A STUDY ON PURIFICATION AND UPTAKE OF GARBAGE LEACHATE BY VETIVER GRASS

Hanping Xia, **Shizhong Liu, and Huixiu Ao**
South China Institute of Botany
Academia Sinica, Guangzhou, China

Abstract

The pollution caused from garbage and its leachate on the environment and creatures is becoming an increasingly conspicuous problem in the process of development of Guangzhou City. Wastewater leached from Likeng Garbage Landfill of Guangzhou contained high concentration of pollutants, and did not reach the effluent standard; such wastewater could be harmful to plants and surroundings. Of the four plant species investigated in this study, water hyacinth (*Eichhornia crassipes*) was poisoned to death in two types of wastewater tested; Bahia grass (*Paspalum notatum*) could not survive in the high-concentrated leachate (HCL) and was severely damaged in the low-concentrated leachate (LCL); alligator weed (*Alternanthera philoxeroides*) was impaired in HCL, but produced a considerably large biomass in LCL, which was possibly due to the result that LCL had an action of eutrophication on alligator weed; vetiver grass (*Vetiveria zizanioides*) was also hurt by the leachates, but was the least of the four species. The tolerance of the four species to garbage leachate was ranked as vetiver > alligator weed > Bahia grass > water hyacinth.

Of the two species growing relatively better in wastewater, alligator weed on the whole was superior over vetiver in purifying LCL, especially in purifying total N and nitrate N; but the effects of vetiver in purifying seven "pollutants" in HCL were all better than that of alligator weed, and the purification of P and COD in LCL by vetiver was also better than by alligator weed. Of all seven items measured in the study, ammoniac N was the best cleansed, and its purification rate was about 80% in HCl and nearly 90% in LCL. Vetiver showed quite a high purification rate for P, over 74%. From the result, it is suggested that vetiver and alligator weed could be used as purifying plants to assist in purifying the high and low concentrated garbage leachates, respectively.

However, both vetiver and alligator weed presented quite limited uptake capacities to the "pollutants" in leachates. The amounts absorbed by the two species were absolutely unequal to those purified by them. The former accounted for only limited part of the latter, some 20-26% for N, 88-94% for P, and 33-96% for Cl^-, but in LCL the N amount absorbed was more than that purified, up to 123-138%. Moreover, ratios of the uptake amount to that in original leachates were lower. This indicated that the main approaches to remove wastes, besides uptake of roots, also contained other functions, thus the plant purification of waste water was a comprehensive influence of the rhizospheric micro-ecosystem on pollutants. All in all, vetiver did not show stronger uptake ability than alligator weed, in spite of the fact that the former had stronger purifying ability than the latter.

Introduction

The city of Guangzhou is developing rapidly to become an international metropolis. However, a series of ecological and environmental problems have emerged with the development of its economy. For example, life garbage landfill and its leakage which pollutes the surroundings are becoming increasingly evident. Currently, life garbage in Guangzhou is treated mainly through filling and burning, and only limited measures are taken to prevent garbage and its wastewater from polluting nearby areas. However, the leachate from landfills usually has high contents of "pollutants" such as COD, organic matter, and compounds of nitrogen, phosphorus, and chloride, in which the most majority of plants and animals cannot survive. Although this kind of sewage is not discharged till "purified", the proper effluent standard is rarely reached; as a result farmlands and fishponds on the lower reaches are polluted to varying degrees, and even the quality of lives, both health and mind, of nearby habitants are influenced (Huang et al.1993). Sometimes the "purified" discharges are far from the effluent standard; as a result, they have to be pumped into the filtration station for a second cycle of cleansing at high cost. In fact, these phenomena are common in some cities of China which need to be urgently settled (Liu 1991).

Many experiments and observations have confirmed that vetiver grass (*Vetiveria zizanioides* (L.) Nash), a perennial grass, has excellent effects in erosion control, extreme soil amelioration, and other environmental mitigation uses (National Research Council 1993; ORDPB 1996; Xia et al. 1997-99). To date it has been widely used for protection of slope farmland, orchard, reservoir, dike and dam, for improvement of extreme (strongly acid, alkaline or infertile) soil, and for reclamation of mine tailings and polluted areas; and furthermore its effects in these aspects have also been proved to be quite good. In addition, vetiver has a huge biomass and it is able to tolerate extremely adverse conditions. Since vetiver has so many excellent properties, it might be possible to use it for sewage purification. This paper aims to record and discuss an investigation into the impacts of landfill leachates on growth of vetiver and its effectiveness in purification and uptake to "pollutants" of leachates, in comparison to alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.), Bahia grass (*Paspalum notatum* Flugge), and common water hyacinth (*Eichhornia crassipes* (Mart) Solms), with the objective of identifying one or two species of plants that have the ability to purify wasterwater, and of comprehending their, especially vetiver's, mechanisms of purifying and absorbing pollutants in leachate.

