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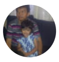
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The use of vetiver (*Vetiveria zizanioides* L.) for the remediation of wastewater discharged from tapioca factories

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Abstract: Three experiments were conducted to study the potential use of vetiver (*Vetiveria zizanioides* L.) to remediate wastewater discharged from a tapioca factory. Two experiments studied the tolerance of vetiver to grow in wastewater, and the other studied the factors influencing the effectiveness of vetiver for the remediation of the wastewater. Vetiver grew well in all wastewater preparations and was able to improve wastewater quality. However, the efficacy of remediation was a function of the remediation system used (wetland or hydroponic) and the density of the plants at the start of the remediation. Vetiver remediation was more efficient in a wetland system. To achieve the water quality standard of the East Java Province, wastewater could be remediated within 30 days using a plant density of approximately 86 g dry biomass/1256 cm^2 at the time of starting the remediation, the equivalent of 6.85 t/ha.

Keywords: organic waste; vetiver; phytoremediation; cyanide; cassava; tapioca.

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1 Introduction

Indonesia is one of the largest cassava producers in the world, and therefore cassava plays an important role in the Indonesian economy. Cassava is an important food crop, mainly for the poor rural and urban sectors of the population, and is consumed directly in the form of *tiwul* during meal times as a substitute for rice, or in a wide range of semi-processed forms like crackers and *tape* (fermented cassava). However, the use of cassava as a food is declining and this now accounts for only 53% of total production (vs. 64% in 2002). Its use for the production of starch, modified starch, sorbitol and fuel-ethanol is becoming more and more important (CBS, 2007). In this paper, the term tapioca, commonly used in the context of food, is used to describe cassava starch.

The tapioca industry in Indonesia, especially in Java, comprises mostly small to medium-scale industries. Of 423 starch factories in Indonesia, 340 factories can be categorised as small-to medium-scale industries, and 299 of these factories are operated in Java (Wargiono and Suyamto, 2006). Such factories play an important role in the rural community, both through employment and the creation of value-added products. However, these small and often simple industries create problems through the generation and discharge of large volumes of solid and liquid waste, into the environment. Many small- to medium-scale tapioca factories lack the infrastructure for efficient wastewater treatment and directly drain their liquid waste into rivers.

Although industrial tapioca waste does not contain heavy metals, it can still cause environmental problems owing to its low pH, high Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and cyanide content. Hien et al. (1999) calculated that to produce 1 ton of starch, a tapioca-processing factory discharges about 12 m^3 of wastewater with a pH of 4.5–5.0, and containing a COD of 11,000–13,500 mg/L and Total Suspended Solids (TSSs) of 4200–7600 mg/L.

These high figures indicate that the wastewater is highly biodegradable and will result in excessive environmental damage. Suspended solids present in the wastewater can settle on the streambed and spoil fish breeding areas. Since these solids are primarily organic in nature, they decompose easily and thus deoxygenate the water. Similarly, the high BOD of the wastewater can also cause rapid depletion of the oxygen content in the receiving water body and promote the growth of nuisance organisms (eutrophication). In addition, cassava is a plant containing cyanoglucosides (cyanide compounds), which are synthesised in the leaf and stored in all tissues of the plant, including the root. Cyanide is a well-known metabolic inhibitor; cyanide-containing effluents cannot be discharged without sufficient detoxification. Mai et al. (2004) reported that the concentration of cyanide in the wastewater of a large-scale tapioca factory in Vietnam could be as high as 19–28 mg/L. The acidic nature of the tapioca wastewater is another serious problem because it can harm aquatic organisms and interfere with normal ecosystem function in the receiving stream.

The simplest system to treat wastewater from a tapioca factory is the open-pond system where solid materials settle and the organic compounds degrade naturally by means of chemical or microbial pathways (Rajbhandari and Annachhatre, 2004). However, this system needs a large area of land. PT Umas Jaya in Lampung, one of the biggest tapioca companies in Indonesia, for example, needed a land area of 11.8 ha for their 15 ponds. With this size of pond, the hydraulic retention can be as high as 100 days, even with the assistance of microbial treatments to promote both anaerobic and aerobic degradation (Hasanuddin, 2008).

