

Research Article

Phytoremediation Potential of Vetiver System Technology for Improving the Quality of Palm Oil Mill Effluent

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Palm oil mill effluent (POME), a pollutant produced by the palm oil industry, was treated by the Vetiver system technology (VST). This technology was applied for the first time to treat POME in order to decrease biochemical oxygen demand (BOD) and chemical oxygen demand (COD). In this study, two different concentrations of POME (low and high) were treated with Vetiver plants for 2 weeks. The results showed that Vetiver was able to reduce the BOD up to 90% in low concentration POME and 60% in high concentration POME, while control sets (without plant) only was able to reduce 15% of BOD. The COD reduction was 94% in low concentration POME and 39% in high concentration POME, while control just shows reduction of 12%. Morphologically, maximum root and shoot lengths were 70 cm, the number of tillers and leaves was 344 and 86, and biomass production was 4.1 kg m^{-2} . These results showed that VST was effective in reducing BOD and COD in POME. The treatment in low concentration was superior to the high concentration. Furthermore, biomass of plant can be considered as a promising raw material for biofuel production while high amount of biomass was generated in low concentration of POME.

1. Introduction

Clean water has increasingly become one of the rare valuable resources. Fast industrialization causes the production and release of considerable amounts of wastes in the water sources. The conventional water sources are easily contaminated by industries wastewater [1, 2]. The palm oil industry, over the last four decades, has become one of the major agroindustries in Malaysia [3, 4]. The palm oil industry caused negative impact on the environment and it may contribute to the alarming increase in the environmental pollution [5]. The processing of palm oil produces large quantities of polluted wastewater commonly named as palm

oil mill effluent (POME). POME is the liquid waste in the processing of oil extraction, washing, and cleaning processes. Up to 1.5 m^3 of water is used to process one tone of fresh fruit bunch (FFB). From this quantity, about 50% of the water results in the POME, the other 50% being lost as steam, mainly through sterilizer exhaust, piping leakages, and wash waters [6–9].

POME has been identified as the main sources of water pollution in Malaysia due to high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) that causes reduction of the biodiversity and ability of aquatic ecosystems. Department of Environment (DOE) enforces

a regulation under the Environmental Quality Act (1997) for the discharge of effluent from the palm oil industry. DOE requires an effective management system in order to treat and dispose of POME with the goal of environmental conservation and increasing the quality of river water.

Several treatment technologies have been developed and applied by palm oil mills to treat POME, such as anaerobic digestion [10, 11], membrane technology [12], aerobic activated sludge reactor [3], and evaporation method [13]. These conventional treatment systems frequently encounter problems associated to their long hydraulic retention time (HRT) and large space requirement; these could be problems with increasing production of POME. The challenge of environmental engineers and scientists is to develop effective and simple methods for treatment of industrial wastewater.

Nowadays phytoremediation as a green technology is one of the main environmentally friendly technologies that scientists are using in their researches. Phytoremediation is the direct use of green plants to clean up contaminated water, soils, or sediments. Phytoremediation is a new, cost effective, aesthetically pleasing, and low cost suitable solution for many environmental problems across the world [14–16]. Suitable plant species used for phytoremediation should have high uptake of both organic and inorganic pollutants, grow well in polluted water, and be easily controlled in quantity spreading dispersion. Furthermore, the plants should not only accumulate, reduce, or volatilize the contaminants but also grow fast in a range of different conditions and lends to harvesting easily [17, 18].

Vetiver grass (*Chrysopogon zizanioides* L.) belongs to the same grass family as maize, sorghum, sugarcane, and lemon grass (Figure 1). It was first used for soil and water conservation purposes by the World Bank. However, in the last two decades, Vetiver role has been successfully extended to environmental protection, particularly in the field of wastewater treatment, due to its prominent morphological and physiological characteristics and tolerance to adverse conditions [19].

Application of the Vetiver system for wastewater treatment is a new and innovative phytoremedial technology. It is a green and environmental friendly wastewater treatment technology as well as a natural recycling method. In the process of treatment, the Vetiver plant absorbs essential plant nutrients such as nitrogen (N), phosphorus (P), and cations and stores them for other uses.

