The effect water hyacinth (*Eichhornia crassipes, L*) compost application on heavy metal concentration and agronomic performance of cabbage

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Abstract

Water hyacinth compost prepared from polluted water bodies that receive municipal waste water has a potential to improve soil fertility and crop yields. However there is a potential health risk of heavy metal toxicity if the compost is used in vegetable production. A field study was conducted at Masvingo Polytechnical College in central Zimbabwe to assess the effect of different application rates of water hyacinth compost on the yield of cabbage and the associated heavy metal accumulation. The research was set up in a randomized complete block design with four treatments replicated three times. The treatments comprised of four levels of decomposed water hyacinth compost applied per planting station at an application rate of 0 t ha^{-1}, 37.0 t ha^{-1}, 55.6 t ha^{-1} and 74.1t ha^{-1}. Variables days-to-maturity, yield and concentration of heavy metals (Pb, Ni, Cu and Zn) in the edible portion of cabbage were measured. Results showed that an increase in water hyacinth compost application rate significantly increases the number of days to maturity by 14%, 18% and 18% for application rates of 37, 55.6 and 74.1tha^{-1}respectively. The days to maturity differ significantly between the control and application rates e"55.6 tha^{-1} but there is no significant difference between application rate of 55.6tha^{-1} and 74.1tha^{-1}. A positive and significant ($p<0.05$) yield response to increased water hyacinth compost rate was recorded. Water hyacinth compost application rates of 37, 55.6 and 74.1 t ha^{-1} recorded yield increases of 13%, 45% and 63% in comparison to the control. Significant differences ($p<0.05$) in the concentration of Pb in edible portions of the cabbage crop amended with different rates of water hyacinth were recorded. Basing on WHO (2003), permissible levels, Cu, Ni, and Zn concentration in cabbages were within the safe limits for human consumption but Pb concentration in cabbages exceeded the permissible levels indicating a threat on human health. Water hyacinth compost has a high potential as a fertility amendment however at higher application rates there tends to be accumulation of some heavy metals beyond the permissible levels for human consumption.

Key words: Municipal waste water, Water hyacinth compost, Heavy metal, and Cabbage yield

Introduction

Eutrophication and contamination of water bodies with heavy metals are matters of major environmental concern where phosphorus and nitrogen rich municipal sewage effluent is disposed into water bodies (Ogwuegbu and Muhanga, 2005). Industrial waste which forms part of urban wastewater contains substantial amounts of toxic heavy metals because of their widespread use in industrial processes (Chen and Wang, 2005; Singh et al., 2004). Eutrophic water bodies tend to promote the growth and proliferation of the invasive aquatic weed, water hyacinth (*Eichhornia crassipes, L*). In cases of water hyacinth proliferation in water bodies, it causes problems of reduced water quality, reduced reservoir capacity and biodiversity of aquatic ecosystem (Wilson et al., 2005).

The use of hyacinth as an organic fertiliser in Zimbabwe is more pronounced in small scale vegetable production in urban and peri urban agriculture. This is largely because of its abundance, stimulated by eutrophication in the urban streams. The city councils and individual horticultural farmers, harvest water hyacinth from waste water ponds and eutrophic rivers, compost it and use it as an organic fertilizer upon decomposition. Water hyacinth compost used as a soil amendment, improves soil physico-chemical parameters apart from supplying the essential nutrients (Khan Iftekhar, 2002) . In heavily polluted river systems as in urban areas, water hyacinth accumulates heavy metals and has actually been used to recover or remove heavy metals from contaminated water bodies through phytoremediation (Lasat, 2000).

The use of water hyacinth from polluted water sources as manure may lead to accumulation of heavy metals in agricultural soils and hence in plants (Cui, 2004) thus compromises vegetable (leaf and fruit) quality and safety (Muchuweti *et al*, 2006). Although some of the heavy metals such as Zn, Mn, Ni and Cu act as micro-nutrients at lower concentrations, they become toxic at higher concentrations. Crops and vegetables grown in soils contaminated with heavy metals have greater accumulation of heavy metals than those grown in uncontaminated soil (Sharma et al., 2007). There is therefore a health risk posed by the use of water hyacinth compost as it can be a source of heavy metal contamination in vegetables grown with it.

Heavy metals can be a health hazard and are harmful if ingested. Chronic exposure to heavy metals at varying concentrations is reported to be linked with lung cancer, prostatic lesions, bone fracture, kidney dysfunction, hypertension, plumbism, anemia nephropathy, gastrointestinal colic and central nervous system symptoms (Zhao et al. 2012). The health risk is made complex by the fact that there is no effective mechanism to eliminate the heavy metals from a human body and they have a very long biological half-life (Kikuchi and Tanaka, 2012).

