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Effectiveness of Vetiver Grass versus other Plants for Phytoremediation of Contaminated Water

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Abstract

Worldwide water pollution level in the last few decades has been exponentially increased as a result of industrialisation. This global increase occurs in both developed and developing countries, but more significantly in the latter. Vetiver System Technology, which is based on Vetiver grass (*Chrysopogon zizanioides* L. Roberty) has been successfully used as a phytoremediation tool to remediate both polluted water (municipal wastewater such as sewage effluent, landfill leachate, urban runoff, drainage channels, industrial wastewater such as food processing factories, contaminated land (mine overburden and tailings, solid waste dumps, etc.), due to its extraordinary and unique morphological and physiological characteristics. This review focuses on the treatment of polluted domestic and industrial wastewater by hydroponics and constructed wetlands treatment methods. Based on the finding, Vetiver grass (*Chrysopogon zizanioides* L. Roberty) has a similar potential and often more effective rather than two other Vetiver genotypes and other commonly used macrophytes such as *Cyperus* species, *Phragmites* species, *Typha* species in treating a wide range of industrial and domestic wastewater, polluted rivers and lakes. In addition, Vetiver has the potential to be used for additional benefits after phytoremediation, such as raw material for handicrafts, essential oil and its derived products, industrial products (raw material for pulp and paper), fibreboard.

Keywords: Vetiver grass; *Chrysopogon zizanioides*; *Cyperus, Phragmites; Typha; Eichhornia; Schoenoplectus;* Phytoremediation; Constructed Wetlands

1 Introduction

1.1 Selection of wetland plants

Species selection is one of the most important considerations for phytoremediation studies, especially using Constructed Wetlands (CW). Different wetland plant species have different capacities for uptake and accumulation of nutrients and heavy metals (1, 2), as well as having variable effects on the functioning and structure of bacterial communities involved in the removal of contaminants in a CW (3, 4). It is also necessary to consider the factors that affect the natural distribution of the selected plants both locally and within the region and locally, as these have a major impact on the successful establishment of the selected plants for phytoremediation purposes (5, 6). With these and other considerations in mind, the following is a list of selection criteria for fit-for-purpose wetland plants to be developed for phytoremediation study.

- The species of interest available/suitable for the proposed area
- Weediness potential of the plants of interest both within and outside the area
- The substrate preferred for the plants to grow in (sand, clay, mud, and peat)
- Aerobic and anaerobic conditions of the constructed wetland
- The depth of water suitable for the plants to grow in (shallow versus deep water)
- Ability of plants to withstand desiccation
- The local climate
- Wastewater contaminants in the wetland
- Potential interaction with animals and the possibility of plant destruction by animals

1.2 Vetiver grass (Chrysopogon zizanioides)

Following the discovery in 1994 in Australia that Vetiver grass had special characteristics suitable to treat landfill leachate and sewage effluent generated from municipal wastewater treatment plants (5). Chinese and Thai scientists later confirmed these results in 1997 and since then the Vetiver Phytoremediation Technology has been adopted widely across the tropical and sub-tropical regions of Asia, Africa, Oceania, the Americas and Mediterranean countries (5). Although Vetiver is a typical C4 tropical grass, it can survive and thrive under subtropical and some mild temperate conditions. Vetiver is a non-invasive plant as it forms flowers but does not set seed, hence it has to be propagated vegetatively by root (crown) splitting (7, 8). Vetiver grass has a deep and massive root system, which is vertical in nature descending 2-3 meters in the first year, ultimately reaching five meters under tropical conditions. Although it originates in India, *Chrysopogon*

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zizanioides is widely cultivated in the tropical and subtropical regions of the world. Vetiver can easily be controlled by uprooting the plant at the crown and drying out the exposed roots or by using herbicide.

1.2.1 Genetic and taxonomic Features

Vetiver grass (*Chrysopogon zizanioides* L.) belongs to the same grass family as maize, sorghum, sugarcane, and lemon grass (Table 1 and Figure 1). It is native to tropical and subtropical India and is one of the most widely distributed Vetiver grass species in South and Southeast Asia.

Besides *Chrysopogon zizanioides* L., there were numerous accessions of *Vetiver ia zizanioides* (L. Nash) and other Vetiver species such as *Chrysopogon fulvus* (Spreng.), *C. gryllus*, *Sorghum bicolor* (L.) and *S. halepense* (L.). Since *Vetiver ia* and *Chrysopogon* are not separable based on Random Amplified Polymorphic DNAs (RAPDs), this led to the merging of the genera *Vetiver ia* and *Chrysopogon*. *Vetiver ia zizanioides* (L. Nash) is now known as *Chrysopogon zizanioides* (L Roberty), (9-11), with chromosome base number, x=5 and 10, 2n= 20 and 40 (12).

1.1 Important features

Vetiver has erected and stiff shoots that can grow to 3 m tall. When planted close together in hedges it forms a living porous barrier that retards surface water flow and acts as an effective bio-filter, trapping both fine and coarse sediment in runoff water (Figure 1). It has a massive, deep, fast-growing root system (Figure 2). Most of the roots in its massive root system are very fine, with an average diameter of 0.5-1.0 mm. This provides an enormous surface area within the rhizosphere for bacterial and fungal growth and multiplication.

Table 1: Taxonomy of *Vetiveria zizanioides*

Scientific classification	
Kingdom	Plantae
Order	Poales
Family	Graminae (Poaceae)
Subfamily	Panicoideae; Tribe-Andropogoneae; Subtribe-Sorghinae
Genus	*Chrysopogon*
Species	*zizanioides*
Common name	Vetiver grass

Source: (9, 12)

Figure 1: The erect, stiff shoots Vetiver grass forming a thick hedge when planted close together

Figure 2: Vetiver Grass roots under hydroponics conditions

Litterature search between 1995 to 2019 on the use of different macrophytes for industrial and domestic wastewater treatment including pig farms, dairy farms, a sugar factory, textile mills, tannery, sewage effluent from municipal plant to septic tank, river and lake water showed that Vetiver was either equally and often more effective in treating the polluted wastewater than other macrophytes such as *Cyperus alternifolius, Cyperus exaltatus, Cyperus papyrus, Phragmites karka, Phragmites australis, Phragmites mauritianus, Typha latifolia, Typha angustifolia, Eichhornia crassipes, Iris pseudacorus, Lepironia articutala* and *Schoenoplectus validus.* Therefore, the main objective of this paper is to compare the effectiveness of Vetiver and other commonly used macrophytes for phyroremediating contaminated water in hydroponics and constructed wetland conditions.