The end product has provided high nutrient material for animal feed, mulch for gardens, roof thatching, handicrafts (ropes, mats, hats, and baskets) raw material for making pulp, and paper and material for organic farming [20] and recently extended to biofuel and carbon sequestration. Despite the potential advantages of Vetiver grass for the treatment of wastewaters, there has been very little information published to date about hydroponic treatment performance by Vetiver. The novelty of this work is the use of Vetiver grass for the first time for treatment of POME. In the present work, Vetiver first was grown on hydroponic solution to obtain well-developed



FIGURE 1: Vetiver grass (*Chrysopogon zizanioides* L.).

roots and then transfer them to two different concentrations of POME, to demonstrate the potential of Vetiver grass in reducing the biological oxygen demand (BOD) and chemical oxygen demand (COD) and investigate biomass production.

2. Materials and Chemical

2.1. Batch Studies. The experiment consisted of two sets of three rectangular plastic containers (0.3 m length \times 0.3 m width \times 0.5 m depths), capacity of 45 L and surface area of 0.09 m². One set contained undiluted POME (high concentration POME) and another set had the POME diluted (low concentration POME) with tap water in a 1 (POME) : 9 (water) ratio. Both diluted and undiluted treatments consisted of three subtreatments. These included culture of Vetiver with density of 15 tillers, culture of Vetiver with 30 tillers, and a container with no Vetiver, referred to as control. Vetivers were obtained from a commercial nursery, Humibox (M) Sdn. Bhd, Malaysia. To allow for some adaption, Vetivers were grown in a hydroponic solution (N, P, K, 18 : 18 : 18), for five weeks until adequate roots and shoots development were obtained (Figure 2). Polystyrene sheets with a dimension of 29 \times 29 \times 5 cm (length \times width \times thickness) were placed on the plastic containers surface as the floating platform to support Vetiver plants.

Vetiver slips were planted into the hole of the polystyrene platform with approximately 8 cm of roots submerged in POME (Figure 3). Aeration facilitates aerobic degradation of organic materials by maintaining oxygen concentration in the wastewater. Several studies have been conducted to improve the quality of effluent from industrial sources using aerated systems [21–23]. Due to this reason, this setup continuously provided 3 m gL⁻¹ oxygen to the solution to maintain good bacterial growth. The experiment was carried out with aerobic condition for two weeks, in which observations were made of changes in appearance and growth of Vetiver plants.



FIGURE 2: Vetiver planting slips in hydroponic solution.



FIGURE 3: Vetivers after five weeks ready for experimentation.

TABLE 1: Characteristics of POME.

Parameter	Concentration
pH	6.5–7.5
Total suspended solid (mg/L) (TSS)	750–800
BOD ₃ (mg/L)	350–400
COD (mg/L)	790–810
Total nitrogen (mg/L)	400–450
Ammoniacal nitrogen (mg/L)	295–310
Turbidity (NTU)	3300–3400
Color (ADMI)	3600–3700

The aeration was carried out using aquarium pump with a porous stone diffuser that was put at the bottom of container. The POME was collected from anaerobic treated pond at Labu Palm Oil Mill in Labu, Negri Sembilan, Malaysia. The characteristic is presented in Table 1. The characteristics of POME highly depend on the operation process in

TABLE 2: Treatment combinations.

POME concentration	LCP*	HCP*	Control
Vetiver density	V30/V15**	V30/V15	Control

*Low concentration POME; high concentration POME; **number of Vetiver tillers.

the mill and seasonal changes in the palm crops. Table 2 shows the treatment combinations, where low concentrated POME (LCP) and high concentrated POME (HCP) are POME concentration and V30 and V15 are the number of Vetiver tillers.

At the beginning of the study whole Vetiver plants were collected; leaves were cut at surface level of polystyrene and rinsed thoroughly with deionized water, and used paper toweling to wiped leaves, and then they were weighed. Plant leaves were placed on the tray and dried in oven which was set at 70°C. They were dried for 72 hours, then cooled

