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Reduction of Mobile Heavy Metals During Composting of Water Hyacinth Weed

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ABSTRACT

Water hyacinth (*Eichhornia crassipes [Mart.] Solms*) invasion in Lake Victoria has become a matter of concern over the last two decades. Composting of harvested water hyacinth biomass can help protect the precious lake from the proliferation of the nuisance weed. This would also go a long way in helping local farmers boost their agricultural production by supplementing the use of commercial chemical fertilizers. However, there is a need to ensure that the final compost is environmentally safe before being applied as a soil conditioner. The study, therefore, assessed the total and mobile concentrations of heavy metals during an above ground aerobic composting of water hyacinth biomass with commercial effective microorganisms (EM), cattle manure and molasses treatments. Samples were digested with concentrated nitric acid to extract total metals and mobile concentrations were extracted with deionized water. The concentrations of heavy metals in the compost were determined using Atomic Absorption Spectrometer, and the data collected was analysed for significant differences ($p < 0.05$). Means were separated using Tukey's test at 5% level. The total concentrations of heavy metals were within the threshold limits prescribed for agricultural application. The range of total heavy metals in compost samples was 1.23-1.46 mg/kg (copper), 0.32-0.35 mg/kg (cadmium), 0.25-0.32 mg/kg (nickel) and 0.95-1.41 mg/kg (lead). However, the water-soluble forms of copper (2.3-4.0% of total Cu), cadmium (1.0-8.7% of total Cd), and lead (1.6-8.7% of total Pb) were lower than that of nickel (7.2-11.3% of total Ni) indicating that nickel in the composts had a higher toxicity potential. To alleviate the possible adverse effects of water hyacinth compost in the environment, the study recommends composting of water hyacinth compost biomass with cattle manure.

1. Introduction

Lake Victoria with an area of about 69000 km2 in the East African region is the second-largest freshwater lake in the world. The lake has a mean depth of 40 metres and a maximum depth of 79 metres (Outa et al., 2020). The lake supports one of the poorest and most populous rural populations within the region that relies on fishing as their main source of food and income (Harris et al., 1995). In the last two decades, the lake has been facing a constant threat from invasion by an alien species of waterweed, water hyacinth (Eichhornia crassipes [Mart.] Solms). The weed can grow rapidly to very high densities (over 60kg m-2), which has not only affected water transport but has also led to a decrease in biodiversity. This has created gaps in the ecosystem and led to reduced fish production, which has put at risk the livelihoods of the many people who directly and indirectly depend on the lake (Yigermal & Assefa, 2019).

Despite concerted efforts to control the proliferation of the weed using both physical and biological methods, little has been achieved in containing the aggressive weed mainly because of the fast rate at which the weed propagates and the huge financial investment required. Some methods used have also had a negative impact on the environment and in some instances, weed removal using floating machines have had to be stopped (Gichuki et al., 2012; Malik, 2007; Shanab et al., 2010). This is because water hyacinth naturally has high levels of nutrients (Nitrogen and Phosphorous) and dumping areas of harvested biomass will have leaching risks which would further sustain the proliferation of the weeds (Sasidharan et al., 2013). In addition, physical methods involve manual removal of the weeds and use of machines like weed harvesters, crusher boats and destruction boats. All these have proved expensive and impractical for the vast lake (Gichuki et al., 2012; Mailu, 1999). Development of a low cost and sustainable method for controlling water hyacinth weeds in Lake Victoria is, therefore, essential (Villamagna & Murphy, 2010).

Composting of water hyacinth followed by a land application can be one of the most efficient and economical methods for the treatment and disposal of the abundant water hyacinth biomass. Composting transforms organic biomass into a safer and more stabilized material (compost) that can be applied as an organic fertilizer or soil conditioner on agricultural lands (Prasad et al., 2013). The use of water hyacinth biomass as feedstock materials in compost production and its subsequent use as an organic source of nutrients for crop production has been reported by Osoro et al. (2014) and Sasidharan et al. (2013). However, water weeds such as water hyacinth act as a biological sink of heavy metals in the environment and there is a possible presence in their biomass (Liao & Lian, 2004). Heavy metals, being persistent pollutants, can accumulate in the environment and consequently contaminate the food chains. Accumulation of potentially toxic heavy metals in living systems causes a potential health threat to their consumers, including humans (Ali et al., 2019).

