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Research article

BIOREMEDIATION POTENTIAL OF COMMON RICEFIELD PLANTS AND ANIMAL SPECIES FOR HEAVY METALS: CADMIUM, CHROMIUM AND LEAD

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ABSTRACT

Bioremediation potential of *Commelina benghalensis*, *Fimbristylis miliacea*, *Cyperus iria, Pomacea canaliculata* and *Hirudo medicinalis* for bioremediation of heavy metals such as cadmium, chromium, and lead was conducted. The experiments were allowed for three (3) days of accumulation. Relative growths, bioaccumulation factors, bioaccumulation coefficients and translocation factors were determined to evaluate the bioremediation potential of the plant and animal species. Presence of heavy metals was quantified using Flame Atomic Absorption Spectroscopy. Results showed that relative growths of plants were generally affected with the increase of heavy metal concentrations. Cadmium concentrations at 100ppm and > 25 ppm demonstrated to be toxic to *C. benghalensis* and *F. miliacea,* respectively, while *C. iria* showed tolerance in 25-100ppm. The concentrations > 50 ppm and > 25ppm of chromium and lead respectively had demonstrated to be detrimental to the growth of the three species. Relative growths of *P. canaliculata* and *H. medicinalis* showed to be sensitive in cadmium, chromium and lead even in very minute amounts. Chromium and lead accumulation of the three species were not statistically significant. *P. canaliculata* and *H. medicinalis* showed to be capable of accumulating cadmium and lead even in minimal amounts (0.050-0.075 ppm). In chromium accumulation, the two species showed accumulation in 0.100 and 0.125 ppm. *C. benghalensis, F. miliacea*, and *C. iria* were classified heavy metal excluders. *P. canaliculata* and *H. medicinalis* are also excluders of the three heavy metals mentioned above. Heavy metal translocation factors classified *C.*

benghalensis as effective translocators of cadmium within the range of 25-75 ppm. *C. benghalensis* proved to be effective translocator of chromium at 50, 100, and 200 ppm. However, the other two species of plants had shown no potential in translocating lead.

Keywords: Bioremediation, Bioaccumulation Factors (BAF), Bioaccumulation Coefficients (BAC), Excluders

INTRODUCTION

In the present years, public concerns relating to ecological threats caused by heavy metals have led to intensive research on bioremediation technologies. The rapid increase in population coupled with fast industrialization growth caused serious environmental problems including the production and release of considerable amounts of toxic waste materials into the environment (Zhuang, Chen, Shim & Bai , 2007).

The existence of heavy metals has been a matter of great concern due to their persistent nature. In an ecological research, any metal or metalloid which cannot be degraded should be considered a heavy metal. Heavy metals are natural components of the Earth's crust, but in many ecosystems the concentrations of heavy metals have reached toxic levels as a consequence of anthropogenic activities. Among the heavy metal pollutants of interest are cadmium, chromium, and lead (Padmavathiamma & Loretta, 2007).

The presence of toxic metals such as cadmium, chromium and lead in the environment has been a source of worry to the environmentalists, concerned government agencies and health practitioners. The presence of these metals in ecosystem has far – reaching implications directly to the biota and indirectly to man. In addition, food chain contamination by toxic metals has become a burning issue in recent years because of their potential accumulation in bio-system through contaminated water, soil and air. (Rajesh, Madhoolika, & Marshall, 2004). It is of this premise that the technology of bioremediation was conceived.

Many researches had identified various plants potential for phytoremediation. However, utilization of animals for remediation is rarely considered owing to ethical concerns or because many of the aquatic organisms currently cultured or harvested commercially are bound for human consumption.

The study aimed to determine the bioremediation potential of common plant and animal species in the rice fields. Relative Growths, bioaccumulation factors (BAF), bioaccumulation coefficients (BAC) and heavy metal translocation factors (TF) were assessed to determine the effects of heavy metal on the growth of plants and animals, quantify toxic element accumulation in plants and animals, determine heavy metal accumulation efficiency, and determine their translocation ability.

Since the Industrial Revolution, the production of heavy metals has augmented dramatically. The world without a doubt is contaminated with a variety of toxic pollutants. These pollutants are present in escalating trend in land, waters and atmosphere affected by contamination from anthropogenic activities. The increase of toxic pollutants in soil, surface water and ground water does not only affect our natural resources but also causes a major strain on ecosystems. This has led many researchers to explore plants and animals for bioremediation of heavy metal contaminated sites.