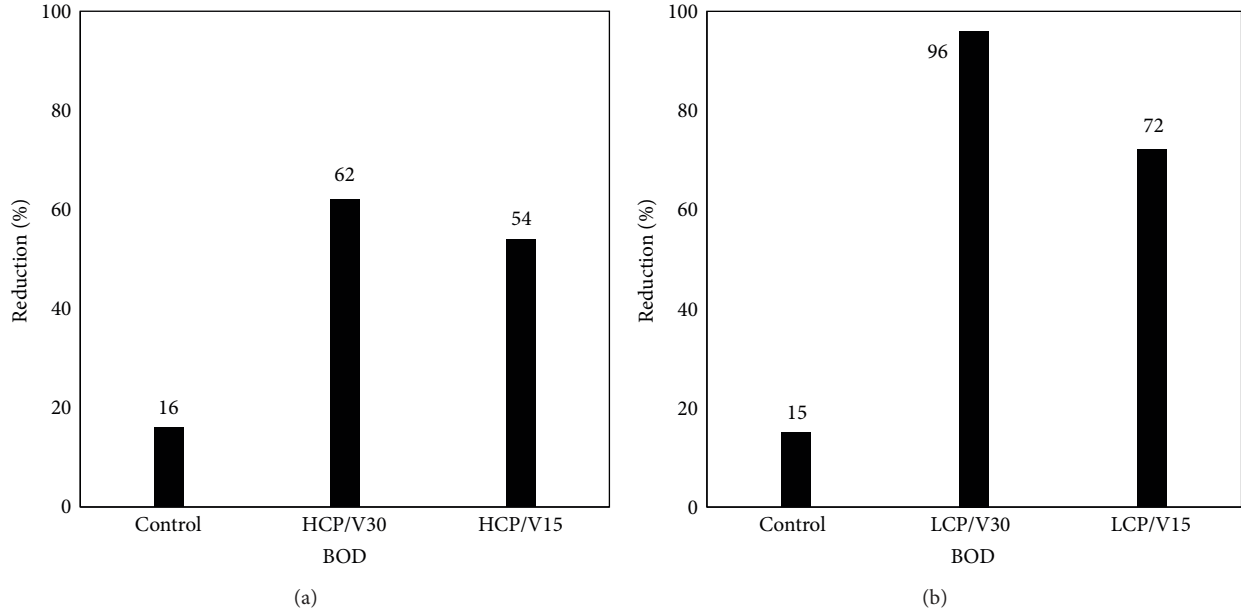


FIGURE 4: Reduction of BOD%: (a) high concentration POME (HCP) and (b) low concentration POME.

in a desiccators jar, and reweighed. Biomass for leaves was calculated by the following formula:

$$\text{Standing Biomass} = \frac{\text{Dry Weight (kg)}}{\text{Surface area (m}^2\text{)}} \quad (1)$$

The morphological parameters such as the number of tillers, height of shoots, and length of roots were recorded and analyzed at the end of experimental period (14 days).

Reduction efficiencies of treatment system were calculated based on the following formula:

$$\% \text{Removal Efficiency} = \left(\frac{C_{\text{inf}} - C_{\text{eff}}}{C_{\text{inf}}} \right) \times 100, \quad (2)$$

where C_{inf} is initial parameter concentration and C_{eff} is final parameter concentration.

2.2. Analytical Method. The treatments were evaluated by measuring parameters, which were consistently taken during midmorning. Samples were obtained by dipping a 100 mL graduated cylinder at three places across the surface of the container and combining them. The wastewater in each container was sampled 8 times over 14-day period, on days 0, 2, 4, 6, 8, 10, 12, and 14. Chemical oxygen demand (COD) and biological oxygen demand (BOD) were measured according to standard methods (APHA.1998).

3. Result and Discussion

3.1. Organic Reduction. The organic compounds reduction takes place with biological decomposition processes by microorganisms. Plant rhizosphere stimulates microbial activity and community density by providing root surface

TABLE 3: Reduction of BOD in high concentration POME with different Vetiver density.

POME/Vetiver	BOD day 0	BOD after 14 days	BOD reduction %
Control	348	292	16
HCP/V30	350	133	62
HCP/V15	356	163.7	54

area for their growth [24, 25]. The organic strength of wastewater measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). BOD assessment is one of the most widely used criteria for water quality [26]. BOD is the amount of dissolved oxygen (DO) that is used by microbial activity for the biochemical degradation of organic matter in water in a given time (usually 5 days) at a certain temperature (20°C) in the dark place [27]. Effects of two parameters' concentration and Vetiver density on BOD reduction were investigated as follows.

3.2. Effect of Concentration on BOD Reduction. The level of contaminants will affect its uptake by Vetiver plant as shown in Figure 4. After two weeks of remediation, the highest reduction BOD was LCP, with 96% of BOD reduction, while the HCP reduction was lower than LCP; it showed 62% of BOD reduction.