Materials and Methods

Materials

The garbage leachate was taken from the sewage-purifying station of Likeng Garbage Landfill of Guangzhou, which is located in the northern suburbs of the city, and approximately 20 km from downtown. The sewage-purifying station, lied below the landfill, purifies 300 t of leachate each day. The two kinds of leachate used in this trial were collected from the entrance and exit of the station; they consisted of the high-concentrated leachate (HCL) that flowed out of the landfill prior to purification, and the low-concentrated leachate (LCL) that had been physically cleansed and ready for discharge into the oxidation pond, respectively.

As with plant materials, vetiver and Bahia were transplanted from the nursery in South China Institute of Botany, and alligator weed and water hyacinth from ditches and ponds.

Trial Designs and Arrangements

The experiment was conducted with a method of hydroponic cultivation in plastic pots, and undertaken in a glasshouse, which was ventilated and pervious to light. The experiment was arranged in three treatments: clean water, LCL, and HCL; and three replications for each treatment. The operation was carried out as follows: adding 2.50 L of one of the three liquids above into each pot, then putting one of the four species whose health and weight were basically similar into each pot. Before the plants were put into the pots, tops and roots of vetiver and Bahia were pruned to 20 cm and 10 cm, respectively; alligator weed was also cut into sections of 20 cm long; but only water hyacinth was kept intact, for the whole plant did not exceed 20 cm long. All plants were weighed and their tiller numbers counted. Hydroponic cultivation lasted 66 days; during the period of cultivation, clean water was added to pots once every 2-4 days to supplement water reduced by transpiration and evaporation, but the amount added each time was no more than that removed. In addition, the two original leachates were also put into four pots, each for two pots and same amount for each pot. They were laid open at the same time as and were given the same arrangements as the other pots to investigate the effects of biological factors and environmental factors, such as microorganisms, evaporation, irrigation, vessel adsorption, sunshine and air, on the water quality of the leachates.

Observations and Analysis

Situations of plant growth in water: The items under observation included: plant height, number of tillers, biomass of shoots, and length of new roots and their net increased weight; then calculated the net increments of the biomass and those items above.

Effects of plants in purifying leachate and absorbing pollutants from leachate: The analytical items included: pH value, COD contents, alkalinity, total N, ammoniac N, nitrate N (NO_3^--N), total P, and Cl^- in the two garbage liquids, and contents of N, P, Cl^- in plants; all the items included values prior to and after water cultivation.

Analytical Methods

The pH was measured with an acid meter. COD values were acquired through measuring the consumption of dissolved oxygen while the leachates were oxidized with $KMnO_4$; and BOD was also referred to as the consumption of dissolved oxygen after the leachates were incubated 5 days at 20°C in an incubator. Alkalinity (HCO_3^- + CO_3^-) in water samples was measured with titration of double indicators, phenothalin and methyl orange; total N was oxidized with $K_2S_2O_8$ and analyzed with an ultraviolet spectrophotometer; ammoniac N and NO_3^--N were determined with direct distillation and colorimetry of phenol disulfonic acid ($C_3(CH)_3(HSO_3)_2OH$), respectively; total P was digested with H_2SO_4–$HClO_4$, then measured colorimetrically; and Cl^- was determined with titration of $AgNO_3$. Metal elements were all measured with an atomic fluorescence spectroscopy. Plant samples were digested with H_2SO_4–H_2O_2; plant N was determined via distillation, and plant P determined with the same method as total P in water; Cl^- in plant was extracted with de-ionized water, and then titrated with $AgNO_3$.

