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Improving Water Hyacinth-Based Compost for Crop Production

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ABSTRACT

A study was carried out to hasten maturity, improve nutrient content and determine agronomic performance of water hyacinth-based composts. Water hyacinth (WH) was composted using pile method and six treatments: WH + cattle manure (WH+CM), WH + poultry manure (WH+PM), WH + effective microorganisms, WH + molasses at 25% total sugar content, WH + molasses at 50% total sugar content and WH composted singly. Macro nutrients, C/N ratio, mineral nitrogen, temperature and pH were monitored. The composts obtained were applied at rates of 3 and 6 t ha^{-1} using maize (LONGE 4) as test crop. All compost treatments reached maturity after 6 weeks and the highest total contents of 2.2%, 1.3% and 1.5% of N, P and K respectively were determined in WH+PM. Grain yields of 6.8 t ha^{-1} harvested in (WH+CM) applied at 6 t ha^{-1} and 6.5 t ha^{-1} harvested in (WH+PM) applied at 3 t ha^{-1} were statistically similar, and the highest in the experiment. Co-composting with poultry manure shortened maturity period and improved nutrient concentrations of mature compost. Highest grain yield was obtained at 6 t ha^{-1} but (WH+PM) compost applied at 3 t ha^{-1} was the most effective.

Key words: Delayed compost maturity, maize yield, nutrient losses, pile composting, water hyacinth

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INTRODUCTION

Water hyacinth is an aquatic weed that is rapidly spreading on Lake Victoria and surrounding fresh water bodies (Kateregga and Sterner, 2007). The weed has continued to spread due to its high productivity rate of 58 - 228 t ha^{-1} yr^{-1} (Amoding et al., 1999) and deposition of nutrients into the lake from surrounding farm lands as well as dumping of raw wastes from industries and communities (Bongomin and Opio, 2013). The water hyacinth spread has threatened water quality and aquatic life although the various biological, chemical and physical methods that have been employed to control the weed have yielded minimal results (Kateregga and Sterner, 2007). While the water hyacinth has proved to be a menace, it accumulates nutrients like nitrogen, phosphorus, potassium and micronutrients. Amoding et al. (1999) reported that water hyacinth absorbs about

99.2 kg N ha^{-1}, 7.7 kg P ha^{-1} and 182.3 kg K ha^{-1} within a week, which if utilised could improve crop production. The water hyacinth challenge could therefore, be turned into an opportunity, by harnessing the nutrients through composting into an organic fertilizer for improving soil fertility. However, studies on water hyacinth composting have exposed challenges; one being the composting process itself. Owing to its high moisture content of >92%, water hyacinth loses nitrogen through leaching and denitrification when composted (Prasad et al., 2013). This delays the composting process and reduces the quality of compost generated. Guo et al. (2012) also reported similar high nitrogen losses mainly through leaching. Nitrogen losses of 26% from 2.31 to 1.7% during composting water hyacinth were reported by Goyal et al. (2005), while Masaka and Ndhlovu (2007) reported N and K losses of 73% (from 2.48 to 0.68%) and 83% (from 2.89 to 0.5%) respectively after composting of water hyacinth. These losses could also have been aggravated by the long period required by the compost to mature. Osoro et al. (2014) reported a compost maturity period of 63 days, Lata and Veenapani, (2011) reported a period of 100 days, while Seoudi, (2013) reported a period of 126 days. There is therefore, the need to improve the composting process of water hyacinth by minimising nutrient losses and shortening the compost maturity period. Improving the composting process of water hyacinth could include addition of materials that can act as bulking materials as well as a source of carbon and nutrients (Epstein, 1997). Material amendment has been demonstrated to improve the quality of compost and reduce the maturity period for example composting of rice straw and maize stover with *Tithornia diversifolia* (Taguiling, 2013). Sangakkara et al. (2008) also reported that cattle manure reduced the maturity period and improved rice compost quality. Therefore, composting water hyacinth with such materials can also help to reduce nutrient losses as well as hasten the decomposition process. In this study, materials that can easily be accessed by farmers like poultry manure, cattle manure, molasses and effective microorganisms were considered.

