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Swine Farm Wastewater Treatment by Constructed Wetland Planted with Vetiver Grass

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ABSTRACT

This research investigated the pollutant removal efficiencies in swine farm wastewater with *Vetiveria zizanioides* (L.) Nash (Sri Lanka ecotype) in a surface flow constructed wetland (SFCW). The SFCW units were set up to 3 treatments at 10, 15 and 30 cm. water levels to find the proper depth for vetiver grass in wastewater treatment. The water quality indicator such as pH, Temperature (T), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP) and heavy metals (Cu, Fe, Pb, Zn) were analyzed and compared with terms of removal efficiency. The 30 cm. water depth has a better removal efficiency of organic substance treatment (BOD and COD). The BOD, COD, TKN and TP removal efficiency had no statistically significant differences between the water depths. TP has the best removal efficiency with average 95.18-96.53%. The treatment of heavy metals such as Cu, Pb, Fe and Zn with vetiver grass in different water depths was showed no statistical significance since it can reduce only a small number of these metals. However, the results showed that the effluent from all the treatment units contained averages of BOD, COD, TKN and pH that followed Thailand's swine wastewater quality standard.

1. INTRODUCTION

Nowadays, the organic waste treatment is a world problem. The waste treatment systems are necessary to decrease the pollution. Livestock farming, especially swine farms, causes a large amount of wastewater, which contains a high concentration of organic substances, solids and nutrients. Without appropriate wastewater treatment methods, the effluent can contaminate water resources. Many small-sized farms fail to do so due to their budget limitations and lack of ability to operate the complicated systems. A simple operation using a low-cost wastewater treatment system can be an alternative to improve water quality of a small-sized swine farms (Klomjek, 2016).

The vetiver system was first developed for soil and water conservation purposes, particularly in the field of wastewater treatment and solid waste landfills. Vetiver grass is internationally recognized for its effectiveness in wastewater treatment in terms of reducing nitrogen (N), phosphorus (P), and absorbing substantial amounts of cadmium (Cd), mercury (Hg), and lead (Pb). This grass is a tolerant plant and able to survive in the wetland area. Therefore, the swine farm wastewater treatment with vetiver grass is the alternative way emphasized this study.

Constructed wetlands are among the recently proven efficient technologies for wastewater treatment. Compared to conventional treatment systems, constructed wetlands can be afforded to low cost with easily operated, particularly by small rural communities with the environmental friendly wastewater treatment system. Recently, the constructed wetland has been used to treat wastewater from various agricultural activities, including pig farming (Kivaisi, 2000; Klomjek, 2016). This study aims to investigate qualities of wastewater after treatment by the vetiver grass under different water levels. The results of the study may present an alternative for wastewater treatment of the small-sized swine farm. If the system can improve water quality, it may encourage the farmers to improve water quality before discharging the effluent into the environment.

2. METHODOLOGY

2.1 Constructed wetland unit preparation

A constructed wetland unit was built with a concrete plot with a width of 1 m, a length of 3 m and a depth of 1 m, three units in total. Each pilot unit was filled up with soil and sand for plant cultivation to a depth of 60 cm and 1% slope. All pilot units were used for wastewater treatment by the flowing surface water system. All pilots were planted with vetiver grass (*Vetiveria zizanioides* L.) for the wastewater treatment. It was planted 25 cm. between each row and column. There were three rows; each row had 11 plants, 33 in total in one unit (Figure 1) (Klomjek, 2006).

2.2 Wastewater treatment

The plants were in the water supply for two weeks for adaptation. When the vetiver grass grew taller than 30 cm, the water was drained out and the wastewater from the swine farm was replaced.