The total concentration of heavy metals in compost and in the soil does not provide useful information about the risk of toxicity of the heavy metals in the environment (Liu et al., 2008). However, total concentrations can only be an overall contamination indicator (Iwegbue et al., 2007). Water-soluble forms of heavy metals in compost represent the most biologically active fraction of heavy metals, which have the greatest potential for contaminating the surface and groundwater and getting into the food chain (Iwegbue et al., 2007). This is because soil solution is the interface between the root system and the soil, and the concentration of heavy metals in the solution form would be directly related to their mobility and bioavailability (Iwegbue et al., 2007). Much work has been carried out on the effect of different composting techniques on the speciation and bioavailability of heavy metals in water hyacinth compost (Singh & Kalamdhad, 2012, 2013, 2014). However, no work has been reported on the effect of commercial starter cultures and organic amendments on the mobile concentration of heavy metals during composting of water hyacinth biomass. Therefore, the aim of the study was to determine the total concentrations of heavy metals and variations in the mobile concentrations of heavy metals following treatment with commercial effective microorganisms (EM), molasses and cattle manure during composting of the water hyacinth biomass in Lake Victoria, Kenya.

2. 2. Materials and Methods

1 Study site

Water hyacinth harvesting and composting were carried out at Korando sub-location, Otonglo Division in Kisumu County (Figure 1). Kisumu County ranges in altitude between 1,144 and 1,525 meters above sea level. It has a hot and moderately wet climate throughout the year. February is the warmest month with an average of 23.6 °C. July has the lowest average temperature of 21.7 °C. The average annual rainfall in the county varies from 1000 to 1800 mm during the long rains (March to May) and 450 to 600 mm during the short rains (September to November) (Nyaoro, 2000).

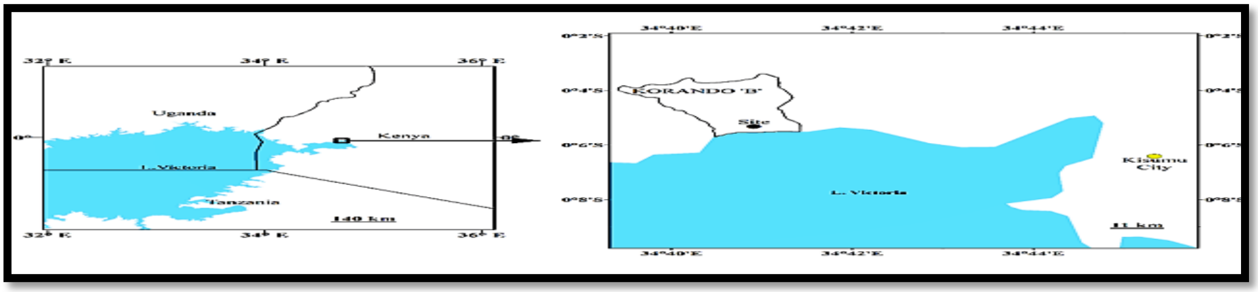

Figure 1: Map of Lake Victoria showing water hyacinth harvesting area and composting site

2.2 Feedstock materials and pile composting

Water hyacinth biomass was harvested manually along the shores of the lake and transported to the composting site using trucks. At the composting site, the water hyacinth biomass was chopped into smaller pieces of about 5-10 cm for better aeration, moisture control and uniform premixing with commercial effective microorganisms (EM) starter culture, cow manure and molasses. The chopped materials were sun-dried for seven days before being introduced into composting boxes. The composting boxes, measuring 1 m in length and width and a height of 1.5 m, were constructed using chicken wire and inner sides fitted with nylon sacks (Figure 2).

