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African vetiver grass cleans abattoir effluent

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Abstract

In many of Africa's growing cities, the pollution emanating from abattoirs is causing health and environmental concerns. The potential was assessed of hydroponically grown African vetiver [*Chrysopogon nigritanus* (Benth.) Veldkamp] and Asian vetiver [*Chrysopogon zizanioides* (L.) Roberty] for cleaning abattoir effluent. Concentrations of zinc and iron pollutants were reduced to below detectable limits within 6 d of treatment. Cyanide, with high pretreatment concentrations (>0.6 mg/L) was reduced in 6 d to below the internationally acceptable limits for irrigation water (0.07 mg/L). In the same period, biochemical oxygen demand, chemical oxygen demand and the concentrations of nitrogen, phosphorus and manganese were reduced by 84%, 86%, 52%, 70% and 88%, respectively, when treated with *C. nigritanus,* and by 84%, 88%, 71%, 77% and 90% when treated with *C. zizanioides*. *C. zizanioides* had significantly higher nitrogen and phosphorus removal rates, whereas *C. nigritanus* had a higher iron removal rate. However, the removal rates of the other contaminants did not differ significantly between the two species. It was concluded that the efficacy of pollutant removal by Asian and African vetiver was comparable. Thus, African vetiver, which is readily available in many parts of Africa, could serve as a cheap and effective green solution to water pollution in that continent.

Introduction

The menace of pollution in rural and urban centers has created a need for cheap, effective, and environmentally friendly remediation strategies, especially regarding abattoirs, where animals are slaughtered for human consumption (Abattoirs Act, 1988), Abattoirs have become more common in developing countries and nearly every neighborhood in every town seems to have a slaughter house or slab, which may not be well built and managed, and as a result pose many dangers. There is increasing concern regarding health and environmental risks for residents with direct or indirect contact with abattoir effluents, especially in developing countries, where the level of awareness of such risks is very low (Bello and Oyedemi, 2009). A cow brought for slaughter in Nigeria produces about 32.4 kg of waste in the form of dung, bone, blood, horn and hoof (Sridhar, 1988). The total amount of waste produced per animal slaughtered has been estimated at 35% of body weight (World Bank, 1998). Omole and Longen (2008) reported that among all the sources of pollution to streams in Nigerian cities, abattoir effluent is the most potent source because of its high organic content, nutrient concentration and waste

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volume. The volume of water required for processing a slaughtered cow is in the range of 2.5–40 m^3, whereas 6–30 m^3 of water is needed per tonne of poultry (Gannon et al., 2004). This high demand for water has resulted in the siting of abattoirs near water bodies, where carcasses may be washed directly into streams or channeled in via drainages. Thus, the concentrations of various nutrients, particularly nitrogen and phosphorus in water, are affected, resulting in eutrophication and toxic accumulation in biological systems (Nwachukwu et al., 2011; Afiukwa, 2013).

Previous studies have examined the efficacy of phytoremediation—the use of plants to resolve environmental problems—for the treatment of various types of wastewater in many countries, including Australia, India, China, Haiti and Vietnam (Truong and Hart 2001; Truong et al., 2008; Jayashree et al., 2011; Mahn et al. 2014; Muhhiriza et al., 2015). One such plant is vetiver grass (*Chrysopogon* spp.), a herbaceous perennial with erect and stiff leaves (about 0.5–1.5 m in length), a large panicle and linear-lanceolate spikelets that grows along river banks and on roadsides (Goudiaby and Diatt, 2003). It belongs to the family Poaceae, subfamily Panicoideae, tribe Andropogonae and subtribe Sorghinae (Angiosperm Phylogeny Group II, 2003; Marcacci, 2004). The three most commonly used species of vetiver grass are: 1) *C. zizanioides*, native to India; 2) *C. nigritanus*, native to western and southern Africa; and 3) *C. nemoralis*, native to South East Asia. Comparative studies of *C. zizanioides* and *C. nemoralis* showed that C. *zizanioides* has a higher potential as a phytoremediation agent. The efficacy of C. *zizanioides* has since been established in Asia and Australia (Truong et al., 2008).