Poultry manure and cattle manure absorb the high moisture of the water hyacinth in addition to acting as nutrient sources for composting microorganisms as well as enriching the compost (Sylvia et al., 2005). Molasses act as a source of energy (sugars) for microorganisms and hence enhance microbial activity. Beneficial microorganisms can accelerate the decomposition process since they are considered efficient. In this study, the effectiveness of different locally available materials on nutrient levels and maturity of water hyacinth-based compost was assessed with the aim of identifying the most suitable combination for enhancing the quality of water hyacinth-based compost. The obtained composts were assessed for agronomic performance at 3 and 6 t ha^{-1} using maize as a test crop.

MATERIALS AND METHODS

Water hyacinth composting

The experiment was set up at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) (32^{o} 36'42.0'' E 0^{o} 27' 03.0''N). The aerobic pile method which was found to reduce nutrient losses and shorten compost maturity was used (Tumuhairwe et al., 2009). However, modified composting boxes of 1.5 m length x 1.5 m width x 1.5 m height; raised at a height of 15 cm from the ground were used. The experiment had six treatments: (i) Water hyacinth co - composted with cattle manure (WH+50%CM), (ii) poultry manure (WH+50%PM), water hyacinth composted with: molasses at 25% total sugar content (WH+25MO), (iv) molasses at 50% total sugar content (WH+50MO), (v) effective microorganisms inoculant (WH+EM) and (vi) the control where the water hyacinth was composted alone (WH alone). The materials were pre-mixed before filling in the boxes and each treatment was replicated three times. The treatments were arranged in a completely randomized design. The water hyacinth was obtained from a drainage channel near Lake Victoria. It was chopped into pieces of approximately 5 cm and spread under shade for four days to reduce excess moisture. Poultry manure was obtained from a poultry farm around MUARIK while cattle manure was obtained from a zero grazing unit at MUARIK. Cattle manure was kept under shade for five days to reduce excess moisture while poultry manure was used directly. The Effective Microorganisms (EM) solution was imported from Kenya and contained microorganisms: *Photosynthetic bacteria, Lactic acid bacteria, Saccharomyces cerevisae, Rhodopseudomonas spp,* and *Lactobacillus plantarium*. Molasses were obtained from a nearby farm and applied at 25% and 50% total sugar content. The rates of 25 and 50% were equivalent to 13.6 g/100g and 27.3 g/100g total sugar content respectively. Use of molasses and EM was to assess whether it is better to provide favourable medium for action of indigenous microorganisms using sugars from molasses or supply isolated microbial strains perceived to be effective in composting to act within a natural environment. Water hyacinth and poultry manure (WH+PM) and water hyacinth and cattle manure (WH+CM) treatments were prepared using a 1:1 (w/w) ratio by alternating 10 kg (dry weight) layers of either water hyacinth and cattle manure or water hyacinth and poultry manure depending on the treatment. For molasses treatments, two litres of the mixture were sprinkled evenly using a watering can on each 10 kg (dry weight) layer of water hyacinth in the box and the pile in boxes was built up to a height of one metre. Molasses that were used in the experiment had 54.5% total sugar content. The EM treatment (WH+EM) was prepared in the same way as the molasses pile using an EM to water ratio of 1:50 (v/v). Table 1 shows selected characteristics of materials used in the experiment.

Table 1. Initial characteristics of the composting materials.

Material	pH	Moisture content (%)	TOC	TON	Total P (mg kg^{-1})	Total cations (mg kg^{-1})			C/N ratio
						K	Ca	Mg	
Water hyacinth	7.1	92.3	34.5	1.8	3.1	39	19	6.7	19.2
Poultry manure	7.7	40.0	27.5	1.7	22.3	25	30	4.2	16.2
Cattle manure	7.6	67.7	19.9	1.4	5.6	13	5	1.7	14.2

Key: TOC= total organic carbon, TON= total organic nitrogen.

Table 2. Selected soil characteristics of the experimental sites.

Sites	pH (1:2.5water)	TON	SOM	Av. P(mg/kg)	Ex. cations (cmol/kg)			Textural class
		(%)			K	Ca	Mg	
MUARIK	5.6	0.16	2.7	3.6	0.57	2.6	1.24	Sandy clay
Bugiri 1	5.4	0.11	1.7	9.2	0.45	2.0	0.85	Sandy loam
Bugiri 2	4.7	0.14	2.1	3.2	0.20	1.3	0.99	Sandy clay
Bugiri 3	5.3	0.13	2.5	10	0.21	1.7	1.01	Sandy clay
Critical values	**5.5†**	**0.25†**	**3†**	**15†**	**0.22†**	**4†**	**0.25†**	

† Okalebo et al. (2002).