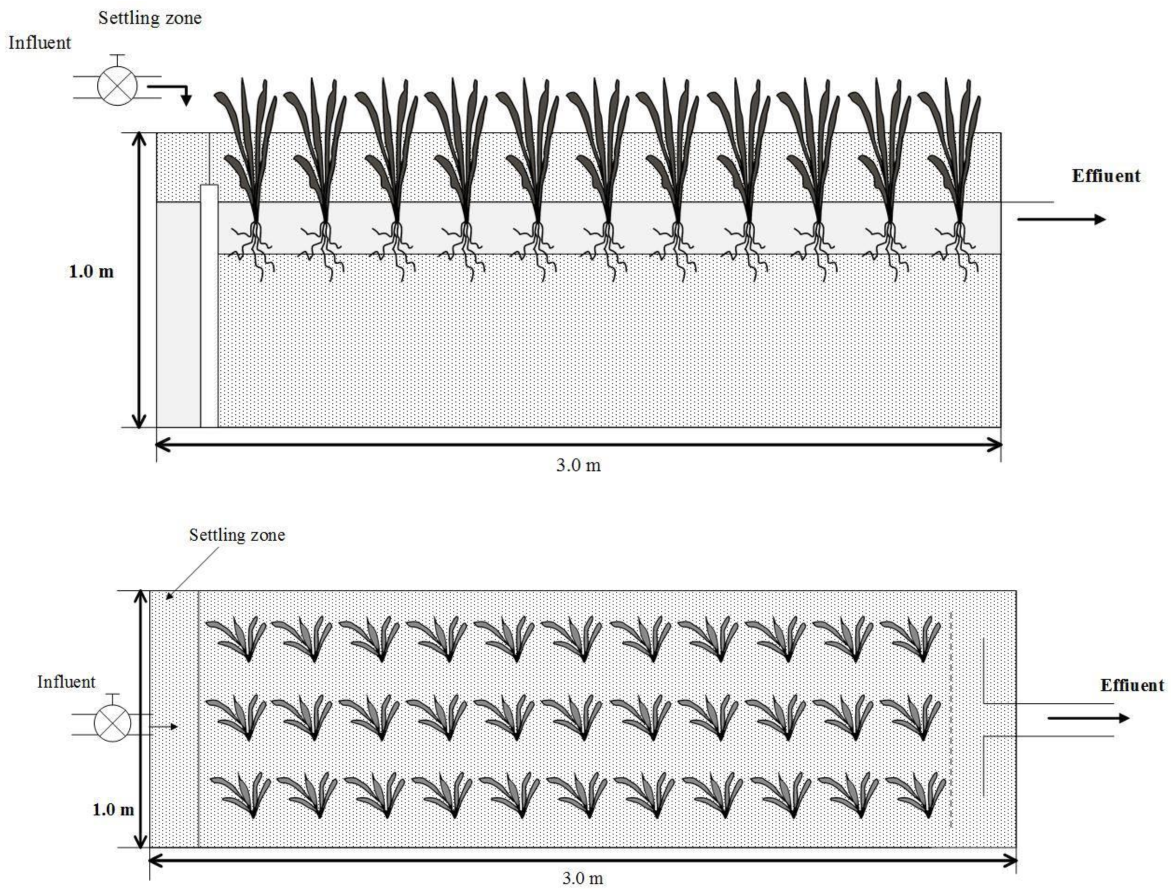

Figure 1. Dimension of constructed wetland

The wastewater was released into the plots by letting it flow through the soil surface. The first pilot had the carrying capacity of 0.9 m^3 of wastewater. The water flowing rate was adjusted to 0.18 m^3/day with a 30 cm. water depth. The second pilot had the carrying capacity of 0.45 m^3 of wastewater. The water flowing rate was adjusted to 0.09 m^3/day with a 15 cm. depth. The third pilot had the carrying capacity of 0.3 m^3 of wastewater. The water flowing rate was adjusted to 0.06 m^3/day with a 10 cm. water depth. The hydraulic retention time was the period of seven days. When the water flew steadily, the treatment process started and the study period continued for eight weeks of plant growth.

2.3 Water quality analysis

When the wastewater was drained into the plot after two weeks, the water samples of influent and effluent from each pilot unit were collected and analyzed. The samplers were analyzed for water quality indicators such as COD, BOD, TKN, TP, metals, pH and temperature. The temperature, pH and DO were measured on-site using a DO meter and a pH meter. Other parameters COD, BOD, TKN, TP and metals (Cu, Fe, Pb, Zn) were performed immediately after the samples were transported to the laboratory by using the standard methods for the examination of water and wastewater treatment. (APHA, AWWA and WEF, 2012).