C. zizanioides has a high affinity for both organic and inorganic compounds, making it suitable for a cost-effective, aesthetic and environmentally friendly approach for remediation of wastewater from various sources (Roongtanakiat and Chairoj, 2001). Different types of wastewater remediation using *C. zizanioides* have been reported (Truong and Stone, 1996; Xia et al., 1999) and its efficacy has been linked to its high transpiration rate (Jayashree et al., 2011). An Australian study by Ash and Truong (2004) reported that the vetiver system provides better results in abattoir effluent treatment than the well-known kikuyu grass (*Pennisetum clandestinum* Hochst.). Similarly, Mahn et al. (2014) observed a 59% reduction in biochemical oxygen demand (BOD) and a 60% reduction in chemical oxygen demand (COD) from abattoir effluent when treated with vetiver in China. These reduction rates were higher than from using biodigesters in the same experiment. They also reported that total nitrogen in abattoir effluent was reduced by 77% and total phosphorus was reduced by 46% when treated with vetiver grass compared with 42% and 11% reductions, respectively, achieved using biodigesters. Smeal et al. (2003) also demonstrated that vetiver has the capacity to reduce nitrogen concentrations to below acceptable limits (<10 mg/L) set by Australian and New Zealand Environment Conservation Council (1997). Roongtanakiat and Chairoj (2001) reported that total suspended solids, dissolved solids (above 2,000 mg/L), electrical conductivity (above 3.0 dS/m), hardness, BOD, COD, nitrogen, phosphorous, heavy metals and other contaminants were brought below toxic levels in India by using vetiver grass (*C. zizanioides*). In Nigeria, soil conservation trials using C. *zizanioides* and *C. nigritanus* have been reported (Babalola et al., 2003; Nzeribe and Nwachukwu, 2008; Oku and Aiyelari, 2014), but the adoption of vetiver technology is still in its infancy. The potential of Africa's indigenous species (*C. nigritanus*) in cleaning wastewater, which is one of Africa's critical challenges, is not well understood (United Nations University-Institute for Natural Resources in Africa, 2013).

In this study, the remediation efficacy of African vetiver (*C. nigritanus*) was compared to that of Asian vetiver (*C. zizanioides*) in order to understand the potential of the former in wastewater cleaning.

Materials and Methods

Study area

This study was conducted in Abakaliki (6°22'N, 8°6'E), the capital city of Ebonyi State, southern Nigeria. The area has a tropical climate with a derived savannah vegetation. Mean annual rainfall ranges from 1200 mm to 1500 mm, with a bimodal pattern and a short dry spell in August. The average annual temperature is 31°C. Relative humidity ranges from 60% to 80% during the rainy season (Madu, 2005). The study site was an abattoir along Ogoja Road in the heart of Abakaliki. This abattoir was selected because it is the main source of meat for the city. The abattoir contained a small cattle ranch and a slow-flowing stream into which abattoir wastes were discharged. About 20 cattle were slaughtered in the abattoir on a typical day, but this number increased on weekends and during festival seasons.

Sample collection

Two species of vetiver grass were used for this study—*Chrysopogon zizanioides* cv. Sunshine (EBSU-H-0201 C) and *C. nigritanus* (EBSU-H-0200 C)—which were obtained from the vetiver grass germplasm bank of Ebonyi State University, Abakiliki, Nigeria. The two species were grown in a nursery for 4 wk for acclimatization. Abattoir effluent was collected at three positions in the stream (point of discharge, midstream, downstream) and the samples were combined to obtain a composite sample.

Experimental design

Floating rafts were constructed using the cover of 40 L buckets turned upside-down (Fig. 1). Fourteen holes were bored into each raft to hold the crowns of vetiver plants. Plants were transplanted from the nursery and inserted into the bottom of the rafts, making sure not to damage the roots. The experiment was designed in a completely randomized pattern with six buckets, three for each vetiver species, representing three replicates. In the first hydroponic setup, tap water was used with additional nutrients (N:P:K at 15:15:15; 1 mL/L of water) to ensure that plant roots were well established (40 cm long) before transferring to abattoir effluent. The setup was mounted in an