Figure 3: The root system of Vetiver grass in a polluted wetland under natural conditions

2 Effectiveness of Vetiver grass in phytoremediating contaminated water

2.1 Negative effect of some severe environmental conditions

Under natural wetland conditions, oxygen is supplied to the water body via atmospheric diffusion, or by direct transfer through the plant's aerenchyma tissues (Figure 3). Darajeh, Idris (13) demonstrated that anaerobic conditions negatively affect growth of vetiver grass in Palm Oil Mill Secondary Effluent (POMSE) when dissolved oxygen (DO) was less than 0.5 mg/L. The plants died after five days, while the other plants survived under 3 mg/L DO (Figure 4).

2.2 Vetiver hydroponic treatment for Nitrogen and Phosphorus, Organic Components, Chemical Oxygen Dermand (COD), Biological Oxygen Demand (BOD) and Total Susspended solids (TSS)

Darajeh, Idris (14) demonstrated a relatively simple, low cost, green, and environmentally friendly solution by using the Vetiver system treatment for POMSE in Malaysia. This eliminates the complexity and high costs associated with chemical and other conventional treatments to achieve strict Dept of Environment effluent regulation limits within less than 4 weeks. Following the experimental duration of four weeks at planting density of 30 plants, an exceptional reduction of 96% for BOD and 94% for COD was achieved. The best and lowest final BOD (2 mg/L) was recorded at planting density of 15 Vetiver plants after 13 days for low concentration POMSE, which had initial BOD of 50 mg/L. The next best result of BOD at 32 mg/L was obtained at density of 30 plants after 24 days for medium concentration POMSE which had initial BOD of 175 mg/L. The study showed that the Vetiver System is an effective method of polishing and treating POMSE to achieve the stringent acceptable effluent standard**.**

Vetiver has a very high capacity of uptaking N and P in polluted water. Zheng et al, (1997) reported that the total N and P levels of the polluted river water (initial concentrations of 9.1 and 0.3 mg/L, respectively) were reduced by 71% and 98%, respectively, after 4 weeks of treatment. In small-scale glasshouse trials under hydroponics conditions, Vetiver takes up considerable quantities of both nitrogen and phosphorous (13,500 and 1026 kg/ha/year, respectively) higher than other plant species (Figure 5).

Healthy root growth in aerobic condition **Dead root growth in anaerobic condition**

Figure 4: Healthy and dead Vetiver roots under aerobic and severe anaerobic conditions

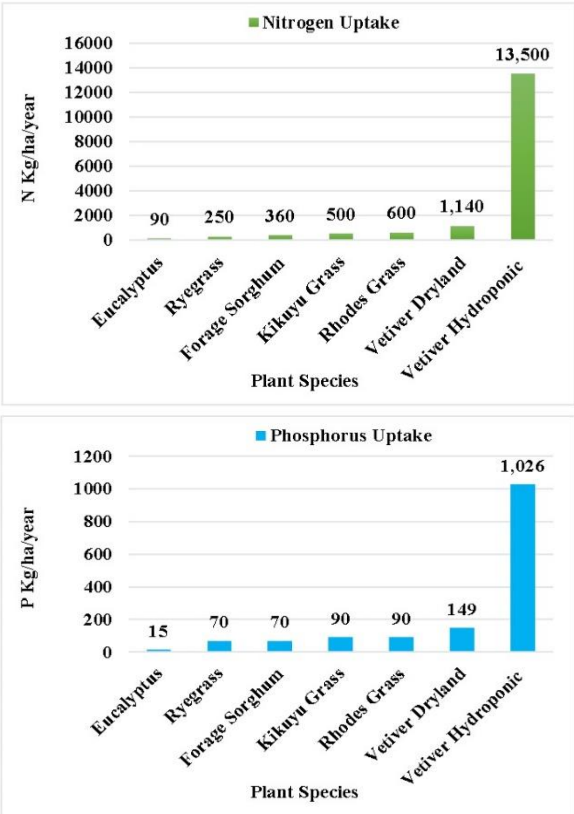

Figure 5: Nitrogen and Phoshphorous adsorbtion by different plant species in the glasshouse

According to Table 2, many researchers have used Vetiver grass; *Cyperus* species, various *Phragmites* species, various *Typha* species for the removal of contaminants of primary, secondary, and tertiary wastewater originating from domestic sources and industries. It has been observed that phytoremediation of contaminated water using the plant system is a predominant method which is economic to construct, requires little maintenance and increase the biodiversity, but plant treatment capabilities depend on different factors like climate, contaminants of different concentrations, temperature, etc. The removal efficiency of contaminants like BOD, COD, TSS, TN, NH_4-N, NO_3 and TP varies from plant to plant (15).

Based on Zhang, Jinadasa (16), the removal of TSS (66.1%) and BOD (65.34%) were satisfactory in treatment efficiency for Floating Treatment Wetland (FWS) systems. FWS exhibited the lowest performance for the reduction of COD by 44.9%. However, FWS CWs were found to be efficient in removing nitrate (NO_3-N) by 51.63%, ammonium (NH_4-N) by 60.87%, and total nitrogen (TN) by 43%. The removal of total phosphorus (TP) (49.16%) was moderate and highly variable from 19.5% to 96%. In Australia, a surface flow Vetiver grass wetland system on a 1.0 ha area was installed in South East Queensland to treat sewage effluent from a small town with 1,500 residents producing 300 KL/day. The Total N of inflow of between 30 and 80 mg/L and total P of 10-20 mg/L were reduced to 4.1-5.7mg/L and 1.4-3.3mg/L respectively (17).

Boonsong and Chansiri (18) studied the efficiencies of Vetiver grass cultivated on a floating platform to treat domestic wastewater with three different retention time values of 3, 5, and 7 days in Thailand. The average TN and NH_4-N removal efficiencies were 9.97-62.48% and 13.35-58.62%, respectively, while the average removal efficiencies ranged for TP from 6.3% to 35.87% and for phosphate from 7.40% to 23.46%. The 7-day HRT had the best treatment performance for BOD, TN, and TP, with removal efficiencies of 90.5-91.5%, 61.0-62.5%, and 17.8-35.9%, respectively.

