USING NATIVE AFRICAN SPECIES TO SOLVE AFRICAN WASTEWATER CHALLENGES: AN IN-DEPTH STUDY OF TWO VETIVER GRASS SPECIES

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Abstract

All known species of vetiver differ in their potential. Literature and research on the potentials of African Vetiver species (*Chrysopogon nigritana)* are limited, particularly in the treatment of contaminated water compared to the Asian species (*Chrysopogon zizanioides*). This study, conducted in Nigeria, assessed the potential of the native African vetiver grass species in addressing the challenges of wastewater management. Effluents from a fertilizer blending company, quarry industry and leachate from a public untreated refuse dumpsite were subjected to treatment using *Chrysopogon nigritana*. In order to compare the effectiveness of *Chrysopogon nigritana* with the well-known and commonly used *Chrysopogon zizanioides*, the latter was also included in this experiment.

Leachate effluent levels of pH, Lead, Arsenic, Zinc, Iron, Cadmium, Mercury, Nickel, Copper, Cyanide, Phosphate, Nitrate, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) were measured. The effluents were then treated with the two grasses and analysed at 2, 4 and 6 days after treatment (DAT). The results indicated that both *C. nigritana* and *C. zizaniodes* significantly reduced contaminant concentrations in leachate, with *C. nigritana* more effective in removing Phosphate, and *C. zizaniodes* in removing Nitrate and Cyanide. Under both grass species, Zinc, Iron and Cobalt could not be traced in the leachate after 2 days of treatment.

Effluents from the quarry and the fertilizer blending company were analysed for Lead, Cadmium, Zinc, Manganese and Arsenic. These were significantly reduced by both species.

The pH levels of effluents from dumpsite, the fertilizer company and quarry industry, improved greatly from pre-treatment level of 5.8 to 6.5-7.33, and from 12.8 to 8.32 - 7.16 respectively.

The BOD of leachate, fertilizer company and quarry industry effluents were also significantly reduced. Low levels of contaminants and in some cases complete removal of contaminants, was recorded for other industrial effluents. This comparative results show that *C. nigritana* is as good as C. *zizanioides* in the management of contaminated water. Africa can rely on its endemic species as a cost-effective, sustainable way of treating wastewater at commercial and micro scale before discharge into water bodies or reuse for irrigation. However the most significant finding is that *C. nigritana* is more effective in removing Phosphate, and *C. zizanioides* in removing Nitrate, the two key pollutants. Therefore, to maximize the treatment efficiency, it is recommended that wherever possible, both species should be used together to gain further benefit from their complimentary attributes.

Keywords: contaminated water, green technology, Vetiver wastewater treatment, carbon footprint, Africa

INTRODUCTION

Exploitation of natural resources, soil erosion (runoff), industrial activities, poor municipal waste management, use of fertilizers and other agro-chemicals continues to convert healthy water to contaminated water round the world. Industrial effluents and domestic wastewater in Nigeria and other Sub-Saharan African (SSA) are traditionally discharged into drainage, or nearby stream/river without primary treatment. In Africa, the management of this contaminated water is faced with a mixture of challenges. This includes: reducing toxic levels of wastewater to safe levels, huge cost of industrial wastewater treatment infrastructure, inadequate technical expertise, high cost of energy in an energy insecure continent and minimizing resultant carbon footprint. Climate change driving fresh water scarcity and reduction in per capita fresh water supply, pollution from above mentioned sources, along with curious toileting attitude makes safe water access difficult. Though the use of untreated wastewater has raised health concerns, no alternative affordable and effective wastewater treatment technology is available for commercial producers and urban agriculture users as in Plate 1. In developed economies, where treatment systems are in place, only a small percentage of the total volume wastewater is being treated for re-use (RUAF, 2008). In SSA, the operating cost for such a system in an energy (using fossil fuel) insecure economy and a changing climate could be huge and unaffordable. According to Dr Elais Ayuk of United Nations University Institute for Natural Resources in Africa (UNU-INRA) quoted by Nutakor (2014), inadequate infrastructure and management systems for the increasing volume of wastewater will be at the heart of the wastewater crisis. As such this will continue to provide the greatest health challenges restricting development and increasing poverty through costs to health care and lost labour productivity. According to Corcoran *et al*., (2010), hospital beds round the world are occupied with more people suffering from illness linked to contaminated water than any other form of illness. Worldwide, almost 900 million people still do not have access to safe water and some 2.6 billion, almost half the population of the developing world do not have access to adequate sanitation (Corcoran et al., 2010).