The utilisation of the open-pond sedimentation method to treat tapioca factory wastewater, especially for small- to medium-sized tapioca companies, often yields poor degradation. In East Java, for example, treated wastewater drained into a river has recorded values as high as: BOD 1638–3390 mg/L, COD 1780–4400 mg/L, TSS 53–7702 mg/L and cyanide 2.4–4.16 mg/L. This is far higher than the standard given by the government of East Java, Indonesia, of 150 mg/L for BOD, 300 mg/L for COD, 100 mg/L for TSS and a cyanide concentration of 0.2 mg/L (Pemprov Jatim, 2000). Toxicity problems in the Brantas River, one of the most important rivers in East Java, owing to wastewater from tapioca factories have been reported since 1996, and continuously occur every year, especially during the dry season (Ecoton, 2003; Rohimah, 2009). Serious environmental problems associated with the discharge of tapioca wastewater have also been reported in many other countries such as India (Padmaja et al., 1990) and Thailand (Rajbhandari and Annachhatre, 2004).

The application of chemical substances to treat wastewater is not recommended because of the price and environmental risk associated with such treatments. It seems that the more appropriate technology for wastewater management of small- to medium-scale tapioca companies is the use of phytoremediation. This technique is relatively simple, cheap, possesses a relatively low risk, and has been proven to work very well for both metals and organic compounds (Alkorta and Garbisu, 2001; Cunningham and Ow, 1996; Salt et al., 1998; Trap and Karlson, 2001).

The application of phytoremediation for wastewater remediation has been discussed extensively by Schröder et al. (2007). Malik (2007) discussed the possibility of water hyacinths (*Eichhornia crassipes*) for wastewater management, and Bindu et al. (2008) used taro (*Colocasia esculenta)* to remove pollutants from domestic wastewater. The potential of water hyacinths for tapioca factory wastewater management has been studied by Jauhari et al. (2002). Truong et al. (2008) extensively studied the use of vetiver grass (*Vetiveria zizanioides* L.) for wastewater management and reported good potential for the use of this species owing to the ability of vetiver grass to tolerate toxic conditions, and to grow very fast with a high yield of biomass (up to 100 t/ha/year). Although the concentration of contaminants in vetiver is often not as high as the concentration in hyperaccumulator species, vetiver will often remove a much higher volume of nutrients, heavy metals and other pollutants from a contaminated medium owing to its high biomass. In a demonstration plot of the potential of vetiver to manage wastewater generated through seafood processing in South Vietnam, vetiver phytoremediation effectively decreased the levels of nutrients in the wastewater. After 48 and 72 h of treatment, nitrogen in the wastewater was decreased by 88 and 91%, respectively, while the concentration of phosphorus was reduced by 80 and 82%, respectively. Studies in Australia have shown that after 5 months of irrigating effluent discharge from a septic tank to five rows of vetiver, the nitrogen content in the wastewater was reduced by 83%, and total P levels were reduced by 82% (Truong, 2008).

The research described in this paper was aimed at studying the use of vetiver to decrease the pollutant content of wastewater generated by the tapioca industry. Specifically, the potential of vetiver to clean wastewater to a standard that will meet the environmental water quality figures mandated by the government was investigated.

2 Materials and methods

2.1 Experimental procedure

Three experiments were conducted in a glasshouse at Brawijaya University, Malang, Indonesia, to investigate the potential use of vetiver to remediate tapioca factory wastewater. Two experiments studied the tolerance of vetiver to grow in tapioca factory wastewater. A third experiment studied the factors influencing the effectiveness of vetiver for the remediation of tapioca factory wastewater.

2.1.1 Experiment 1: Tolerance of several hydrophyte species to tapioca factory wastewater

In the first experiment, vetiver and four other common hydrophytes or semi-hydrophytes namely *Commelina nudiflora* (nakedstem dewflower), *Cyperus iria* (rice flatsedge or umbrella sedge), *Ipomoea aquatica* (water spinach) (all hydrophytes) and *Oryza sativa* (rice) (a semi-hydrophyte) were planted in a model 'wetland' system constituting a plastic pot containing about 7 kg soil submerged by wastewater (about 10 cm depth). The five plant species were arranged in a Complete Randomised Design with four replications. For the experimental control, the five species were planted in the model wetland systems submerged with de-ionised water. Each treatment in the experimental control was also replicated four times. A further non-planted control was included in the experimental design (4 replicates). This control constituted soil submerged by wastewater, but without plants.

To obtain homogeneous plant materials for planting, young plants of all species were prepared in the soil used for the experiments, and irrigated with de-ionised water to maintain an approximate water content of field capacity until they were 21 days old. The young plants were subsequently transplanted to the treatment pots and the wetland or hydroponic system established (1 plant/pot). The plants were grown under wetland or hydroponic conditions for 45 days, and every seven days the plants were watered with wastewater (or de-ionised water) to maintain the height of the inundated water.

