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Water hyacinth for heavy metal scavenging and utilization as organic manure

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ABSTRACT

Study on phytoremedial capability of water hyacinth as a safe organic manure source was done at the Regional Agricultural Research Station, Kumarakom during 2010-12. The heavy metals and other minerals in water hyacinth were Fe (33038 ppm), Al (13075 ppm), Ca (2234.80 ppm), Mn (1440.1 ppm), Mg (1608.3 ppm), Zn (77.08 ppm), Cu (49.80 ppm), Cr (23.37 ppm), As (5.276 ppm), Pb (0.531 ppm), and Hg (0.151 ppm). The heavy metal contents in all the three forms of composts were almost similar, except for Fe, Cr and Cd. The biomass yield of *Amaranthus viridis* in a pot culture study was higher in water hyacinth than ordinary compost during the initial harvest, while yields for the final harvest and total yields were significantly higher for the farmyard waste compost. The heavy metals Pb, Hg and Cd content in *Amaranthus* remained unaltered by the organic sources, while As, Cr and Ni content were enhanced significantly by the water hyacinth treatments.

Key words: *Eichhornia crassipes,* Heavy metal contamination, Nutrient scavenger, Phytoremediation, Vermi compost, Water hyacinth, Wetlands

The Vembanad–Kole wet lands, the largest among the three Ramsar sites in Kerala, is now on the verge of deterioration as there is high concentration of heavy metals and pesticide residues in water and sediment. The heavy metal content in sediments of the Vembanad estuary was reported to be above the critical limits (Varma et al., 2007). Sabitha and Nagaraj (2007) also reported the severe qualitative degradation in wetlands of Kerala.

The high degree of pollution by plant nutrients, *viz.* nitrates, nitrites and phosphates has contributed to prolific growth of *Eichhornia crassipes (*water hyacinth*)*, with coverage of 75% of the water bodies of Kerala state. This weed is widely seen in paddy fields, lakes, streams and channels making large areas inaccessible, non-navigable and uncultivable. Though the ill effects of water hyacinth have been dealt by many workers, its services as a cleansing macrophyte of polluted water bodies has seldom been appreciated. Phytoremedial capability of aquatic macrophytes is a cost effective green technology based on the use of specially selected metal accumulating plants. Wetland plants are preferred over other plants due to their low cost, frequent abundance in aquatic ecosystem and easy handling (Raj 2008). Though the capability of water hyacinth to accumulate plant nutrients and heavy metal contaminants present in water bodies is well known, however, disposal of biomass wiith accumulated heavy metals is a major constraint. The phytoremedial capability of *E. crassipes* and its utility as an organic source of nutrients for crop production has been reported by Sasidharan *et al.* (2012). However, elevated heavy metal content in plant tissues and composts of water hyacinth and the possible contamination of vegetables and agricultural produces through food chain are points of concern. In the present investigation, assessment of the capability of water hyacinth in recovering plant nutrients and heavy metals from polluted water bodies and evaluation of composting techniques for its easy disposal and the possible heavy metal contamination of crops produced are addressed.

MATERIALS AND METHODS

Studies were undertaken up at the Regional Agricultural Research Station, Kumarakom ($9^0$36’46’’N; $76^0$25’51’’E) during 2010-12. Samples of mature water hyacinth plants were randomly collected from different parts of the Vembanad Lake during March 2011 and January 2012 and were subjected for assessing the mineral composition and compost production. Simultaneously, sediments and water from these locations were collected for assessment the extent of heavy metals. A pot culture experiment with *E. crassipes* compost (EC), water hyacinth vermi compost (EVC), farm yard waste compost (FMC) and a no manure control as treatments with *Amaranthus* (*Amaranthus tricolour*) variety ‘*Arun*’ as the test crop was conducted for two seasons during 2011-

