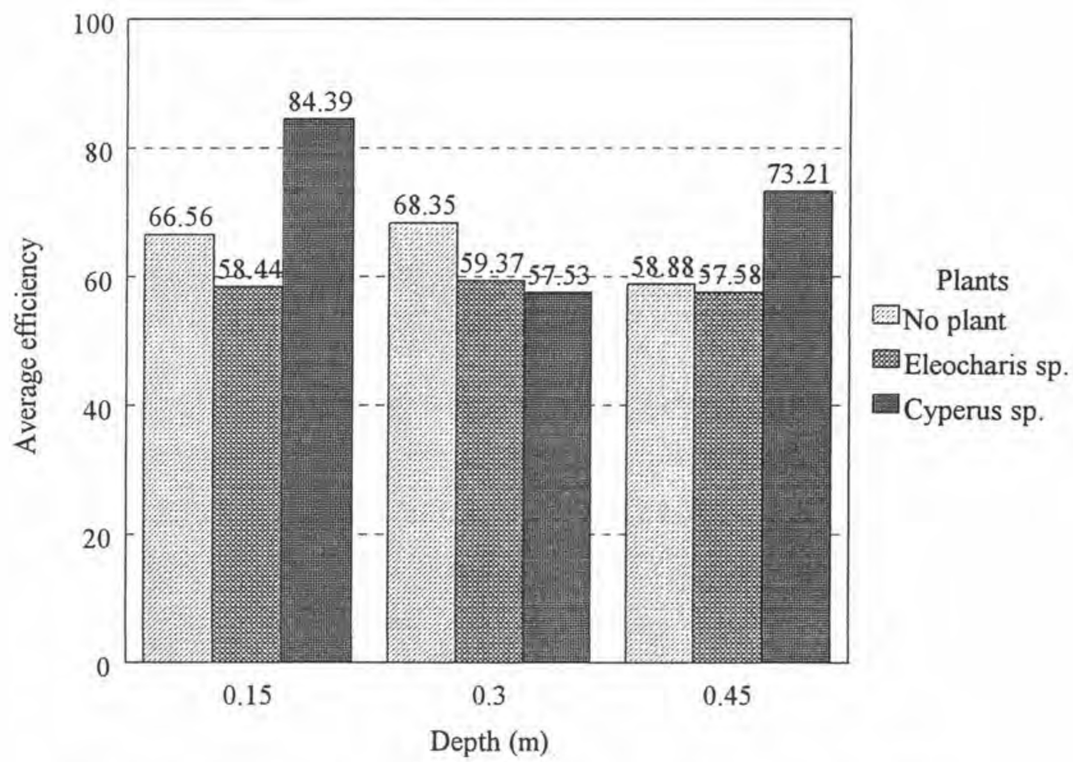

Figure 4.12 Average efficiency of plants for TSS removal at three wastewater depths