Yang, Zheng (19) investigated the purification of nitrate by Vetiver grass in agricultural runoff in China, with effluent concentrations of TN (3.8-7.9 g/m^3) and TP (1.2-1.5 g/m^3) using FTWsystem. They reported an efficient removal of nitrate-nitrite-nitrogen (NOx-N) of 91%, 97% and 71% respectively in 3, 2 and 1 day HRTs, and (17-47%) removal of COD and (8-15%) of TP. In another study in China, Sun et al. (2009) investigated TN removal from a polluted river, by using the FTW system. They reported removal of TN (72.1%), NO_3-N (75.8%), NO_2-N (95.9%), and COD (94.6%) using Vetiver. Numerous reports indicated that high levels of NH_3, COD and BOD caused the death of a few macrophytes. For example Tanner (1) reported piggery wastewater with NH_3 level of 222 mg/L killed root of macrophytes. In laboratory-scale models treated with anaerobic ammonium oxidizing bacteria, *Juncus effusus* died at 91 mg/L of NO_3 and 156 mg/L of NH_4 (Paredes et al. (2) . Roongtanakiat, Nirunrach (20) also reported that Vetiver grass died in leachate with high concentration of COD at160 mg/L and BOD at 6,607 mg/L.

2.3 Vetiver hydroponic treatment of heavy metals

Due to its persistence and toxicity the existence of heavy metals and metalloids in the environment in general and particularly in aquatic environment is a thread to the wellbeing of human, fauna and flora by onsite or offsite pollution (21, 22). It is possible that the pollutants could further contaminate the environment in the long term, by contaminating the soil and groundwater. Therefore feasible measures are demanded in order to prevent or control this pollution problem (23, 24). Very high removal rates of Fe (81%) and Pb (81%) and low removal of Ni (38%), Zn (35%), SO_4^{2-} (28%), Mn (27%), Cr (21%), Al (11%) and Cu (8.0%) obtained by Kiiskila, Sarkar (25) over one year experimental period to determine the effectiveness of Vetiver grass for treating acid mine drainage. Fe was mainly localized on the root surface as plaques, whereas Mn and Zn had higher translocation from root to shoot. It was also found that metal accumulation in Vetiver biomass was not a hazardous waste.

Vetiver grass was shown to be effective in removing heavy metals, but the rate of removal and accumulation depends on the plant root length and density, and the heavy metals concentrations (Suelee, Hasan (26). Vetiver removal efficiency for heavy metals in water was in the order of Fe>Pb>Cu>Mn>Zn. Except for Fe at low concentration, the longer the root length and higher planting density increased the uptake of heavy metals. The distribution of heavy metal uptake was significantly different in plant parts at different heavy metals concentrations, root had a high tolerance towards higher concentrations of heavy metals.

The removal of heavy metals by Vetiver grass decreased after seven days, with 96% of Fe was removed. The removal rate of other heavy metals was in the order of Fe>Zn>Pb>Mn>Cu, Hasan, Kusin (27) also found that Vetiver grass with longer root and higher root density was more effective in removing heavy metals such as Cu, Fe, Mn, Pb, and Zn.

Table 2: The removal of nutrients by different plant species in different types of wastewater

Plant Species	Wastewater Types	Removal Performance (%)							Country	References
		BOD	COD	TSS	TN	NH_4-N	NO_3	TP		
Chrysopogon zizanioides	Aquaculture Effluent	-	-	-	-	0-67	-	0-75	Indonesia	(28)
Chrysopogon zizanioides	Piggery Effluent	74	70	-	87	-	-	83	Thailand	(29)
Chrysopogon zizanioides	Sewage Effluent	96	90	-	49	94	-	89	Peru	(30)
Chrysopogon zizanioides	Palm Oil Mill Secondary Effluent	96	94	-	-	-	-	-	Malaysia	(13)
Chrysopogon zizanioides	Landfill Leachate	67	69	-	-	-	43	56	Nigeria	(31)
Chrysopogon zizanioides	Fertilizer Processing	74	64	-	-	-	94	78	Nigeria	(31)
Chrysopogon zizanioides	Pinora Juice Effluent	94	95	82	-	41	10	85	Ghana	(32)
Chrysopogon zizanioides	Palm Oil Proc. Effluent	51	10	71	-	40	6	19	Ghana	(32)
Chrysopogon zizanioides	Biogas Effluent	91	82	95	-	42	99	35	Ghana	(32)
Chrysopogon zizanioides	Sewage Effluent	92		92	-	-	-	87	Ethiopia	(33)
Chrysopogon zizanioides	Pig farm WW	-	-	-	75	-	-	15-58	China	(34)
Chrysopogon zizanioides	Septic tank	-	-	-	99	-	-	85	Australia	(5)
Chrysopogon zizanioides	River Water	-	-	-	71	-	-	99	China	(35)
Chrysopogon nigritana	Landfill Leachate	66	67	-	-	-	59	79	Nigeria	(36)
Chrysopogon nigritana	Fertilizer Processing	69	60	-	-	-	93	80	Nigeria	(36)
Phragmites karka	Sewage Effluent	90	-	91	-	-	-	86	Ethiopia	(33)
Scirpus spp	Piggery Effluent	76	80	-	85	_	_	65	Thailand	(29)
Cluysopogon zizanioides /Cypress tenuifolius	Pig farm WW	68	64	-	-	20	-	-	China	(34)
Chrysopogon zizanioides/Phragmites mauritianus	Textile WW	67.5	46.2	81.5	-	-	-	-	Tanzania	(37)
Typha angustifolia	Piggery Effluent	81	84	-	88	-	-	65	Thailand	(29)
Eichhornia crassipes	Wastewater	-	80	-	75	-	-	75	Malaysia	(38)