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12. *Eichhornia crassipes* vermi compost and aerobic compost were prepared as per standard practice. Vermi compost was prepared using a mixture of partially dried (50% moisture) water hyacinth and cow dung in 8:1 (V/V basis) ratio. Earth worms (*Eudrillus eugineae*) were introduced 2 weeks later and resulting vermi compost was collected after 45 days. Composts, sand and soils were mixed in 1:1:1 proportion and 2 kg each of the potting mixture was filled in polyethylene pots. The different compost samples (EC, EVC and FMC) and the potting mixture were analysed for various physico- chemical parameters. One month old *Amaranthus* seedlings were transplanted at four seedlings per pot. No extraneous plant nutrients and plant protection chemicals were administered other than the treatments. Soil samples from all the pots were analysed for various physico–chemical properties. Two plants from each pot were uprooted at 20 and 40 days interval after planting and yields was recorded. *Amaranthus* samples were oven dried and analysed for plant nutrients and heavy metals as per the following methods.

Plant samples were washed thoroughly with deionised water and oven dried at 60^{o}C for 48 h and powdered using Wiley mill and analysed for plant nutrients and heavy metals. water hyacinth plants were analysed tissue wise for which the plants were separated to root, stem + petiole and leaf lamina while, whole plants of *Amaranthus* were similarly prepared for chemical analysis. Oven dried plant samples were weighed and placed in teflon vessels and digested by diacid method. The volume of the extract was made up to 50 ml with distilled water and the metal content was estimated using AAS.

The potting mixture was analysed for pH, EC, OC, P_2O_5, K_2O, Ca, Mg, S, Fe, Mn, Cu and Zn as per standard methods. Compost samples were oven dried at 60^{0} C for two days and samples were analysed for pH, EC, moisture (gravimetric method), nitrogen (micro kjeldhal), carbon (Walkey and Black), total potash (diacid extract), total phosphates (vanadomolybdo phosphoric yellow method), Cu, Zn, Fe, Mn, Pb, Cr, Hg, As, Cd, and Ni (diacid extract method) using AAS. The water and sediments of Vembanad lake were collected from different locations and analysed for Cu, Zn, Fe, Mn, Al Pb, Cr, Cd and Ni using AAS. The data for two seasons were pooled and analysed using ANOVA to test the significance level of variations in physico-chemical properties of potting mixture, yield of *Amaranthus*, and chemical composition and heavy metal content of *Eichhornia*, and *Amaranthus*.

RESULTS AND DISCUSSION

Heavy metals composition

Range of different heavy metals in lake sediments and water of lake are given (Table 1). Content wise, heavy metals were in the order of Fe > Al > Mn > Zn > Cu >Cr > As > Pb > Hg > Ni >Cd in their abundance (Table 2). The pattern was almost similar to that of lake water in order of Fe > Al > Mn > Zn > Cr > Pb > Ni > Cu >Cd. Elevated content of Cu in *E. crassipes* compared to the lake water is the most significant variation in heavy metal composition between *E. crassipes* and its habitat. The strong ability of *E. crassipes* to remove Cu from contaminated water bodies and the high bio-concentration factor (BCF) for Cu has been reported by Chaohua *et al.* (2007). Among the heavy metals and secondary nutrients, Fe contributed major share (3.3%) followed by Al (1.3%), Ca (0.23%) and Mg (0.16%). In water hyacinth tissues, Fe, Al and Mn were significantly higher in roots (94.6, 90.7 and 40.8%, respectively) while, Ca and Mg were more in the leaf lamina and stem + petiole (98 and 71%, respectively) and were significantly lesser in roots. The higher content of Fe may be due to the comparatively higher availability of the metal in the sediments and field water of the Vembanad wetlands (Table 1). Similarly, higher content of Al and Mn may also be attributed to the higher concentration of these metals in its habitat. Bio accumulation of these metals has further contributed to the present level in *E. crassipes*.

