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The Effect of Water Hyacinth (*Eichhornia crassipes*) Compost on Tomato (*Lycopersicon esculentum*) Growth Attributes, Yield Potential and Heavy Metal Levels

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Abstract

The potential of different water hyacinth compost application rates in influencing growth attributes, yield and heavy metal accumulation of lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn) in tomato fruit was studied in Masvingo. Four treatments of water hyacinth compost rates of 0, 37, 55.6 and 74.1 t·ha^{-1} were each replicated three times and applied in a randomized complete block design set up. Results showed that water hyacinth compost application rates significantly affected plant height, days to maturity and yield but had no influence on the number of tomato fruits per plant. The plant height at application rate of 74.1 t·ha^{-1} was 25%, 56% and 63% higher than the control at week 6, 9 and 12, respectively. At application rates of 56.6 t·ha^{-1}, plant heights were 11%, 13% and 12% higher than the control whilst marginal plant height differences of −4%, 6% and 4% were recorded between application rate of 34.7 t·ha^{-1} and the control at week 6, 9 and 12, respectively. Tomato plants under compost rates of 34.7, 56.6 and 74.1 t·ha^{-1} in comparison to the control delayed maturity by 10, 17 and 20 days, respectively. Yields of 52, 55, 60 and 68 t·ha^{-1} were realized from hyacinth compost rates of 0, 34.7, 56.6 and 74.1 t·ha^{-1}, respectively. Heavy metal concentrations increased with increase in the water hyacinth compost rate but at all application rates, the average concentrations were 85%, 93% and 86% lower than the Codex Alimentarious Com-

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mission permissible levels for Pb, Cu and Zn. Water hyacinth compost at a rate of 74 t·ha^{-1} therefore can be used for increased tomato yield without exposing consumers to heavy metal toxicity.

Keywords

Heavy Metal Concentration, *Lycopersicon esculentum*, Water Hyacinth Compost, Tomato Production

1. Introduction

Tomato, *Lycopersicon esculentum*, is regarded as one of the important vegetable fruits in the human diet. Its world production which can be equated to consumption has increased from 106 million tonnes in 2006 to 141 million tonnes in 2010 [1] [2]. In Southern Africa, consumption of tomatoes has increased by 75% over the years. However, the increase in consumption only represents a per capita per year consumption of 5 kg for the whole of Southern African and 1.8 kg for Zimbabwe [3]. This per capita consumption of tomatoes is very low for consumers to maximize the potential health benefits. The potential human health benefits of tomato are derived from its chemical composition. Tomato is rich in oxalic acid, ascorbic acid, β-carotene and lycopene. Lycopene is important as a stable and active antioxidant [4]. The antioxidants contained in tomato are strongly believed to reduce the risk of chronic diseases like cancer, cardiovascular diseases, age-related muscular degeneration, cataracts and diseases related to low immune function [5]-[10].

The current trend of increasing tomato production in various parts of the world and the drive to increase per capita consumption in Africa will lead to the use of cheaper organic fertilizer including those derived from water hyacinth. Water hyacinth, *Eichhornia crassipes*, is increasingly being used as a nutrient supplier as composted material [11] and like other organic composts, it increases physical and biological nutrient storage capacity, water holding capacity, cation exchange capacity, micro aggregation in soils and can reduce the effect of over-fertilization by slow release of nutrients [12]. Use of water hyacinth compost in fruit and leaf crops production is reported to increase yield [13]. Water hyacinths has a high potential to supply nitrogen as it can store up to 3.2% in its dry mass and it generally has a carbon to nitrogen ratio (C/N) of around 8 to 15 [12] [14].

Although water hyacinth has a high concentration of nutrients and is abundant, especially in urban polluted water systems, it has a potential to accumulate heavy metals in its biomass. In urban water bodies, the source of eutrophicants and heavy metals is mainly phosphorus and nitrogen rich municipal sewage and industrial effluent from smelting of metalliferous ores, automobile exhaust and liquid fuel production [15] [16]. The accumulated heavy metals have a potential to cause heavy metal toxicity in tomato if hyacinth compost is applied without specific considerations. The accumulation of heavy metals presents a potential health risk to humans even at very low concentrations. So whilst it may give some benefit in tomato production, the use of water hyacinth may cause adverse environmental effects.