Much research efforts on water hyacinth, because of its undesirable effects have been directed towards control or eradication through biological, mechanical or chemical means. Lately there have been efforts committed towards the beneficial exploitation of this invasive weed. It has been used for phyto-remediation of contaminated water bodies(Liao and Chang, 2004); as raw material in the manufacture of ethanol (Mishima et al., 2008) and as an organic fertilizer (Zirbes et al., 2011). This study seeks to determine the effects of different water hyacinth compost application rates on cabbage growth parameters and yield. It also seeks to determine the heavy metal contamination and or accumulation levels associated with the different water hyacinth compost application rates. This is very pertinent given that cabbage is a common crop and is increasingly being produced using the water hyacinth composts in urban and peri-urban centers of Zimbabwe. The produce is dominantly for consumption by the public community in the urban areas, therefore the health risk this may pose to the urban population needs to be ascertained based on the 2003 World Health Organisation (WHO) standards.

Materials and Methods

Study site

The study was conducted at Masvingo Polytechnic (20°05' south and 30°50' east) which falls in natural region IV and with an altitude of 1240 m above sea level. The area receives an annual mean rainfall of 600 mm and its average annual temperatures are 10°C and 20°C in winter and summer respectively. The soils are fersiallitic, derived from granites (Balaria, 1982).

Preparation of water hyacinth compost

Fresh water hyacinth with a water content of 93.08% and dry mater 6.83% was collected from Mucheke River. Water hyacinth compost measuring 2 m x 2 m x 2 m was prepared by heaping alternate layers of water hyacinth (45 cm thick) and ordinary soil (10 cm thick). Regular watering once every week to achieve moisture of 50-55% according to Larry and Bilderback (2003) was done for 90 days until the hyacinth had fully decomposed. Temperature decrease to a stable range of 25°C was used as an indication of compost maturity. Decomposed water hyacinth was taken straight from the compost weighed using a scale and assigned to experimental plots.

Water hyacinth, irrigation water and soil sample collection and preparation

Water hyacinth samples were collected from Mucheke River randomly. Whole water hyacinth plants (including shoots and roots) were collected, taken to the laboratory within an hour of harvesting and washed to remove all surface deposits. The water hyacinth sample was then air dried before being further oven dried at 105°C for 24 hours.

Ten soil samples were collected from a 0.3 ha to a depth of 150 mm using a 50 mm diameter soil auger. The ten samples were mixed and a composite sample was prepared in a plastic bucket. Samples were air dried and then sieved (2mm) before being oven dried at 105°C for 24hrs. Irrigation water was obtained from municipal treated potable water. A 50 ml tape water sample was collected from a tap and was filtered using the Whatman filter paper (USEPA, 2001) to remove suspended matter. Nitric acid was added to the sample to keep pH below two.

Determination of heavy metal concentration in soil, water hyacinth and irrigation water

Samples of soil and water hyacinth were digested using aqua regia (HCl: $HNO_{3;}$ 3:1) (USEPA, 2001). From the soil composite sample, 2 g were accurately weighed in polyvinyl containers and 8 ml of aqua regia added. The polyvinyl containers were then capped and put on a carousel for 20 minutes. The polyvinyl, carousel set up was then transferred to a microwave digester irradiated for 30 minutes. The samples were then filtered using Whatman filter papers in borosilicate funnels into 50 ml volumetric flask and topped to the required level with distilled water. Solutions were then taken to the Perkin Elmer Analyst 800 atomic absorption spectrophotometer for heavy metal detection and quantification.

Land preparation

Deep ploughing to a depth of 25-30 cm was done two weeks before transplanting using a hand digger. Three blocks of 8.5 m long and 1.0 m wide, spaced at 45 cm were marked. In each block individual experimental units of size 1 m x 2 m, spaced at 15 cm were marked. In each plot two planting rows were marked at a row spacing of 90 cm. Planting stations with an inter-row spacing of 30 cm were marked and planting holes of depth 25 cm dug. Incorporation of decomposed water hyacinth was then done into holes and thoroughly mixed with the soil.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design. Four treatments applied were different levels of water hyacinth at 2.0, 1.5, 1.0 and 0.0 kg per planting stations giving application rates of 74.1, 55.6, 37.0 and 0.0 t/ha respectively.