Tissue wise, concentration of Cu (55.5%) and Zn (55.8%) in the root was evident, while almost 93% of Cr and As were present in the stem + petiole portion. Pb, Hg, and Ni also followed the same trend of higher concentration in the stem + petiole portion. However, Cd revealed to be located differently with 39.5% in leaf lamina, 22.9% in the stem + petiole and the rest in the roots. Among the heavy metals, Cd, Pb and Ni content in the samples were below the safe limits, while that of Cu, Cr and Zn were above the prescribed threshold, revealing the potential of the plant to absorb higher quantities of these heavy metals. Though *E. crassipes* was reported to be an indicator plant of the level of contamination of the water bodies, in the present investigation, the content of all the heavy metals studied were not in proportion to its availability in the lake water (Table 1). While Cd, Pb and Ni concentration in the lake water was higher than Cu and Zn, their content in *E. crassipes* were lesser than Cu, Cr and Zn. This may be due to the differential response of *E. crassipes* to dissolved metals in the growing media. The higher uptake of Cu and Zn might be due to their nutritional role in plants

Table 1. Heavy metal in sediments and lake water in the Vembanad lake during 2010-2012

	Zn	Cu	Mn	Fe	Al	Pb	Ni	Cd	Cr
Sediments (mg/kg)	0.64 -26.21	0.00-4.30	0.19-462.90	210-7581	0.00-222	84-102	34.8-45.4	3.90-7.90	6.90-13.2
Water (mg/l)	0.0-0.05	0.00-0.03	0.00-0.92	0.00-5.78	0.0-2.0	0.14-0.20	0.05-0.70	0.04-0.05	0.31-0.42

Table 2. Composition of heavy metals in water different parts of water hyacinth (mg/kg)

Plant part	Ca	Mg	Al	Cu	Zn	Fe	Mn	Pb	Cr	Hg	As	Cd	Ni
Leaf lamina	3310	1834	1134	33.73	20.9	4248	1095	0.04	1.54	0.094	0.45	0.019	0.021
Stem+petiole	3420.6	1572	1003	32.73	81.3	4961	1463	1.18	65.90	0.229	14.76	0.011	0.083
Root	123.1	1419	37090	82.93	129.0	89906	1762	0.36	2.66	0.130	0.62	0.018	0.043
Mean	2284	1608	13075	49.80	77.0	33038	1440	0.53	23.37	0.151	5.28	0.016	0.049

as essential nutrients. The Cr content in *E. crassipes*plants were higher than Ni and Cd, which can be attributed to its higher concentration in the lake water (Table 1 and 2)

Quality of compost

The *Eichhornia crassipes* aerobic (EC) and *Eichhornia* vermi composts (EVC) were comparable to farmyard waste compost (FMC) in pH, EC, moisture, nitrogen, organic carbon and C: N ratio (Table 3). Total potash was 46% and 28% higher in EVC and EC, respectively compared to FMC. The higher content of potash was due to the elevated level of K in raw *E. crassipes*. Among micronutrients, Cu was available almost equally in all the three forms of composts. Zn content in all forms of composts were considerably higher than Cu. The availability of Zn on the other hand was highest in EC followed by EVC and FMC. Fe and Mn content were considerably higher in EVC than the other two forms of composts. The present findings were in confirmation with that of Waturu (2011). The difference in the composting process might have contributed to the variation in Fe content between the *E. crassipes* based composts.

Among heavy metals, Cr content in both EC and EVC were considerably high. This has been contributed by the higher content of Cr in *E. crassipes* plants (Table 2). It was interesting to note that the content of the heavy metals Pb, As, and Ni were considerably high in FMC than EC and EVC, while the Cd content in FMC was considerably less compared to the ten fold higher content in EC. The As content in *E. crassipes* composts were considerably less compared to the high concentration of this heavy metal in *E. crassipes* plants. The favourable physico chemical characteristics other than the higher Fe and Mn content and lesser heavy metal concentration indicate the suitability of *E. crassipes* composts for crop production. Montoya *et al.* (2012) also reported the suitability of *Eichhornia* biomass for producing quality compost suitable for horticultural crops.