Results and Discussion

Chemical Characteristics of Garbage Leachates

The contents of COD, total N, ammoniac N, total P, and Cl^- in HCL were very high (Table 1), which were many times (from several to dozens) higher than the highest allowable discharge concentrations of industrial sewage and irrigation water for farmland. After purifying, the contents of these items significantly decreased; and artificial purifying rates were between 30-80%. However, the concentrations of these "pollutants" in LCL remained beyond the effluent standard, which exceeded 100 mg/L COD, 210-240 mg/L total N, 1.6 mg/L P and 500-600 mg/L Cl^-, even compared to the second standard of "the standard for comprehensive discharge of sewage of China (China National Standard 8979-88)". BOD of the two liquids was relatively low, was within the effluent standard after purifying. Of all items analyzed, only NO_3^--N in LCL was much higher than that in HCL, suggesting that the nitrification probably took place in the process of artificial purification and in LCL, for oxygen in the air was easy to dissolve in water when the leachate was mechanically cycled and transported, thus aerobic nitrifying bacteria multiplied greatly and rapidly in LCL, which changed NH_4^+-N and NO_2^--N into NO_3^--N (Dai *et al.* 1990). Summerfelt et al.(1996) also observed the contents of nitrate N in sludge from aquaculture rose rapidly from 0.057 mg/L to 45.41 mg/L in the process of its purification.

Table 1. The water quality of the two types of leachate from Likeng Garbage Landfill of Guangzhou and the artificial purification effects via the purifying station

Water sample	pH	COD	BOD	Alkalinity	Total N	Ammoniac N	Nitrate N	Total P	Cl^-
		mg/L							
HCL	7.38	1120.1	120.8	1882.9	1125.0	313.7	0.55	4.43	1406.4
LCL	6.50	246.0	43.3	395.5	293.8	87.2	63.5	2.60	812.0
Purifying rate (%)	-	78.0	64.2	79.0	73.9	72.2	-	41.3	42.2

Effects of Environmental Factors on Leachates

After the two leachates had remained undisturbed in the greenhouse for 66 days, it was found that the main factors relating to water quality had changed (Table 2). The pH in LCL and HCL was increased by 0.42 and 0.45, respectively. The COD, alkalinity, N, P, and Cl^-, which are perhaps detrimental, or over-nutritious, to the environment, all went up or down in varying degrees. The four items that were decreased were COD, alkalinity, total N, and nitrate N; all were tangibly reduced, in the order of 29-47%, which confirmed that pollutants could be broken down, diluted, oxidized, and evaporated under the impacts of microorganism, rain water, atmosphere, sunshine; and thus the polluted degree of contaminated water could be alleviated. Among these the lowering of nitrate N concentration probably resulted from denitrification, which made it become volatile N_2.

It can be seen from Table 2 that the amounts of ammoniac N, total P and Cl^- were slightly rose. It is interesting that the contents of total N in the two liquids were decreased, but ammoniac N increased. This was probably the result of amination and ammonification of organic substances, which was also perhaps the reason why water pH rose. The two chemical reactions broke down complex organic substances into simple organic and inorganic substances, including volatile

Table 2. The changes of water quality of the two liquids 66 days after open incubation in the glasshouse

Liquid	pH	COD	Alkalinity	Total N	Ammoniac N	Nitrate N	Total P	Cl^-
					mg/L			
HCL	7.80	742.5	1004.4	790.6	351.7	0.40	4.62	1493.1
		(-33.7)*	(-46.7)	(-29.7)	(+12.1)	(-27.3)	(+4.3)	(+6.1)
LCL	6.95	174.4	253.2	167.5	94.0	42.0	2.94	838.5
		(-29.1)	(-36.0)	(-43.0)	(+7.8)	(-33.8)	(+13.1)	(+3.2)

** Figures in parentheses are percent of concentration changes; "-" indicates a decrease, and "+" an increase*

NH_3, as a result lowered the amount of organic N and accordingly lessened total N in leachates and moreover products of amination, amino acid, amine and amide, made ammoniac N in water increase; and one of the products of ammonification, NH_3, with the exception of that one part volatilized, was susceptible to combine with H^- in water to form NH_4^- , which made H^+ decrease and comparatively made OH^- increase. The possible chemical reactions are as below:

- Amination:

$$\text{Protein and the like} \longrightarrow \text{Polypeptide} \longrightarrow RCHNH_2COOH + CO_2 + \text{Other N-contained organic compounds}$$