Crop establishment and management

Cabbage seedlings (Star 3301) were transplanted from the nursery five weeks after crop emergence. Only well hardened young, stocky plants transplanted onto moist soil to avoid the effect of soil heat on roots. Weeding using hand hoe was done from transplanting up to cabbage head development stage and thereafter weeds were hand pulled to avoid mechanical damage on the developing heads. The crop was harvested by hand with knives when the heads had reached horticultural maturity, firm and tender. Colour of the head was used as the maturity index (lighter shade of green).

Measured parameters

Plant height, days to maturity, head diameter at maturity, fresh yield and concentration of heavy metals (Pb, Ni, Cu and Zn) were determined. Plant heights were measured on the 2nd, 7th, 10th and 12th week after transplanting. Plant days to maturity were assessed on the basis of a predetermined harvest index combining head firmness and the appearance of a lighter shade of green. When at least half of the cabbage heads in a plot met the set index the whole plot was considered to have attained its physiological maturity.

Six physiologically mature cabbage heads were randomly selected for the determination of fresh weight, head diameter and heavy metal concentrations. Fresh cabbage yield was measured using a digital scale before the determination of head diameter. Using a sharp knife, a horizontal or transverse cut was made on the middle of the cabbage and the diameter of the head was measured using a ruler. The concentration of Pb, Ni, Cu, and Zn in cabbage was determined using the Perkin Elma Analyst 800 atomic absorption spectrophotometer following Ferrante et al. (2013) procedure.

Results

Plant mineral nutrient and heavy metal concentrations of water hyacinth, field soil and irrigation water

All the heavy metals (Zn, Cu, Pb and Ni) tested for were found present in water hyacinth and soil sample (Table 1). Zn was the most abundant heavy metal in water hyacinth and soil samples (Table 1). Soil sample from the experimental site had low levels of all the metals tested. The four heavy metals analyzed in the research (Zn, Cu, Pb and Ni) were not detected in the irrigation water.

Table 1: Plant mineral nutrient and heavy metal concentrations in water hyacinth, field soil and irrigation water, mg/kg

Parameter	Water hyacinth	Field soil	Irrigation water
Zinc	0.01	0.12x10^{-2}	-
Copper	0.1x10^{-2}	0.35x10^{-3}	-
Lead	0.16x10^{-3}	0.49x10^{-3}	-
Chromium	0.22x10^{-2}	0.13x10^{-3}	-
Nickel	0.21x10^{-2}	0.36x10^{-3}	-
Magnesium	0.10	0.03	0.14x10^{-2}
Iron	0.38	0.19	0.92x10^{-3}
Calcium	0.15	0.26x10^{-2}	0.21x10^{-2}
Potassium	0.42	0.09	0.97x10^{-3}
Sodium	0.25	0.02	0.34x10^{-2}
Total nitrogen	1.81	1.37	

Effect of water hyacinth compost application rate on cabbage plant height

Plant height from transplanting to week 4 was not significant ($p>0.05$) at different application rates. There were significant ($p<0.05$) height differences between application rates of d" 37tha^{-1} and e" 55.6tha^{-1} at week 7. At all stages there were no significant ($p>0.05$) height differences between application rates of 37 and 74.1tha^{-1} (Figure 2). The height of cabbage plants ranged from 14-23 cm at week 12 after transplanting. Plant height was highest at application rate of 74.1 t ha^{-1} followed by 55.6 t ha^{-1}; 37.0 t ha^{-1} and 0 t ha^{-1}. Overally the plant height was significantly different ($p<0.001$) for the four treatments.