The study seeks to ascertain the effect of different water hyacinth compost application rates on the growth attributes, on yield and on heavy metal accumulation rates in the tomato fruit. The ultimate goal is to strike a balance between increasing tomato production using water hyacinth compost so as to meet the demand and increasing per capita consumption without compromising the health of consumer by heavy metal toxicity which can result from the use of the water hyacinth as a source of nutrients.

2. Materials and Methods

2.1. Study Site

The research trials were carried out at Masvingo Polytechnic College (20˚05'S, 30˚50'E) in Masvingo District in the southern part of Zimbabwe. Masvingo is in natural region IV and receives an average annual rainfall of 600 mm, has hot, dry summers and cold winters with average annual temperatures of 20˚C and 10˚C, respectively. The average maximum temperature ranges from 15˚C in winter to 31˚C in summer [17]. The soils are of the fersiallitic group, with appreciable reserves of weatherable minerals. The clay content has some fractions of 2:1 lattice minerals. Generally the soils are moderately deep to deep reddish brown granular clay soils formed on mixed mafic and granites rocks [18].

2.2. Cultivation and Cropping History of the Experimental Site

The experimental fields were first cultivated in 2003 and were planted to a variety of vegetable crops such as cabbage (*Brassica oleraceae*; tomato (*Lycopercicon esculentum*); spinach (*Spinacia oleracea*); carrots (*Docus carota*); rape (*Brassica napus*) and covo (*Brassica acephala*) among others. Ammonium Nitrate, compound D, Urea and Foliar 15 as well as lime have been used as occasional fertility amendments at different application rates dependent on the soil tests. Pesticides ranging from dimethoate, copper oxychloride 85% WP, dithane M45 to vegidust a combination of malathion 5%, copper oxychloride 6.5%, dusting sulphur 65% and inert ingredients 23.5% were used.

2.3. Compost Preparation and Management

Water hyacinth was collected from Mucheke river and a compost of pile 2 m × 2 m × 2 m was prepared by putting alternate layers of water hyacinth (450 mm) and soil (10 mm thick). The compost moisture was monitored using a 2 m moisture meter and watering was done to maintain the moisture level at 50% - 55%. The compost pile was mixed on weekly basis to aerate the compost, break compost clumps and to ensure that peripheral exposed materials were incorporated into the pile and homogeneously decomposed. A compost thermometer was used to monitor the temperatures so as to determine when the compost material was ready for curing. After 9 weeks the temperature in the compost pile dropped to steady mesophilic levels of between 30˚C - 40˚C. The compost pile was transferred for curing and was mature and ready for use after an additional 4 weeks. For curing the stable compost was taken into a garden shed with free air circulation. A water impermeable plastic sheet was spread on the ground before heaping the stable compost to avoid leaching. Water was periodically added to the curing compost to keep it barely moist.

2.4. Determination of Heavy Metal Concentration in Water Hyacinth and Soil

Entire water hyacinth (shoots and roots) were collected from the cross sectional profile of the river, cleaned using distilled water and air dried in the laboratory. Ten soil samples were randomly collected from the area under greenhouses (0.3 ha) using a 50 mm diameter soil augur to a depth of 150 mm. Composite samples (soil and water hyacinth) were prepared; air dried at an average room temperature of 24˚C and sieved using a 2 mm sieve. The samples were then oven dried at 105˚C for 24 hrs. The soil and hyacinth were ground into powder using an agate mortar and 2.0 g were weighed into a perfluoroalkoxy polymer made container. Eight milliliters of aqua regia ($HCl:HNO_3$, 3:1) was added to 2 g of each powdered sample. The container was capped and put on a carousel for 20 minutes. Thereafter the perfluoroalkoxy container was transferred to a microwave digester and irradiated for 30 minutes. After irradiation the samples were then filtered using Whatman filter papers in borosilicate funnels into 50 ml volumetric flask and topped with distilled water. The filtrates were then analyzed for heavy metals (Pb, Ni, Cu and Zn) using the Perkin Elmer Analyst 800 atomic absorption spectrophotometer. To determine the concentrations of, water hyacinth samples were digested and analysed by ICP-AES (ICP LIBERTY) with an ultrasonic nebulizer. This was done to account for heavy metals present in the compost.