- Ammonification:

$$RCHNH_2COOH + O_2 \xrightarrow{\text{Aerobic decomposition}} RCOOH + NH_3 + CO_2$$

$$RCHNH_2COOH + 2H \xrightarrow{\text{Anaerobic decomposition}} RCH_2COOH + NH_3 \text{ or } RCH_3 + CO_2 + NH_3$$

$$RCHNH_2COOH + H_2O \xrightarrow{\text{Hydrolysis}} RCH_2OH + NH_3 + CO_2$$

- Combination of NH_4^+

$$H_2O = H^+ + OH^-$$

$$NH_3 + H^+ \longrightarrow NH_4^+$$

Growth Situations of Plants in Garbage Liquids

The four species selected are all characteristic of rapid growth, large biomass, and somewhat or strong resistance to a polluted or poor environment. The clean water cultivation experiment showed that they all could grow and develop in clean water, of which water hyacinth thrived best, covering the entire water surface within 5-7 days; vetiver grew second, and alligator weed and 'Bahia' poorest. Vetiver and alligator weed were capable of surviving in the two types of leachate; Bahia was severely impaired in LCL and died 2-3 days after putting into the HCL; water hyacinth was immediately poisoned to death by the HCL only 24-48 hours after it began to incubate, and gradually became wilting and died 3-6 days after putting into LCL. The reason why water hyacinth died was probably due to too highly concentration of COD in leachates. A lot of observations have indicated that water hyacinth is very excellent in purifying and uptaking pollutants from waste water; but it has been poorly documented about its resistance to pollution. Tang *et al.* (1994, 1996) found that the optimal condition for water hyacinth to cleanse wastewater was that COD concentrations in water were between 65 and 131 mg/L, and the highest value was 262.6 mg/L; otherwise the plant would be severely impaired, and even its population diminished and died out. The concentration of COD in the HCL was much higher than 262.6 mg/L, and that in the LCL near to this value (Table 1), and therefore the reason resulting in the death of water hyacinth in the two leachates was most likely to the excessively high COD contents. It is suggested not to put water hyacinth into wastewater with too high concentration of COD when it is applied to mitigate the environment; and further measures should be taken to control it to extend excessively due to its extremely rapid growth and multiplication, otherwise it would become an ineradicable weed. It is thus clear from the above phenomenon that: (1) the sewage from garbage landfills of Guangzhou indeed had very high toxicity, polluting the surroundings and poisoning organisms; and (2) water hyacinth assumed inferiority in resistance to sewage compared to the other three species.

The biomass and other growing indexes of vetiver, alligator weed and Bahia in clean water and the two kinds of wastewater is showed in Table 3. It is noted that the growth of plants, no matter what species, presented quite big differences in the three kinds of water. The biomass of 'Bahia' was significantly less in LCL than in clean water, which indicates further that the toxicity of garbage sewage to it was considerably serious. The growth situations and biomass of alligator weed in the three liquids produced the largest disparities, presenting clearly in order of LCL > HCL > clean water. It is suggested that wastewater being no high concentrations of pollutant could make alligator weed eutrophy, which is coincident with the phenomenon that alligator weed widely creeps in filthy sludge

Table 3. The increments (mean±SD) of three species before and after cultivating in water for 66 days

Species	Treatment	Increment of shoot weight (g DW/pot)	Increment of Root weight (g DW/pot)	Increment of plant height (cm)	Increment of root length (cm)	Increment of total tillers
Vetiver	Clean water	13.32±0.73	1.23±0.14	99.0±20.2	22.7±8.1	14
	LCL	11.40±1.45	1.27±0.31	100.0± 5.3	27.7±0.6	10
	HCL	7.28±1.41	1.07±0.45	78.0±10.1	24.6±2.5	3
	LSD (0.05)	2.49	n.s.	n.s.	n.s.	/
Aligator weed	Clean water	2.80±0.11	0.39±0.07	25.3±2.1	6.7±3.8	1
	LCL	14.88±4.46	1.27±0.31	59.7±0.6	19.3±1.5	69
	HCL	3.73±0.84	1.07±0.45	46.7±14	11.7±4.2	-2
	LSD (0.05)	5.24	0.67	16.4	6.7	/
Bahia	Clean water	3.09±1.18	0.74±0.19	44.7±0.6	30.6±6.6	1
	LCL	0.05±0.56	0.32±0.01	34.0±1.7	28.3±6.7	-5
	LSD (0.05)	2.09	0.76	2.9	n.s.	/

or drainage. The growth of vetiver assumed a trend of clean water > LCL > HCL, but had no statistical differences expect for the increment of shoot weight which was significantly less in HCL than in clean water and LCL, indicating that the leachates did not imposed the plant serious damages.