Eichhornia crassipes	POME	-	50	-	88	-	-	64	Indonesia	(39)
Typha angustifolia/phragmites	Domestic WW	66	48.2	-	-	66	-	61	Saudi arabia	(40)
Typha latifolia/Typha angustifolia	Dairy WW	-	-	-	9	21	-	94	Canada	(41)
Canna/Phragmites cyprus	Municipal WW	93.6	92.2	94	-	-	-		Egypt	(42)
Phragmites australis	River Water	15.4	17.9	70	83.4	-	-	96	China	(43)
Phragmites australis	Oil Produce WW	88	80	-	10.2	-	-	18.5	China	(44)
Phragmites australis	Greywater/Secondary	70.3	65.9	82.2	36	-	-	32.4	Egypt	(45)
Phragmites australis	Black Water/Secondary	86.4	83.5	89	69.3	-	-	56.2	Egypt	(45)
Phragmites australis	Municipal Sludge/Tertiary	90	72	81	67	-	-	75	India	(46)
Phragmites australis	Tannery WW/Secondary	98	98	55	-	86	-	87	Bangladesh	(47)
Phragmites australis	Municipal WW /Secondary	22	56	84.2	39.3	-	-	-	ElSalvador	(48)
Phragmites australis/Typha orientalis	WW /Industrial	70.4	62.2	71.8	-	40.6	-	29.6	China	(49)
Phragmites australis/Zizania aquatica	River Water	90.5	73.5	92.6	10.6	10.5	-	30.6	China	(50)
Phragmites australis/ Iris australis	Municipal WW/Secondary	-	-	-	91.3	91.2	88.8	-	Turkey	(51)
Typha angustifolia/Scirpus grossus	Municipal WW/Secondary	68.2	71.9	-	74.7	50	19	-	Sri Lanka	(52)
Typha angustifolia	Lake Water	-	16.5	-	19.8	22.8	34.2	35.1	China	(53)
Typha angustifolia	Municipal WW /Secondary	80.8	65.2	-	58.6	95.75	-	66.5	ElSalvador	(48)
Typha angustifolia	Lake Water	-	36.9	-	52.1	32	65.3	65.7	China	(53)
Typha angustifolia	Lake Water	-	40.4	-	51.6	45.9	62.9	51.6	China	(53)
Typha latifolia/Phragmites mauritianus	Municipal Sludge/Tertiary	-	60.7	-	-	23	44,3	-	Tanzania	(54)
Typha latifolia	River Water	-	35	-	64.9	71.25	-	61.24	China	(55)
Typha latifolia/Canna indica	Municipal WW /Secondary	89.3	64.2	85.3	50.6	61.2	67.8	59.61	China	(56)
Typha latifolia/Phragmites australis	Municipal WW /Secondary	52	68	79	-	-	-	14	Mexico	(57)
Typha angustifolia/Canna iridiflora	Municipal WW	65.5	-	-	-	81.6	50	88.5	Sri Lanka	(58)
Cyperus alternifolius	Sewage Effluent	99	93	_	57	98	-	91	Peru	(30)
Cyperus alternifolius	Aquaculture Effluent	-	-	-	-	0-67	-	42-71	Indonesia	(28)
Cyperus papyrus	Sugar Factory WW	-	-	76	-	36	-	29	Kenya	(59)

Cyperus papyrus	Municipal W\V /Secondary	53	43.9	72.9	-	17.13	22	57.14	Kenya	(60)
Cyperus papyrus	Tannery WW /Tertiary	-	-	-	72.5	75.43	60.9	83.23	Uganda	(61)
Cyperus papyrus	Tannery WW /Tertiary	-	-	-	89.7	89.3	-	84.53	Uganda	(61)
Cyperus alternifolius	Municipal WW /Secondary	90	70	-	46	50	-	60	China	(62)
Cyperus alternifolius	Municipal WW /Secondary	-	83.6	99	64.5	71.4	-	68.1	China	(63)
Cyperus alternifolius	Municipal WW /Secondary	-	84.1	99.6	-	79.6	-	84.5	China	(63)

This is probably related to increased root surface area for metal absorption from contaminated water. However, these findings indicated that accumulation of heavy metals in plant biomass was higher in Vetiver shoot than in root due to metal translocation from root to the shoot. In a study conducted by Darajeh (64), Vetiver was used to remove Fe, Zn and Mn concentrations (0.5, 1.0, 2.0, 4.0, 8.0 and 10.0 mg/L) in aquoas solution. They reported that concentrations of Fe, Zn and Mn were decreased sharply during the first 40 hours of expriement and a plateau reached within a narrow range afterwards (Figure 6). Vetiver survived and grew in all metal concentrations and removed 85% to 99% of the metal ions at the different concentrations. The results showed that as the retention time increased, the metal removal efficiency also increased. It has been observed that an 88-hour retention time decreased the Fe, Zn and Mn from 10 mg/L to below 1.65 mg/L.

3 Effectiveness of Vetiver grass in treating N and P in comparison with forage and agriculture crops, and trees

In a study to determine the effectiveness of Vetiver grass in treating domestic sewage effluent Hart, Cody (65) found that Vetiver grass was the most effective species compared to some crop and trees which commonly grown in Australia (Table 3).