Availability and toxicity of heavy metals in the environment, responses and adaptive strategies of plants to metal toxicity and phytoremediation technology etc. have been comprehensively discussed and superbly reviewed several authors (Orcutt & Nilsen, 2000; Cseh, 2000; Fodor, 2002). The present study is quite similar with that of the studies conducted by the authors mentioned as this study is geared towards identifying plants species capable of removing heavy metals from the environment. However, in terms of plant metal toxicity, the researcher used relative growth to somehow describe the plants adaptive strategies to heavy metals under consideration.

Elevated concentrations of both essential and non-essential heavy metals in the soil and water can lead to toxicity symptoms and growth inhibition in most plants (Jindal & Kaur, 2000; Hall, 2002). Absorption, translocation and accumulation of heavy metal ions of Hg, Pb, Cr, and Cd by plants, reduce qualitative and quantitative productivity of the species and cause serious health hazards through the food chain to other life forms (Cobbett, 2003; Stolt, Asp, & Hultin, 2006). These brilliant studies of authors were also similar to the study at hand considering the heavy metals they have utilized and the factors they considered such as translocation, accumulation and toxicity.

Bioremediation is the use of biological entities especially plants, fungi, or microbes which are capable of degrading, detoxifying, immobilizing or transforming pollutants into less hazardous forms (Raymundo, 2006; Eweis, Ergas, Chang, Daniel,& Schroeder 1998). From the Latin word *remediare*, "to heal", bioremediation is a method that can rehabilitate and restore the contaminated environment. The basis for bioremediation is the enormous natural metabolic capabilities of biological entities to degrade or transform hazardous compounds into simpler non-harmful forms (Markandey & Rajvaidya, 2004).

MATERIALS AND METHODS

The study utilized descriptive-comparative-experimental type of research. It investigated the phytoremediation of potential of Day Flower *(C. benghalensis),* Globe Fringerush (*F. miliacea),* and Rice Flat Sedge *(C.iria)* in heavy metals cadmium (Cd), chromium (Cr VI), and lead (Pb). Same metals were also used for Golden Apple Snails *(P.canaliculata L)* and Leech *(H. medicinalis),* which were chosen to represent the animal species. The researcher distinguished the morphology of the plants and animals were based on weed management sheet of International Rice Research Institute (IRRI), Asian-Pacific Alien Species Database and Biota of Freshwater Leeches Identification Manual No. 8 (Annelida: Hirudinea) of Environmental Protection Agency respectively.

There were 315 samples of each species: Day Flower *(C.benghalensis),* Globe Fringerush (*F. miliacea),* and Rice Flat Sedge *(C. iria)* were collected to represent the plant samples. A total of 800 pieces of Golden Apple Snails *(P.canaliculata L)*and 800 pieces of Leech *(H.medicinalis)* were collected in the rice fields of Sitio Kanagkaan, Patrocenio, Claveria, Misamis Oriental .

The samples were exposed to varied heavy metal concentrations in a hydroponic set up for three (3) days in indoor light. The concentrations of cadmium and lead were 0, 25, 50, 75, and 100ppm respectively. For chromium, the concentrations were 0, 50, 100, 150, and 200 ppm respectively. Every concentration was assigned seven (7) plants which were weighed before and after exposure to determine relative growth. Three replicates were considered in each concentration. Animal samples were exposed to cadmium concentration of 0.01, 0.025, 0.050, and 0.075 ppm. Chromium and lead concentrations were at 0.05, 0.075, 0.100, and 0.125 ppm respectively. At the end of the exposure, the plants and animals were removed from the solution and washed with tap water to eliminate external heavy metals, air dried for 3 days and was kept in a ziplock cellophane. The collected samples were ashed in the furnace (Barnstead/ Thermolyne F4801), acid digested, and were introduced to the Atomic Absorption Spectroscopy (Perkin Elmer Analyst 200) for the determination of cadmium, chromium, and lead.

RESULTS AND DISCUSSION

Growth of plants in various heavy metals

Growth changes are often the first and most obvious reactions of plants under heavy metal stress. The relative growth is determined by the ratio of the final fresh weight (FFW) and initial fresh weight (IFW) of plants (Table 1).

Table 1. Relative growths of plant species in different cadmium concentrations.