Figure 2: Water hyacinth composting boxes

Compost piles were set up by putting 20 kg of the dried and chopped water hyacinth biomass into the boxes to form a layer of about 10 cm depth at the base. This was then sprayed with 10 litres of commercial effective microorganisms (EM) solution prepared in the ratio of 1:50 for commercial EM: water (EM mixed at a ratio of 1:50 L of water). This was repeated until the heap got to 1.2 m high, holding about 240 kg of the water hyacinth biomass in 12 layers per heap. The heaps were manually turned after every fifteen days to reduce the compaction and improve aeration of the composting materials (Osoro et al., 2014). Other heaps were also set up using molasses prepared in a 1:50 dilution ratio with water, cattle manure (5 kg for every water hyacinth layer amounting to 6 kg of cattle manure per heap). Control heap was set up with 240 kg of pure water hyacinth biomass. On maturation of the compost, compost material in the boxes was thoroughly mixed before sampling. Samples were collected from the four corners of compost boxes and at the centre of the box. From each point, approximately 100g of the material was collected from near the surface, another 100g of material midway to the core, and another 100g material from near the core. The collected materials were thoroughly mixed in a bucket to make a homogenized composite sample of about 1.5 kg (Muoma, 2016).

2.3. Physico-chemical and heavy metal analysis

Temperature changes during composting were monitored using steel temperature probes between the months of January and March 2015. Readings were recorded from the four corners of compost boxes and at the top centre of the box. The average temperature readings from the 5 points were used. The moisture content was maintained at sixty percent throughout composting and monitored using pin type moisture meter. Buck Scientific 210VGP Flame Atomic Absorption Spectrometer was used for the analysis of copper (Cu), nickel (Ni), lead (Pb) and cadmium (Cd) concentrations after digestion of 1 g of dry compost sample with 50 ml of concentrated nitric acid (Zeng, 2004). Mobile concentrations of heavy metals were determined after extraction of 2.5 g of dry compost sample with 50 ml of deionised water (sample: solution ratio = 1:20) at room temperature for two hours in a shaker at 100 rpm (Singh & Kalamdhad, 2013). Compost samples were analysed in triplicates. The data collected were analysed for significant differences ($p < 0.05$) with Analysis of Variance (ANOVA) and the means were separated using Tukey's test at 5% level. Statistical Package for the Social Sciences (SPSS) software was used in data analysis.

3. Results and Discussion

3.1 Temperature changes during composting of water hyacinth

The temperatures of the piles increased rapidly within the first 3 days and ranged between 26 ºC and 38 °C during the entire period of the composting process. The compost pile temperature also went through the three typical phases (mesophilic, thermophilic and cooling phases) before settling at around 26 ºC. Control had the highest mean temperature of 33.52 ºC, followed by molasses 30.26 ºC, EM 30.21 ºC and manure treatment 29.97 ºC (Figure 3).

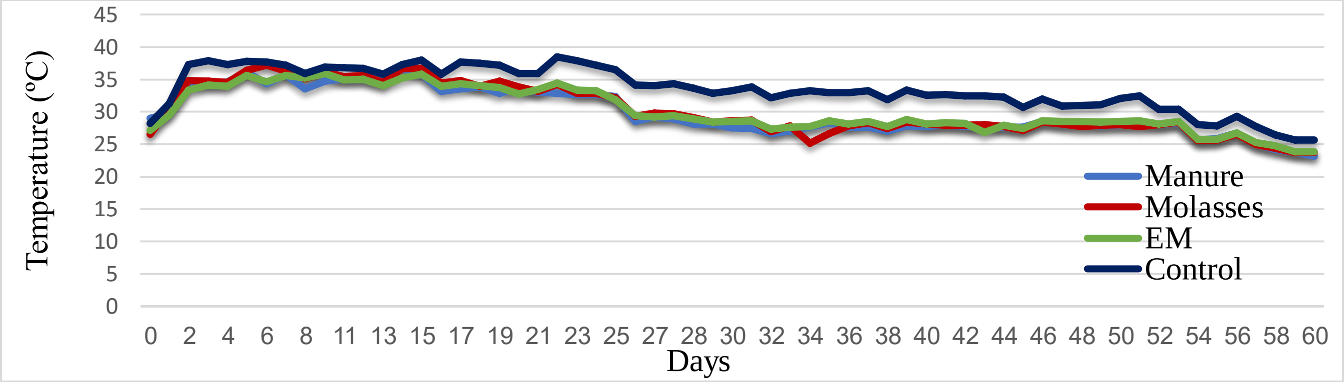

Figure 3: Temperature evolution in water hyacinth compost prepared using different treatments. EM-effective microorganisms