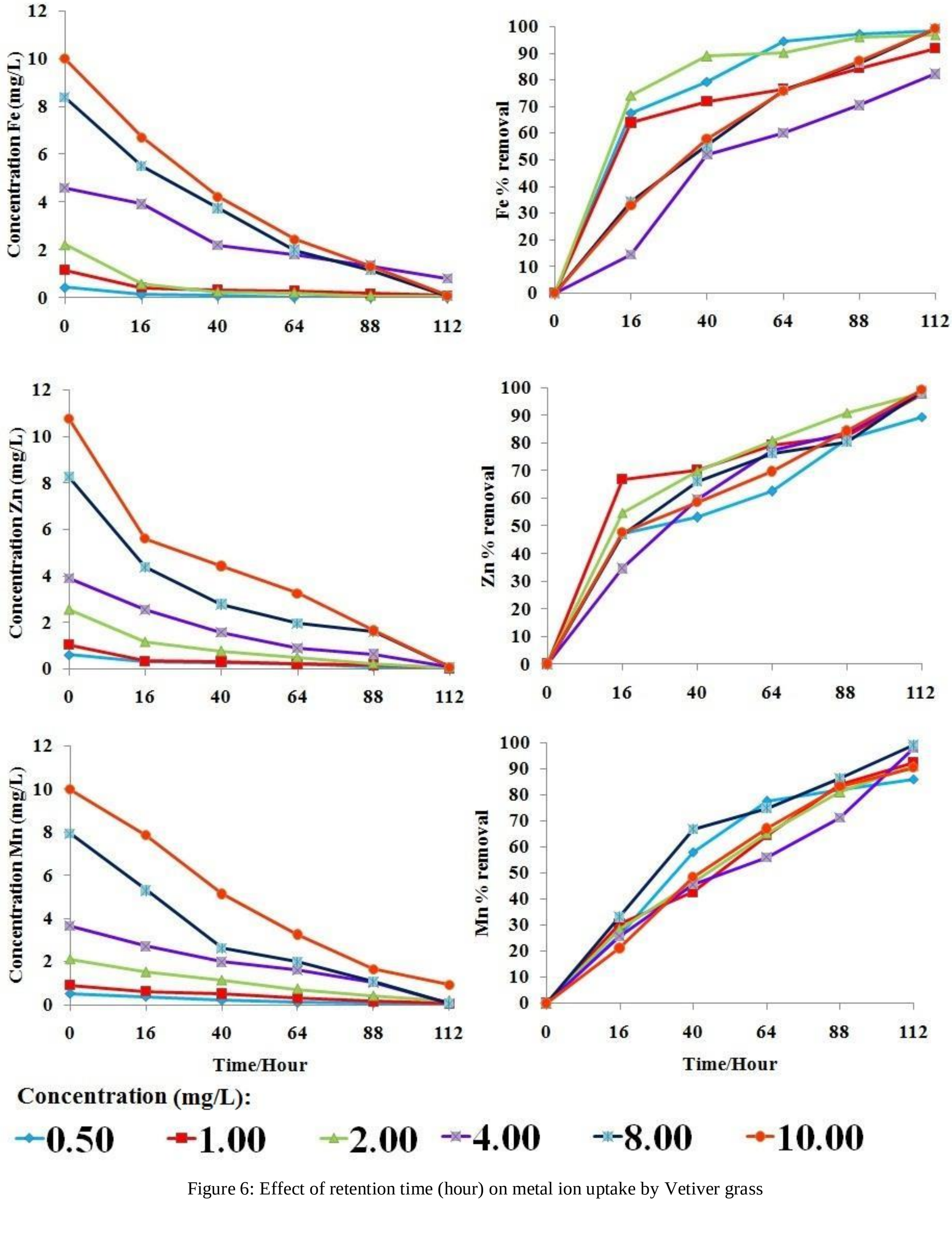

Figure 6: Effect of retention time (hour) on metal ion uptake by Vetiver grass

Table 3: Nutrient reductions by hydroponically grown Vetiver grass, and nutrient uptake in selected crops

Plant species	Nitrogen (kg/ha/year)	Phosphorus (kg/ha/year)
Vetiver pot trials	2,040	153
Vetiver field trial	1,142	149
Rhodes grass	600	90
Kikuyu	500	90
Green Panic	430	70
Forage sorghum	360	70
Sorghum + Ryegrass	620	110
Bermuda grass	280	30-35
Clover	180	20
Rye grass	200-280	60-80
Oats	60	50
Lucerne	269-504	20-39
Wheat	23-208	3-27
Eucalypts trees	90	15

4 Performance of Vetiver grass (*C. zizanioides*) compared with other Vetiver Species

4.1 Vetiver grass (C. zizanioides) and Upland Vetiver grass (C. nemoralis)

Truong, Hart (66) studied the potential of Vetiver grass in managing wastewater using two species of Vetiver grass: the commonly known in Thailand as Upland type - *C. nemoralis*- (variety Roi Et and Prajoub Kirikhan) and the lowland species - *C. zizanioides* (variety Songkhla 3 and Sri Lanka). They were grown at three depths of wastewater 5, 10, and 15 cm. It was found that plant tillering and dry weight of *C. zizanioides* Vetiver variety. Songkhla 3 (a local variety known only in Thailand) were significantly higher than those of *C. nemoralis* variety Prajoub Kirikhan, and Roi Et. The results also showed that lowland types of Vetiver grass, *C. zizanioides*, consumed more water than upland types *C. nemoralis* by 30-70 percent. *C. nemoralis* varieties were more effective in changing wastewater quality, but they could tolerate water levels at 10-15 cm for only 10 weeks, whereas the lowland types continued with normal growth. The efficiency in chromium removal by two species of Vetiver grasses, *C. zizanioides* (Surat Thani ecotype) and *C. nemoralis* (Prajoub Kirikhan ecotype), in constructed wetlands was investigated for tretamnet tannery wastewater (62). To study the efficiency of Chromium removal 12 constructed wetlands were built, nine were for the test and other three units were used to observe plant growth. The depths of wastewater were 0.10m, 0.15m and 0.20m in all wetland units. Results showed that *C. zizanioides* (Surat Thani) at water level 0.10m were the best performance for Cr removal at efficiency of 89.29%. While the Cr removal efficiency of *C. nemoralis* (Prajoub Kirikhan) at water level 0.15m was 86.30%. The lowest efficiency (80.72%) was found in control unit at 0.10m depth. The overall efficiency of Cr removal at the same depth of wastewater, *C. zizanioides* was better than *C. nemoralis.*

4.2 Vetiver grass and African Vetiver grass (C. nigritana)

As South Asian Vetiver species (*C. zizanioides*) has been widely used successfully globally, Oku, Asubonteng (31) investigated the potentials of African Vetiver species (*C.nigritana),* which is native and widely grown in West Africa, in treating contaminated water in Nigeria. Leachate effluent levels of pH, Pb, As, Zn, Fe, Cyanide, P, NO_3, COD, and BOD were measured from quarry and public untreated landfill. The results indicated that:

- *C. nigritana* more effective in removing P, and *C. zizaniodes* in removing N and Cyanide.
- No trace of Zn, Fe and Co were found in the leachate after 2 days of treatment in both species.
- The BOD of leachate from both sites were also significantly reduced.

When comparing the effectiveness of *C. nigritana* and C. *zizanioides* in treating contaminated water, it was founded they were equally effective. As *C. nigritana* is endemic to Africa, it should be used to sustainably treat wastewater for reuse. In addition, and most importantly for the two key pollutants N and P, *C. nigritana* is more effective in removing P, and *C. zizanioides* in N. Therefore, to maximize the treatment efficiency, it is advisable to use both species to gain further benefit from their complimentary attributes.

Oku, Asubonteng (31) assessed the potential of hydroponically grown African Vetiver (*C. nigritana*) and Asian Vetiver (*C. zizanioides)* to treat slaughterhouse effluent. The root lengths of these two species did not differ significantly. Concentrations of zinc and iron pollutants were reduced to below detectable limits within 6 days of treatment. Cyanide, with high pretreatment concentrations (>0.6 mg/L), was reduced in 6 days to below the World Health Organization (WHO) acceptable limits for irrigation water (0.07 mg/L). In the same time frame, the concentration of BOD by 84%, and COD by 86%, and concentrations of N, P and Mn were reduced by 52%, 70% and 88%, respectively, using *C. nigritana*. In addition, the concentation of BOD by 84%, COD by 88%, N by 71%, P by 77%, and Mn by 90% were reduced using *C. zizanioides*. As a result, *C. zizanioides* showed significantly higher N and P removal rates, whereas *C. nigritana* showed a higher Fe removal rate. However, removal rates of other contaminants did not differ significantly between the two species. It can be concluded that the efficacy of pollutant removal by Asian and African Vetiver is comparable. Thus, African Vetiver, which is readily available in many parts the

Africanb continent, could serve as a cheap and effective green solution to water pollution in Africa.