3.3. Effect of Vetiver Density on BOD Reduction. The number of Vetiver tillers will affect BOD reduction efficiency, as shown in Tables 3 and 4 after two weeks of remediation in both concentrations; reduction of BOD with 30 tillers of

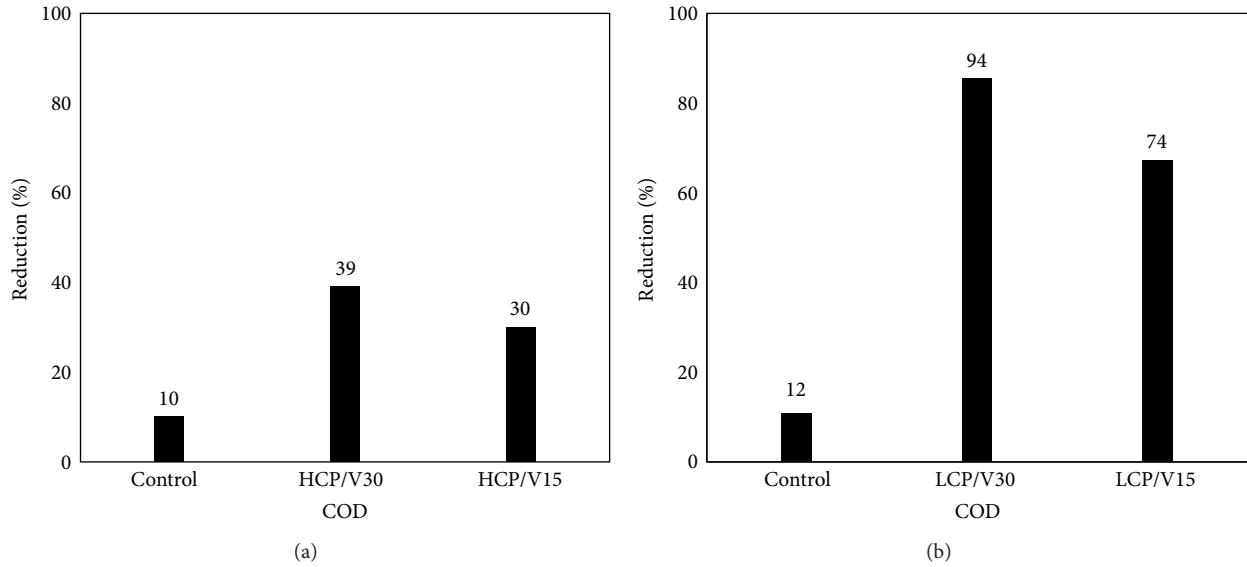


FIGURE 5: Reduction of COD%: (a) high concentration POME and (b) low concentration POME.

TABLE 4: Reduction of BOD in low concentration POME with different Vetiver density.

POME/Vetiver	BOD day 0	BOD after 14 days	BOD reduction %
Control	56	47.6	15
LCP/V30	52	2	96
LCP/V15	56	15.7	72

TABLE 5: Reduction of COD in high concentration POME with different Vetiver density.

POME/Vetiver	COD day 0	COD after 14 days	COD reduction %
Control	763	686	10
HCP/V30	721	440.3	39
HCP/V15	784	548.2	30

Vetiver was higher than 10 Vetiver tillers. On concentration of LCP, with 15 tillers of Vetiver the reduction was 72%, while in the same concentration but with 30 tillers of Vetiver the BOD reduction was 96%. Also in concentration of HCP with 15 Vetiver tillers the reduction was 54%, while it was 62% for 30 Vetiver tillers. So it is shown that with the increase of the number of initial Vetiver tillers the uptake will increase, because more root surface is available for bacterial growth, and also the plant can absorb more nutrients.

Chemical oxygen demand (COD) is oxygen requirement to decompose organic and inorganic materials through chemical pathways. High COD level indicates the toxic condition and the presence of biologically resistant organic substances. Effects of two parameters' concentration and Vetiver density on COD reduction were investigated as follows.