2.4 Treatment efficiency

Data was analyzed to find the efficiency of the treatment system by comparing the percentage of removal and concentration in each indicator. Duncan's Multiple Range Test (DMRT) was used to compute the statistical differences among the three different groups of treatment. All statistical analyses were performed at the 0.05 significant levels.

3. RESULTS AND DISCUSSION

3.1 Swine farm wastewater characteristics

The wastewater was collected from the primary wastewater tank of the swine farm. The result showed that the wastewater has high organic substance contamination. The COD, BOD, TKN, and TP in wastewater are average 710.13, 334.33, 39.80, 217.66 mg/L, respectively. Heavy metals such as Cu, Fe, Pb and Zn in the wastewater are average 0.05, 1.38, 0.40 and 0.19 mg/L, respectively (Table 1).

Table 1. Wastewater quality of swine farm influent (N=24)

Indicators	Unit	Ranges	Average ± SD	Effluent standard for pig farm [1/]
Temperature	°C	28.0-30.8	30.10±1.35	-
pH	-	7.33-7.70	7.43±0.26	5.5 – 9.0
DO	mg/L	0.06-0.43	0.42±0.05	-
BOD	mg/L	100.0-512.0	334.33±39.45	100
COD	mg/L	270.0-957.0	710.13±94.49	400
TKN	mg/L	17.0-74.7	39.80±0.39	200
TP	mg/L	130.0-322.2	217.66±68.79	-
Cu	mg/L	0.04-0.06	0.05±0.01	-
Fe	mg/L	1.00-2.10	1.38±0.36	-
Pb	mg/L	0.40-0.40	0.40±0.0	-
Zn	mg/L	0.10-0.27	0.19±0.05	-

Note: 1/ = Standard for effluent of swine farms with 50-500 pigs
- = Not enforced

Reference to Thailand's swine wastewater quality standard type C, which occurs on the farms with 50-500 pigs, indicates that COD, BOD and TKN should not exceed 400, 100 and 200 mg/L, respectively. The wastewater samples from the sedimentation tank at the small sized farms contained the average amounts of BOD and COD that exceeded the country's standard while the average quantity of TKN was under the standard.

3.2 Wastewater treatment efficiency

3.2.1 Water quality

The effluent from the SFCW indicated that the average pH values of all the treatments were within the criteria of Thailand's standard. The pH value of all the treatments has no statistically significant difference ($P < 0.05$). The wastewater influent has DO between 0.06-0.43 mg/L. From the beginning of the treatment until the end of the experiment, DO in each treatment continued increasing but had no statistically significant difference of water depth. The wastewater treatment by emergent plant relies on major factors which are the plants' growth and microorganism living in the plant roots. Then, the microorganisms in the roots bring in oxygen which is necessary for wastewater degradation by oxygen from emergent photosynthesis. The wastewater treatment is able to reduce BOD, which is the amount of oxygen needed for oxidation organic substance in the water to become carbon dioxide. (Klomjek, 2009).