2.5. Land Preparation, Experimental Plots Design and Management

A Randomized Complete Block Design with four treatments in three blocks was used. Three blocks each measuring 8.5 m long and 1 m wide were established in the green house. Within each block four plots (2 m × 1 m) were prepared with 0.15 m buffer strips between adjacent plots. To the four plots within a block four treatments (one in each block) were applied. The treatments were four levels of water hyacinth compost *i.e.* 2.0, 1.5, 1.0 and 0.0 kg per planting station which transform to application rates of 74.1, 55.6, 37.0 and 0.0 $t\cdot ha^{-1}$ respectively. The highest application rate of 74.1 $t\cdot ha^{-1}$ was chosen based on the sustainable harvest rate of water hyacinth. The hyacinth compost was incorporated into 25 cm deep planting stations dug at 60 × 25 cm to give a plant population of 37,000 $plants\cdot ha^{-1}$.

2.6. Crop Establishment and Management

Two tomato seedlings of the high yielding Roma VF variety were planted per planting station and drip irrigated using treated municipal water using a predetermined irrigation schedule with a frequency of 3 days. Thinning of tomato plants to leave one established plant per planting station was done seven days after planting. Weeding was done using hand hoes when necessary. At five weeks, the first three axillary shoots were removed from each plant to improve crop vigor and fruit quality. Trellising was done using a bar and twine at five weeks, so as to maximize the yield potential of the crop and reduce disease incidents. A fruit index of colour was used to determine fruit maturity and the first appearance of a pale red colour on fruits was used as an indication for fruit maturity. The fruit index of colour was checked for at 10:00 hrs every morning.

2.7. Measurements of Plant Height and Days to Maturity

Tomato plant height at 2 week interval, days to maturity *i.e*. from transplanting to the time when first fruit has ripened, number of fruits per plant at maturity were measured together with the fresh yield. In each plot within a block 6 plants were randomly selected and marked. To the selected plants plant height was measured at two week intervals from transplanting to the reproductive phase. The days to maturity, number of fruits per plant and yield were measured on the same selected and marked plants. After harvesting the tomato fruit was also analysed for concentration of selected heavy metals (Pb, Ni, Cu and Zn). The concentration of Pb, Ni, Cu, and Zn in tomato fruit were determined using the Perkin Elma Analyst 800 atomic absorption spectrophotometer.

2.8. Data Analysis

The data on plant height, days to maturity, yield and heavy metal concentration was statistically analysed using Analysis of Variance (ANOVA) technique with GenStat 14 version software. Treatment means were compared by the Least Significance Difference (LSD), at 5% significance level.

3. Results

3.1. Plant Mineral Nutrient and Heavy Metal Concentrations of Water Hyacinth Compost, Field Soil and Irrigation Water

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

Table 1. Heavy metal and nutrient content of water hyacinth, field soil and irrigation water.