3.4. Effect of Concentration on COD Reduction. The COD reduction increased significantly during the growing time, because the root system developed well. As shown in Figure 5, LCP had the highest COD reduction, up to 90%, while phytoremediation in HCP showed lower COD reduction up to 30%. Phytoremediation in LCP was more effective than in HCP as it shows more reduction of BOD and COD during remediation.

TABLE 6: Reduction of COD in low concentration POME with different Vetiver density.

POME/Vetiver	COD day 0	COD after 14 days	COD reduction %
Control	114	100.3	12
LCP/V30	102	6.1	94
LCP/V15	113	29.3	74

3.5. Effect of Vetiver Density on COD Reduction. As shown in Tables 5 and 6 the highest reduction of COD was for LCP with 30 Vetivers tiller, with 94% removed, while at the same concentration but with 15 Vetiver tillers the COD reduction was 74%. Same as BOD results, with increasing Vetiver tillers the reduction efficiency increased. In HCP, with 15 Vetiver tillers the COD reduction was 30%, while at this concentration with 30 Vetiver tillers the reduction increased to 39%.

During the entire time series analysis, it can be shown that the concentration of BOD and COD of experimental sets planted with Vetiver was lower than that of the control set. This clearly shows the beneficial effect of Vetiver in treating POME. Comparing results with other studies showed that

the range of COD reduction is between 16.5 and 98%, for different types of wastewater and macrophytes.

None of the reported studies have used Vetiver on aerobic POME treatment. Due to the lack of studies in the field of Vetiver wastewater treatment, the results were compared with other studies published between 1997 to 2014, that have been used different macrophytes such as: *Typha angustifolia*, *Canna*, *Phragmites australis*, *Cyperus papyrus*, *Typha orientalis*, *Zizania aquatica*, *Iris australis*, *Scirpus grossus*, *Phragmites mauritianus*, *Canna iridiflora*, for the treatment of industrial or domestic wastewater such as: pig farm, dairy, sugar factory, textile, tannery, septic tank, municipal, black water and grey water.

Kantawanichkul et al. [28] planted Vetiver to treat diluted settled pig farm wastewater in Thailand. They reported 78.8 reduction percent of COD. Jiang and Xinyuan [29] used floating and submerged and emerged plants in the zoo wastewater and they reported 44% reduction of COD. Ji et al. [30] studied treatment of oil products wastewater in China, with *Phragmites australis*; they reported 80% COD reduction. Ahmed et al. [31] reported 72% COD reduction for treatment of municipal sludge, in India, with *Phragmites australis*. Chan et al. [32] conducted a study in China, for treatment of municipal secondary wastewater, with *Cyperus alternifolius*; they reported 83.6% COD reduction. Abdel-Shafy et al. [33] studied treatment of secondary greywater in Egypt, with *Phragmites australis*; they reported 65.9% reduction of COD. Song et al. [34] reported 62.2% COD reduction for municipal wastewater treatment in China with *Phragmites australis* and *Typha orientalis*. Katsenovich et al. [35] studied treatment of secondary municipal wastewater treatment in El Salvador, with *Typha angustifolia*; they reported 65.18% reduction of COD. Zhai et al. [36] conducted a study for treatment of secondary wastewater treatment in China with *Cyperus alternifolius*; they reported 83.6–84.1% COD reduction. Chang et al. [37] studied COD reduction of secondary municipal wastewater treatment with *Typha latifolia* and *Canna indica*, in China; they reported 64.15% COD reduction. Saeed et al. [38] studied secondary Tannery wastewater treatment with *Phragmites australis*, in Bangladesh; they reported 98% COD reduction. Abou-Elela et al. [39] reported 92.2% COD reduction for treatment of municipal wastewater in Egypt, with *Canna*, *Phragmites*, and *Cyperus*. Liao et al. [40] conducted a study with Vetiver and *Cyperus alternifolius*, in China, for treatment of pig farm wastewater; they reported 64% COD reduction. Kaseva [41] reported 60% of COD reduction for tertiary municipal sludge treatment, with *Typha latifolia* and *Phragmites mauritianus*, in Tanzania. Chan et al. [32] studied treatment of secondary municipal wastewater, with *Cyperus alternifolius*, in China; they reported 70% COD reduction. Abdel-Shafy et al. [33] used *Phragmites australis*, for treatment of secondary black water, in Egypt; they reported 83.5% COD reduction. Song et al. [34] studied municipal wastewater treatment with *Phragmites australis* and *Typha orientalis*, in China; they reported 62.2% COD reduction. Njau and Mlay [42] studied treatment of textile wastewater, with Vetiver and *Phragmites mauritianus*, in Tanzania; they reported 46.2% COD reduction. Li et al. [43] used *Typha angustifolia* on lake water, in China; they reported 39.6–40.4%