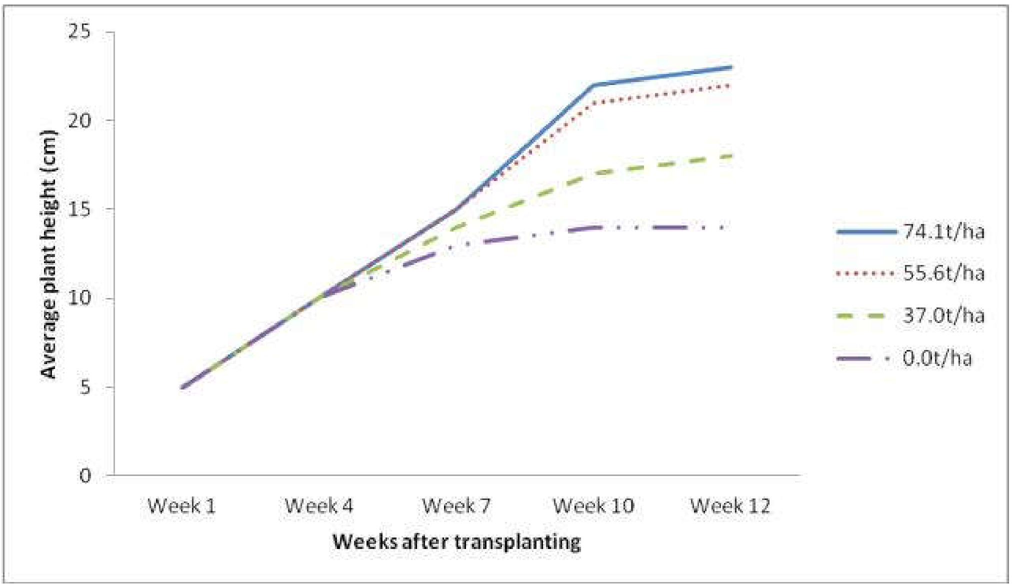

Figure 1: Average plant height at different water hyacinth application rates

Effect of water hyacinth compost application rate on number of days to maturity

The number of days to physiological maturity of cabbage at four levels of application rates ranged from 94-111 days (Figure 1). Analysis of results showed that an increase in water hyacinth compost application rate from 0 t ha^{-1} to 56.6 t ha^{-1} significantly increases the number of days to maturity of cabbages. The days to cabbage maturity differ significantly between 0 and e"55.6 t ha^{-1} but there is no significant ($p<0.05$) difference between application rate of 55.6 and 74.1 t ha^{-1}.

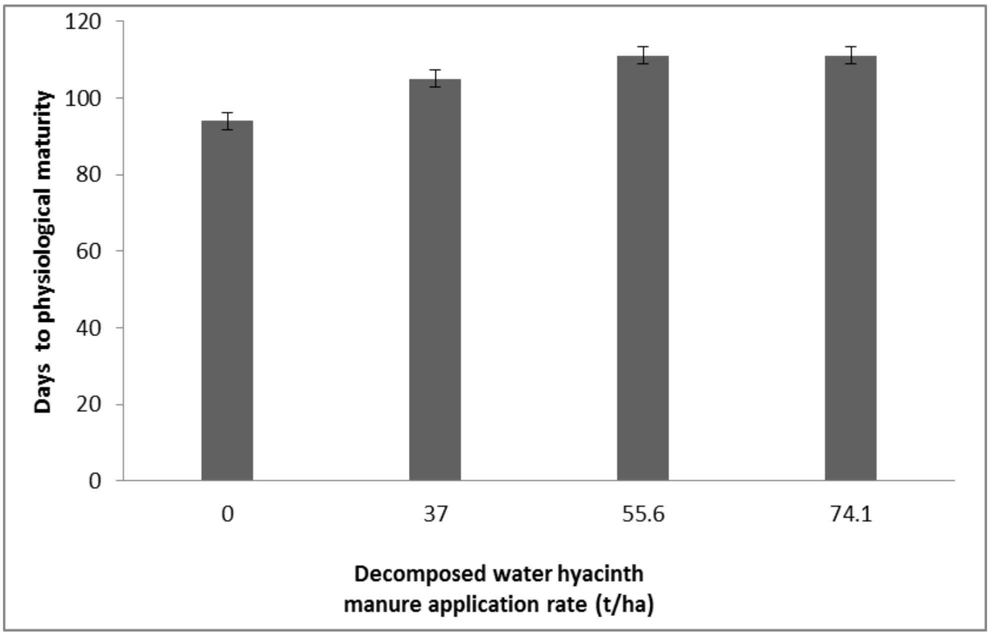

Figure 2: Average days to physiological maturity at different application rates of water hyacinth compost

Effect of water hyacinth compost application rate on cabbage head diameter

Cabbage head diameter at physiological maturity ranged from 15–23cm across all application rates (Table 2). Application rate of water hyacinth compost significantly ($p<0.05$) affect head diameter ($p< 0.05$). Head diameter of cabbage treated to hyacinth application rates of 74.1 t ha^{-1} and 55.6 t ha^{-1} were not significantly different from each other. However the two application rates showed greater differences on cabbage head diameter when compared with hyacinth application rates of 0 and 37 t ha^{-1}. Head diameter of cabbages at application rates of 37.0 t/ha and 0 t ha^{-1} were not statistically different from each other.