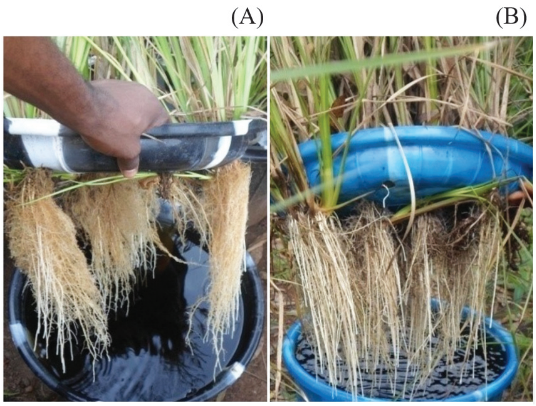

Fig. 1 Root growth in a hydroponic setup: (A) *C. zizanioides*; (B) *C. nigritanus*

open field for 8 wk. Plants were then transferred to a second hydroponic setup containing abattoir effluent of the same volume (40 L) collected on the same day. These setups were mounted in a greenhouse for 6 d (humidity, 55%; temperature 30°C; photoperiod, 12 hr). Initial values of pH, BOD and COD and total nitrogen, total phosphorus, cyanide, lead, zinc, iron, cobalt, cadmium, mercury, manganese, arsenic, nickel and copper concentrations were determined in the abattoir effluent before treating with vetiver. The same water quality parameters were determined at 2 d, 4 d and 6 d after treatment started (DAT) to obtain the respective removal rates.

Water quality determination

Biochemical oxygen demand (BOD_5) was determined following the standard 5-day method (American Public Health Association, 2005). COD was determined using a spectrophotometer (DR 5000; Hach; Loveland, CO, USA). pH was determined using a pH meter (sensION+; Hach; Loveland, CO, USA). Cyanide was analyzed using a flame atomic absorption spectrophotometer (Lambda ASTME201; PerkinElmer; Waltham, MA, USA) at a wavelength of 328 nm. Instrument conditions were maintained according to the manufacturer's specifications. Standard solutions and dilutions were made using the indirect method, as described by Gurkan and Yilmaz (2013). Total phosphorus and total nitrogen were analyzed using a spectrophotometer (DR 5000; Hach; Loveland, CO, USA) and standard assay kits following the manufacturer's instructions. The arsenic concentration was determined following the standard titrimetric procedure described by Garba et al. (2012), represented in Equation 1:

$$As_2O_3 + 2H_2O + 2I_2 \rightarrow As_2O_5 + 4H^+ + 4I^- \quad (1)$$

Metal (lead, zinc, iron, cobalt, cadmium, mercury, manganese, arsenic, nickel, copper) concentrations were determined using standard methods (Association of Official Analytical Chemists, 2004) and the atomic absorption spectrophotometer. All determinations were made in triplicate, so that the three replicates were analyzed three times each.

Statistical analysis

The effectiveness of both species in reducing each kind of pollutant from abattoir effluent was compared using a Student's t test at the 5% level of significance.

Results

Biochemical oxygen demand, chemical oxygen demand and pH

Both *C. nigritanus* and *C. zizanioides* significantly reduced the concentrations of pollutants from abattoir effluent during hydroponic treatment. Contaminant pretreatment levels (day 0) were substantially reduced after 48 hr. At 2 DAT, the initial BOD of 206 mg/L was reduced to 99 mg/L and 102 mg/L by *C. zizanioides* and *C. nigritanus*, respectively (50% and 49% reductions, respectively). A greater than 80% reduction in BOD was achieved by both species at 6 DAT (Fig. 2A). COD was reduced from 204 mg/L at pretreatment to 99 mg/L and 64 mg/L by *C. zizanioides* and *C. nigritanus*, respectively, at 2 DAT. At 4 DAT and 6 DAT, COD showed a greater than 80% reduction in both treatments, and the removal rate did not differ significantly between the two species (Fig. 2B). pH changes were observed in the abattoir effluents during treatment, with reductions from 7.5 to 6.8 by *C. zizanioides* and from 7.5 to 6.2 by *C. nigritanus*.