The most conspicuous feature of vetiver is its deep and massive root system, which makes it called "a herb with the longest root system in the world" (ICV-1). In the present study, however, this species did not assume the characteristics at all (Table 3). Except growing out a slightly more root biomass in clean water than the other two species, vetiver was inferior to Bahia in root length and to alligator weed in net increment of root weight in wastewater. Thus it is likely that the aquatic environment was unfavorable for the root growth of vetiver.

It can be calculated out from Table 3 that the net increment of total biomass (root + shoot) of vetiver in clean water was significantly more than those of alligator weed and of Bahia (results not shown), which might be because the former was better than the latter two with respect to the endurance to infertility. The biomass gained by alligator weed in LCL was far more than that by other two species and/or in other two treatments. Like in the clean water, vetiver in HCL presented again the most increment of biomass among the three species. These results suggested that: (1) vetiver's endurance to infertility and pollution was stronger than that of water hyacinth and Bahia, which were an excellent infertility- and pollution-resistant species; (2) alligator weed showed a very poor resistance to infertility, but it could make advantage of "pollutants/nutrients" in water, when their concentrations were not very high, to nourish itself, resulting in a diffusion of growth; and (3) Bahia was not appropriate for the aquatic habitat, especially for harmful wastewater, as compared with vetiver, despite the fact that it has lots of similarity with vetiver in the aspects of ecological features. Truong *et al* (1999) also found that vetiver is highly tolerant to toxicity of heavy metals.

The Purification of Vetiver and Alligator Weed for Garbage Sewage

Quality situation of leachates after incubating plants: Since Bahia was severely damaged in LCL and killed in HCL, and its biomass was extremely low in the two leachates, it was unlikely to have good purifying effects for garbage sewage. Bahia's ability to purify leachate was not considered here. The water quality and the decrease of "pollutants" in thw two types of leachate after cultivating plants for 66 days are tabulated in Tables 4 and 5, respectively. The concentrations of all "pollutants" measured in the two liquids had decreased substantially, as compared to their original concentrations (Table 1). Among these items, the content of total N in LCL cultivating alligator weed alligator weed declined the most, dwindling down from 293.8 mg/L to 23.9 mg/L, or a reduction of 92%. The element that had the highest reduction was alkalinity in HCL supporting vetiver, which dropped from 4707 mg/pot to 914 mg/pot, or a reduction of 3794 mg/pot. Furthermore, some "pollutant" concentrations produced significant differences between the two liquids after affecting vetiver and alligator weed. This indicated that they both indeed exerted influences on wastewater, and moreover,

Table 4. The water quality (mean±SD, mg/L) of two liquids 66 days after being affected by vetiver and alligator weed

Treatment	COD	Alkalinity	Total N	Ammoniac N	Nitrate N	Total P	Cl^-
			High-concentrated leachate				
Vetiver	347.2±13.1	365.5±14.1	232.2±31.2	79.8±7.3	0.35±0.06	1.33±0.46	1103.9±46.3
Alligator weed	461.2±50.8	392.9±25.0	280.5±39.7	109.1±11.2	0.38±0.08	2.57±0.46	1186.3±40.0
LSD (0.05)	84.1	n.s.	n.s.	21.4	n.s.	1.04	n.s.
			Low-concentrated leachate				
Vetiver	93.7±4.9	162.0±28.5	84.8±19.8	16.2±0.3	41.2±5.0	0.91±0.09	748.3±34.8
Alligator weed	111.8±18.5	74.9±30.4	23.9±11.3	16.0±1.2	6.7±0.7	1.93±0.34	710.4±42.5
LSD (0.05)	n.s.	66.7	36.6	n.s.	8.1	0.56	n.s.

their influences on sewage were pronouncedly different, which is presented more clearly in Table 5.

Table 5. Decrease of "pollutants" (mg/pot) in two leachates 66 days after being affected by vetiver and alligator weed

Treatment	Species	COD	Alkalinity	Total N	Ammoniac N	Nitrate N	Total P	Cl^-
HCL	Vetiver	1932.3	3793.5	2232.0	584.8	0.50	7.75	756.3
		(69.0)*	(80.6)	(79.4)	(74.6)	(36.4)	(70.0)	(21.5)
	Alligator weed	1647.3	3725.0	2111.3	511.5	0.43	4.65	550.3
		(58.8)	(79.1)	(75.1)	(65.2)	(30.9)	(42.0)	(15.6)
LCL	Vetiver	380.8	583.8	522.5	177.5	39.3	4.23	160.0
		(61.9)	(59.0)	(71.1)	(81.4)	(24.7)	(65.0)	(7.9)