A study of countries in Sub Saharan Africa by Nikiema *et al*., (2013) showed that settling ponds are the predominant technology used in managing wastewater. Under this system concentration of contaminants is still high. For example, Chemical Oxygen Demand (COD) for such ponds across Africa have been reported to be higher than 2000 mg l^{-1} compared with treatment pond in other continents with about 400 mg l^{-1} (Wang *et al*., 2009 and Wang et al.,2013;). Most of the conventional remedial technologies like leaching of pollutant, vitrification, electrokinetic treatment, excavation and off-site treatment are expensive and technically limited to relatively small areas (Barceló and Poschenrieder, 2003). The technologies available for wastewater treatment in developed countries of Europe and America are expensive beyond the meager foreign exchange of most African countries particularly the Sub Saharan Africa (SSA). *Chrysopogon. zizanioides* was first used for wastewater treatment in Australia in 2001 by P.N. Truong. This technology offers an effective, efficient low-cost green solution (Truong and Hart, 2001; Truong *et al*., 2008) for the removal of high organic and inorganic contents of wastewater.

Three well-known species of commonly used vetiver are: *Chrysopogon zizanioides* (of South Indian origin), *Chrysopogon nemoralis* (of South East Asian origin) and *Chrysopogon nigritana* (of Africa origin). Earlier study showed significant difference in the potentials of *C. zizanioides* and *C nemoralis* in soil erosion control (Truong *et al*., 2008). Literatures abound on the effectiveness of *C zizanioides* in the treatment of wastewater (Truong and Hart, 2001; Truong *et al*., 2008 and Golabi and Duguies, 2013). Whereas, the potentials of *C nigritana* in decontamination of wastewater is not well known or documented (UNU-INRA, 2013). This could be attributed to the fact that the usage and research on the African species is still at its infancy in Africa. Therefore the objective of this study is to assess the effectiveness of African species of vetiver grass in removing contaminants from wastewater and to compare with the well-known South Indian species.

Plate 1. Wastewater of variable mixture (A) used for irrigation (B) in a city in Eastern Nigeria

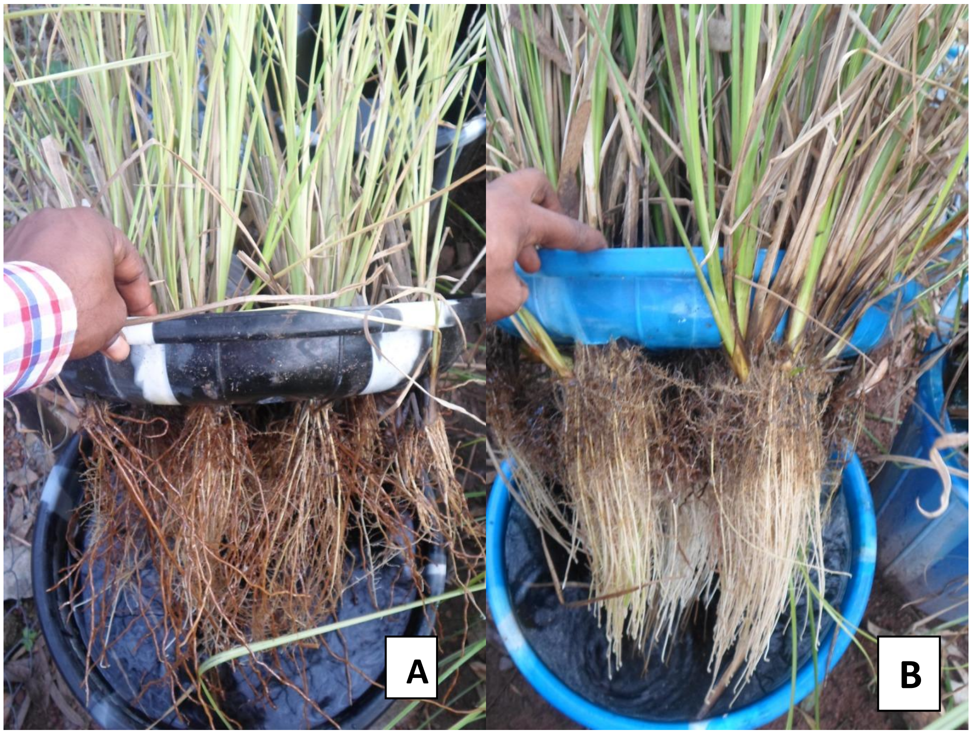

Plate 2. Showing treatment set-up in the screen house with *C, zizanioides* (**A**) and *C. nigritana* (**B**) under effluent from fertilizer company.