Physico-chemical properties of potting mixture

Significant variation in the physico-chemical properties of the potting mixture (Table-3) could be observed ($P < 0.05$) due to the treatments. FMC and EVC improved the pH of the soil and were significantly superior to the other treatments, which in their turn were at par with each other. Organic carbon and phosphorus content were, however, significantly higher for FMC while the other treatments were at par. The beneficial effect of farm yard manure on physico-chemical and biological properties of soil is an established fact. The higher nitrogen content in FMC and the improved biological properties might have enhanced the organic carbon and available P_2O_5 content of the soil. Potassium was significantly higher for EVC treated soil. This may be attributed to the higher content of potassium in *E. crassipes* based composts. Calcium content was higher in EVC and FMC treated soils, which were at par and significantly superior to soil treated with EC. Iron content in both types of *E. crassipes* composts was significantly higher than the other treatments with significantly lesser Fe in EC than EVC. Among micronutrients all the three composts forms had significantly higher copper content than the control. The over all picture indicated that the soils treated with *Eichhornia* vermi composts (EVC) were equally good as that of the FMC as far as most of the soil physico-chemical properties studied except the higher Fe, Mn content and lesser OC, and available P in EVC.

Yield of *Amaranthus*

The initial harvest of fresh weight of *Amaranthus* indicated significantly higher ($p<0.01$) yields in EC than EVC and no manure control which was at par with FMC.

Table 3. Physico–chemical properties of composts

Parameter	*Eichhornia* compost	*Eichhornia* vermi compost	Farmyard waste compost
pH	6.8	6.8	6.8
EC (dS/m)	0.02	0.02	0.02
Moisture (%)	14.0	15.3	13.4
Nitrogen (%)	2.9	2.8	3.2
Organic carbon (%)	41.4	37.6	41.4
C:N ratio	14.2	13.2	13.1
Total potash (K_2O %)	1.4	1.6	1.1
Total phosphates (P_2O_5 %)	2.72	2.7	2.5
Copper (Cu mg/kg)	63.4	60.7	68.1
Zinc (Zn mg/kg)	180.3	142.0	126.2
Iron (Fe mg/kg)	1405.8	12576.5	7936.8
Manganese (Mn mg/kg)	1041.6	1064.1	541.4
Lead (Pb mg/kg)	0.26	0.20	0.35
Chromium(Cr mg/kg)	20.0	21.5	4.93
Mercury (Hg mg/kg)	0.24	0.20	0.23
Arsenic (As mg/kg)	0.84	0.53	1.75
Cadmium (Cd mg/kg)	0.05	0.02	0.01
Nickel (Ni mg/kg)	0.05	0.04	0.07

The dry weight during the first harvest however, did not differ among the composts. Fresh weight and dry weight corresponding to second harvest and total yield, confirmed the superiority of FMC over *E. crassipes* composts. Among *E. crassipes* composts, aerobic compost (EC) had significantly higher fresh biomass yield than EVC (Table 4). However this superiority was not reflected on the corresponding dry weight. The higher yields from FMC may be due to better soil reaction, higher organic carbon content and other nutrients. The lesser Fe in the soil treated with FMC might also have contributed to the higher yields (Table 3). Similarly the higher content of Fe in EC might be the major yield limiting factor. The role of higher concentration of Fe as a yield limiting factor has been reported by Bridgit (1999). The low yield from *Eichhornia* composts treatments might be due to the higher content of Fe in its composts (Table 3).