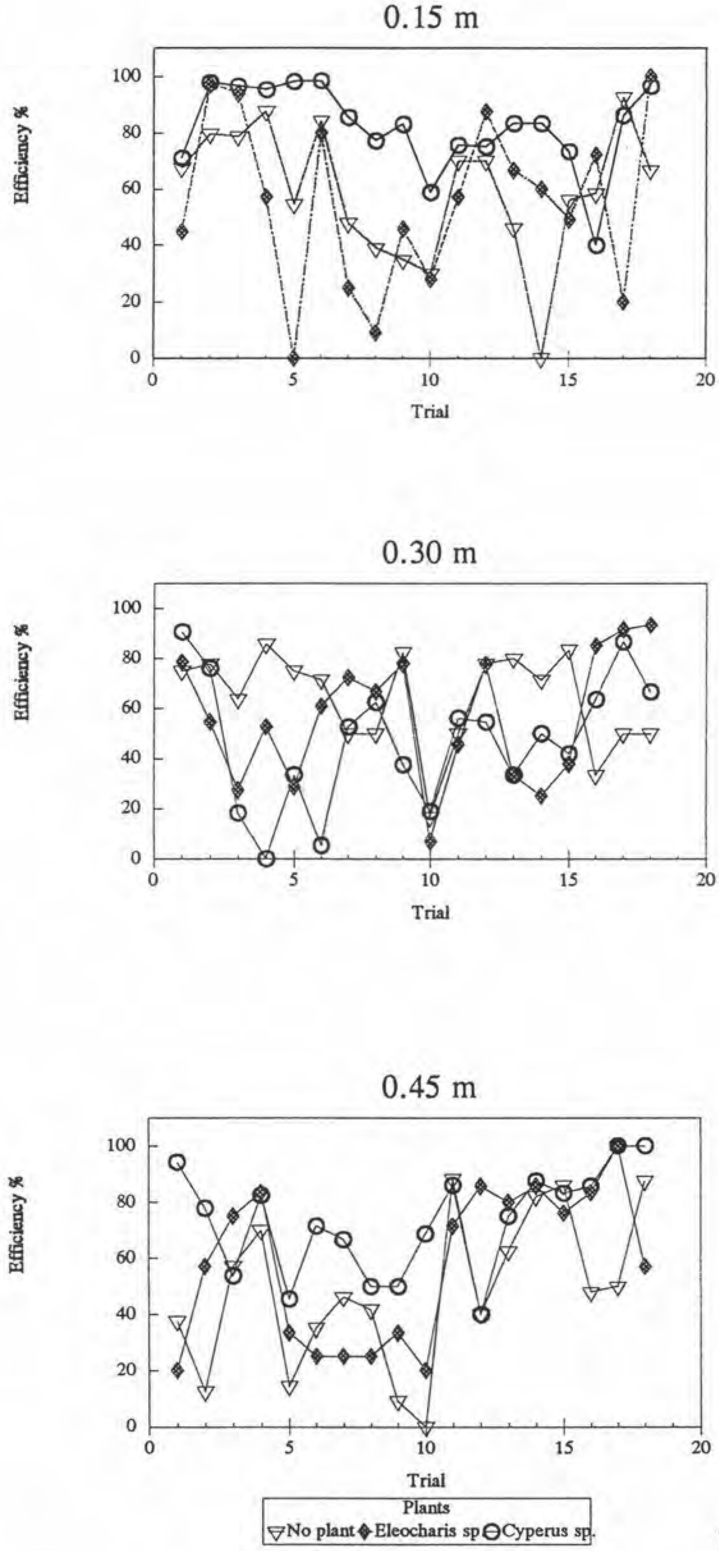

Figure 4.13 Efficiency of plants for TSS removal at three wastewater depths

Table 4.9 Mean comparison tested by ANOVA (one-way) on efficiency of TSS removal by depths and plants.

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	$^{a}64.59 \pm 16.19^{a}$	$^{a}68.35 \pm 13.79^{a}$	$^{a}58.88 \pm 19.20^{a}$	0.2833	0.15, 0.30, 0.45
Eleocharis dulcis	$^{a}60.27 \pm 28.15^{a}$	$^{a}59.37 \pm 23.32^{a}$	$^{a}57.58 \pm 27.90^{a}$	0.8793	0.15, 0.30, 0.45
Cyperus corymbosus	$^{b}84.39 \pm 11.61^{a}$	$^{a}54.04 \pm 22.19^{b}$	$^{a}73.21 \pm 18.78^{a}$	0.0002	0.15, 0.45
F.prob	0.0018	0.2474	0.0873		
Suitable plant group	3.00	all 3 grs	all 3 grs		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

systems. Some times effluent TSS was higher than influent TSS, it may be due to TSS of effluent in wetland systems was resulted from sloughed biofilm and decaying plant material.

TDS Removal

At 0.15 m Wastewater Depth

TDS of influent and effluent in the system with no plant were ranged from 156-424 mg/l and 132-460 mg/l. For system with spikerush, its TDS of influent and effluent were in the range of 154-412 mg/l and 120-440 mg/l. TDS of influent and effluent in system with chufa were ranged from 136-408 mg/l and 110-508 mg/l.

The efficiency for TDS removal of all 3 systems were lower than 15 %, the system with spikerush had 12.73 % TDS removal, the system with chufa and with no plant had 10.61 % and 9.93 % TDS removal, respectively. From statistical analysis, it was found that there was no significant difference among the three constructed wetland systems for TDS removal at 95 % confidence interval (Table 4.10).

At 0.30 m Wastewater Depth

TDS of influent in the system with no plant, with spikerush and with chufa were ranged from 150-456 mg/l, 145-512 mg/l and 105-476 mg/l. TDS of effluent in the system with no plant, with spikerush and with chufa were 95-364, 114-464 and 105-348 mg/l, respectively.

For all systems, the average efficiencies were 9.63 %, 9.11 % and -0.53 % for the system with chufa, with spikerush and with no plant, respectively. Moreover, plant types had no effective against the efficiency for TDS removal at 0.30 m, significantly (F.prob > 0.05).

At 0.45 m Wastewater Depth

For constructed wetland system with no plant, its TDS of influent and effluent were in the range of 130-556 and 100-320 mg/l. In the system with spikerush TDS of influent and effluent were ranged from 140-420 and 112-340 mg/l. TDS of influent and effluent in the system with chufa were in the range of 120-420 and 65-304 mg/l.