Plant/Taxon	Cadmium Concentration (ppm)	Initial Fresh Weight(IFW) (g)	Final Fresh Weight(FFW) (g)	Relative Growth (FFW/IFW)	p-value	Remarks
C. benghalensis	0	22.342	22.416	1.003		
	25	23.122	23.131	1.002	0.468	NS
	50	23.044	23.046	1.000	0.065	NS

	75	23.341	23.112	0.990	0.276	NS
	100	22.849	22.701	0.994	0.003	S
F. miliacea	0	38.920	38.945	1.001		
	25	37.613	35.254	0.937	0.001	S
	50	37.904	33.584	0.886	0.001	S
	75	35.925	30.456	0.848	0.001	S
	100	36.259	29.567	0.815	0.001	S
C. iria	0	97.398	97.410	1.000		
	25	97.010	95.569	0.985	0.819	NS
	50	100.150	89.997	0.899	0.222	NS
	75	95.710	95.710	0.900	0.226	NS
	100	94.893	94.893	0.896	0.213	NS

In this study, *C. benghalensis* showed high tolerance to elevated cadmium levels. The increased relative growths of 1.002 and 1.000 at concentrations 25 ppm and 50 ppm are good indicators of plant's tolerance to metal stress. On the other hand, the relative growths of *F. miliacea* and *C. iria* marked a decreasing pattern at 25, 50, 75, and 100 ppm respectively. During the three-day exposure, leaf chlorosis were very evident in higher concentrations (75, 100 ppm) than in lower concentrations (25, 50 ppm) as compared to the control which did not show any signs of leaf discoloration . This can be supported by the findings of Arduini , Godbold & Onis (1996) who cited that the most common effect of cadmium toxicity in plants were stunted growth and leaf chlorosis.

The result of the present study generated same inference with the study of Wu et al. (2011) when they concluded that plant growth is suppressed with the increase of cadmium concentration. Moreover, Kabata-Pendias and Pendias (1992) stipulated that plants had a critical range and normal range for in plants is from 0.1-2.4 ppm and the critical range is from 10-30 ppm. However, in the present study, cadmium at 100ppm is the critical range for *C. benghalensis.* For *F. miliacea*, the critical range is from 25-100 ppm and for *C iria* is >100 ppm.

The decrease on the relative growth among the three plant species can be attributed to the effect of cadmium in the physiological processes of the plants. Cadmium affects the process of mitosis or somatic cell division. The process of cell division is the prime process for growth and development of plants

In case of chromium, results revealed a declining trend in the relative growths of *C. benghalensis* , *F. miliacea, and C. iria* (Table 2). The relative growths of each plant species with respect to the different cadmium concentrations were observed to be significantly different. This only means that levels 50, 100, 150, and 200 were toxic to *C. benghalensis, F. miliacea,* and *C. iria* based on the result of the study. Chromium affects somatic cell division, the basic physiological process for growth and development of plants. When this process is hampered, relative growth of plants declines. Metal toxicity reduces vigor and growth of plants, causes death in extreme cases interferes with photosynthesis, respiration, water relation, reproduction etc. and causes changes in certain organelles, disruption of membrane structure and functions of different plant species.

Table 2. Relative growths of plant species in different chromium concentrations.

Plant Species/ Taxon	Chromium Concentration (ppm)	Initial Fresh Weight (IFW) (g)	Final Fresh Weight(FFW) (g)	Relative Growth (FFW/IFW)	p-value	Remarks
C. benghalensis	0	22.377	22.432	1.002		
	50	20.740	18.945	0.913	0.001	S
	100	24.645	18.043	0.732	0.001	S
	150	20.531	15.117	0.736	0.001	S
	200	20.701	14.347	0.693	0.001	S
F. milicea	0	36.677	36.78	1.003		
	50	37.260	36.993	0.993	0.001	S
	100	41.720	35.694	0.856	0.001	S
	150	38.882	33.115	0.852	0.001	S
	200	43.053	29. 623	0.668	0.001	S
C. iria	0	98.631	98.754	1.001		
	50	100.046	95.234	0.952	0.001	S
	100	102.423	91.398	0.892	0.001	S
	150	100.063	89.765	0.897	0.001	S
	200	101.438	83.345	0.822	0.001	S

Legend: S- significant, NS- not significant at 95%

From the data obtained, lead is very perceptible that elevated concentrations of lead caused a decline in the relative growths of *C. benghalensis, F. miliacea and C. iria* in concentrations 25ppm, 50ppm, 75ppm, and 100ppm concentrations, respectively (Table 3). T-test result showed significant difference on the relative growths of the three species. The three species have low tolerance to lead contamination resulting to dark leaves, wilting of older leaves and stunted growth of the foliage.