2.1.2 Experiment 2: Tolerance to vetiver grass to various concentrations of tapioca factory wastewater

The second experiment was conducted to study the growth of vetiver at different wastewater concentrations in both the wetland system (with soil, as in experiment 1) and a purely hydroponic solution without soil. The treatments used were concentrated wastewater and diluted (with de-ionised water) wastewater (90 : 10; 80 : 20; 70 : 30; 60 : 40 and 50 : 50). Huttner nutrient solution was used as the experimental control. Vetiver plants were grown in both the wetland and the hydroponic system as described under Experiment 1.

2.1.3 Experiment 3: Factors influencing remedition with vetiver grass

The factors considered to influence the effectiveness of vetiver for wastewater remediation were considered in a third experiment. Two factors were tested, the type of growth medium and the plant density at the time of starting the remediation. Again, two types of growth medium were investigated in this experiment: a wetland system and a hydroponic system. To vary plant density (or biomass, expressed as g of dry biomass/cm^2), the remediation was started using different age plants (7, 15, 30, 45 and 75 days). The controls for this experiment were a wetland inundated with wastewater and a hydroponic (wastewater) medium, both without plants. The 12 treatment combinations of this experiment were arranged in Complete Randomised Design and replicated four times.

The pots used in this experiment had a capacity of about 25 L with surface area of 1256 cm^2. For the wetland system, it was filled with about 15 kg soil and then inundated to a height of about 10 cm. One vetiver plant with a uniform height of 30 cm and root length of 5 cm was transplanted into each pot of either the wetland or the hydroponic system. Plants in the wetland system were maintained with de-ionised water prior to the start of the remediation period, while those in the hydroponic system were maintained using nutrient Huttner solution (Caicedo et al., 2000). At the start of remediation period, the de-ionised water or Huttner solution was drained and replaced by wastewater. Starting the remediation period at different times (7, 15, 30, 45 or 75 days after planting) allowed for plants of variable age at the start of the remediation. Remediation was conducted over a fixed period of 60 days for each treatment, and wastewater quality was measured periodically at 4, 8, 15, 30, 45 and 60 days after planting. The biomass of the different aged plants at the start of the remediation period was measured through using separately designated experimental pots.

Wastewater for these experiments was obtained from PT Sumber Timur, a medium-sized tapioca factory located at Dampit, about 30 km southwest of Malang. This wastewater had been processed in an open pond by natural sedimentation. The important chemical characteristics of this wastewater are presented in Table 1.

Table 1 Important biochemical characteristics of the wastewater used for this study

	mg/L				
Materials	*pH*	*BOD*	*COD*	*Cyanide*	*DO*
Soil	6.7	–	–	–	–
Wastewater (Exp1)	3.9	2530	2870	3.38	undetected
Wastewater (Exp2)	4.2	4128	4322	5.17	undetected
Wastewater (Exp3)	4.6	3390	3840	4.20	undetected

2.2 Laboratory analysis

Biomass samples were collected at appropriate times, rinsed in de-ionised water, oven-dried (70°C) until constant weight, and the dry biomass recorded. Wastewater was measured for pH using a pH meter (Jenway 3305).

Dissolved Oxygen (DO) and BOD were measured using a dissolved oxygen meter (Doran). For analysis, each collected sample was split, with one-half tested immediately for DO, and the other incubated at 20°C in the dark for 5 days. The solution was then retested for the amount of DO remaining. The amount of BOD was the difference in oxygen levels between the first test and the second test. To determine COD, the sample was oxidised with $K_2Cr_2O_7$ in concentrated sulphuric acid with silver sulphate as a catalyst (APHA, 1992). Cyanide in wastewater and soil was determined by titration using a standard titration with silver nitrate as described in APHA (1992).

3 Results and discussion

3.1 Tolerance of vetiver and other hydrophytes to tapioca factory wastewater (Experiment 1)

The experimental results presented in Table 2 show that *Commelina nudiflora* produced the highest total dry biomass, followed by *Ipomoea aquatica*, *Vetiveria*

Table 2 The mean aerial (stem + leaf), root and total biomass of five species grown in soil inundated with tapioca factory wastewater (Experiment 1: model wetland system)

	g/pot				
Plants	*Stem and leaves*	*Root*	*Total*	*Control (total)*	*TI**
Vetiveria zizanioides	18.74 bc	17.24 c	35.98 c	33.62	121 c
Commelina nudiflora	37.66 d	17.87 c	55.43 d	61.96	90 b
Cyperus iria	3.42 a	2.10 a	5.52 a	10.25	55 a
Ipomoea aquatica	25.30 c	7.05 ab	32.35 c	35.67	91 b
Oryzasativa	10.42 ab	8.83 b	19.25 b	23.15	83 b

Means followed by the same letters in each column are not significantly different ($p = 0.05$). Each species was planted in soil and inundated by tapioca factory wastewater (10 cm).