5 Comparison with other plant species

5.1 Vetiver grass, Cyperus alternifolius and Cyperus exaltatus

China is the biggest pig raising country in the world, China accounts for 57.4% of the total in the world (34). In the recent years pig-raising has concentrated production on larger farms, each produces over 10,000 commercial pigs, resulted in 100-150 tons of generation of wastewater daily, which has high contents of nutrients N and P. As a result, the pig farm wastewater needs treatments by anaerobic then aerobic methods. Since 1970's some hydrophilic plants such as water hyacinth was introduced to oxygenate effluent ponds in the anaerobic phase. However, this method needs large area for ponds, the treatment sites are prone to deterioration, water hyacinth did not work satisfactorily through the whole year.

Liao (67) found that from among twelve species, the two wetland plants, *Cyperus alternifolius* (Umbrella plant) and *Chrysopogon zizanioides*, were most suitable as vegetation in constructed wetlands for treatment of pig farm effluent in South China. Both plants were better in terms of pollution resistance, biomass accumulation, root growth, landscape beauty and management costs. This showed that *C. alternifolius* and *C. zizanioides* could grow in pig farm wastewater with a COD of 825 mg/L, BOD of 500 mg/L, NH_4-N of 130 mg/L and TP of 23 mg/L which reduced to 64%, 68%, 20%, and 18%, respectively, in HRT of 4 days. Another plant *Cyperus exaltatus* came third but wilted and dry during autumn did not grow until next spring. Therefore, this species cannot grow the whole year to treat the polluted water.

5.2 Vetiver grass, Typha angustifolia and Cyperus papyrus

In a study to select suitable plant species for the treatment of landfill leachate at Lorong Halus landfill site in Singapore, Vetiver grass, *Typha angustifolia* and *Cyperus papyrus* were used**.** The leachate composition is relatively high in nutrient, salt and heavy metal concentrations. The followings are summary of the results:

- *The nutrient removal efficiencies of all three species are quite comparable*
- *Vetiver had the highest removal on total N*
- *Typha and Papyrus performed better in nitrate removal*
- *Vetiver and Papyrus are better in total P removal*
- *Papyrus is associated with better COD, BOD and TSS removal*
- *Papyrus growth was severely affected by high salinity level*

Vetiver was selected as the preferred species for the wetlands as Vetiver was better than Typha and Papyrus in pollutant removal efficiency in 4 out of the 10 important selected criteria (Table 4). It should be noted that Vetiver had the highest removal rate of total N and best performance in total N and total P among the three species.

In addition, the following information on Vetiver and Papyrus performance was considered in the final selection:

1. During this study, it was noted that Papyrus was heavily attacked by an insect pest (Figure 7).
2. Papyrus growth was significantly affected by high salinity level of the leachate, resulting in very poor regrowth after harvesting (Figure 8).
3. Vetiver grass produced the highest biomass, which was crucial in the disposal of the volume of leachate (68).

5.3 Vetiver grass and Cyperus alternifolius

GÓMEZ (30) studied several parameters of phytodepurative treatment of wastewater in vertical artificial wetlands that were planted with *Cyperus alternifolius* and *Chrysopogon zizanioides*. The wetlands were located in the pilot water treatment plant at the National Agrarian University La Molina, Peru from January to November 2016. Both plants had a good adaptation during the whole research period. A maintenance cut was made to evaluate the biomass in dry weight of both plants. For *Cyperus alternifolius* 31.3 Tn/ha/year of dry Biomass was obtained and 31.1 Tn/ha/year for *Chrysopogon zizanioides*. There were no bad oders in both wetlands, waterlogging, and the presence of pests on the surface. There were no statistically significant differences in the removal of organic matter and solids between both plants.

5.4 Vetiver grass, Cyperus alternifolius and water hyacinth (Eichhornia crassipes)

Roongtanakiat, Nirunrach (20) compared the effectiveness of Vetiver grass (*C. zizanioides*), a Cyperus (*Cyperus alternifolius*) and Water Hyacinth (*Eichhornia crassipes*) in treating ammonia and phosphate in wastewater discharged from Catfish (*Clarias gariepinus*) aquaculture. Wastewater from aquaculture is highly contaminated with nutrients from feed and animal wastes, if untreated these pollutants seriously contaminated the environment. The constructed wetland system is cheap to build and maintain, and effective in controlling pollution caused by aquaculture wastewater, as it combines plant and microbe's activity in the treatment process. In this study, the Surface Flow Water system with plants on floating platforms were used in four treatments: control (bioball without plant), Vetiver grass, Cyperus plant and Water Hyacinth.

The results showed that each species has a different ability to eliminate ammonia and phosphate.

- Vetiver removal rate of NH_3 was from 2 to 66.7% and PO_4 from 0 to 75.4%
- Cyperus removal rate of NH_3 was from 0 to 66.7% and PO_4 from 42.4 to 71.2%
- Water Hyacinth removal rate of NH_3 was from 0 to 15.8% and PO_4 from 33.1 to 89.7%
- These results show that Vetiver and Cyperus were more effective in treating ammonia and Water Hyacinth in removing phosphate.

5.5 Vetiver grass and Common Reed (Phragmites karka)

Ghimire (69) compared the effectiveness of *Phragmites karka* (Common reed) and Vetiver grass in treating wastewater (a mixture of toilet, kitchen and chemistry laboratory effluents). The trial was made in four constructed wetlands: Vetiver grass alone, common reed alone, mixture of both and no plant-control. In term of soil organic matter, organic carbon, available phosphorus and total nitrogen, Vetiver grass pond showed the highest value followed by mixed species pond, Common reed pond and lastly control pond (Table 5). Based on the experimental results, Vetiver was found to be more efficient in wastewater treatment compared to *Phragmites karka* (Common reed) and a mixture of both was found to be intermediately efficient. In the subtropical highland climate of Addis Ababa, Ethiopia (33) Horizontal Subsurface Flow Constructed Wetlands were used to compare the performance of two macrophytes: *Chrysopogon zizanioides* and *Phragmite karka* in treating municipal wastewater.