3.2.2 Organic substance treatment

A reduction of organic substances is indicated by COD and BOD. The removal efficiencies of the organic substance treatment for BOD and COD were average 69.39-74.89% and 61.87-75.36%, correspondingly. The effluent BOD averages concentration of 10, 15 and 30 cm. water depths were 50.16, 63.90 and 56.62 mg/L, correspondingly. Moreover, the average COD of the treatment effluent were 130.38, 165.69 and 119.78 mg/L, respectively. The organic substance concentration and removal efficiency have a statistical significance ($P < 0.05$) in each water level. The 30 cm. water depth has a better removal efficiency of organic substance treatment (BOD and COD) (Table 2 and Figure 2). The vetiver grass can reduce BOD by 74.69 % and COD 75.36 %. Chankaew et al. (2003) use Indonesia and Cylon vetiver grass to treat the wastewater from a community in Phetchaburi and found that Indonesia vetiver grass can reduce BOD by 85.5 % and Cylon vetiver grass by 82.2 %. BOD and COD concentration can be reduced because the vetiver grass grow well and has more photosynthesis. Therefore, the grass can produce more oxygen and carry more oxygen to the root. Oxygen helps microorganisms to increase the number and activities to digest organic substance in the water. This means that vetiver growing can reduce lots of BOD in wastewater. Considering the period of growing, it is found that the vetiver aged eight weeks gave lower BOD and a more effective treatment than four-week-old vetiver grass. The result also showed that the vetiver can reduce BOD to the standard wastewater since as the vetiver grows, it can absorb more organic substances and various nutrients. Moreover, as they are growing, it can maximize the photosynthesis and produce more oxygen. This oxygen will go through their roots and increase a number of microorganism and decomposing organic substances, which help reduce BOD. All sources of vetiver have this capacity since they are fully grown, but after this period, they will need fewer nutrients for growing. Kantawanichkul et al. (2004) planted vetiver to treat diluted settled pig farm wastewater in Thailand. They reported 78.8% reduction of COD. Liao et al. (2003) studied pig farm wastewater treatment with vetiver and *Cyperus alternifolius* in China and 68% of BOD reduction was reported. That may be due to the action of aerobic bacteria attached to the media and to the plant roots (Shivhare and Roy, 2013). According to Vipat et al. (2007), BOD and COD associated with settleable solids in wastewater are removed by sedimentation while that in colloids and soluble form is removed as a metabolic activity of microorganisms and physical and chemical interaction within the root zone.

3.2.3 Nutrient treatment

Mostly nitrogen was removed through the mechanism called Nitrification reaction, and Denitrification. The former reaction would happen in the water or the soil, where there was sufficient oxygen. For phosphorus removal mechanism was being absorbed by plants and period of time retaining the wastewater over the soil surface. The TKN and TP removal efficiencies have no statistical significance. Furthermore, the TKN average removal efficiency was 66.11-75.74%. The average TKN treatment efficiency of 30, 15 and 10 cm. water depths were 67.25, 69.73 and 70.93 %, respectively, TP has an average removal efficiency of 95.18-96.53% without statistically significant difference between the water depths. At a 10 cm water depth, it has a better TP treatment outcome (97.98%) (Table 2), which was consistent with the report of Wongpankamol (2007) that found the vetiver grass can reduce TP by 81.74 % in the constructed wetland for wastewater treatment from the cattle farm. The wastewater treatment from Chulalongkorn university found that vetiver grass can reduce TKN and TP between 61.01-62.48 and 17.78-35.87%, respectively (Boonsoong and Chansiri, 2008). From the result, TKN and TP decrease because the vetiver grass absorbs the nutrients to grow. Saetang et al. (2008) used vetiver grass for wastewater treatment from the milk factory. The result found that treatment efficiencies were 93 and 90 % of TKN and TP, respectively. In the process to treat TP, the plants can use available P for growing stage (Hosoi et al. 1998). However, phosphorus can come back to the system by decomposition process. Therefore, the plants can reduce TP in a short term. The specific process to reduce TP in a constructed wetland is the precipitation process. Microorganism is the principal things to reduce TP in the constructed wetland. Nitrification in plants takes part around the root area and uses oxygen in this process. As for the CW system, microorganisms are considered an important factor to eliminate TKN in wastewater by transforming the organic nitrogen compounds into inorganic nitrogen, including those that are essential for plant (Saeed and Sun, 2012; Kantawanichkul et al., 2004). The treatment of wastewater from a Chulalongkorn university community with vetiver showed that total Nitrogen and Phosphorus were reduced around 61.01-62.48 and 17.78-35.87 %, respectively (Boonsong and Chansiri, 2008). It obviously means that all reduced Nitrogen, Nitrate, Nitrite and Phosphorus were as the result of the absorption of all these nutrients by vetiver for their growing. The studies by Boonsong and Chansiri (2008) reported that phosphorus removal can be achieved in constructed wetlands by burial adsorption and precipitation, sedimentation, exchange process between soil and overlying water column and a small amount is also taken up by plant growth. Nitrogen undergoes several transformations in wetlands, including ammonification, nitrification, denitrification, volatilization, adsorption, plant and bacteria uptakes and these mechanisms are considered as the key process for nitrogen removal from wetlands (Shivhare and Roy, 2013).