*TI is the tolerance index for the total biomass of each species (see Section 3.1). The control biomass is the total biomass recorded for plants of this experiment growing in soil inundated by de-ionised water.

zizanioides L., *Oryza sativa* and *Cyperus iria*. The highest above-ground biomass production was also recorded for *Commelina nudiflora*. With respect to the root dry matter production, the biomass of *Commelina nudiflora* was not significantly different to that of *Vetiveria zizanioides* L. High biomass production by *Commelina nudiflora* may be a genetic characteristic of this species as *Commelina nudiflora* yielded the highest biomass of all tested species under both the control and the wastewater treatment. Instead of total dry biomass, the 'Index of Tolerance' (TI) has been described as a better measurement for the resistance of plants to wastewater (Shi and Cai, 2009; Wilkins, 1978). The TI for each species was, therefore, calculated according to equation (1) and is presented in Table 2.

$$TI = 100 \times (PlW)/(PlC) \quad (1)$$

PlW is the growth parameter of plant in wastewater and PlC is the growth parameter of control plant.

The highest TI was not obtained for *Commelina*, but for vetiver (121 compared with 90). Vetiver was, therefore, the most tolerant of the species used in this study and was able to grow in tapioca factory wastewater characterised by parameters of pH, BOD, COD and cyanide content of 3.9, 2530 mg/L, 2870 mg/L and 3.38 mg/L, respectively, with no visible signs of adverse effect. Vetiver total biomass was nominally greater when inundated with wastewater relative to the control treatment.

All plants studied in this work were able to improve the quality of tapioca wastewater (Table 3). All treated wastewaters had a higher pH and DO, and a lower BOD, COD and cyanide concentration compared with the control. Values of BOD and COD decreased with time for all experimental units (including non-planted controls) relative to the initial parameters. However, the recorded improvement for the planted treatments was significantly greater than that for the non-planted control. This indicates that there is a strong plant effect on remediation. Vetiver was the most effective plant at improving the quality of the tapioca factory wastewater. After 45 days of remediation with vetiver, the wastewater pH increased from the initial value of 3.9–7.2, the BOD decreased from

Table 3 The effect of phytoremediation using five species on the biochemical characteristics of tapioca factory wastewater (Experiment 1: model wetland system)

	mg/L				
Treatments/plants	*pH*	*BOD*	*COD*	*DO*	*CN*
Vetiveria zizanioides	7.23 b	20.33 a	30.67 a	5.52 c	0.64
Commelina nudiflora	6.51 b	25.33 ab	35.67 ab	4.87 bc	0.78
Cyperus iria	7.70 b	31.67 b	44.67 b	4.73 b	0.85
Ipomoea aquatica	7.05 b	45.33 c	61.33 c	4.54 ab	0.73
Oryza sativa	7.40 b	79.33 d	95.67 d	3.75 a	0.80
Control/no plant	4.97	645.12	678.28	undetected	2.78

Means followed by the same letters in each column are not significantly different ($p = 0.05$). Each species was planted in soil inundated by wastewater (10 cm).

2530 to 20.33 mg/L, COD decreased from 2870 to 30.67 mg/L, DO increased from a value below the detection limit to 5.52 mg/L and the cyanide concentration decreased from 3.38 to 0.64 mg/L. These same parameters for the non-planted control were pH of 4.97, BOD of 645.12 mg/L, COD of 678.28 mg/L, undetected DO and a cyanide concentration of 2.78 mg/L.

The results in Table 3 show that the increase in DO was associated with a decrease in BOD and COD. BOD is an estimation of the quantity of organic matter in the wastewater in terms of the amount of oxygen required by bacteria to break it down. This oxygen (as DO) would otherwise be used by aquatic life. A high BOD, therefore, represents a high concentration of organic matter that will remove a significant amount of oxygen from water to the detriment of aquatic life. The decrease in BOD as a result of remediation can be directly attributed to a reduction in the concentration of nutrients and organic matter in the wastewater as a result of plant growth. The increase in DO in the solution is attributed to plant photosynthesis; no DO was detected in the control at the time of harvest, whereas the concentration of DO in the medium with remediated plants varied from 3.75 mg/L in *Oryza* sp. to 5.52 mg/L in vetiver. An increase in DO in wastewater through phytoremediation has been shown by Truong and Hart (2001) who used vetiver to remediate domestic and toilet wastewater. These authors showed an increase in DO from 1 mg/L to 8 mg/L during 4 weeks of phytoremediation using a hydroponics system.