Table 4: Effectiveness of Vetiver as compared with *Typha angustifolia* and *Cyperus papyrus* in treating various contaminants

Comparative Removal Efficiency between Vetiver; Typha and Papyrus				
	Removal Efficiency (%)			
Contaminants	**Vetiver**	**Typha**	**Papyrus**	**Better Performance**
BOD	53	58	54	Typha
TOC	24	22	21	Vetiver
TDS	5	2	1	Vetiver
NH_3	6	4	4	Vetiver
Total N	9	7	7	Vetiver
COD	13	15	15	Typha+Papyrus
NO_3	7	38	38	Typha+Papyrus
TSS	72	69	73	Papyrus
PO_4	67	47	68	Papyrus
Total P	33	23	39	Papyrus


Figure 7*: Cyperus papyrus* attacked by Insects

The loading rate of the wastewater was 0.025 m^3/d and that of BOD was at maximum of 6.16g/m^3d, with a hydraulic retention time of 6 days. *C. zizanioides* had better removal efficiencies of TSS (92.3%); BOD (92.0%) and PO_4 (86.7%) than *P. karka* TSS (91.3%); BOD (90.5%) and PO_4 (85.6%). *P. karka* performed better with NH_4 (86%), NO_3 (81.8%) and SO_4 (91.7%) than *C. zizanioides* which had removal efficiencies for NH_4 (83.4%), NO_3 (81.3%) and SO_4 (90.5%). Removal rates in unplanted wetlands were lower for all parameters: TSS (78%), BOD_5 (73%), NH_4 (61.0%), NO_3 (55.5%), PO_4 (67.6%), SO_4 (78.1%).

High levels of faecal Coliform and *Escherichia coli* are major concerns in the disposal of municipal sewage effluent. Very high removal rates of these two pathogens were obtained in wetland trials planted with Vetiver and *P. karka* compared to control (1.9 units of total Coliform and 1.2 units of *E. coli*). These are well below the concentrations of the pollutants limits for sewage effluent discharge set by World Health Organisation for directly disposed into surface water bodies or used for irrigation. Therefore, both Vetiver and *P. karka* are good candidates for remediation of sewage effluent using a constructed wetland system.

5.6 Vetiver grass, reed (Phragmites australis) and cattail (Typha latifolia.)

Xin and Huang (70) conducted a study to identify differences in boron (B) accumulation and tolerance as differences in B tolerance and accumulation mechanisms in many species are still poorly understood. Reed, cattail, and Vetiver were used in this greenhouse study to identify changes in plant biomass and B accumulation. All three species survived at up to 750 mg/L of B. Biomass of all three decreased significantly when B concentrations increased from control 0 to 1, 50 and 500 mg/L. At B concentrations lower than 250 mg/L, B accumulations were significantly different among the species in the order of Reed > Cattail > Vetiver grass. Cattail had a higher ability to uptake and transport B from the roots to the shoots than reed and Vetiver at B concentrations higher than 250 mg/L. Results of this study suggested that Vetiver grass could be a promising species in B phytoremediation in high B-contaminated environments. As Vetiver showed the highest tolerance to external B supply, followed by cattail and reed. It is most likely that the differences in B tolerance among the three species is due to their ability to restrict B uptake rather than restricting B translocation from root to shoot or tolerating high B accumulation.

5.7 Vetiver grass, Phragmites australis, Typha latifolia, and Lepironia articutala

To compare the efficiencies in treating wastewater from an oil refinery in China which had very high concentrations of organic and inorganic pollutants, Xia, Ke (71) planted *Chrysopogon zizanioides*, *Phragmites australis*, *Typha latifolia*, and *Lepironia articutala* in a constructed Vertical Flow Wetland system.

Figure 8: From left to right: Vetiver (*C. zizanioides*), *Typha augustifolia* and *Cyperus papyrus* at the start and the end of the treatment period

Table 5: Effectiveness of Vetiver grass compared with *Phragmites karka* (Common Reed) in treating various contaminants

	Treatments and Reduction (%)		
Contaminants	**Vetiver**	***Phragmites karka***	**Control**
BOD5	92.3	76.9	53.8
COD	92.3	35.3	28.1
Nitrate N	80.7	81.1	30
Total P	90.9	55	32.5
Chloride	81.1	52.8	26.4

In the wastewater with high concentration of pollutants, results after two-month treatment showed that all species had a very high with removal of NH_3 (97.7%), COD (78.2%), BOD (91.4%) and 95.3% of oil. In the wastewater with low concentration of pollutants, the removal rates for NH_3 (97.1%), COD (71.5%), BOD (73.7%) and 89.8% of oil were recorded. However, the performance of the wetlands decreased and remained stable and the removal efficiencies of all four species are similar in longer term. It was also noted that the tillering rate of *C. zizanioides* was much higher in comparison with that of the other three species. Therefore *C. zizanioides* might have a stronger adaptation to the polluted environment than other species in the oil- contaminated water.

5.8 Vetiver grass, Phragmites australis and Cyperus alternifolius

Using a constructed wetland designed to test the purification capacity of several wetland species to Acid Mine Drainage (AMD): *Chrysopogon zizanioides, Phragmites australis, Cyperus alternifolius, Panicum repens, Gynura crepidiodes, Alocasia macrorrhiza and Chrysopogon aciculatus*. Shu (72) found that an extremely acidic AMD collected from the Lechang lead/zinc mine tailings contained very high levels of Zn, Mn, Pb, Cd, Cu and Sulfate. Results after 75-day treatment indicated *C. alternifolius* had the highest and G. crepidiodes had the lowest index of tolerance to AMD among the six plants tested and C. zizanioides also had a high index of tolerance to the AMD.

5.9 Vetiver grass and Phragmites mauritianus

Njau and Mlay (73) used Horizontal Subsurface Flow Constructed Wetlands to treat wastewater with Vetiver grass and common reeds (*Phragmites mauritianus*) in removing Total P and Ortho P, and Total Kjeldahl N (NH_3-N + organic-N). The effluent ponds wastewater originated mainly from domestic duischarge from the main campus of Dar es Salaam University, Tanzania. Results showed that overall Vetiver performed much better than *P. mauritianus* in removing pollutants in this order: Organic nitrogen, Vetiver (83.8%) and reeds (55.3%); TSS, Vetiver (81.42%) and reeds (79.4%); COD, Vetiver (46.2%) and reeds (37.9%); Cu, Vetiver (73.6%) and reeds (64.6%). Effluent colour improvement, Vetiver (78.2%) and reeds (50.87%). Over the period of one-month, while all Vetiver plant growth were not affected, two out of six *P. mauritianus* plants died. Generally, it can be concluded that Vetiver grass performed better than *P. mauritianus* in removing of pollutants. These findings strongly support the use of macrophytes as an environmentally friendly and low-cost method for removal of pollutants from contaminated wastewater.