Kabata- Pendias and Pendias (2001) suggested that the normal range of lead in plants is at 0.2 to 20 ppm and the critical range is at 30 to 300 ppm. Lead as a toxic substance affects the somatic cell division among plants. Metal toxicity reduces vigor and growth of plants; causes death in extreme cases interferes with photosynthetic process, respiration and water absorption efficiency of plants and causes changes in certain organelles, disruption of membrane structure and functions of different plant species.

Table 3. Relative growths of plants in different lead concentrations.

Plant/Taxon	Lead Concentration (ppm)	Initial Fresh Weight (IFW) (g)	Final Fresh Weight(FFW) (g)	Relative Growth (FFW/IFW)	p-value	Remarks
C. benghalensis	0	23.636	23.874	1.010		
	25	23.616	23.413	0.991	0.001	S
	50	22.034	21.549	0.978	0.001	S
	75	24.082	19.065	0.792	0.001	S
	100	23.887	18.234	0.763	0.001	S
F. milicea	0	40.257	40.263	1.000		
	25	31.736	30.051	0.947	0.001	S
	50	37.073	33.564	0.905	0.001	S
	75	38.183	28.624	0.750	0.001	S
	100	38.021	25.867	0.668	0.001	S
C. iria	0	106.000	106.123	1.001		

25	98.969	94.561	0.955	0.001	S
50	94.556	89.345	0.945	0.001	S
75	95.001	87.432	0.920	0.001	S
100	98.123	81.456	0.830	0.001	S

Legend: S- significant, NS- not significant

Growths of animals in various heavy metals

Cadmium concentrations of 0.050 and and 0.075 resulted to the decrease in weight of *H. medicinalis* at 0.997 and 0.980, respectively (Table 4). Based on the computed p- value (0.001), it is apparent that the growths *P. canaliculata* in metals concentrations 0.025, 0.050, and 0.075 were proven to be statistically significant. These concentrations proved to be toxic to *P. canaliculata* because it was in these concentrations where the organisms were observed to be immobile at 24-48 hour exposure and have shown early signs of mortality. On the other hand, *H. medicinalis* relative growths were also significantly different. Cadmium concentration of 0.05–0.100 ppm of Cd is unfavorable to freshwater organisms. This will cause the organisms to be immobile and inhibit food and air consumption (Dobson, 1992).

Table 4. Relative growths of animals in different cadmium concentrations.

Plant Species	Cadmium Concentration (ppm)	Initial Fresh Weight(IFW) (g)	Final Fresh Weight(FFW) (g)	Relative Growth (FFW/IFW)	p-value	Remarks
P. canaliculata	0.000	106.715	106.723	1.000		
	0.010	102.437	102.416	1.000	1.000	NS
	0.025	104.632	103.056	0.985	0.001	S
	0.050	106.113	103.567	0.976	0.001	S
	0.075	104.275	99.437	0.954	0.001	S
H. medicinalis	0.000	31.064	31.406	1.011		
	0.010	36.426	36.431	1.000	0.001	S
	0.025	34.964	34.97	1.000	0.001	S
	0.050	31.753	31.65	0.997	0.001	S
	0.075	32.896	32.231	0.980	0.010	S

The data concerning relative growth of animals in varying concentrations of chromium are shown in Table 5. It is obvious that at chromium levels 0.100 and 0.125 ppm, growth of *P. canaliculata* (0.930, 0.930) *and H. medicinalis*.(0.941, 0.859) declined. T-test for two sample means revealed that the relative growths of *P. canaliculata* and *H. medicinalis* subjected in various concentrations were statistically significant.

The result simply means that at higher doses, animals tend to show sensitivity to chromium as indicated with its mortality rate in higher concentrations (0.100 and 0.125 ppm) of cadmium. Dose-dependent responses reflecting exposure to heavy metals such as immobility, survival, and mortality was noticeable in both species. This only means that freshwater macro invertebrates have limits of tolerating significant amounts of chromium.

Table 5. Relative growths of animals in different chromium concentrations.