Table 2. Concentration and removal efficiency of pollutants in effluent of treatment

Indicators	**Period (Weeks)**	**10 cm**		**15 cm**		**30 cm**	
		Mean	**%Removal**	**Mean**	**%Removal**	**Mean**	**%Removal**
pH	4	7.98	-	7.76	-	7.53	-
	8	7.77	-	7.92	-	7.51	-
BOD	4	63.48	81.29	68.64	84.48	58.15	87.85
(mg/L)	8	49.75	61.93	59.17	57.49	42.18	64.96
COD	4	96.66	82.07	126.62	80.63	118.52	84.55
(mg/L)	8	142.91	61.93	205.22	57.49	142.18	64.90
TKN	4	22.50	70.93	27.00	69.73	37.00	67.25
(mg/L)	8	9.80	75.74	10.30	72.03	12.10	67.48
TP	4	7.88	95.03	7.40	95.23	9.85	93.68
(mg/L)	8	5.75	97.98	6.00	97.83	9.03	96.69
Cu	4	0.035	45.50	0.038	36.40	0.038	36.40
(mg/L)	8	0.035	16.70	0.035	16.70	0.030	22.20
Pb	4	0.350	12.50	0.350	18.80	0.350	18.80
(mg/L)	8	0.325	12.50	0.325	12.50	0.350	12.50
Fe	4	1.325	23.90	0.925	35.10	1.150	7.00
(mg/L)	8	1.075	17.00	1.150	13.20	1.100	18.90
Zn	4	0.115	26.20	0.135	16.90	0.163	29.20
(mg/L)	8	0.140	55.70	0.153	30.70	0.098	36.40

Note: Means value from 3 replications, Sample size (N) = 12

3.2.4 Heavy metals treatment

The result of treatment of heavy metals such as Cu, Pb, Fe and Zn with vetiver grass in distinct depths of water showed no statistical significance ($P > 0.05$) and only a small number of heavy metals were reduced (Table 2). The removal efficiency of metals was significantly different; however, the amounts of Pb were not significantly different with respect to the 15 cm and the 30 cm depths (Figure 2). At the same depth, the vetiver has the highest efficiency in terminating copper and zinc. Fe becomes lower because the plants need it for growing and metabolism and it may also subside in wastewater.