3.2 Tolerance of vetiver grass to various concentrations of tapioca factory wastewater (Experiment 2)

The results presented in Table 4 show that vetiver is tolerant of concentrated wastewater (pH of 4.2, BOD of 4128 mg/L, COD of 4322 mg/L and cyanide of 5.17 mg/L). However, dilution of the wastewater led to improved vetiver growth as indicated by the increase in dry biomass yield. This observation was more pronounced in the wetland system relative to the hydroponic system.

Table 4 Dry biomass of vetiver grown in different concentrations of tapioca factory wastewater (Experiment 2)

	Dry biomass (g/pot)	
Waste water concentration	*Wetland medium (W)*	*Hydroponic medium (H)*
Concentrated	15.18 a	15.85 ab
Diluted (90 : 10)	19.17 abc	17.20 ab
Diluted (80 : 20)	20.78 abc	20.23 abc
Diluted (70 : 30)	20.50 abc	19.46 abc
Diluted (60 : 40)	26.65 cd	20.13 abc
Diluted (50 : 50)	30.95 de	20.51 abc
Huttner solution	40.95 e	13.90 a

Means followed by the same letters are not significantly different ($p = 0.05$). Dilutions were made in de-ionised water.

3.3 Factors influencing the effectiveness of remediation using Vetiver grass (Experiment 3)

To study the factors influencing the effectiveness of vetiver to improve wastewater quality, the term ‘purification’ for pollutant removal efficiency introduced by Lin et al. (2002) was used. Here, purification (η) is defined as the percentage of the pollutant removed by the plant and is calculated according to equation (2) where *Ci* is the initial concentration of pollutant and *Cf* is the final concentration.

$$\eta = (C_i - C_f)/C_i \times 100\% \tag{2}$$

Purification values for the pollutants BOD, COD and cyanide show that the effectiveness of vetiver in improving the quality of tapioca factory wastewater was influenced by both the type of growth medium and the plant density at the start of remediation (Table 5).

Table 5 The effect of the remediation system and plant age (biomass) at time of planting on the purification (η) of tapioca factory wastewater after 60 days of remediation (Experiment 3)

Vetiver at the start of remediation		η (%)					
		BOD		*COD*		*CN*	
Ages (days)	*Dry biomass* (g/pot)	*W*	*H*	*W*	*H*	*W*	*H*
Control/no plant		86.87 ab	81.77 a	87.76 a	82.60 a	65.23 bc	38.09 a
7	5.1	95.13 b	87.82 ab	94.81 b	88.28 a	76.42 bcd	50.47 ab
15	9.4	97.49 cd	88.94 ab	97.39 b	89.84 a	85.00 cd	61.66 ab
30	11.5	99.11 cd	90.41 bc	99.11 b	90.88 a	85.23 cd	65.47 bc
45	22.6	99.00 d	92.50 bcd	99.21 b	92.23 b	93.33 d	64.04 bc
75	37.4	99.82 d	92.18 bcd	99.37 b	91.67 ab	93.80 d	66.67 bc

Means followed by the same letters for each characteristic measurement are not significantly different ($p = 0.05$). All experimental units had a remediation period of 60 days. The time variable was the age, and thus biomass, of plants at day 0 of the remediation period. *W* is the model wetland system. *H* is the hydroponic system.

At the end of the remediation period (after 60 days), remediation using vetiver in a wetland system, even with the lowest planting density of 5.1 g/1256 cm^2 (7-day-old vetiver at the start of remediation), was able to purify the wastewater for BOD and COD by about 95%. In the hydroponics system, however, this level of purification could not be achieved even at the greatest plant density of this phase of Experiment 3 (37.4/1256 cm^2–75-day-old vetiver). These data suggest that for the remediation of tapioca wastewater using vetiver, a wetland medium is more effective than a hydroponic system. The soil-plant system contains many organisms, which act as decomposers of constituent organic compounds. Our data suggest that the decomposition of pollutants in this soil-plant system is more rapid than in a hydroponics system, which may have less microbiological diversity.