MATERIALS AND MATHODS

The study was carried out in Southeastern Nigeria, using native African vetiver grass species (*Chrysopogon nigritana*) while the South Indian species (*Chrysopogon zizanioides*) was introduced as control. Effluents were collected from quarry and fertilizer factories and leachate from public untreated refuse dumpsite. The wastewater was collected during the dry spell within the raining season though the toxic level was not at its highest due to rainfall dilution. But high levels of heavy metals and some properties such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Nitrate, Phosphate, Cyanide, Lead, Zinc, Iron, Cobalt, Cadmium, Mercury, Manganese, Arsenic, Nickel and Copper according to standard procedures (APHA, 2005 and Udo et al., 2009) were recorded. Vetiver plants were raised hydroponically as described by Truong and Hart (2001) when the system was first developed in Queensland, Australia. The set-up in this study were plastic buckets of 40 cm diameter and 60 cm height. A low concentration of NPK soluble fertilizer added to serve as nutrient for the vetiver (Truong and

Hart, 2001). This was allowed to stand for 10 weeks under full sunlight to allow the vetiver roots and shoots to establish as in Plate 2.

The experimental design (phyto-engineering set-up) consists of using hydroponically raised vetiver plants in the wastewater pool as described, then transferred to the different effluents over the treatment period to determine the uptake of contaminants by the roots (Plate 2A and 2B). The treated wastewater was collected at 2, 4 and 6 days intervals for post-treatment laboratory analysis. The levels of contaminants after treatment were compared with allowable international levels by FAO 1985; WHO 1993 and WHO/FAO, 2007).

RESULTS AND DISCUSSION

Improving wastewater quality with African species of vetiver.

Pre and Post treatment contaminant levels of the studied effluents are presented in Tables 1, 2 and 3. Results from *C. zizanioides* are well established (Truong *et al*., 2008) hence they are used use as control.

○***On the pH scale***, leachate from public dumpsite was acidic (< 6), the fertilizer company effluent was slightly acidic and alkaline for the quarry industry. Treatment with *C. nigritana* (African species) and *C. zizanioides* (South Indian species), brought the pH to or near recommended levels (7.25) for wastewater before discharge or reuse for agriculture (WHO 1993; FAO 1985 and WHO/FAO, 2007).

○***The BOD and COD*** measured the biodegradable and non-biodegradable substances in the effluents. Both species were effective in treating and reducing the levels far below allowable standards.

○***Cyanide*** content of effluent was significantly reduced by both species.

○***Heavy metal*** contaminants present were: Lead, Zinc, Iron, Manganese, Cobalt and Arsenic. Contaminant levels detected at pre-treatment stage in the refuse dumpsite leachate were in some cases above allowable limits. Intervention with vetiver either significantly reduced the level or completely removed the contaminant from the effluent. For instance, Zinc contaminant could not be detected after 2 days of treatment.

- African species removed 18 % of Iron contaminants after 2 days of treatment with no trace of the contaminant on the 4 and 6 day of treatment. The corresponding removal rate for Indian species was 34 %, 94 % and 96 % at 2, 4 and 6 days.

- Cobalt content in the leachate was completely removed with introduction of *C. nigritana*, whereas *C. zizanioides* could completely removed Cobalt by the 4 day of treatment.

- Manganese could not be detected by the 6th day under *C. nigritana*, whereas some traces were still present in the leachate under *C. zizanioides* treatment.

- Traces of Arsenic contaminant were only detected with 2 days treatment, and with no trace in leachate at 4 and 6 day after *C. nigritana* treatment, whereas under *C. zizanioides*, it was on the 6th day that it could not be detected in the effluent.