Table 2: Cabbage head diameter at different water hyacinth compost application rate

Water hyacinth compost application rate (tha^{-1})	Cabbage head diameter (cm)
0.0	15.00[a]
37.0	15.07[a]
56.6	20.63[b]
74.1	23.00 [b]
Grand mean	18.43
Lsd	2.78
cv%	7.50
P	<0.05

Effect of water hyacinth compost on fresh yield of cabbage

Application rate of 74.1 t ha^{-1} produced the highest yield of 101 t ha^{-1} and the un-amended control was lowest with 62 t ha^{-1} (Figure 3). Compared to the un-amended rate (0 t ha^{-1}) yield increase of 13, 45 and 63% were realised at hyacinth application rates of 37, 55.6 and 74.1 t ha^{-1} respectively. Increase in water hyacinth compost application rate significantly increase the yield of cabbage ($p<0.05$).

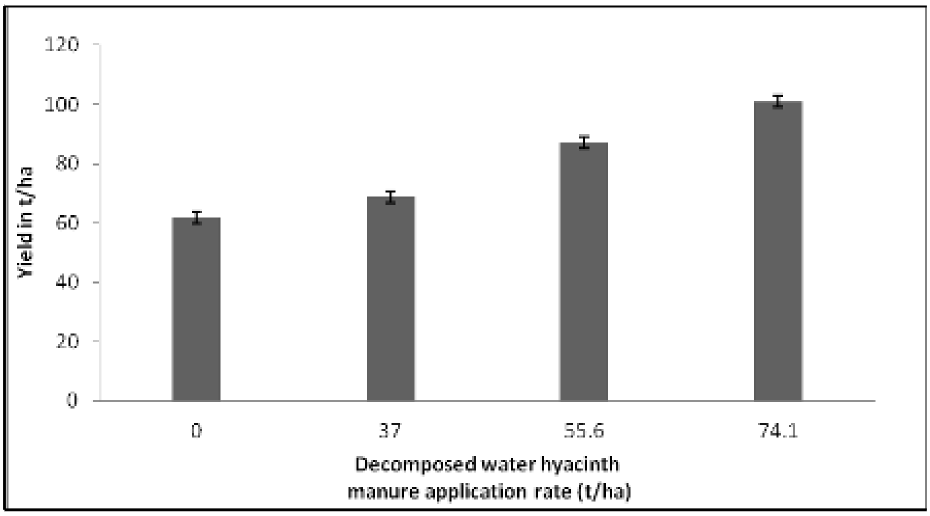

Figure 3: Fresh yield of cabbage at different water hyacinth application rates

Heavy metal accumulation at different water hyacinth compost application rate

Lead, Cu, Ni and Zn concentration in cabbages ranged from 3.4–8.28 mg kg^{-1}, 1.01–1.51mg kg^{-1}, 2.23–5.16 mg kg^{-1} and 14.99–1855mg kg^{-1} respectively over an application rate of 074.1tha^{-1} (Table 3). Lead, Cu, Zn and Ni concentrations in cabbage increased significantly ($p<0.05$) with increasing application rate.

Table 3: Heavy metal accumulation at different water hyacinth compost application rate

Hyacinth compost application rate (tha^{-1})	Heavy metal concentration ($mgkg^{-1}$) Pb	Cu	Zn	Ni
0.0t/ha	3.40 ^{a}	1.01 ^{a}	14.99 ^{a}	2.23 ^{a}
37.0t/ha	3.75 ^{a}	1.03 ^{a}	16.50 ^{ab}	3.67 ^{b}
55.6t/ha	7.29 ^{b}	1.30 ^{b}	17.20 ^{bc}	4.45 ^{c}
74.1t/ha	8.28 ^{c}	1.51 ^{c}	18.55 ^{c}	5.16 ^{d}
Grand mean	5.68	1.21	16.81	3.88
L.S.D	0.75	0.12	1.73	0.62
P-value	<0.05	<0.05	0.05	<0.05
Cv%	6.60	5.10	5.20	8.00

Discussion

Heavy metal concentrations in soil were within the WHO/FAO (2003) categories of uncontaminated soils (3.8 – 93.8 mg kg^{-1}). This can be attributed to natural occurrence of the metals, micro-nutrients in applied inorganic fertilizers and copper-based pesticides, Zn-containing dithane M45 and vegi-dust contributing Pb (Alan *et al.,* 2003). The comparatively higher concentration of heavy metals in the water hyacinth compost may be attributed to the high hyacinth heavy metal extractive capacity from the environment (Goel *et al.*, 1998). The experimental plot soils exhibited low plant nutrient content due to continuous cultivation since 2003. Heavy metal concentration recorded on soil sample could have come from inorganic fertilizers applied during cultivation or natural means (Alan *et al.*, 2003). Irrigation water was treated for domestic consumption and did not have any heavy metals in it. The relatively high nutrient content of the water hyacinth therefore justifies its use as composted manure.