COD reduction. In another study conducted by Li et al. [44], they used *Phragmites australis*, for river water, in China; they reported 17.9% COD reduction. Tang et al. [45] used *Typha latifolia*, in river water, in China; they reported 35% COD reduction. Mburu et al. [46] studied treatment of secondary municipal wastewater, with *Cyperus papyrus*; in Kenya, they reported 42.7–43.89% COD reduction. Christwardana and Soetrinanto [47] reported 50% of COD reduction for treatment of POME, in Indonesia, with water hyacinth. Hussain et al. [48] used *Typha angustifolia* and *Phragmites*, for treatment of domestic wastewater, in Saudi Arabia; they reported 48.15% COD reduction. Katsenovich et al. [35] used *Phragmites australis*, for treatment of secondary wastewater, in El Salvador; they reported 56% of COD reduction. Rivas et al. [49] studied treatment of secondary wastewater, in Mexico, with *Typha latifolia* and *Phragmites australis*; they reported 68% COD reduction. Chang et al. [37] studied COD reduction of secondary municipal wastewater treatment with *Typha latifolia* and *Canna indica*, in China; they reported 64.15% COD reduction.

Comparing results with other studies showed that the range of BOD reduction is between 15.4 and 98%, for different types of wastewater and macrophytes. Liao et al. [40] studied pig farm wastewater treatment with Vetiver and *Cyperus alternifolius*, in China; they reported 68% BOD reduction. Njau and Mlay [42] reported 67.47% BOD reduction for textile wastewater treatment in Tanzania, with Vetiver and *Phragmites mauritianus*. Jinadasa et al. [50] conducted a study in Sri Lanka, for treatment of secondary municipal wastewater, with *Typha angustifolia* and *Scirpus grossus*; they reported 68.2% BOD reduction. Abdel-Shafy et al. [33] used *Phragmites australis*, in order to treat secondary black water in Egypt; they reported 86.4% BOD reduction. Song et al. [34] reported 70.4% BOD reduction on municipal wastewater treatment in China, with *Phragmites australis* and *Typha orientalis*. Weragoda et al. [51] reported 65.5% BOD reduction for municipal wastewater treatment in Sri Lanka, with *Typha angustifolia* and *Canna iridiflora*. Mburu et al. [46] used *Typha angustifolia* and *Canna iridiflora*, in order to treat municipal wastewater, in Sri Lanka; they reported 65.5% BOD reduction. A study was conducted by Hussain et al. [48], in Saudi Arabia, in order to treat domestic wastewater, with *Typha angustifolia* and *Phragmites*; they reported 66% BOD reduction. In another study, Klomjek and Nitisoravut [52] reported 74.3% BOD reduction from municipal saline condition treatment, with *Typha angustifolia*, in Thailand. Ji et al. [30] used *Phragmites australis*, for treatment of oil products wastewater; they reported 88% BOD reduction. Ahmed et al. [31] conducted a study for treatment of secondary wastewater, with *Phragmites australis*, in India; they reported 90% BOD reduction. Chan et al. [32] reported 90% BOD reduction for secondary municipal wastewater treatment in China, with *Cyperus alternifolius*. Chen et al. [53] studied secondary municipal wastewater treatment in China, with *Cyperus alternifolius*; they reported 90% BOD reduction. Abdel-Shafy et al. [33] reported 86.4% BOD reduction from secondary black water treatment, with *Phragmites australis*, in Egypt. Katsenovich et al. [35] studied treatment of secondary municipal wastewater treatment in El

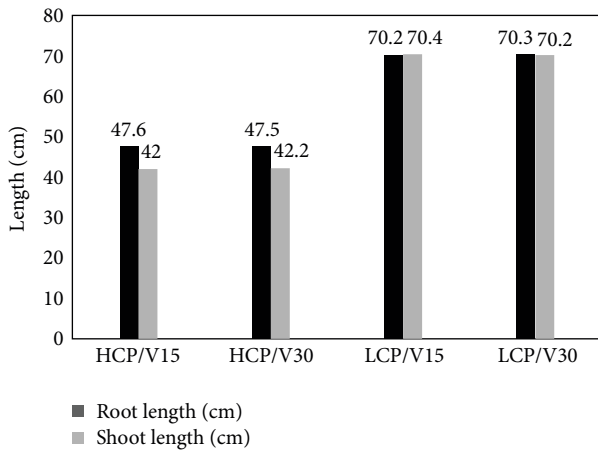


FIGURE 6: Root and shoot length of Vetiver (cm) (HCP is high concentration POME and LCP is low concentration POME).