Mineral composition of *Amaranthus*

Both the forms of *E. crassipes* composts significantly ($P<0.05$) increased the Ca content of *Amaranthus* (Table 5). EVC and EC recorded 60 and 46% higher Ca content, respectively than FMC. The variation in Ca content might be brought about by differential availability of Ca from the compost sources. However, the uptake of Mg was not seen influenced by the different nutrient sources. Among the micro nutrients differential response could be seen with respect to Fe, Mn, Zn and Cu. Fe content in *Amaranthus* was the highest for FMC which however, was at par with EVC and control treatment. Fe content between the two forms of *Eichhornia* composts , varied significantly with the higher content for EVC than EC. This may be due to the higher Fe content in EVC (Table 3) than EC. The antagonism between Fe and Ni may be another factor that contributed to lesser Fe content in EC than the other treatments. The Ni content of the latter was significantly higher than the former (Table 5).

Shreyakova *et al.* (2011) attributed reduced Fe uptake in *Amaranthus* on account of antagonism between Fe and Ni. Though there was no significant variation due to composts, the Cu content in *Amaranthus* was 4 to 5 fold higher than Zn in the compost treatments. Enhanced uptake of Cu by *Amaranthus* and its utility as a phyto extractor of Cu from industrial soil was reported by Rahman *et al.* (2013). In the present study the effect of the treatments on Zn content in *Amaranthus* was significant ($P<0.05$). The control treatment had the highest Zn content which was 157 % higher than EVC which had the next highest Zn content. The decreased Zn content in the compost treated *Amaranthus* may be due to antagonism between Zn and Cu which was an established fact

The heavy metals Pb, Hg and Cd content in *Amaranthus* did not show any variation due to the treatments. The highest values for Pb (0.445 mg/kg for EVC), Cd (0.022 mg/kg for EC) and Hg (0.055 mg/kg for control) in *Amaranthus* plants were well with in the safe limit prescribed by the Indian Standards (Awashthi 2000). Among the other heavy metals, differential response to Cr, As and Ni were evident as revealed by significantly ($P<0.01$) higher concentration of these metals in *Amaranthus*. Cr content was the highest in EVC, which was at par with all the other forms of composts and superior to no manure control. Though the Cr content in *E. crassipes* composts were high (Table 3), the same was substantially less in FMC. Since Cr content in *Amaranthus* treated with all the three forms of composts did not vary significantly it is inferred that the manure sources didn't influence the Cr content. The availability of all essential nutrients in the desired level in the composts and the consequent synergetic action might have contributed to the elevated Cr status in *Amaranthus*. Shreyakova *et al.* (2011) also reported enhanced heavy metal uptake of *Amaranthus* when industrial soils were treated with fertilizer nitrogen.

The As content in *Amaranthus* was the highest for EC with significantly lower content for the other two forms of composts. Since the control treatment enjoyed significant higher content of As than EVC, the possibility of

Table 4. Physico-chemical properties of soil treated with different composts

Treatment	pH	EC dS/m	OC (%)	P_2O_5 (mg/kg)	K_2O (mg/kg)	Ca (ppm)	Mg (ppm)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
EC	5.87^{b*}	0.15	0.72^{b}	80.1^{c}	327.7^{c}	409.2^{b}	8.8	99.9	114.2^{a}	104.3^{b}	1.96	8.72^{a}
EVC	6.32^{a}	0.027	0.99^{b}	129.9^{b}	493.2^{a}	426.0^{a}	8.7	143.4	93.6^{b}	148.7^{a}	2.62	11.90^{a}
FMC	6.45^{a}	0.185	1.89^{a}	171.4^{a}	424.1^{a}	428.2^{a}	9.0	103.7	2.2^{c}	106.9^{b}	2.19	11.01^{a}
Control	5.73^{b}	0.457	0.74^{b}	87.9^{c}	226.1^{c}	368.2^{c}	8.6	149.8	1.7^{c}	65.5^{c}	1.66	3.31^{b}
LSD (P=0.05)	0.362	NS	0.545	27.81	138.84	3.286	NS	NS	16.46	32.84	NS	4.305

*Values followed by the same alphabet do not differ significantly, EC - *Eichhornia crassipes*, EVC - *E. crassipes* vermicompost, FMC Farmyard waste compost

Table 5. Biomass yield of *Amaranthus* (g/plot)