Animal Species	Chromium Concentration (ppm)	Initial Fresh Weight(IFW) (g)	Final Fresh Weight(FFW) (g)	Relative Growth (FFW/IFW)	p-value	Remarks
P. canaliculata	0.000	108.631	108.638	1.000		

	0.050	106.345	98.364	0.925	0.001	S
	0.075	102.523	95.459	0.931	0.001	S
	0.100	100.163	93.123	0.930	0.003	S
	0.125	101.338	92.432	0.912	0.001	S
H. medicinalis	0.000	30.101	30.103	1.000		
	0.050	31.590	29.942	0.948	0.001	S
	0.075	31.806	30.000	0.957	0.001	S
	0.100	30.005	28.233	0.941	0.001	S
	0.125	31.806	27.320	0.859	0.001	S

The relative growths of *P. canaliculata* and *H. medicinalis* contaminated with lead would simply tell us that decrease in relative growths are highly dependent on the dose of lead. However, when treated statistically, *P. canaliculata* noted in 0.050ppm signifies that there is no significant difference in the relative growths of the animals at 0.050 ppm but shows significant differences at 0.075, 0.100, and 0.125 levels. *H. medicinalis* showed a significant difference in growth. The results of the present study revealed that the critical range of toxicity for lead in *P. canaliculata* is from 0.075- 0.125 ppm. For leech, the range of toxicity is from 0.050- 0.125.

Bioaccumulation coefficients of plants in various heavy metals

Bioaccumulation coefficient is one of the indices used to determine the phytoremediation potential of plants. This coefficient is used to determine the heavy metal accumulation efficiency in plants by comparing the concentration in the plant parts (Table 6).

Four categories of heavy metal accumulation are proposed: < 0.01 non accumulator plants, 0.01-0.1 low accumulator plants, 0.1-1 moderate accumulator plants, 1-10 high accumulator/hyper accumulator plants. The content value of metal per plant or organ is a better estimate of heavy metal extraction efficiency in a given plant species (Huang et al., 1997).

Table 6. Bioaccumulation coefficients of plant species in cadmium, chromium and lead.

Plant/ Taxon	Cd Concentration	***Cadmium (ppm)***		Cr Concentration	***Chromium (ppm)***		Pb Concentration	***Lead (ppm)***	
Plant Part		*Shoots*	*Roots*		*Shoots*	*Roots*		*Shoots*	*Roots*
C. benghalensis	25	*0.356*	*0.323*	50	*0.502*	*0.364*	25	*0.297*	*0.761*
	50	*0.335*	*0.293*	100	*0.573*	*0.486*	50	*0.250*	*0.512*
	75	*0.306*	*0.291*	150	*0.241*	*0.296*	75	*0.116*	*0.259*
	100	*0.218*	*0.450*	200	*0.127*	*0.067*	100	*0.082*	*0.149*
F. miliacea	25	*0.333*	*0.819*	50	*0.244*	*0.362*	25	*0.275*	*0.483*
	50	*0.372*	*0.877*	100	*0.182*	*0.310*	50	*0.263*	*0.411*
	75	*0.347*	*0.387*	150	*0.223*	*0.272*	75	*0.239*	*0.496*
	100	*0.213*	*0.254*	200	*0.111*	*0.143*	100	*0.104*	*0.234*
C. iria	25	*0.289*	*0.396*	50	*0.254*	*0.453*	25	*0.298*	*0.410*
	50	*0.131*	*0.310*	100	*0.138*	*0.259*	50	*0.253*	*0.386*
	75	*0.072*	*0.122*	150	*0.088*	*0.155*	75	*0.222*	*0.428*
	100	*0.045*	*0.056*	200	*0.051*	*0.094*	100	*0.133*	*0.195*

The data presented in Table 6 described the accumulation efficiency of the three plant species. There are several points that could be generated from the data shown: (1) Bioaccumulation coefficient decreases with the corresponding increase in concentration. This can be noted in all three species. (2) BAC in the shoots is lower than the BAC in the roots which indicates that the three plant species are capable of phytostabilizing metals in their roots.

For cadmium and chromium, low bioaccumulation coefficients were noted roots than in shoots which simply means that cadmium and chromium is poorly translocated to the aerial parts of the plant than lead. Plants may stabilize more metal in the roots being the main point of entry among plants for the absorption of dissolved substances. As to their accumulation efficiency, it can be concluded that none of the three species qualified as hyperaccumulators because their BAC coefficients were below 1.

Translocation factor of plants in various heavy metals

Heavy metal translocation can be used to compare the metal concentrations in the shoot and the root in plants (Table 7). TF > 1 signifies that the plant effectively translocate heavy metals from roots to the shoots (Baker and Brooks, 1989).