Table1. Rate of contaminant removal in leachate from public untreated refuse dumpsite in Eastern Nigeria by African and South Indian Vetiver species

Parameter/ contaminants	**African species (*Chrysopogon nigritana*)** Post treatment level/days after treatment (mg l^{-1})			Pre-treatment level (mg l^{-1})	**Indian species (*Chrysopogon zizanioides*)** Post treatment level/days after treatment (mg l^{-1})			Acceptable limit for irrigation
	6	4	2		2	4	6	
pH	6.5	6.0	5.88	5.80	6.67	7.30	7.33	7.25[WHO]
BOD	52.24	57.27	68.02	152.95	67.76	50.50	49.95	80[UNESCAP]
COD	50.57	54.66	60.45	151.78	68.46	52.06	47.79	150[UNESCAP]
Nitrate	48.41	47.76	52.04	115.60	51.56	47.58	42.90	50[WHO]
Phosphate	19.71	25.98	46.97	92.90	52.72	41.04	40.70	5-30 SHC
Cyanide	0.075	0.083	0.68	1.02	0.71	0.085	0.056	2[UNESCAP]
Lead	nil	nil	nill	nill	nil	nil	nill	0.5[UNESCAP]
Zinc	*	*	*	0.05	*	*	*	2.0[FAO]
Iron	*	*	0.856	1.04	0.683	0.06	0.02	5.0 [FAO]
Cobalt	*	*	*	0.1	0.073	*	*	0.05 [FAO]
Cadmium	nil	nil	nil	nil	nil	nil	nil	0.01 [FAO]
Mercury	nil	nil	nil	nil	nil	nil	nil	0.01 [FAO]

Manganese	*	0.06	0.063	0.14	0.05	0.036	0.01	0.20 FAO
Arsenic	*	*	0.063	0.1	0.05	0.05	*	1 UNESCAP
Nickel	nil	nil	nil	nil	nil	nil	nil	1 UNESCAP
Copper	nil	nil	nil	nil	nil	nil	nil	1 UNESCAP

*= contaminant reduced to below detection; nil = not detected in collected effluent; WHO = WHO 1993 drinking water guidelines; UNESCAP = UNESCAP 2000 wastewater management policies and practices in Asia and the Pacific; FAO = FAO irrigation and drainage paper 47.

Table 2: Rate of contaminant removal from fertilizer company effluent in Eastern Nigeria by African and South Indian species of Vetiver grass

Parameter/ contaminants	African species (*Chrysopogon nigritana*) Post treatment level/days after treatment (mg l^{-1})			Pre-treatment level (mg l^{-1})	Indian species (*Chrysopogon zizanioides*) Post treatment level/days after treatment (mg $^{l-1}$)			Acceptable limit for irrigation
	6	4	2		2	4	6	
pH	7.42	6.83	6.53	6.30	6.54	6.77	7.50	7.25 WHO
BOD	13.26	13.32	19.43	41.57	19.55	14.5	11.27	80 UNESCAP
COD	12.35	13.00	13.52	29.77	15.99	13.34	10.6	150 UNESCAP
Nitrate	8.70	18.72	56.88	122.2	58.73	28.39	7.38	50 WHO
Phosphate	10.86	15.54	24.27	55.05	36.47	15.27	12.08	5-30 SHC
Cyanide	nil	nil	nil	nil	nil	nil	nil	2 UNESCAP
Lead	nil	nil	nil	nil	nil	nil	nil	0.5 UNESCAP
Zinc	0.015	0.05	0.40	0.89	0.38	0.06	0.03	2.0 FAO
Iron	0.06	0.07	0.083	0.31	0.37	*	*	5.0 FAO
Cobalt	*	*	*	0.09	*	*	*	0.05 FAO
Cadmium	*	*	0.1	0.20	0.073	*	nil	0.01 FAO
Mercury	nil	nil	nil	nil	nil	nil	nil	0.01 FAO
Manganese	0.03	0.07	0.1	0.20	0.076	0.046	0.035	0.20 FAO
Arsenic	*	*	0.1	0.20	0.07	*	*	1 UNESCAP
Nickel	nil	nil	nil	nil	nil	nil	nil	1 UNESCAP
Copper	nil	nil	nil	nil	nil	nil	nil	1 UNESCAP

*= contaminant reduced to below detection; nil = not detectedt in collected effluent; WHO = WHO 1993 drinking water guidelines; UNESCAP = UNESCAP 2000 wastewater management policies and practices in Asia and the Pacific; FAO = FAO irrigation and drainage paper 47.