The purity of the remediated wastewater increased with the increasing age and biomass of the vetiver plants used at the start of the remediation. This is more likely due to the fact that as the plants grow older, their root and top biomass will develop, and hence their nutrient absorption and photosynthesis rates will increase; older plants at the start of the remediation period had a greater starting biomass (Table 5) and thus greater degradation potential. Furthermore, in older plants, with increasing root biomass, there will be an increase in surface area for biological processes that occur at the root-soil interface. These processes assist in the decomposition of organic compounds in the wastewater.

Compared with BOD and COD, the purification of cyanide occurred much more slowly. After 60 days of remediation, a maximum of nearly 94% purification was achieved in the wetland system that used 75-day-old vetiver. In the hydroponics system, a maximum of only 67% purification of cyanide was recorded.

The term 'purification' is useful to compare the effectiveness of the remediating plant and the plant-system to improve the quality of the wastewater. However, this parameter cannot be used directly to evaluate whether this purified water has met a prescribed standard of quality, or is safe for discharge into the environment and for human life. Therefore, the real concentration of the pollutant in wastewater is still important. The experimental results in Table 6 show that after 60 days of remediation, only the system that used 75-day-old vetiver growing in the wetland system was able to meet (almost) the wastewater quality standard of the East Java Government (BOD of 150 mg/L, COD of 300 mg/L and cyanide content of 0.20 mg/L), whereas no hydroponic treatment was able to meet these quality standards.

The influence of the age of vetiver on the remediation of tapioca factory wastewater (Tables 5 and 6) was due to the biomass of the vetiver at the start of remediation. Any remediation system using vetiver will require regular pruning, and hence it is important to know a minimum biomass at which the remediation system can achieve prescribed targets. Therefore, the term biomass, or more generally the term 'plant density', is more useful than plant age. Plant density is defined as the dry biomass/planting area (in this work, planting area was the surface area of the pot used for growing vetiver: 1256 cm^2).

The results of Experiment 3 (Tables 5 and 6) show that if remediation is conducted under the correct parameters (growth medium and plant density), then phytoremediation can improve the quality of tapioca wastewater and will likely meet the quality standard mandated by the government. The results presented in Table 6 show that the most difficult standard to achieve is that for the cyanide concentration in tapioca factory wastewater. The quality standards for BOD and

Table 6 The effect of the remediation system and plant age (biomass) at time of planting on the quality of tapioca factory wastewater quality after 60 days of remediation (Experiment 3)

Vetiver at the start of remediation		*Solution concentration (mg/L)*							
		BOD		*COD*		*DO*		*CN*	
Ages (days)	*Dry biomass (g/pot)*	*W*	*H*	*W*	*H*	*W*	*H*	*W*	*H*
Control/no plant		445 g	618 h	470 e	688 f	1.10 a	0.96 a	1.46 cd	2.60 e
7	5.1	165 c	413 f	199 b	450 e	2.42 b	1.06 a	0.99 bc	2.08 de
15	9.4	85 b	375 f	100 b	390 c	3.04 b	0.98 a	0.63 ab	1.61 cd
30	11.5	30 a	325 e	34 a	350 c	3.48 c	1.24 a	0.62 ab	1.45 cd
45	22.6	36 a	270 d	30 a	298 c	5.98 cd	2.36 b	0.28 ab	1.51 cd
75	37.4	6 a	265 d	24 a	320 c	6.40 d	2.46 b	0.26 a	1.40 cd

Means followed by the same letters for each characteristics measurement are not significantly different ($p = 0.05$). All experimental units had a remediation period of 60 days. The time variable was the age, and thus biomass, of plants at day 0 of the remediation period *W* is the model wetland system. *H* is the hydroponic system.

COD had been fulfilled by the remediation system using a plant density of 9.4 g/1256 cm^2 (15-day-old vetiver) in the wetland system. However, the data given in Table 6 show that at the end of the 60-day remediation period, the cyanide concentration under all plant densities was still higher than the required standard (at least 0.06 mg/L over).

To determine the remediation period required to attain the quality standard for cyanide concentration, a further experiment investigating the cyanide concentration in solution as a function of biomass at different remediation periods was conducted using the wetland system. The wastewater for this experiment had an initial BOD concentration of 3600 mg/L; COD concentration of 3840 mg/L and cyanide concentration of 4.2 mg/L. Remediation was performed using initial vetiver biomass values of 0 (control); 5.1 g/pot; 9.4 g/pot; 17.7 g/pot; 35.1 g/pot and 51.4 g/pot for up to 60 days. Measurement was performed for two replicates and the results (Table 7) show that for a 60-day remediation period, the prescribed cyanide quality standard could only be approached using initial vetiver biomass values of 35.1 g/pot and 51.4 g/pot.