The heat generated during composting was as a result of the rapid breakdown of organic materials by microbial organisms (Nwankwo et al., 2014). The heat got trapped within the composting mass, leading to the phenomenon of self-heating that brings about the increase in temperature (Semple et al., 2001). The state of self- heating was sustained differently in different treatments (Figure 3). This was because of the differences in the insulating properties of the compost matrices brought about by the different amending materials and treatments used in the compost piles (Nwankwo et al., 2014). The early thermophilic phase in control treatment meant quicker microbial establishment. Delayed thermophilic phases in other treatments meant slower microbial establishments because the microorganisms could have taken more time to acclimatize (Nwankwo et al., 2014). The highest temperature recorded in the study was 38 °C. This was lower compared to 59 °C recorded by Singh and Kalamdhad (2014). The differences could only be attributed to the different amending materials and the composting design used. Following the thermophilic phase was a period of cooling. This came as a result of a decrease in microbial activity as well as the heat produced. Decreased microbial activity is caused by the reduction in the readily available organic substrates as the composting process progresses (Semple et al., 2001). After 60 days of composting, the temperature in all the compost piles stabilized, an indication that maturity of the compost had been attained (Waikhom et al., 2012). At this stage, all the compost piles were much darker in colour, granular and more homogeneous than the initial feedstock materials.

3.2 Total concentrations of heavy metals in water hyacinth compost

The mean range of total heavy metals in the compost samples was 1.23-1.52 mg/kg (copper), 0.32-0.35 mg/kg (cadmium), 0.25-0.32 mg/kg (nickel) and 0.95-1.41 mg/kg (lead) (Table 1). The concentrations of all the heavy metals analysed were within the acceptable limits (Table 2).

Table 1: Mean total heavy metals (concentrations of mg/kg) in water hyacinth compost

Treatment	Copper mean± SE^{x}	Cadmium mean± SE^{x}	Nickel mean± SE^{x}	Lead mean± SE^{x}
Control	1.40±0.03^{ab}	0.34±0.01^{a}	0.32±0.01^{a}	0.95±0.08^{b}
EM	1.52±0.07^{a}	0.33±0.01^{a}	0.25±0.01^{b}	1.09±0.11^{b}
Manure	1.24±0.01^{bc}	0.32±0.00^{b}	0.32±0.01^{a}	1.41±0.01^{a}
Molasses	1.23±0.02^{c}	0.35±0.01^{a}	0.30±0.00^{a}	1.07±0.06^{b}
P-value	<0.001	0.040	0.001	0.006

EM - effective microorganisms.

^{x}Means followed by the same letter within the same column do not differ significantly according to Tukey's test at 5% level.

Table 2: Acceptable heavy metal limits (mg/kg) for compost in different countries

Element	A Class^1	A Class^2	B Agr	B park	CH	DK	F	G	I	NL A	NL AA	SP	CAN
Cadmium	4	1	5	5	3	1.2	8	105	105	2	1	40	3
Copper	400	100	100	500	150	-	-	100	300	300	90	1750	100
Lead	500	150	600	1000	150	120	800	150	140	140	120	1200	150
Nickel	100	60	50	100	50	45	200	50	50	50	20	400	-

(Vander Derf et al., 2002).

Country codes: A-Austria; B-Belgium; CH- Switzerland; DK-Denmark; F-France; G-Germany; I- Italy; NL-Netherlands; SP-Spain; CAN-Canada.

Class ^{1} versus class^2 or class A versus AA; Agr- agricultural use; Park-horticultural use.

Class^2 and Class AA are calculated on a 30 % organic matter basis.