Element	Amount in compost ($mg \cdot kg^{-1}$)	Amount in soil ($mg \cdot kg^{-1}$)	Amount in irrigation water ($mg \cdot kg^{-1}$)
Zinc	0.01	0.12×10^{-2}	-
Copper	0.1×10^{-2}	0.35×10^{-3}	-
Lead	0.16×10^{-3}	0.49×10^{-3}	-
Chromium	0.22×10^{-2}	0.13×10^{-3}	-
Nickel	0.21×10^{-2}	0.36×10^{-3}	-
Magnesium	0.10	0.03	0.14×10^{-2}
Iron	0.38	0.19	0.92×10^{-3}
Calcium	0.15	0.26×10^{-2}	0.21×10^{-2}
Potassium	0.42	0.09	0.97×10^{-3}
Sodium	0.25	0.02	0.34×10^{-2}
Total nitrogen	1.81	1.37	-
pH	6.6	6.8	7.1

3.2. Effect of Water Hyacinth Compost Application Rate on Plant Height

Water hyacinth compost application rate had no significant effect on plant height up to 6 weeks from transplanting ($p > 0.05$). However, significant height differences were recorded from weeks 9 to 12. An application rate of 74.1 t·ha^{-1} had significantly higher mean plant height of 65, 86 and 93 cm at week 6, 9 and 12 respectively (**Table 2**). The plant heights at application rate of 74.1 t·ha^{-1} were 25%, 56% and 63% higher than the control at week 6, 9 and 12 respectively. At application rate of 56.6 t·ha^{-1} plant heights were 11%, 13% and 12% higher than control. Marginal plant height differences of −4%, 6% and 4% were recorded between application rate of 34.7 t·ha^{-1} and the control at week 6, 9 and 12 respectively. Compost rate of 34.7 t·ha^{-1} and un-amended were not significantly different from each other but all the other compost rates differed significantly from each other in influencing plant height ($p < 0.01$).

3.3. Effect of Water Hyacinth Compost Rate on Days to Maturity

Days to maturity for all the compost rates ranged from 74 - 93 and they were increasing due to the increase in compost application rate. Water hyacinth compost rate of 74.1 t·ha^{-1} recorded the highest number of days to maturity (93) followed by compost rate of 56.6 t·ha^{-1} with 90 days and the control recorded the least number of days (74) to maturity (**Table 3**). Tomato plants at compost rates of 34.7, 56.6 and 74.1 t·ha^{-1} in comparison to un-amended treatment (control) delayed maturity by 10, 17 and 20 days respectively. The compost rate significantly affected ($p < 0.001$) the number of days to maturity of tomato crop.

3.4. Effect of Water Hyacinth Compost on Number of Tomato Fruits per Plant

The highest number of tomato fruits per plant (30) was recorded in tomato plants treated with compost at 74

Table 2. Average tomato plant height at different compost rates and growth stage.

Compost application rate (t·ha^{-1})	Average plant height (cm) at week 1, 3, 6, 9 and 12				
	1	3	6	9	12
0	12	40^{a}	52^{a}	55^{a}	57^{a}
37	13	38^{b}	50^{a}	58^{a}	59^{a}
56.6	12	35^{c}	58^{b}	62^{a}	65^{b}
74.1	12	46^{d}	65^{c}	86^{b}	93^{c}
l.s.d	1.1	1.53	3.65	5.61	3.25
cv (%)	4.5	1.9	3.3	4.3	2.4
p-value	0.123	<0.001	<0.001	<0.001	<0.001

Means with different superscripts in the same column are significantly different.

Table 3. Number of days to maturity at different compost rates.

Compost rate (t·ha^{-1})	Number of days to maturity
0	74^{a}
34.7	84^{b}
56.6	91^{c}
74.1	94^{d}
l.s.d	2.85
cv (%)	1.7
p-value	<0.001

Means with different superscripts in the same column are significantly different.

t·ha^{-1}. Compost application rates of 56.6 and 37 t·ha^{-1} recorded 27 fruits per plant each whilst the un-amended treatment recorded the lowest number of fruits per plant of 22 (**Table 4**). Although the number of fruits per plant recorded at application rates of 74, 56.6 and 37 t·ha^{-1} were 36%, 22% and 22% higher than the un-amended rate, there were no significant differences among the number of fruits per plant as influenced by different compost application rates ($p > 0.05$).