Their average efficiency for TDS removal of the system with chufa, with no plant and with spikerush were 23.63 %, 8.82 and 4.35 %, respectively. The efficiency of system with chufa was better than efficiency of system with no plant and with spikerush, significantly at 95 % confidence.

Plant Type

For all constructed wetland systems with no plant, with spikerush and with chufa, their efficiencies for TDS removal were no significant difference at all 3 wastewater depths. In other words, wastewater depths had no effective against the efficiency of all constructed wetland systems with no plant, with spikerush and with chufa, significantly.

From statistical analysis (ANOVA) by plant types and wastewater depths, it was found that there was no significant interaction between plant type and wastewater depth. So, all systems could be used for TDS removal because they were not significantly difference. Thus, suitable constructed wetland systems were the system with chufa at 0.45 m wastewater depth, system with no plant at 0.15 m wastewater depth and the system with spikerush at 0.15 m wastewater depth.

TDS removal were able to cope with large efficiencies fluctuations (Figure 4.14). Their efficiency had both good and worse (effluent more than influent) or effluent concentration were not relate to influent concentration. This latter result is consistent with an effective filtration system. TDS of effluent from the no plant system were consistently higher than from system with plant. This may be due to the release of salts or fines from the wetland soil bed of no plant system (Heritage,1995).