The compost samples had high concentrations of copper regardless of the treatment. A previous study on the phytoremediation potential of water hyacinth showed that water hyacinth had a high biocencentration factor (BCF) of Cu as compared to other heavy metals because it is a micro-nutrient for the plant. Copper (Cu) is a component of plastocyanin, a blue copper protein that acts as an electron carrier during photosynthesis (Yapoga et al., 2013). The concentrations of heavy metals reported in the study were much lower compared to values of 100 mg/kg, 220 mg/kg, 1500 mg/kg and 80 mg/kg for Cu, Ni, Pb and Cd respectively reported by Singh and Kalamdhad (2014). Variations in total concentrations of heavy metals in composts have been attributed to factors such as the differences in the composting methods used, which may cause more loss of materials hence the increased concentration of heavy metals (Singh & Kalamdhad, 2013), extraction methods applied (Zeng, 2004) and the levels of heavy metal contaminants in the environments from which the feedstock materials were collected (Vitoria et al., 2010).

3.3 Effect of treatments on the mobile concentrations of heavy metals in water hyacinth compost

The mean range of mobile concentrations of heavy metals in the compost samples was 0.027-0.055 mg/kg (copper), 0.018-0.035 mg/kg (cadmium), 0.027-0.036 mg/kg (nickel) and 0.023-0.093 mg/kg (lead). The treatments had a significant effect on the mobile concentrations of copper, cadmium, nickel and lead (Table 3).

Table 3: Effect of treatments on the concentration of mobile heavy metals (mg/kg) in water hyacinth compost

Treatment	Copper mean± SE ^{x}	Cadmium mean± SE ^{x}	Nickel mean± SE ^{x}	Lead mean± SE ^{x}
Control	0.054±0.003 ^{a}	0.023±0.001 ^{ab}	0.036±0.021 ^{a}	0.043±0.013 ^{bc}
EM	0.055±0.003 ^{a}	0.032±0.005 ^{ab}	0.027±0.016^{bc}	0.061±0.004 ^{ab}
Manure	0.027±0.004 ^{b}	0.018±0.000^b	0.033±0.016 ^{c}	0.023±0.002 ^{c}
Molasses	0.049 ±0.000 ^{a}	0.035±0.004 ^{a}	0.031±0.013^{ab}	0.093±0.014 ^{a}
P-value	< 0.001	0.020	0.001	< 0.001

EM-effective microorganisms.

^{x}Means followed by the same letter within the same column do not differ significantly according to Tukey's test at 5% level.

The mobile concentrations of heavy metals in composts expressed as a percentage of total concentrations were between 2.3-4.0% for copper, 1.0-8.7% for cadmium, 1.6-8.7% for lead and 7.2-11.3 %for nickel (Table 4).

Table 4: Water-extractable metals fractions (mg/kg) relative to the total metal concentrations (mg/kg) in the water hyacinth compost

Treatment	Copper	Cadmium	Nickel	Lead
Control	0.039 (3.9)	0.068 (6.8)	0.113 (11.3)	0.047 (4.7)
EM	0.036 (3.6)	0.087 (8.7)	0.108 (10.8)	0.057 (5.7)
Manure	0.023 (2.3)	0.058 (5.8)	0.072 (7.2)	0.016 (1.6)
Molasses	0.040 (4.0)	0.100 (1.0)	0.104 (10.4)	0.087 (8.7)

EM-effective microorganisms. Values in parentheses represent percentages.

Compost piles amended with cattle manure had the least percentage of water-soluble (mobile) concentrations of heavy metals (Table 4). This was an indication that the cattle manure could have substantially reduced the mobile concentrations of heavy metals with the consequent redistribution of the water-soluble fraction into more stable forms, which were non-extractable with water (Prasad et al., 2013). In a previous study of mobile heavy metals in municipal compost treated with cattle manure, Guan et al. (2011) reported that heavy metals could form immobile complexes after binding to –OH and –COOH groups supplied by cattle manure. In addition, cattle manure has been found to enhance the composting process. This consequently improves humic substance formation. Humic substances have a higher affinity to complex with heavy metals due to their contents of carboxyl groups which are always ready to complex with heavy metals (Liu et al., 2008). Nickel had the highest percentage of mobile concentrations compared to other key metals studied. Nickel had previously been reported to be the weakest bound element in the compost matrix, a property that could have contributed to its enhanced solubility in matrices of the studied composts (Smith, 2009). The high percentages of mobile nickel in the studied compost do not necessarily limit its use because nickel attracts a very low hazard ranking in the human food-chain and terrestrial ecosystems compared to other heavy metals (Smolders et al., 2004).