Alligator weed	335.5	801.5	674.8	178	142.1	1.68	254.0
	(54.6)	(81.1)	(91.8)	(81.7)	(89.5)	(25.8)	(12.5)

** Values in parentheses are percentage of "pollutant" decrease*

Purifying effects of vetiver on leachates: Compared the figures in parentheses in Table 2 with those in Table 5, it can be seen that almost all the decreasing extents of "pollutants" in Table 5 were larger than those in Table 2 no matter what type of leachate was, implying both vetiver and alligator weed had decontaminating functions to wastewater. Concentrations of "pollutants" after incubating open (Table 2) minus those after cultivating plants are just the net purifying effects of plants on wastewater (Table 6). Obviously, vetiver and alligator weed had both different contents of purifying effects on the investigated 7 "pollutants", and their purifying rates varied from 1.3 to 89.4%. Among these items, ammoniac N was purified most completely, and its purifying rates were up to 77.3-89.4%. This is perhaps because plants absorbed lots of ammoniac N into their cells or it was transformed more easily into volatile N_2 under the impact of rhizospheric micro-ecosystem. The second was vetiver's purification for P, and the purifying rates reached as high as 74.3% in HCL and 78.1% in LCL, which was perhaps due to its strong uptake capacity to P. The previous studies have showed that vetiver planted even in infertile soil could enhance the contents of organic matter, total N, available N and K

Table 6. A comparison of purifying effects of vetiver and alligator weed on leachates

Treatment		COD	Alkalinity	Total N	Ammoniac N	Nitrate N	Total P	Cl^-
High-concentrated leachate								
Vetiver	mg/L	395.3	638.9	358.4	271.9	0.05	3.29	389.2
	mg/pot	988.3	1579.3	896.0	679.8	0.125	8.23	973.0
	(%)*	(35.3)	(33.9)	(31.9)	(86.7)	(9.1)	(74.3)	(27.7)
Alligator weed	mg/L	281.3	611.5	310.1	242.6	0.02	1.75	306.8
	mg/pot	703.3	1528.8	775.3	606.5	0.05	4.38	767.0
	(%)	(25.1)	(32.5)	(27.6)	(77.3)	(3.6)	(39.5)	(21.8)
Low-concentrated leachate								
Vetiver	mg/L	80.7	91.2	82.7	77.8	0.80	2.03	90.2
	mg/pot	201.8	228.0	206.8	194.5	2.00	5.08	225.5
	(%)	(32.8)	(23.1)	(28.1)	(89.2)	(1.3)	(78.1)	(11.1)
Alligator weed	mg/L	62.6	178.3	143.6	78.0	35.3	1.21	128.1
	mg/pot	156.5	445.8	359.0	195.0	88.3	3.03	320.3
	(%)	(25.4)	(45.1)	(48.9)	(89.4)	(55.6)	(46.5)	(15.8)

** Figures in parentheses are purifying rates (%) as compared to the original liquids (Table 1)*

in soil, but dwindle the content of available P (Xia et al.1996); and vetiver established in eutropic water had a very strong ability to remove "pollutants", purifying P over 97% only within four weeks (Zheng et al.1998). These results suggested that vetiver is likely to be a "phosphorus-sucking plant". In HCL, the effects of vetiver in purifying seven "pollutants" were all better than those of alligator weed, especially its purification for COD, ammoniac N, and P was significantly better than that of alligator weed ($P<0.05$). Summerfelt *et al.*(1996) found that vetiver established in wetland could effectively remove extra solids and nutrients in aquaculture sludge, and the removal rates to suspended solids, total COD, total Kjeldahl N, total P, and dissolved P were 96-98%, 72-91%, 86-89%, 82-90%, and 92-93%, respectively. Therefore it is suggested from the results above that: (1) vetiver could survive and establish in water; (2) it had a strong resistance to polluted water; and (3) it had a good effect in purifying "pollutants", particularly in purifying P. However, vetiver can not suspend directly in water to grow as alligator weed do, it is in need of a prop system to fasten. In addition to this, its shoots should be trimmed 2-3 times per year as it grows rapidly and has a huge large biomass, and only by doing so can it sustainably take up "pollutants" from water, and make itself become a "super-bioaccumulator".