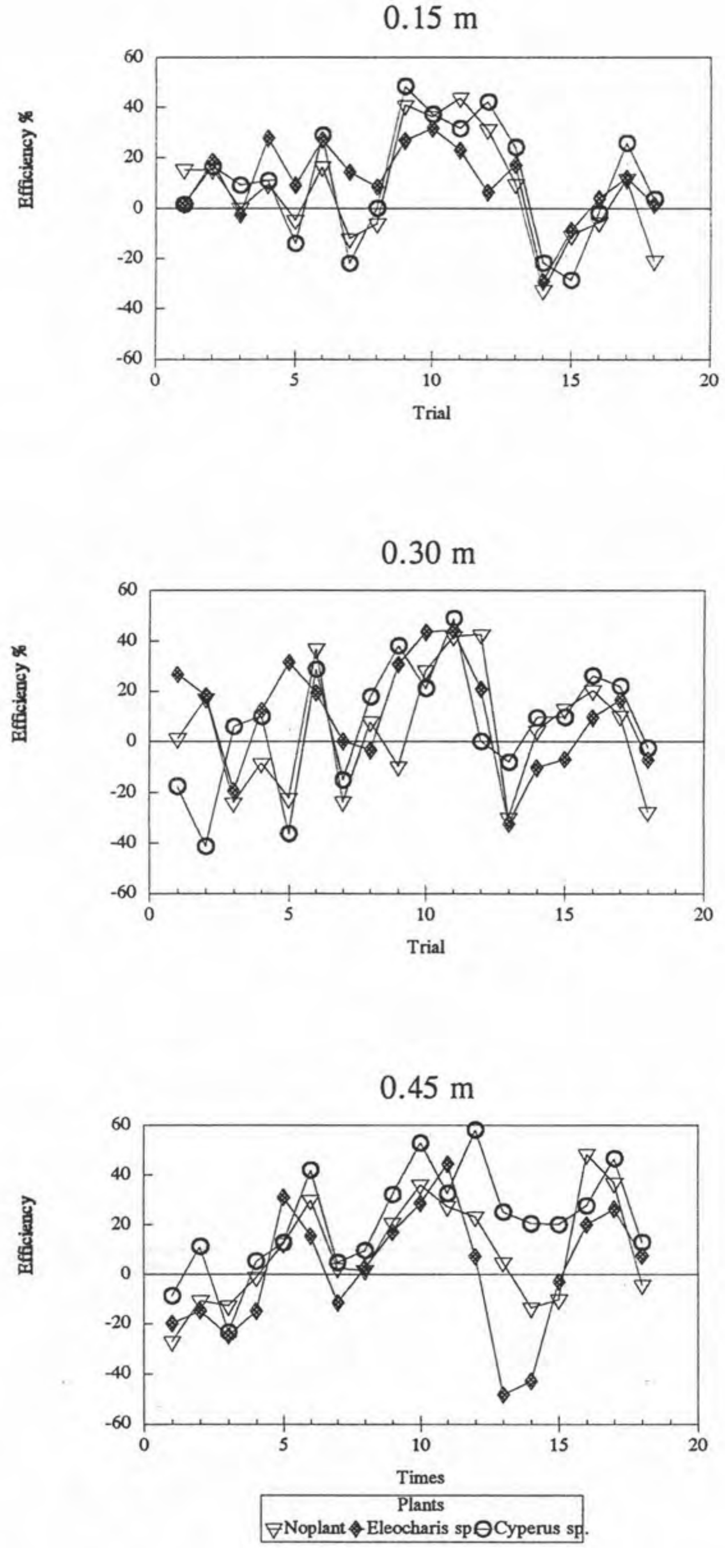

Figure 4.14 Efficiency of plants for TDS removal at three wastewater depths

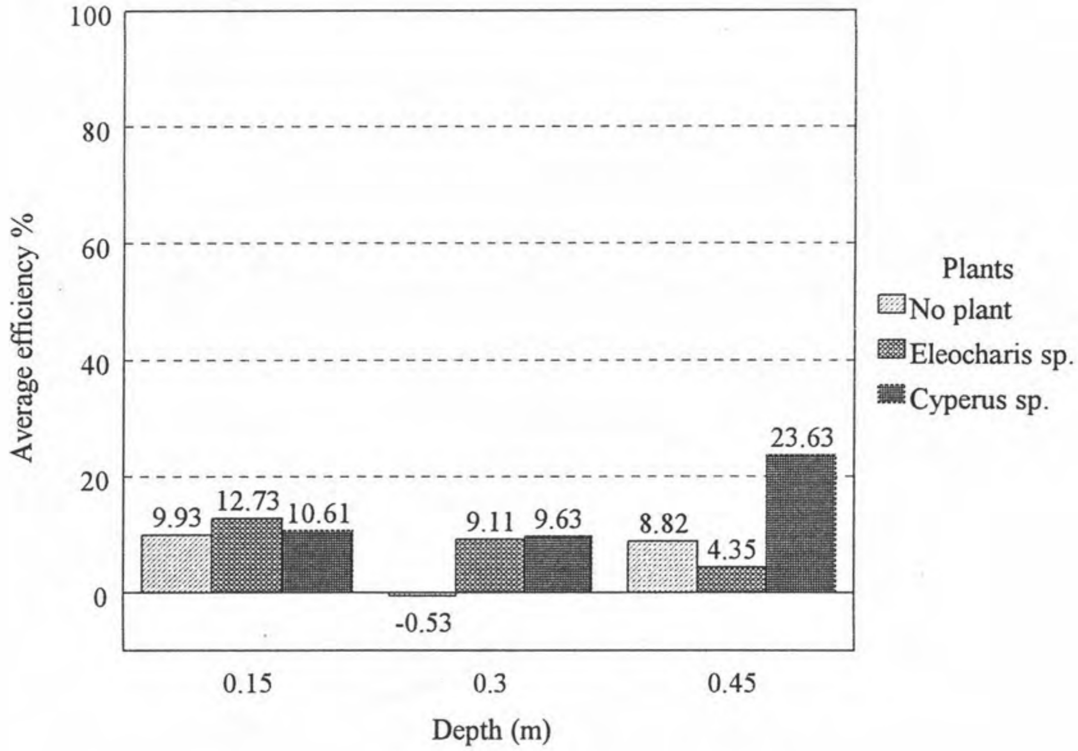

Figure 4.15 Average efficiency of plants for TDS removal at three wastewater depths

Table 4.10 Mean comparison tested by ANOVA (one-way) on efficiency of TDS by depths and plants.

Plants	Wastewater depths (m)			F.prob	Suitable depth (m)
	0.15	0.30	0.45		
No plant	[a]12.95±23.81[a]	[a]-0.53±21.05[a]	[a,b]8.82±17.82[a]	0.1651	0.15, 0.30, 0.45
Eleocharis dulcis	[a]12.73±11.84[a]	[a]9.11±16.05[a]	[a]4.35±17.55[a]	0.3240	0.15, 0.30, 0.45
Cyperus corymbosus	[a]10.61±23.01[a]	[a]9.63±16.26[a]	[b]23.63±16.08[a]	0.0810	0.15, 0.30, 0.45
F.prob	0.9313	0.2183	0.0097		
Suitable plant group	all 3 grs	all 3 grs	3, 1		

Note : The difference alphabet on the left corner means there is significance difference at 95 % confidence interval within the same column.

:The difference alphabet on the right corner means there is significance difference at 95 % confidence interval within the same row.

: grs1 = No plant, grs2 = Eleocharis dulcis , grs3 = Cyperus corymbosus

In different environmental factors that out of control such as pH, temperature, sunlight and rainfall, these factors may probably effect against dissloved inorganic into water or it is possible that effected against decaying wetland soil bed. Furthermore, a proportion of the wastewater entering constructed wetlands is expected to be lost by evapotranspiration through plant shoots. As in the latter of experimental period which TSS of influent were higher than the beginning, these might be due to TSS increasing by loss of water, by evapotranspiration or by pan evaporation from water surface contacted sunlight. There was no interference of rainfall (<3mm) at the site during the latter part of experimental period (Appendix B : Table B-1).