4. Conclusion

Water hyacinth biomass in Lake Victoria could be a safe source of organic fertilizer as heavy metals in compost samples were much below the critical limits allowable for agricultural land application. Composting of water hyacinth biomass with the addition of cattle manure enhanced the reduction of the mobile (water soluble) concentrations of heavy metals, hence reduced toxicities in the composts. The mobile concentrations of copper (2.3-4.0% of total Cu), cadmium (1.0-8.7% of total Cd), and lead (1.6-8.7% of total Pb) were comparatively lower than nickel (7.2-11.3% of total Ni), showing a higher toxicity potential of nickel in water hyacinth compost. Transformation of water hyacinth biomass into compost may help in protecting of Lake Victoria by providing a cheap and safe source of organic fertilizers.

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References

[1] Ali, H., Khan, E. & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry, 14, 1-14.

[2] Gichuki, J., Omondi, R., Boera, P., Okorut, T., Matano, S. A., Jembe, T. & Ofulla, A. (2012). Water hyacinth Eichhornia crassipes (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (East Africa): implications for water quality and biodiversity conservation. The Scientific World Journal, 10, 1-10.

[3] Guan, T. X., He, H. B., Zhang, X. D. & Bai, Z. (2011). Cu fractions, mobility and bioavailability in soil-wheat system after cu-enriched livestock manure applications. Chemosphere, 82, 215-222.

[4] Harris, C. K., Wiley, D. S. & Wilson, D.C. (1995). Socioeconomic impacts of introduced species in Lake Victoria. In: T.J. Pitcher and P.R.B. Hart (eds). The Impact of Species Changes in African Lakes. Chapman and Hall, London: pp. 215-242.

[5] Iwegbue, C. M. A., Emuh, F. N., Isirimah, N. O. & Egun, A. C. (2007). Fractionation characterization and speciation of heavy metals on composts and compost amended soils. African Journal of Biotechnology, 6(2), 67-78.

[6] Liao, S. & Lian, C. W. (2004). Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. Journal of Aquatic Plant Management, 42, 60-68.

[7] Liu, S., Wang, X., Lu, L., Diao, S. & Zhang, J. (2008). Competitive complexation of copper and zinc by sequentially extracted humic substances from manure compost. Agriculture Science China, 7, 1253-1259.

[8] Mailu, A. M., Ochiel, G. R. S., Gotonga, W. & Njoka, S.W. (1999). Water hyacinth:an environmental disaster in the Winam Gulf of Lake Victoria and its control. In: M.P. Hill, M.H. Julien & T.D. Center (eds). Proceedings of the first IOBC global working group meeting for the biological and integrated control of water hyacinth. Weeds Research Division, Pretoria: pp. 101–105.

[9] Malik, A. (2007). Environmental challenge vis a vis opportunity: the case of water hyacinth. Environmental International, 33, 122–138.

[10] Muoma, J. (2016). Production of organic compost from water hyacinth (Eichhornia crassipes [Mart.] Solms) in the Lake Victoria Basin: a Lake Victoria research initiative (VicRes). Research & Reviews: Journal of Agriculture and Allied Sciences, 5(2), 50-57.

[11] Nwankwo, C. A., Edoho, S. & Mohammed, A. (2014). Recycling of sawdust and water hyacinth into compost. International Journal of Engineering Science Invention, 3(7), 72-76.

[12] Nyaoro, W. (2000). Choice and use of rural water supply systems. In: M.A.M. Salih (eds). Local environmental change and society in africa, Springer, Dordrecht: pp. 39-66.