Treatment	20 days after planting		40 days after planting		Total	
	Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight
EC	41.25^{a*}	3.55^{a}	49.15^{b}	4.88^{b}	90.40^{b}	8.43^{b}
EVC	20.23^{b}	2.83^{a}	23.53^{b}	2.40^{b}	43.76^{c}	5.23^{bc}
FMC	32.96^{ab}	3.20^{a}	86.76^{a}	9.17^{a}	119.72^{a}	12.37^{a}
Control	10.25^{c}	1.12^{b}	18.0^{b}	1.98^{b}	28.25^{c}	3.1^{c}
LSD (P=0.05)	16.54	2.03	31.38	3.55	27.92	3.58

*Values followed by the same alphabet do not differ significantly

Eichhornia as the source of As can be ruled out. Similarly the As content in raw *E. crassipes* (Table 2) and in its composts were considerably higher than in the *Amaranthus* plants and hence transfer of As from *E. crassipes* and its biomagnification is a very distant possibility. Ni content was also the highest for EC which was significantly superior to the other two forms of composts. Similar to As, the Ni content in *Amaranthus* was very much less than the *E. crassipes* plant tissues and its composts. Hence the transfer of Ni to *Amaranthus* plants beyond the permissible limit did not taken place. The content of all the heavy metals in *Amaranthus* studied were well with in the permissible limit prescribed by Indian/WHO Standards.

Table 6. Mineral composition of *Amaranthus* at 40 DAS (mg/kg)

Treatment	*Ca*	*Mg*	*Cu*	*Zn*	*Fe*	*Mn*	*Pb*	*Cr*	*Hg*	*As*	*Cd*	Ni
EC	3504^{a*}	1625	32.8	6.3^{b}	2079^{b}	188	0.150	1.053^{a}	0.053	0.020^{a}	0.022	0.0146^{a}
EVC	3870^{a}	1664	37.6	8.8^{b}	6594^{ab}	303	0.445	1.249^{a}	0.053	0.002^{c}	0.013	0.0009^{b}
FMC	2404^{b}	1551	36.5	7.2^{b}	7545^{a}	147	0.179	1.059^{a}	0.024	0.001^{c}	0.011	0.0009^{b}
Control	2548^{b}	1490	27.3	22.6^{a}	4686^{ab}	192	0.101	0.538^{b}	0.055	0.009^{b}	0.006	0.0005^{b}
LSD (P=0.05)	956.6	NS	NS	8.9	4622	NS	NS	0.374	NS	0.007	NS	0.0005

*Values followed by the same alphabet do not differ significantly

Water hyacinth absorbed very high levels of dissolved plant nutrients and heavy metals from the Vembanad wetland system, which had dissolved plant nutrients and heavy metals in concentrations exceeding the prescribed safe limit. The pattern of heavy metal content in their abundance in *E. crassipes* resembled that of the concentration of the heavy metals in the lake water except that of Cu. The enormous quantities of plant nutrients and heavy metals accumulated by *E. crassipes* made it an ideal aquatic macrophyte for scavenging mineral pollutants from water bodies. The large volume of biomass obtained from *E. crassipes* could be converted as composts, comparable in quality with farm yard waste compost. *E. crassipes* composts were of less Pb, As and Ni and almost similar Hg concentration and considerably higher Cr and Cd content than farm yard waste compost. Significant increase in yield of *Amaranthus*, a green leaf vegetable crop could be obtained by *E. crassipes* compost application compared to the control. The heavy metals Zn, Cu, Pb, Cr, Hg, As, Cd and Ni in *Amaranthus* were well below the safe limit prescribed by Indian/WHO standards. Thus the aquatic macrophyte, *E. crassipes* could be used as a phytoremedial agent capable of cleansing the water bodies off plant nutrients and heavy metals and the biomass generated could be converted to composts. *E. crassipes* composts were effective as organic manure source for production of green-leaved vegetables devoid of heavy metal contamination.

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