5.10 Vetiver grass, Water hyacinth (Eichhornia crassipes), Alligator weed (Alternanthera philoxeroides) and Bahia grass (Paspalum notatum)

Hanping, Huixiu (74) compared the capacity of four plants: *C. zizanioides*, *Eichhornia crassipes* (Water hyacinth), *Alternanthera philoxeroides* (Alligator weed) and *Paspalum notatum* (Bahia grass) in treating polluted water. A study was conducted to determine the effectiveness of four plants in treating leachate from the Likeng Domestic Landfill in Guangzhou, Guangdong Province, China. To test the tolerance to highly polluted environment four macrophytes (*Eichhornia crassipes, Paspalum notatum, A. philoxeroides and Chrysopogon zizanioides*) were selected for their characteristics of rapid growth producing large biomass. The levels of COD, total N, ammonia N, total P and Chloride in the leachate were several dozen times higher than the levels permitted to be discharged for industrial use or irrigation water for farmland. Results of this study showed that:

- *E. crassipes* died in both low (LCL) and high concentrations (HCL) of leachate.
- *P. notatum* could not survive in the HCL and was severely damaged in the low concentrations (LCL).
- *Philoxeroides* was impaired in the HCL but formed a considerably large biomass in the LCL.
- *Zizanioides* was also affected by the leachates but was the least affected of the 4 species.

The order of tolerance of the four species was C. *zizanioides* > *A. philoxeroides* > *P. notatum* > *E. crassipes*. Overall A. philoxeroides was superior to *C. zizanioides* in regard to total N and nitrate N in LCL. In addition, *C. zizanioides* was able to purify seven kinds of "pollutants" in the HCL better than *A. philoxeroides.*

Among the seven parameters measured in this study *C. zizanioides* showed the best results in Ammonia purification at the rate between 77% - 91%. It also showed a high purification rate for P (>74%). Based on the above findings, *C. zizanioides* showed a greater potential in treating the leachate discharge from this landfill.

5.11 Vetiver grass, Bulrush (Scirpus spp.) and Cattail (Typha angustifolia L.)

The effectiveness of three grass species: Vetiver, Bulrush (Scirpus spp.), and Cattail (Typha angustifolia L.) in treating piggery wastewater was investigated by Pongthornpruek (29), using the surface flow constructed wetland system, with flow volume at 0.18 m^3/day and 5-day hydraulic retention time (HRT). The results showed that Cattail improved BOD, COD and total Kjeldahl nitrogen (TKN) with efficiencies of 80.59%, 84.11% and 88.08%, respectively. Vetiver grass was most effective in treating total phosphorus (TP). The efficiency of Bulrush and Cattail treatment for TP was not significantly different. Although this treatment with a 5-day HRT was able to reduce the level of pollutants in the piggery wastewater, it could not meet the wastewater quality standard. Therefore, the periods for hydraulic retention time should be increased to reach the standard required**.**

6 Productivity, Utilization Options and Economic Potential of Vetiver Grass

Vetiver is a highly productive plant species (34). Truong (75) recommended that Vetiver planted for phytoremediation should be harvested two or three times a year for biomass utilization purposes or to export nutrients. Chomchalow (76) and Raman, Alves (77) reported that harvested leaves, stems and roots of the Vetiver plant in the form of dried, partly dried, or even fresh material have some other uses either with no processing, or with some degree of processing.

- Non-processed products

Construction and building material (thatching), compost, agricultural (mulch), mushroom medium, animal fodder (for dairy cows, cattle, sheep, horses or rabbits) and biofuel.

- Semi processed products

Raw material for handicrafts (weaving of hats, mats, baskets etc.), an energy source such as ethanol production, botanical pesticides, pressed-fiber pots, furniture.

- Fully processed products

Essential oil and its derived products, herbal medicine, industrial products (raw material for pulp and paper), fiberboard.

7 Conclusion

Vetiver System Technology has been used successfully as a phytoremediation tool to counteract polluted waters, due to its extraordinary and unique morphological and physiological attributes. The reduction of contaminants is strongly affected by plant growth rate and hydraulic retention time. Hence the integration of available knowledge and techniques for removal of water contaminants and advances in waste water treatment is important in assessing and controlling water pollution. Th**ese** reported results show that Vetiver grass is either equally and often more effective in treating these contaminated wastewaters than other Vetiver genotypes and other commonly used macrophytes including several Cyperus species, *Phragmites* species, Typha species and another 14 plant species. Studies showed that Vetiver grass is most effective species among the top three, including *Phragmites australis* and *Cyperus alternifolius*. The following is the summary of the conclusions:

- The high efficiency of Vetiver grass in treating both organic and inorganic chemicals suggests that the grass could be used to develop a cost effective and environment friendly remediation for wastewater. Vetiver tolerates a wide range of pH (3.5-11.5), salinity and heavy metals such arsenic, Cadmium, Copper, Chromium, Lead, Mercury, Nickel, Selenium and Zinc. It could also absorb large amount of Nitrogen, Phosphorous and Potassium. Its extensive and deep root system could reduce or eliminate deep nitrate leaching to groundwater.

- Vetiver has fine purple flowers that can be well incorporated in landscape design. It also has a large biomass and a dense root system extending up to 5 m depth.
- Under wet conditions or high-water supply, it has a very high-water use rate, up to 7.5 times more than other common wetland plants such as *Typha latifolias*, *Phragmites australis* and *Schoenoplectus validus*.
- It is highly resistant to pests and diseases.
- It is sterile so no potential for becoming an aquatic weed.
- Vetiver can tolerate extreme temperatures from -14 ℃ to 55℃.
- It is recommended that further research to be undertaken in the following areas, as more information on Vetiver phytoremediation is needed to obtain more scientifically proven with an ever-increasing degree of accuracy. These include:
- Implement a study at larger scales and in continuous flow conditions;
- Study the use of Vetiver plant by-product as biomass used for biofuel production;
- Assess the effect of Vetiver on the removal of methane produced in anaerobic treatment processes.

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