Salvador, with *Typha angustifolia*; they reported 80.78% BOD reduction. Saeed et al. [38] used *Phragmites australis*, in order to treat secondary tannery wastewater, in India; they reported 98% BOD reduction. Chang et al. [37] studied BOD reduction of secondary municipal wastewater treatment with *Typha latifolia* and *Canna indica*, in China; they reported 89.3% BOD reduction. Abou-Elela et al. [39] reported 93.6% BOD reduction for treatment of municipal wastewater in Egypt, with *Canna*, *Phragmites*, and *Cyperus*. Li et al. [44] used *Phragmites australis*, for river water, in China; they reported 15.4% BOD reduction. Katsenovich et al. [35] studied treatment of secondary municipal wastewater treatment in El Salvador, with *Typha angustifolia*; they reported 22% reduction of BOD. Rivas et al. [49] studied treatment of secondary wastewater, in Mexico, with *Typha latifolia* and *Phragmites australis*; they reported 52% BOD reduction. Mburu et al. [46] reported 52.98–60.93% BOD reduction, for treatment of secondary municipal wastewater, with *Cyperus papyrus*; in Kenya.

The observed differences in reduction efficiencies with literatures could be due to differences in method of Vetiver application such as soil as a growing medium or hydroponic system with no supporting medium. Furthermore another factor such as the variation of wastewater concentration of wastewater, setting up the hydroponic system in an open space or green house, hydraulic retention time (HRT), quantity of Vetiver applied and temperature could alter the result.

3.6. Morphological Parameters. Growth parameters results such as shoot length, root length, number of leaves, and number of tillers in Vetiver in 14 days are given in Figures 6 to 8. The root length showed a higher increase in LCP in both densities, rather than HCP. The maximum root length was 70 cm in LCP where the root length in HCP was 47 cm. The shoot length was maximum 70.3 cm in LCP, where the shoot length was 42 cm for HCP in both densities of plant. There was an increase in the number of leaves and tillers almost in all treatments. The increase in leaf number was 344 in LCP/V30 and 260 in LCP/V15 (Figure 7). The tiller number

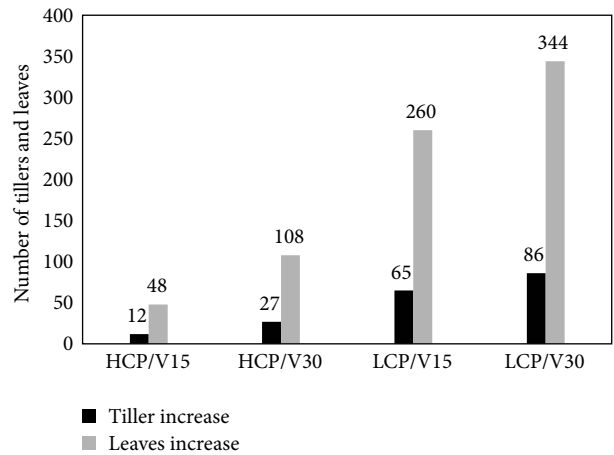


FIGURE 7: Tillers and leaves increase in Vetiver (HCP is high concentration POME and LCP is low concentration POME).

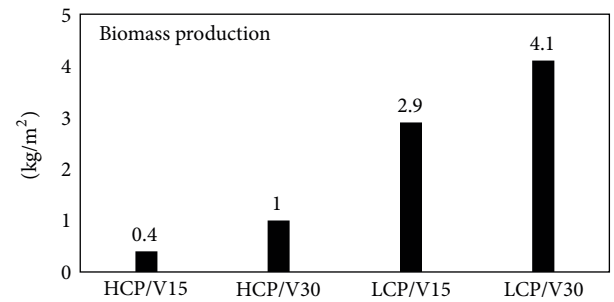


FIGURE 8: Biomass production of Vetiver (kg m⁻²) (HCP is high concentration POME and LCP is low concentration POME).

increased by 86 in the LCP/V30 treatment, which was highest among the treatments. The minimum tiller increase was 12, which is seen in the HCP/V15 (Figure 8).