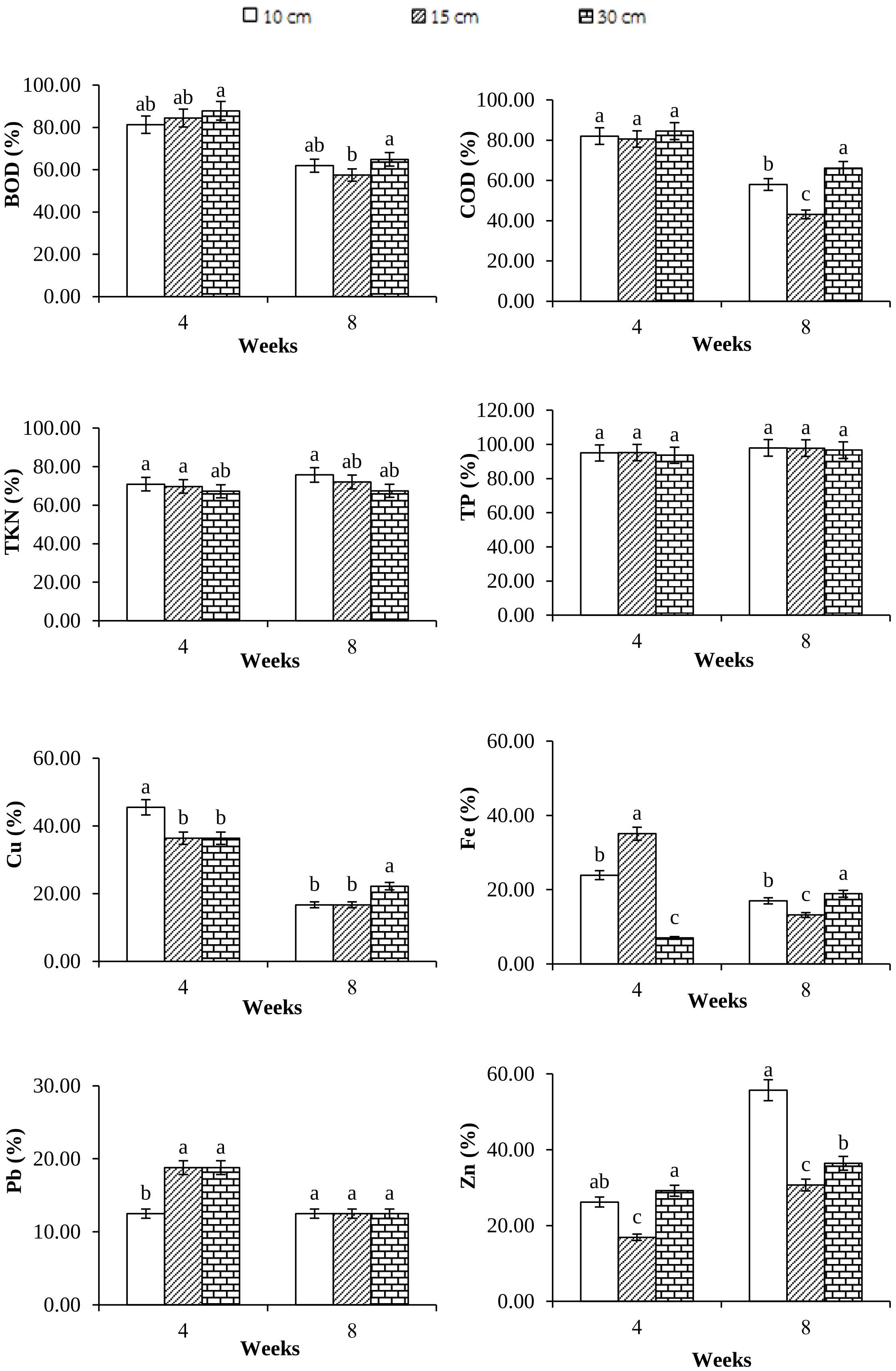

Figure 2. Removal efficiency (%) of BOD, COD, TKN, TP, Cu, Fe, Pb and Zn from wastewater using 3 different water depths at 4 and 8 weeks of growth. The different letters are significantly different among treatments at 95% by DMRT.

Inorganic substance, namely, Pb will transform into a nontoxic inorganic compound. Apart from nutrients, wetland plants help reduce heavy metals by root absorption. Even though the root is the main part of the plants to absorb nutrients and other solutions, but it was also found that the wetland plants can absorb heavy metals through both roots and leafs (Klomjek, 2009). The plant root's ability to absorb heavy metals in sediment and in the water through its above ground part is frequently found, especially in the high contamination water by the absorption of ion through the root (Guilizzoni, 1991). The plants will accumulate the pollutant in each part if the plant digestion is not fast enough completed (Susaria et al., 2002). Most of the wetland plants have the ability for heavy metals treatment and the root is the main part used to absorb and accumulate the heavy metals. The results showed removal efficiency increased as time progressed, Zinc had the highest removal efficiency and this was consistent with a study by Aksorn and Chitsomboon (2013) that established that all vetiver ecotypes display a high capability for Zn uptake in both shoots and roots and concluded that vetiver grass is a good hyper accumulator only for Zn. However, in many studies, the level of uptake depended on the amount of Zn in the media and the retention time. Das et al. (2008) referred to it as an 'immobilised microbial biomass' that can be reused in extracting more pollutants in a bioreactor setup. In the study on phytoextraction of Cu, Zn, and Pb enhanced by chelator with vetiver grass, Chen et al. (2012) also attributed some discrepancies in their data to metal adherence to the experimental tank. This mechanism could be largely responsible for heavy metal reduction in the effluent. The roots of vetiver grass could have supported microbial life through the provision of a habitat in the rhizosphere. The roots of grasses can produce exudates that can increase the bio-availability of heavy metals (Jabeen et al., 2009).