To investigate the minimum required initial vetiver biomass necessary to reduce the solution cyanide concentration to the quality standard, the cyanide concentration (ConCN) at day 60 of the remediation period was plotted against Vetiver Biomass (Vb) at the start of the experiment (Figure 1). The relationship between these two parameters is modelled by equation (3).

$$\text{ConCN} = 1.1398\, e^{-0.0358\text{Vb}}. \quad (3)$$

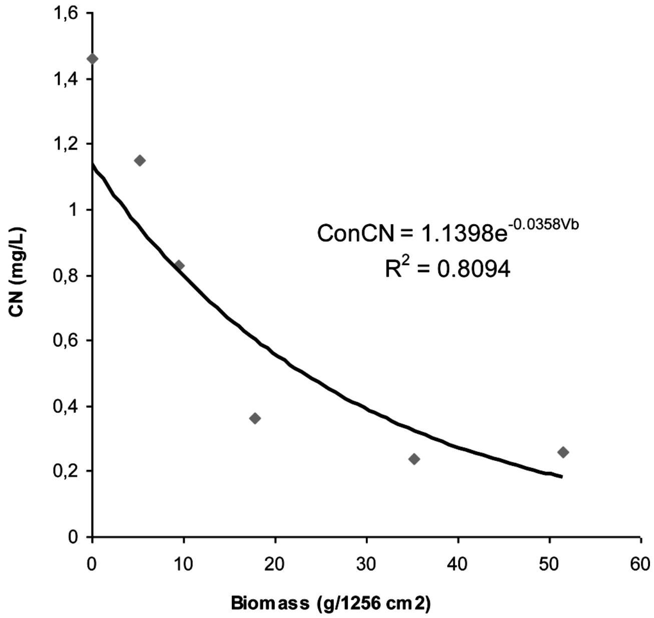
Using equation (3), we can calculate the specific vetiver biomass (or plant density) required for a remediation period of 60 days to improve the wastewater quality to meet the prescribed East Java Province standard (cyanide content of 0.2 mg/L). Solving equation (2) for Vb using a ConCN of 0.2 yields 48.61 g of vetiver dry biomass/1256 cm^2. This is the required biomass at the start of the 60-day remediation period.

Table 7 The cyanide concentration in tapioca factory wastewater as a function of varying initial vetiver biomass and the length of the remediation period (up to 60 days) for a model wetland system (Experiment 3)

	Cyanide concentration in wastewater (mg/L)					
	Vetiver biomass at the start of the remediation period (g/pot)					
Remediation period (days)	*0*	*5.1*	*9.4*	*17.7*	*35.1*	*51.4*
0	4.22	4.22	4.22	4.22	4.22	4.22
7	3.64	3.54	3.21	3.23	2.98	2.04
15	3.06	2.96	2.34	1.76	1.45	0.76
30	2.22	1.95	1.62	1.25	0.86	0.36
45	1.94	1.21	0.97	0.84	0.33	0.26
60	1.46	1.15	0.83	0.36	0.24	0.26

Values are the mean of two replicates.

Figure 1 The cyanide concentration of the supernatant wastewater at the end of the 60-day remediation period as affected by the initial biomass for plants growing in a wetland remediation system (Experiment 3) (see online version for colours)



For small- to medium-sized tapioca factories, with limited land resources, the other important factor that should be considered is the length of the remediation period. The shorter the length of the remediation period, the more practical the remediation system will be. To determine the amount of biomass required to improve wastewater quality to meet the quality standard for any time (t), several more calculations were made.

Through plotting the cyanide concentration of the wastewater as a function of remediation time (t) for each biomass value (from Table 7, individual figures not shown), we obtained equations (4)–(9) for the control (0 biomass), vetiver biomass of 5.1, 9.4, 17.1, 35.1 and 51.4 g/1256 cm^2, respectively.