Table 7. Translocation factors of plant species in cadmium, chromium and lead.

Plant/ Taxon	Cd Concentration	***Cadmium***	Cr Concentration	***Chromium***	Pb Concentration	***Lead***
C. benghalensis	25	*1.104*	50	*1.378*	25	*0.391*
	50	*1.145*	100	*1.178*	50	*0.489*
	75	*1.049*	150	*0.815*	75	*0.448*
	100	*0.485*	200	*1.907*	100	*0.553*
F. miliacea	25	*0.407*	50	*0.675*	25	*0.569*
	50	*0.424*	100	*0.588*	50	*0.639*
	75	*0.898*	150	*0.818*	75	*0.482*
	100	*0.837*	200	*0.776*	100	*0.443*
C. iria	25	*0.730*	50	*0.562*	25	*0.728*
	50	*0.424*	100	*0.532*	50	*0.654*
	75	*0.588*	150	*0.565*	75	*0.517*
	100	*0.806*	200	*0.538*	100	*0.685*

C. benghalensis have shown to be effective translocators of cadmium in 25, 50, and 75 ppm concentrations; however, at 100 ppm reduction on the shoot accumulation and root accumulation led to the decrease in its translocation. *F. miliacea* and *C. iria* were classified as not effective translocator in all cadmium concentrations because its translocation values were below 1. The result of the present study, revealed the efficient mobility of cadmium in *C. benghalesis*. As with the other two species, the accumulations are highly concentrated in the roots which only means that they are effective phytostabilizers of cadmium.

The result concurs with other researchers which obtained similar results . Many researchers have concluded that accumulation of metals occur mainly in the roots of plants, due to the slow mobility of metal transport from root to shoot. Chandra et al. in 2004 have shown that the accumulation of most metals was higher in roots as compared to shoots. The study suggested that the least accumulation of metals in the shoots is due to the slow mobility of metal transport from root to shoot *C. benghalensis* is an effective translocator of chromium at concentration levels 50, 100, and 200 ppm. Though, there is a noticeable fluctuation at 150 ppm, the overall mean which is 1.320 suggests that it is still an effective translocator. Better translocation is advantageous to phytoextraction; (1) it can reduce Cr concentration and thus reduce toxicity potential to the root, and (2) translocation to the shoot is one of the mechanisms of resistance to high Cr concentrationOn the other hand, *F. miliacea* and *C. iria* showed inhibition of heavy metals in the shoots. Thus, the two species are classified as not effective translocators since their computed values are below 1.

CONCLUSIONS AND RECOMMENDATIONS

Elevated heavy metal concentrations generally affected relative growth of plants. As the amount of heavy metal increases, relative growth decreases. Tolerance level of plants varies in terms of concentration and the type of heavy metal. *P. canaliculata* and *H. medicinalis* are capable of accumulating heavy metals even in minute concentrations

C. benghalensis, F. miliacea, and *C. iria* are not capable of hyper accumulating heavy metals cadmium, chromium and lead. The named species possessed the characteristics of being moderate accumulators as shown by their BAF and BAF values Among the three species, *C. benghalensis* qualified as effective translocators of cadmium in concentrations not greater than 75 ppm and chromium concentrations not greater than 200 ppm respectively. *F. miliacea* and *C. iria* were noted to be deprived translocators of cadmium, chromium and lead.

In general, bioremediation has a long way to go, but it is undoubtedly developing. It is still in its infancy and more research is needed to perfect the technology. Its development depends on the Philippines' recognition and realization of its value. As this under-standing increases, the efficiency and applicability of bioremediation will grow rapidly. For bioremediation technology to be fully realized and developed by scientists, appropriate and sufficient funding from the government must be provided for and policies or laws must be enacted to strengthen its development. The Department of Agriculture and the Department of Environment and Natural Resources may serve as the core departments to do the task.

Bioremediation is currently applied, but only in laboratory, small-scale operations, and side studies. Hence, it is of necessity to make use of the technology in a larger scale to test its ability to decontaminate heavy metal contaminated sites.Researchers are encourage to do intensive studies on bioremediation to find out heavy metal accumulator plants and to identify genes involved in heavy metal tolerance and accumulation.

Future researchers may also consider reducing the concentration levels of heavy metals to further determine the tolerance levels of plants. The Department of Agriculture is also encouraged to conduct heavy metal monitoring on the rice fields located near the industrialized areas to determine the possible heavy metal contamination and ensure public health safety.

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