3.3 The growth of vetiver grass

The results indicated that the vetiver could grow well and was not affected by water depth. The growth of vetiver grass showed that has average heights of 85.92 cm, 91.37 cm and 88.87 cm. at 30, 15 and 10 cm of water depths, respectively. The vetiver grown in the 15 cm deep water had the best growth (Figure 3). From the result, the higher the vetiver grass grows, the more efficiently it can treat the wastewater. The vetiver grass has a high ability to absorb organic substances and nutrients during its growth stage. The vetiver growths at all levels of water have no statistical differences in height during the four week period. The vetiver is grown the best in 15 cm. of water depth, but there are no statistically significant differences from 10 cm. of water depth as in eight weeks. It is found that at the 30 cm water depth, the vetiver has the least growth. The vetiver grown in the 10 cm water depth had the highest Cu and Zn removal efficiencies of 45.5and 55.7 %, respectively in a 4 week period. The vetiver reached the maximum height during 1-5 weeks. After the sixth week, the vetiver has grown slowly.

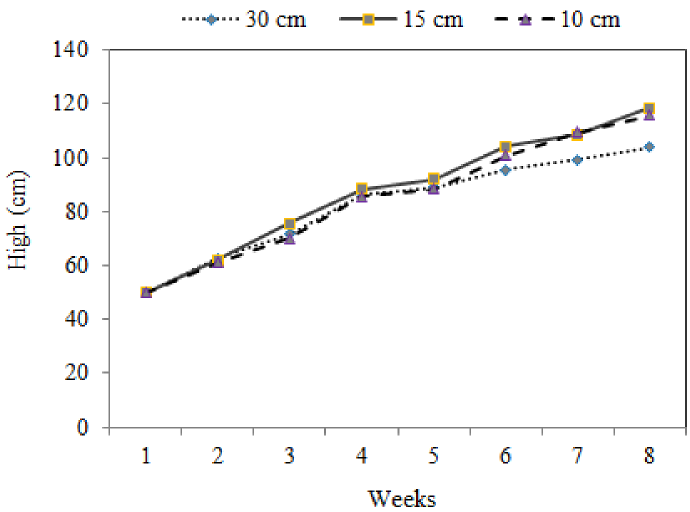

Figure 3. The growth of vetiver grass in the 10, 15, and 30 cm water depth in SFCW system

The grass needs nutrients for its growth, which could be found in the wastewater. This affirms that there are useful nutrients in wastewater for plants growing. After that, the vetiver grass will be flowering, getting older and absorbing fewer nutrients. Sakranukit (2006) reported that the 8 week old vetiver grass will have a better treatment quality than the 16 week old one because, at 16 weeks, the grass started flowering and stop growing.

4. CONCLUSIONS

Using vetiver grass to treat the swine farm wastewater in the constructed wetland with different water levels revealed that the 30 cm. water depth has a better removal efficiency of organic substance treatment (BOD and COD). The vetiver grass can reduce BOD by 74.69 % and COD by 75.36 %. The BOD and COD in the effluent wastewater were also within the standard of wastewater on the swine farm. The average TKN treatment efficiency of 10, 15 and 30 cm. water depths were 67.25, 69.73 and 70.93 %. However, the removal efficiency of TKN and TP were not significantly different at 10, 15 and 30 cm water depths. At the 10 cm of water depth, TKN showed the highest removal efficiency (75.74%) and the grass had a higher efficiency in the treatment of TP (97.98%) in the period of eight weeks. The treatment of heavy metals such as Cu, Pb, Fe and Zn by the vetiver grass in different water levels had no statistical significance and could only reduce only a small number of heavy metals. The result also showed that the vetiver grass's growth rate in terms of height had no differences, but at the 30 cm of water depth, its growing rate and height were the least compared to those in the 10 and the 15 cm water depths.

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