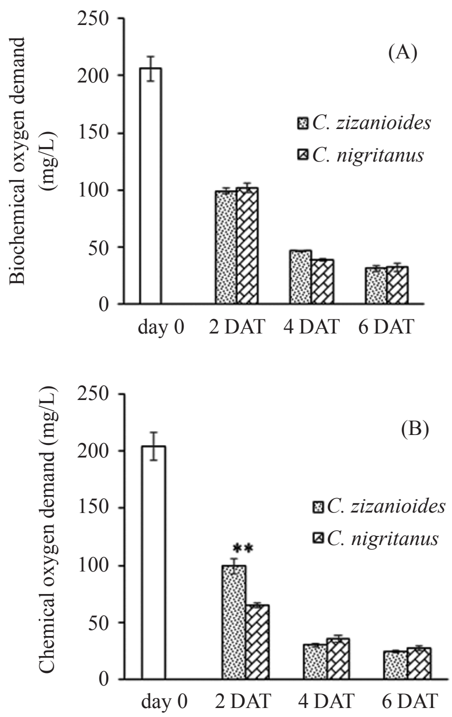

Fig. 2 Biochemical oxygen demand (A) and chemical oxygen demand (B) of abattoir effluent before (day 0) and after treating with vetiver (2, 4 and 6 days after treatment, DAT); ** = significant difference ($p < 0.01$) between the performance of the two vetiver species.

Nitrogen, phosphorus and cyanide

The nitrogen concentration was reduced from 130.6 mg/L at pretreatment to 61 mg/L and 69 mg/L by *C. zizanioides* and *C. nigritanus*, respectively, at 2 DAT. The reduction rate with *C. zizanioides* was higher ($p < 0.05$). Nitrogen was further removed by both species at 4 DAT and 6 DAT, and again, the reduction rate with *C. zizanioides* was higher ($p < 0.01$; Fig. 3A). Similarly, the phosphorus concentration was reduced from 56 mg/L at pretreatment to 29 mg/L and 23 mg/L by *C. zizanioides* and *C. nigritanus*, respectively, at 2 DAT. Compared to that of *C. zizanioides*, the reduction rate by *C. nigritanus* was higher at 2 DAT, but lower at 6 DAT (Fig. 3B). Cyanide was reduced from 0.82 mg/L at pretreatment to 0.35 mg/L and 0.32 mg/L by *C. zizanioides* and *C. nigritanus* respectively, at 2 DAT, and more cyanide removal occurred at 4 and 6 DAT (Fig. 3C), although the rate was similar in both species.

Heavy metals

Cobalt, cadmium, mercury, arsenic, nickel and copper were not detected in the abattoir effluent before treatment. *C. zizanioides* and *C. nigritanus* each reduced the zinc concentration from 1.43 mg/L at pretreatment to 0.6 mg/L at 2 DAT, and by 4 DAT zinc had been reduced below detectable limits in both species (Fig. 4A). Similarly, the iron concentration was reduced from 1.30 mg/L at pretreatment to 0.73 mg/L by both species at 2 DAT, and it was further reduced below detectable limits by *C. nigritanus* at 4 DAT and to 0.15 mg/L and 0.01 mg/L at 4 DAT and 6 DAT, respectively, by *C. zizanioides* (Fig. 4B). Furthermore, *C. zizanioides* and *C. nigritanus* reduced the manganese concentration from 1.03 mg/L at pretreatment to 0.77 mg/L and 0.74 mg/L, respectively, at 2 DAT. The rate of reduction by *C. zizanioides* was higher at 4 DAT, but at 6 DAT the rate did not differ from that of *C. nigritanus* because manganese was again detected in the *C. zizanioides* treatment (Fig. 4C).