Purifying effects of alligator weed on leachates: Besides its high purification rate to ammoniac N, alligator weed also had a good removing rate to nitrate N in LCL, which went up to 55.6%, far higher than other three treatments to nitrate N (Table 6). The reason in producing the phenomenon is possibly because alligator weed absorbed a relative plenty of nitrate N in LCL, but it is most likely that nitrate N in water is not stable as it was resulted from ubiquitous nitrification and denitrification in water. Nitrification increases nitrate N in water but denitrification decreases it; therefore the instability of nitrate N in water is a common phenomenon. For example, Dai et al.(1990) observed that the removal rate of nitrate N in water varied from –100-70% when removed by water hyacinth and from –210% up to 33% by activated sludge. Table 6 also indicates that this plant had the highest purifying rate to ammoniac N, up to 77-89%, but the removal of P by it was not so ideal, and the removal rate was only 39-48%. According to a report from Gao et al. (1997), the removing rates of alligator weed to N, P in runoff were 77 and 64%, respectively, nearly coincident with the above results. In addition, the purification of alligator weed for LCL was on the whole more effective than that of vetiver, especially for alkalinity, nitrate N, and total N in LCL, suggesting that alligator weed is a relative good purifier, too. Liu et al. (1988) reported that alligator weed produced the best effect in decontaminating wastewater from the process of paper-making as compared to water hyacinth, water lettuce *(Pistia stratioites)*, and duck weed *(Lemna trisulca)*.

Uptake Effects of Vetiver and Alligator Weed on N, P, and Cl^- in Garbage Leachates

Concentrations of three elements in vetiver and alligator weed: Table 7 showed concentrations of N, P, and Cl^- and their changes in vetiver and alligator weed prior to and after being cultured by the two garbage liquids, from which it can be seen that their concentrations and changes in bodies of two species were all different; Cl^- in the two species increased with increasing concentration of wastewater; N did, too, with exception of that in alligator weed cultivated in HCL that trended to dwindle;

Table 7. Concentrations of N, P, Cl^- (DW mg/g) in plants prior to and after being established in leachates

Element	Species	Prior to culture in leachate	After culture in leachate			
			LCL		HCL	
			Concentration	Increment	Concentration	Increment
N	Vetiver	9.9	16.5	4.6	19.2	9.3
	Alligator weed	14.8	26.0	11.2	22.3	7.5
P	Vetiver	1.05	0.61	–0.44	0.98	–0.07
	Alligator weed	1.50	0.47	–1.03	1.15	–0.35
Cl^-	Vetiver	11.4	14.6	3.2	25.5	14.1
	Alligator weed	13.2	17.1	3.9	39.6	26.4

whereas the concentrations of P in the two species were decreased while those in the leachates increased, more distinct especially in the treatments of LCL. Cl^- up to 39.6 mg/g in any plants is obviously a quite high concentration. The reason why the biomass of alligator weed in this Cl^- concentration dwindled tangibly was perhaps because it was severely damaged by such high concentration of Cl^-.

Uptake of plants to three elements: The concentration of one element in plant multiplied by plant weight (DW) is just the total amount of the element in the plant. Since vetiver and alligator weed produced significantly different amounts of biomass (Table 3) after they both were cultured with leachates, and moreover concentrations of three elements in plants were also different (Table 7), as a result the amounts of three elements contained in plants per pot and their uptake from leachates were all producing distinct differences (Table 8). In sum, both species of plants took up three elements as “nutrients” into their cells. The largest and smallest uptake, both from alligator weed, were 495.1 mg N/pot and 2.87 mg P/pot, respectively. It is worth noting that vetiver and alligator weed growing in LCL absorbed 255.4 and 495.1 mg N/pot respectively, exceeding by a large margin their respective purifying capacities to total N –206.8 and 359.0 mg (Table 6) and approaching their respective decreases of total N –522.5 and 674.8 mg/pot (Table 5). Therefore, these results seem to indicate that parts of total N in LCL removed originally by decomposition and volatilization due to influence of environmental factors when open incubation were not removed at all, but absorbed by vetiver and alligator weed when it was cultivated the two species.

Table 8. Contents and net uptake amounts (DW mg/pot plant) of N, P, Cl^- in vetiver and alligator weed prior to and after being cultivated in two types of leachate.