$$\mathrm{ConCN} = 4.0599\,\mathrm{e}^{-0.017t} \tag{4}$$

$R^2 = 0.98$

$$\mathrm{ConCN} = 4.1965\,\mathrm{e}^{-0.025t} \tag{5}$$

$R^2 = 0.98$

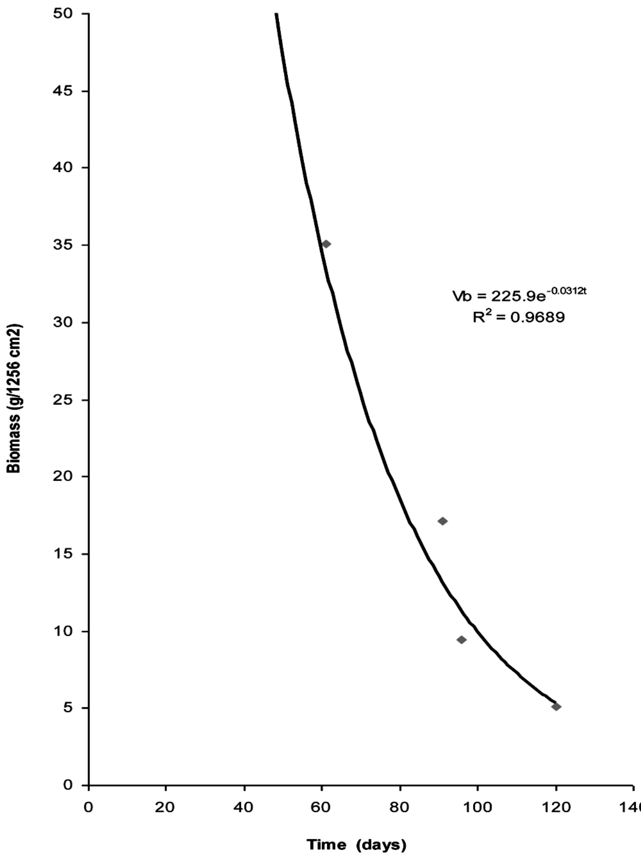
$$\mathrm{ConCN} = 4.007\,\mathrm{e}^{-0.031t} \tag{6}$$

$R^2 = 0.99$

$$\mathrm{ConCn} = 3.6156\,\mathrm{e}^{-0.032t} \tag{7}$$

$R^2 = 0.95$

Figure 2 Relation between the remediation time (days) and the vetiver biomass at the start of the remediation period, required to reduce the solution concentration of cyanide in the wastewater to 0.2 mg/L (see online version for colours)



$$\text{ConCN} = 3.6676\,e^{-0.047t} \tag{8}$$

$$R^2 = 0.96$$

$$\text{ConCn} = 2.96\,e^{-0.059t} \tag{9}$$

$$R^2 = 0.89$$

Using equations (4)–(9), and a target cyanide concentration of 0.2 mg/L, the necessary remediation times were 174 days, 120 days, 96 days, 91 days, 61 days and 45 days, for the control (0 biomass), vetiver biomass of 5.1, 17.1, 35.1 and 51.4 g/1256 cm^2, respectively.

Finally, a plot of vetiver biomass, Vb (from Table 5), against remediation time for cyanide, *t* (obtained from equations (4)–(9)), was generated (Figure 2). This relationship yielded equation (9), which is the model for calculating the required plant density (g dry biomass/1256 cm^2) necessary to remediate tapioca factory wastewater to a cyanide concentration of 0.2 mg/L for any remediation time. For example, for a target remediation period as low as 30 days, the required vetiver biomass at the time of planting, calculated using equation (10), is approximately 86 g dry biomass/1256 cm^2 (6.85 t/ha). For this planted biomass, BOD, COD and cyanide concentration will all be reduced below the East Java Government environmental guidelines.

$$\text{Vb} = 225.9\,e^{-0.0321t}. \tag{10}$$

4 Conclusions

The experimental results presented and discussed show that vetiver has good potential for the remediation of tapioca factory wastewater. However, the remediation system and plant density (biomass) are the key parameters that control remediation efficiency. If remediation is conducted under the correct parameters, the quality of tapioca wastewater can be improved to meet the water quality standards mandated by the East Java government. The limiting parameter for reaching the water quality standard is the cyanide concentration in the wastewater. The wetland system is the most appropriate system for wastewater remediation using vetiver. The time of remediation is strongly influenced by the plant density (in this work expressed as dry biomass/planting area); the higher the plant density, the shorter the remediation time. To achieve the water quality standard mandated by the East Province of Java, wastewater with initial parameters of BOD 3600 mg/L, COD 3840 mg/L and cyanide content 4.2 mg/L, remediation within 30 days can be effected using a vetiver biomass of approximately 86 g dry biomass/1256 cm^2 at the time of planting. This is equivalent to a planted biomass of 6.85 t/ha.

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