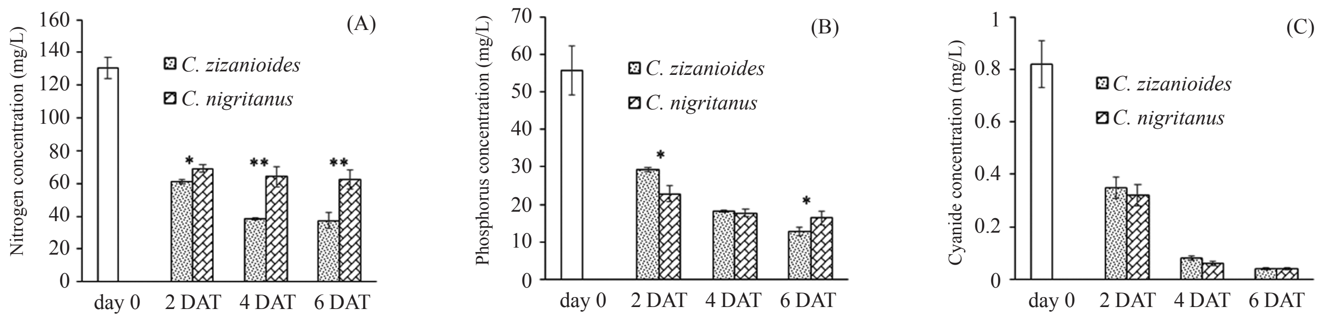

Fig. 3 Mean±SD of nutrient and cyanide concentrations in abattoir effluent before (day 0) and after treating with vetiver (2, 4 and 6 days after treatment, DAT): (A) nitrogen; (B) phosphorus; (C) cyanide; comparison between species was based on the rate of pollutant reduction from pretreatment levels (day 0); * = $p < 0.05$, ** = $p < 0.01$.

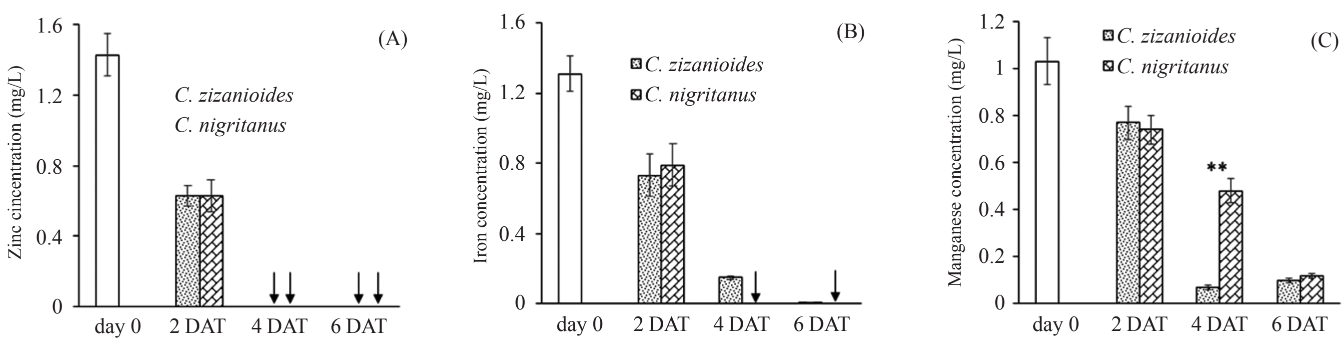

Fig. 4 Mean±SD of heavy metal concentrations in abattoir effluent before (day 0) and after treating with vetiver (2, 4 and 6 days after treatment (DAT): (A) zinc; (B) iron; (C) manganese; comparison between species was based on pollutant reduction from pretreatment levels (day 0); ** = $p < 0.01$; arrows indicate reduction below detectable limits.

Discussion

Biochemical oxygen demand, chemical oxygen demand and pH

The use of vetiver grass in Africa is still in its infancy and the potential of the African species in wastewater cleaning is poorly understood. In the current study, African vetiver grass demonstrated an efficacy similar to that of the well-known Asian vetiver. BOD is the amount of dissolved oxygen needed by aerobic organisms to break down organic material present in wastewater, whereas COD gives an idea of the total amount of oxidizable (biodegradable and non-biodegradable) substances in the wastewater (Esener et al., 1981). Both vetiver species reduced the BOD in abattoir effluent by 84% within 6 d. Similarly, COD was reduced by 88% and 86% by *C. zizanioides* and *C. nigritanus*, respectively. The rates of BOD and COD removal were in line with Zheng et al. (1997), Truong et al. (2008) and Darajeh et al. (2016). Wastewater is considered to be well treated if the BOD/COD ratio is higher than 0.05 (Tran and Ngo, 2002). In the current study, the BOD/COD ratio of effluent treated by each species was above 0.05, indicating that the abattoir effluent was reasonably treated by vetiver within 6 d. However, the final pH values obtained after treatment (6.8 and 6.2 for *C. zizanioides and C. nigritanus*, respectively) were lower than the recommended value (7.25; World Health Organization, 2004).