Element	Species	Prior to cultivation		After cultivation			
		LCL	HCL	LCL		HCL	
		Content		Content	Uptake	Content	Uptake
N	Vetiver	69.3	76.7	324.7	255.4	308.9	232.2
	Alligator weed	73.0	84.5	568.1	495.1	241.3	156.8
P	Vetiver	7.35	8.14	12.01	4.66	15.77	7.63
	Alligator weed	7.40	8.57	10.27	2.87	12.41	3.87
Cl^-	Vetiver	79.8	88.4	287.6	207.8	410.3	321.9
	Alligator weed	65.1	75.4	373.6	308.5	428.5	353.1

Uptake rate: If the ratio of amount of uptake to amount of purification is referred to as uptake rate, then the amounts of uptake (Table 8) divided by those of purification (Table 6) is just the uptake rates of vetiver and alligator weed to N, P, and Cl^- (Table 9). However, since the uptake amounts of two species to N in LCL surpassed their respective purifying amounts to total N, as a result their uptake rates were all over 100%, indicating that the practical impact of plants on leachate was stronger than that presented by the purifying rates. Table 9 showed that two species of plants all had very high uptake rates to P, almost all over 90%; but P concentrations in plants unexpectedly decreased with the increasing solution P concentrations (Table 7), implying that both vetiver and alligator weed still could absorb a plenty amount of P. The uptake rates of vetiver and alligator weed to any one of three elements in the HLC

Table 9. Uptake rates of vetiver and *Alternanthera* to N, P, Cl^- in garbage leachates (%)

Uptake rate	Garbage leachate	N: Vetiver	N: Alligator weed	P: Vetiver	P: Alligator weed	Cl^-: Vetiver	Cl^-: Alligator weed
Ratio of uptake to purification	HCL	25.9	20.2	92.7	88.4	33.1	46.1
	LCL	123.5	137.9	91.5	94.7	92.2	96.3
Ratio of uptake to original liquid	HCL	8.3	5.6	68.9	35.0	9.1	10.0
	LCL	34.8	67.4	71.5	44.2	10.2	15.2

did not present big differences, and they were nearer to each other in the LCL; but the uptake rates of the identical species to N or to Cl^- in different types of leachate presented very big disparities; and the uptake rates to N in LCL were 5-7 times those in HCL, and to Cl^- in LCL 2-3 times those in HCL.

In addition, another uptake rate can be defined and calculated according to the following formula:

$$\text{Uptake rate} = \frac{\text{Uptake amount by root}}{\text{Content in original liquid}} \times 100\%$$

The uptake rates calculated with the formula were also presented in Table 9. They all dwindled when compared to those calculated with the former approach. The two species of plants all had very big potentials with respect to their uptake to P. However, both did not present high uptake rates to P, especially alligator weed, which only had the purifying rates of 40% or so. The reasons why they produced the phenomenon was probably because a considerable part of P in garbage leachates was organic P that was hard to be decomposed or could not be absorbed by plants. It can also be seen from this kind of uptake rates that they were not equal to the purifying rates at all, but smaller than them, except for those of N in LCL, which further indicated that the former was only composed of part of the latter, namely the purified “pollutants” by plants by no means were all absorbed into roots. In the system of phyto-purification, besides the root’s absorption function, the purifying effect is also intimately associated with the rhizospheric micro-ecosystem, which includes the purification of microorganisms and micro-animals around the rhizosphere and the adsorption of roots, etc. For example, in the purifying effect of water hyacinth on cyanogen in wastewater, the uptake amount only accounted for 32%, whereas the adsorption by roots went up to 68% (Wu et al. 1984). Also water hyacinth, it removed only 13% of COD in dyed effluent after its roots were disinfected, but up to 35% if not being disinfected (Sun et al. 1990). Of course, the decomposition, precipitation, conglomeration, and volatilization of elements and compounds themselves can mitigate wastewater and make it gradually become clear; moreover, these physical and chemical reactions can become stronger when there are plants established in wastewater, as secretion from out of roots usually catalyze and accelerate them. Li et al. (1995) found that the purification of reed for NH_3–N in wastewater was finished via a successive series of chemical reactions of nitrification and denitrification, but for PO_4–P mainly via physical reactions such as precipitation, filtration, adsorption, conglomeration. In addition, Table 9 also shows that the uptake rates of vetiver to N and Cl^- were not so high as those of alligator weed, and even less than them in spite of the fact that vetiver had stronger purifying ability than alligator weed, especially in LCL, which indicates that the purification of vetiver, compared with alligator weed, for N and Cl^- was to take the non-absorb approach as the chief purifying way.

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