The differences noted on cabbage days to maturity is attributed to different amounts of nitrogen (N) supplied at different application rates of hyacinth compost. The cabbage crop applied with higher rates of hyacinth compost took more days to reach their physiological maturity this was possibly caused by increased nitrogen associated with higher application rates of water hyacinth compost. Plants supplied with high concentrations of nitrogen take more days to reach maturity due to rank growth at the expense of reproductive phase (Majid *et al.*, 1980). The results concur with the findings by Azam (1993), which highlighted that crops supplied with high amounts of nitrogen tend to spend many days on vegetative growth, thus extending days to maturity.

Water hyacinth compost is reported to improve soil aggregation due to increased organic matter, increased water retention capacity and cation exchange capacity of the soil (Khan and Sarwar., 2002; Rashid and Iftekhar, 1992). The fore mentioned soil parameters were found to increase with increase in hyacinth compost application rate. The combined effect of the hyacinth compost on the soil is directly related to the increased cabbage head diameter and yield at higher application rate. The increased cation exchange capacity increases the availability of other plant nutrients such as phosphorous and potassium together with increasing the buffering capacity thus maintaining a stable soil solution (Dann, 2003). Water retention capacity is enhanced by the fact that organic matter has a high water retention capacity and it can also influence other properties like hydraulic conductivity, density and porosity among others (Khan and Sarwar, 2002). This increases the water use efficiency through increased yield per water applied.

Research findings indicated the concentrations of heavy metals as Zn> Pb >Ni> Cu which is almost similar to the trend that was found by Redwan *et al.*, (2006) where Zn>Cr>Cu>Pb>Cd. Of the heavy metals, zinc is accumulated the most and this is in agreement with Radwan and Salama (2006) based on a research carried out in Egypt in which Zn concentration was highest of all heavy metals present in samples of vegetable found on the market. It should be noted that Charles, *et al*, (2011) found a different order in the accumulated heavy metals in cabbages (Zn>Cr>Cu>Pb>Cd). Extrapolating the results there is an indication that more Pb is accumulated in cabbage than Cu and this is in contrast to findings by Charles *et al,* (2011) although there is consensus in Zn being the metal with the highest concentrations in cabbage. Wong and Li, (1996) on their study with the Chinese cabbage noted that cabbage picks up Pb more readily than any other heavy metals such as Ni, Cd and Cu. This explains why more Pb was taken up than Ni and Cu by the cabbage crop on all decomposed water hyacinth manure application rates used.

High concentrations of Zn in all situations can be explained in terms of retardation factors of Zn in the soil which are smaller than any other metal making its mobility and availability in soils very high (Matas *et al.,* 1996). High mobility of Zn could be contributed to its high absorption by the cabbage crop. Cu release from contaminated soil is very slow thus its accumulation in cabbages was also low as also attested by Wong *et al.,* (1996) and Sukreeyapongse *et al.,* (2002). Although cabbage is highly responsive to Cu its uptake could have been inhibited by high organic matter which readily and tightly forms complexes with the Cu thus reducing its availability. The Cu concentrations which are not statistically significant at higher application rates can be attributed to high levels of N and P. High N content inhibits Cu transportation to the growing parts of the plant whilst high P content in the soil reduce Cu uptake due to reduced soil exploration by mycorrhizas associated with plant roots (Spectrum Analytic Inc, 2014). The high concentration of zinc is thought to reduce translocation of the Cu as supported by Yoon *et al.*, 2006 that there is a correlation between the translocation of Zinc and Cu.

Conclusion

Use of water hyacinth compost as manure significantly increases the yield of cabbages. Water hyacinth compost application rate of 74.1 t/ha proved to be beneficial if one aspires for high cabbage yields. But at this application rate there is a risk of Pb poisoning to the consumers as it surpasses the acceptable range by FAO/WHO standards. Therefore production of cabbage with water hyacinth compost can be done at an application rate of 37t/ha. There is need for further study to assess the risk associated with continuous use and its effects on levels or concentrations of heavy metals in soils and in the produce.

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