[13] Osoro, O. N., Kawaka, F., Naluyange, V., Omwoyo, O., Muoma, O. J., Amoding, A., Mukaminegae, D., Muthini, M. & Maingi, J. M. (2014). Effects of water hyacinth (Eichhornia crassipes [mart.] solms) compost on growth and yield of common beans (Phaseolus vulgaris) in Lake Victoria Basin. European International Journal of Science and Technology, 3, 173-186.

[14] Outa, J. O., Kowenje, C. O., Avenant-Oldewage, A. & Jirsa, F. (2020). Trace elements in crustaceans, mollusks and fish in the Kenyan part of Lake Victoria: bioaccumulation, bio indication and health risk analysis. Archives of Environmental Contamination and Toxicology, 78(4), 589–603.

[15] Prasad, P., Singh, J. & Kalamdhad, A. S. (2013). Assessment of nutrients and stability parameters during composting of water hyacinth mixed with cattle manure and sawdust. Resource Journal Chemistry Science, 3(4), 70-77.

[16] Sasidharan, N. K., Azim, T. & Ambika, D. (2013). Water hyacinth for heavy metal scavenging and utilization as organic manure. Indian Journal of Weed Science, 45(3), 204–209.

[17] Semple, K. T., Reid, B. J. & Fermor, T. R. (2001). Impact of composting strategies on the treatment of soils contaminated with organic pollutants. Environmental Pollution, 112, 269-283.

[18] Shanab, S., Shalaby, E., Lightfoot, D. & El-Shemy, H. (2010). Allelopathic effects of water hyacinth (Eichhornia crassipes). PLoS One, 5(10), 132-137.

[19] Singh, J. & Kalamdhad, A. S. (2012). Effects of heavy metals on soil, plants, human health and aquatic life. International Journal of Research Chemistry and Environment, 1(2), 15-21.

[20] Singh, J & Kalamdhad, A.S. (2013). Bioavailability and leachability of heavy metals during composting. International Research Journal of Environment Sciences, 2(4), 59-64.

[21] Singh, J. & Kalamdhad, A.S. (2014). Uptake of heavy metals by natural zeolite during agitated pile composting of water hyacinth composting. International Journal of Environmental Sciences, 5, 1-6.

[22] Smith, S.R. (2009). A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environmental International, 35, 142-156.

[23] Smolders, E., McGrath, S., Fairbrother, A., Hale, B. A., Lombi, E. & McLaughlin, M. (2004). Hazard assessment of inorganic metals and metal substances in terrestrial systems. Environmental Toxicology Chemistry, 23(2), 33–40.

[24] Vander Derf, P., Carter, C., Browne, G. & Hosty, M. D. (2002). Assessment of evaluation of outlets of compost produced from municipal waste (2000 MS-6-MI). Environmental Protection Agency, Wexford.

[25] Villamagna, A. & Murphy, B. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. Freshwater Biology, 55, 282–298.

[26] Vitoria, A. P. Lage-Pinto, F., Campaneli, L. P., Almeida, M. G., Souza, C. M. M., Rezende, C.E., Azevedo, R. A. & Oliveira, J. G. (2010). Ecophysiological adaptation and metal accumulation in water hyacinth from two tropical rivers Brazilian. Journal of Plant Physiology, 22(1), 49-59.

[27] Waikhom, R., Singh, A. D. & Kalamdhad, A. (2012). Composting of water hyacinth using a pilot-scale rotary drum composter. Environmental Engineering Resource, 17(2), 69-75.

[28] Yapoga, S., Yapo, O. & Kouamé, V. (2013). Phytoremediation of zinc, cadmium, copper and chrome from industrial wastewater by Eichhornia Crassipes. International Journal of Conservation Science, 4, 81-86.

[29] Yigermal, H. & Assefa, F. (2019). Impact of the invasive water hyacinth (Eichhornia crassipes) on socio-economic attributes: a review. Journal of Agriculture and Environmental Sciences, 4(2), 46-56.

[30] Zeng, Y. H. (2004). Evaluating heavy metal contents in nine composts using four digestion methods. Biological Resource Technology, 95, 53–59.