3.5. Effect of Water Hyacinth Compost Rate on Fresh Yield

Tomato yield increased significantly with increasing hyacinth compost rate ($p < 0.05$). Yields of 52, 55, 60 and 68 t·ha^{-1} were realized from hyacinth compost rates of 0, 34.7, 56.6 and 74.1 t·ha^{-1} respectively (**Table 5**). Compared to the control, there were significant yield increases of 6%, 15% and 30% at compost rates of 34.7 56.6 and 74.1 t·ha^{-1} respectively. Amongst the different compost rates, there was a significant yield difference at application rates of 74.1, 56.6 and 34.7 t·ha^{-1} ($p = 0.003$). The yield from un-amended soil was significantly lower than the other three compost rates indicating that tomato yield responded to increased hyacinth compost rates.

3.6. Effect of Water Hyacinth Compost Rate on Heavy Metal Accumulation in Tomato Fruits

Significant concentrations of Pb, Cu and Zn were detected in tomato fruits at different compost rates ($p < 0.001$) whilst Ni concentration was not significant at different compost rates ($p > 0.05$). Cu concentration in tomato fruit was highest at compost rate of 74.1 t·ha^{-1} (5.51 mg·kg^{-1}) and the control crop had the least concentration of 1.22 mg·kg^{-1}. Zn concentrations in tomato fruit amended with 0, 34.7, 56.6 and 74.1 t·ha^{-1} were 11.5, 11.9, 12.9 and 18.7 mg·kg^{-1} respectively (**Table 6**). In comparison with FAO/WHO, (2003), Codex Alimentarious Commission permissible levels of heavy metals in vegetables, the concentrations of Pb, Zn, Ni and Cu detected in

Table 4. Average number of tomato fruits per plant at different levels of water hyacinth compost.

Compost rate (t·ha^{-1})	Average number of tomato fruits per plant
0	22
34.7	27
56.6	27
74.1	30
l.s.d	6.58
cv (%)	12.6
p-value	0.132

Table 5. Average tomato yield at different compost rates.

Compost rate (t·ha^{-1})	Average yield (t·ha^{-1})
0	52^{a}
34.7	55^{a}
56.6	60^{a}
74.1	68^{b}
l.s.d	5.65
cv (%)	4.8
p-value	0.03

Means with different superscripts in the same column are significantly different.

Table 6. Heavy metal concentration in tomato fruit at different water hyacinth compost rates.

Compost rate ($t\cdot ha^{-1}$)	Pb $mg\cdot kg^{-1}$	Cu $mg\cdot kg^{-1}$	Zn $mg\cdot kg^{-1}$	Ni $mg\cdot kg^{-1}$
0.0	0.24[a]	1.22[a]	11.52[a]	2.23[a]
34.7	0.89[b]	2.01[a]	11.93[a]	2.26[a]
56.6	0.91[b]	2.00[a]	12.87[a]	2.49[a]
74.1	1.04[b]	5.51[b]	18.73[b]	2.70 [a]
Mean	0.77	2.69	13.76	2.42
Maximum permissible levels ($mg\cdot kg^{-1}$)	**5**	**40**	**99.4**	**40**
l.s.d	0.16	1.15	2.52	0.54
cv (%)	10.13	21.50	9.20	11.2
p-value	<0.001	<0.001	0.001	0.216

Means with different superscripts in the same column are significantly different.

tomato fruit were within the permissible ranges. On average Ni concentration in the tomato fruit was 90% lower than the maximum permissible levels, Pb was 85% lower, Cu was 93% and Zn was 86% lower than the permissible levels.

4. Discussion

The presence of heavy metals in the soil media can be attributed to natural occurrence of the metals, applied inorganic fertilizers and pesticides like copper oxychloride contributing Cu, dithane M45 contributing Zn and vegi-dust contributing Pb [19]. Though present, the amounts of heavy metals in the soil thereof were within the WHO/FAO, 2003 ranges of uncontaminated soil. The comparatively higher concentration of heavy metals and plant mineral nutrients in the water hyacinth compost are attributed to the ability of the water hyacinth to take up and retain nutrients and heavy metals from nutrient and heavy metal laden river systems [20]. The relatively high nutrient content of the water hyacinth therefore justifies its use as composted manure in tomato production.