Nitrogen, phosphorus and cyanide

Nitrogen and phosphorus are the most common nutrients causing eutrophication and subsequent algal blooms, which are a major environmental problem in Sub-Sahara Africa (Oku et al., 2016). The nitrogen concentration in the effluent was reduced by 71% and 52% by *C. zizanioides* and *C. nigritanus*, respectively. Previous studies reported that *C. zizanioides* removed between 62% and 93% of nitrogen (Truong 2000; Truong and Hart 2001). The nitrogen removal rate was significantly higher in the *C. zizanioides* treatment. Although the reason for this variation is not clear, it may have been due to better adaptation by *C. zizanioides* to nitrogen removal since it has long been employed in phytoremediation (Truong and Stone, 1996; Xia et al., 1999). Similarly, 77% and 70% of phosphorus was removed by *C. zizanioides* and *C. nigritanus*, respectively, and these rates were similar to those reported by Mahn et al. (2014). Although the phosphorus removal rate was significantly greater in the *C. zizanioides* treatment, *C. nigritanus* also showed a strong potential for cleaning water contaminated with high nutrient concentrations.

Cyanide is often associated with mining and manufacturing industries but may sometimes find its way into water bodies (Elbel et al., 2007), especially in regions with poor environmental regulations. The conventional treatment systems in developed countries, such as reverse osmosis and ion exchange, are too expensive for many developing economies and are sometimes not environmentally friendly (Maegala et al., 2011; Oku et al., 2016). In the current study, the pretreatment cyanide concentration of 0.82 mg/L was reduced within 6 d to below the internationally acceptable limits for irrigation water of 0.07 mg/L (World Health Organization, 2004). The reduction rate was about 90% for both species. Wachirawongsakorn et al. (2015) reported a 100% removal of 5 mg/L cyanide within 2 wk using a *C. zizanioides* ecotype (Monto). This further proved that the African species, like its Asian counterpart, is capable of absorbing toxic compounds without showing toxicity.

Heavy metals

Heavy metals such as zinc, iron and manganese are required in minute quantities by organisms, but an increase in the concentrations of these elements beyond a certain threshold may become harmful to organisms (Beldi et al., 2006; Ndome et al., 2010). Zinc, iron and manganese pollution have been previously reported in abattoir effluents (Raheem and Morenikeji, 2008; Magaji and Chup, 2012). In the current study, zinc was reduced below detectable limits by both vetiver species at 4 DAT. This reduction rate was similar to a report from Zimbabwe (Muhhiriza et al., 2015), but higher than one reported for China (Chen et al., 2009). Iron was reduced below detectable limits at 4 DAT by *C. nigritanus* and at 6 DAT by *C. zizanioides.* The reduction rates of manganese were 88% and 90% by *C. zizanioides and C. nigritanus*, respectively. The absorption of iron and manganese by plants is usually associated with the release of phytosiderophores (substances that chelate iron) (Chen et al., 2009). The mechanisms underlying the absorption of these substances by vetiver are complex and not well understood. The cleaning of abattoir effluent with vetiver may have occurred through rhizofiltration and rhizodegredation. Most substances are absorbed into plant roots via various mechanisms that depend on factors such as solubility, polarity and hydrophobicity (Schnoor et al. 1995). According to Simpson (2011), soluble substances may enter the apoplast of roots through intercellular spaces, while others may pass through the xylem where they encounter the impermeable Casparian strip, and as such may require membrane pump mechanisms for translocation. However, most ionic substances mimic nutrients and travel through channels intended for essential nutrients (Hall, 2002). The current study showed that African vetiver (*C. nigritanus*) has an efficacy similar to that of Asian vetiver (*C. zizanioides*) in cleaning wastewater. Based on the similar rates of reduction of BOD, COD, nitrogen, phosphorus, cyanide, zinc, iron and manganese from abattoir effluent within 6 d, we conclude that *C. nigritanus*, which is readily available in Africa, is a cheap, effective, and environmentally friendly tool for wastewater cleaning.

Limitations

The current research demonstrated the effectiveness of both vetiver species in removing pollutants from wastewater. Although, beyond the scope of this study, a few concerns might limit the wide scale use of this technology in Africa. The question of what can be done with vetiver plants after accumulating heavy metals has yet to be satisfactorily answered. In wide scale industrial applications, important metals may be recovered from plant tissues (phytomining). However, in rural areas, there is a high possibility of livestock grazing on heavy metal accumulated vetiver grass. These issues require further research.

Conflict of Interest

The authors declare that there is no conflict of interests.

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