Biomass production of Vetiver increased with decrease in POME concentration. The maximum biomass production was 4.1 kg m⁻² in LCP with 30 tillers and minimum biomass production was 0.4 kg m⁻² in HCP with 15 tillers. Biomass production of Vetiver is given in Figure 9. The leaves of Vetiver are used for mulching, mat weaving, making basketry, animal fodder, and roof thatching.

4. Conclusion

Results showed that under hydroponic conditions for 2 weeks, Vetiver plants with well-developed root and shoots were able to reduce the BOD up to 90% in low concentration POME and 60% in high concentration POME, while control sets (without plant) only was able to reduce 15% of BOD. The COD reduction was 94% in low concentration POME and 39% in high concentration POME, while control just shows reduction of 12%. Morphological parameter shows that highest root and shoot length number of tillers and leaves and biomass production were 70 (cm), 70 (cm), 86, 344, and 4.1 kg m⁻², respectively. These results showed that Vetiver system technology (VST) was effective in reducing BOD and

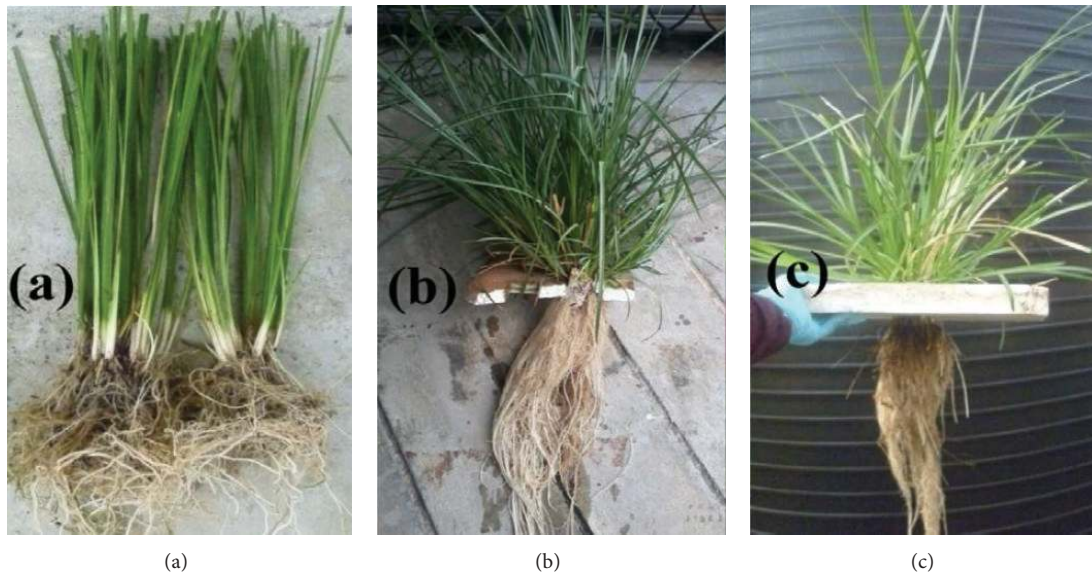


FIGURE 9: Vetiver growing on POME: (a) Vetiver starting day, (b) low concentration POME, and (c) high concentration POME.

COD in POME. The treatment in low concentration was superior to the high concentration. Furthermore, biomass of plant can be considered as a promising raw material for biofuel production while high amount of biomass was generated in low concentration of POME.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

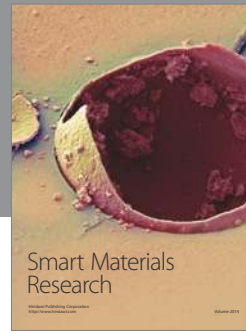
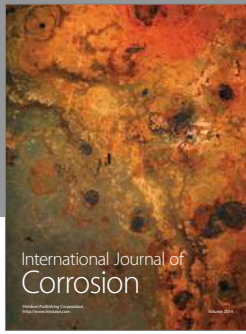
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