The delayed maturity at higher compost rates is a result of increased N which increases plant growth and promotes vegetative growth at the expense of fruiting and maturing [21]. Furthermore, high levels of N at higher application rates of compost reduce the red tomato fruit colour and increase the green intensity in the tomato fruit [21] [22] thus, tomato grown in high compost rates delayed on reaching the set fruit colour index of pale red as it needed more time for the high green intensity induced by high N to decrease. The number of fruits per plant was not significantly different at different application rates; this agrees with [23] who indicated that the number of fruits is not usually affected by plant nutrient supply. In an environment with limited nutrients, fruit size and quality are usually poor.

There was a significant increase in the yield at increasing compost application rate and the increase in yield was significantly different compared to the un-amended rate. This can be explained by the comparatively high K content in the water hyacinth compost ($0.42\ mg\cdot kg^{-1}$) compared to $0.09\ mg^{-1}$ in the un-amended soil. Potassium is essential in water regulation in the plant. It is also a key component in enzymic activities, carbohydrate metabolism and translocation, nitrogen metabolism and protein synthesis; therefore, its increase with increasing concentration increases the efficiency of the tomato plant in the production and distribution of photosynthates leading to higher yields. Increasing K content is believed to improve the yield of tomato (fruit) crops [24] as it is responsible for tomato growth vigor and it stimulates early flowering and fruit setting thereby increasing the number of tomato fruits per plant and thus increasing yield. Based on the trend of increasing yield with increasing compost rates, one would have expected the yield at compost rate of $74.1\ t\cdot ha^{-1}$ to double the yield achieved at compost rate of $34.7\ t\cdot ha^{-1}$ but this was not the case, it should therefore be noted that under field conditions K availability can be affected by the growth habit of tomato variety, high soil K fixation potential and competing ion effects [25].

Water hyacinth compost could have improved soil aggregation water retention capacity and cation exchange capacity of the soil as noted by *Khan and Sarwar*, 2002; *Rashid and Iftekhar*, 1992 [12] [26]. The compost can have a direct effect on the availability of other plant nutrients and their uptake. The increased cation exchange capacity increases the availability of phosphorous and potassium with a simultaneous increase in buffering capacity thus maintaining a stable soil solution conducive for tomato production [27]. Water retention capacity is enhanced by the fact that hyacinth compost (organic matter) has a high water retention capacity and it can also influence other properties like hydraulic conductivity, density and porosity among others [12]. This increases the water use efficiency and yield per water unit applied.

Research findings show that the concentrations of Zn at all hyacinth compost rates were higher than all other heavy metals. This trend seems to contradict with *Mohamed et al.* (2003) [28] who found that Cu and Ni were highly concentrated in tomatoes compared to other heavy metals but the findings are in agreement in relation to Pb concentrations which were found in their lowest concentration in tomato fruits. High concentrations of Zn in tomato fruit at all hyacinth compost application rates can be attributed to its relatively high mobility and thus availability for uptake by plants [29]. Cu concentration in tomato fruit was relatively low and it is suspected that the hyacinth compost increases the cation exchange capacity of the soil and Cu readily substitutes other minerals on the exchange complex to form stable complexes. The soil pH of 6.8 which is almost in the same range as that of the hyacinth compost (6.6) and irrigation water (7.1) favors the adsorption of Cu by the soil than its absorption by the plant.

5. Conclusion

Use of water hyacinth compost positively improves the growth rate and yield of tomatoes without compromising the health of consumers by heavy metal toxicity build up. However, it should be noted that the water hyacinth compost rate does not influence the number of fruits per plant. The optimum application rate for high potential yield in tomato could be higher than 74 $t \cdot ha^{-1}$. However, based on sustainable water hyacinth yields from the local water bodies, a compost rate of 74 $t \cdot ha^{-1}$ can be recommended as it leads to significant higher yields.

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