Table 3: Rate of contaminant removal from Quarry site effluent in Eastern Nigeria by African and South Indian species of Vetiver grass

Parameter/ contaminants	African species (*Chrysopogon nigritana*) Post treatment level/days after treatment (mg l^{-1})			Pre-treatment level (mg l^{-1})	Indian species (*Chrysopogon zizanioides*) Post treatment level/days after treatment (mg l^{-1})			Acceptable limit for irrigation
	6	4	2		2	4	6	
pH	8.32	8.40	11.93	12.8	12.37	8.29	7.16	7.25[WHO]
BOD	53.80	57.38	61.25	124.29	61.17	54.8	50.45	80[UNESCAP]
COD	52.47	52.25	54.81	119.8	56.54	52.48	50.80	150[UNESCAP]
Nitrate	6.65	15.03	56.03	120.8	53.77	18.14	5.86	50[WHO]
Phosphate	4.17	12.4	29.09	64.65	40.68	10.73	4.59	5-30 SHC
Cyanide	nil	nil	nil	nil	nil	nil	nil	2[UNESCAP]
Lead	0.05	0.05	0.06	0.30	0.26	0.07	0.01	0.5[UNESCAP]
Zinc	*	*	0.056	0.18	0.073	*	*	2.0[FAO]
Iron	0.09	0.07	0.35	0.83	0.3	*	*	5.0[FAO]
Cobalt	*	*	0.01	0.04	0.04	*	*	0.05[FAO]
Cadmium	nil	nil	nil	nil	nil	nil	nil	0.01[FAO]
Mercury	nil	nil	nil	nil	nil	nil	nil	0.01[FAO]
Manganese	*	0.07	0.10	0.21	0.076	0.056	*	0.20[FAO]
Arsenic	*	*	0.09	0.2	0.11	*		0.1[WHO/FAO]
Nickel	nil	nil	nil	nil	nil	nil	nil	1[UNESCAP]
Copper	nil	nil	Nil	Nil	nil	nil	nil	1[UNESCAP]

*= contaminant reduced to below detection; nil = not detected in collected effluent; WHO = WHO 1993 drinking water guidelines; UNESCAP = UNESCAP 2000 wastewater management policies and practices in Asia and the Pacific; FAO = FAO irrigation and drainage paper 47.

- In the treatment of effluent from Fertilizer Company, Iron contaminants were not detected after 2 days of treatment with *C. zizanioides*, whereas *C. nigritana* only reduced the levels slightly. Cobalt was not detected from the second day after treatment under the two species. Cadmium and Arsenic were equally removed beyond detection from the 4th day of treatment by the African and Indian species.

- For effluent from quarry industry, both species completely removed Zinc, Cobalt and Arsenic contaminants beyond detection from 4^{th} day after treatment. Manganese was not detected under both species by the 6th day.

High content of nitrate and phosphate in the studied effluents is a major cause of enthrophication of water bodies. However, vetiver usage significantly removed the nitrate and phosphate in the effluents. Similarly results of effectiveness of *C. zizanioides* had been reported (Truong and Hart, 2001; Truong P.N., 2006 and Mohammed and Dugules, 2013)

CONCLUSION

Both *C. zizanioides* and *C. nigritana* were effective in improving the pH and removing contaminants such as BOD and COD and pH, nitrate, phosphate, cyanide, lead, zinc, iron, cobalt, cadmium, Arensic and manganese. After a short time (2 days) of treatment, *C. nigritana*, removed more contaminants than *C. zizanioides*. As the time for treatment increased to 4 to 6 days, *C. zizanioides* became more effective. Shorter treatment time is critically important for production outfits that generates, large volume of wastewater on regular bases and has limited storage or sedimentation capacity before discharge.. The long time *C. zizanioides* takes in removing contaminants could be a major criticism for vetiver in such industries. However, the most significant finding is that *C. nigritana* is more effective in removing Phosphate, and *C. zizanioides* in removing Nitrate, the two key pollutants. Additionally, the African species is as good as the Indian species in the management of contaminated water. On one hand, it is recommended that, to maximize the treatment efficiency, wherever possible both species should be used together to gain further benefit from their complimentary attributes. On the other hand, Africa can rely on its endemic species as a low cost-effective, sustainable way of treating wastewater at commercial and micro scale.

ACKNOWLEDGEMENT

The first author gratefully acknowledges the African Women in Agricultural Research and Development (AWARD) for a partial travel grant awarded to him to present this paper at this conference.

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