Data collection

Temperatures were recorded daily between 10:00 am and 11:00 am using five composting digital thermometers which were inserted 15 cm into the five parts of the pile. Turning was done weekly to ensure uniform decomposition and aeration within the pile. Compost maturity was monitored weekly using changes in temperature, mineral nitrogen, pH and ratios of C/N, mineral nitrogen (NH_4^+-N/NO_3^-N) and water soluble carbon/ TON. Changes in nutrient concentrations were determined in the third and six weeks. Nutrient analysis was done using compost samples that were air dried for five days at room temperature while mineral nitrogen, water soluble carbon and pH were analyzed from fresh samples. Laboratory analyses were done at Soil Science laboratory of Makerere University.

Laboratory analysis

Compost samples were analysed for total organic nitrogen, phosphorus and potassium. Total organic nitrogen was determined using the Kjeldahl method following procedures described in Okalebo et al. (2002) while total organic carbon was determined using the wet oxidation method (Nelson and Sommers, 1982). Total P was determined using the Bray 1 method while K was determined using the atomic absorbance spectrometer method following procedures outlined in (Okalebo et al., 2002). Compost pH was determined using aqueous extracts of 1:10 (w/v) compost to distilled water. The pH was read using an electrode after mechanically shaking the samples for 1 hour. Nitrate and ammonium nitrogen were determined calorimetrically by extracting from compost using potassium sulphate (0.5M) at a ratio of 1:4 (w/v) for 30 minutes. The compost solution then filtered through Whatman No. 1 filter paper. The filtrate was then used for the determination of nitrate and ammonium nitrogen using the atomic absorbance spectrophotometer. For ammonium nitrogen, 0.2 ml of the filtrate was complexed for colour development by adding 5 ml of solution N1 (consisting of sodium nitroprucide, sodium salicyclate, sodium citrate and sodium tartarate) and 0.5 ml of solution N2 consisting of sodium hydroxide and sodium hypochlorite. For nitrate nitrogen, 0.5 ml of the filtrate was complexed by adding 1 ml of solution N1 (4M NaOH) and N2 (salicicyclic acid). The standard solutions for ammonium and nitrate nitrogen were potassium sulphate and potassium nitrate respectively. Nitrate and ammonium nitrogen absorbencies were then read from the atomic absorbance spectrophotometer at 419 and 655 nm respectively. Total sugar content in molasses was determined using the phenol sulphuric acid method (AOAC International, 2003).

Field experiment

Field experiments were set up on four sites in Wakiso district, Central Uganda. The sites were: MUARIK (E 32° 36’42.0’’N 0° 27’ 03.0’’), Bugiri 1 (E 32° 34’ 256’’), Bugiri 2 (E 32° 34’106’’ N 0°06’ 184’’), and Bugiri 3 (E 32° 33’ 668’’ N 0 ° 06’ 604’’). Farmers near Lake Victoria that have access to the water hyacinth were involved in the study. Table 2 shows selected soil characteristics of the sites. Soils in all sites were acidic, with low levels of organic matter, nitrogen, phosphorus and calcium. Magnesium was sufficient in all sites while potassium levels for Bugiri 2 and Bugiri 3 were slightly below critical values for East Africa soils (Okalebo et al., 2002). Earlier classification categorized the soils in the area as Ferralsols formed from pre-Cambrian acid rocks and belonging to the Buganda catena (Aniku, 2001). The composts obtained from composting experiment were air

Table 3. Chemical characteristics of composts used in field experiments.

Compost Formulation	(%)			pH(1:2.5 water)	Total cations (%)			C/N ratio
	TON	TOC	Total P		K	Ca	Mg	
WH+PM	2.21	16.1	1.36	8.3	1.5	0.84	0.18	7.3
WH+CM	1.94	14.5	0.46	8.2	0.8	0.46	0.17	7.5
WH+MO	1.62	8.6	0.36	7.9	1.1	0.47	0.15	5.3
WH	1.36	10.4	0.38	7.6	1.1	0.55	0.18	7.6

Key: WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water hyacinth alone.

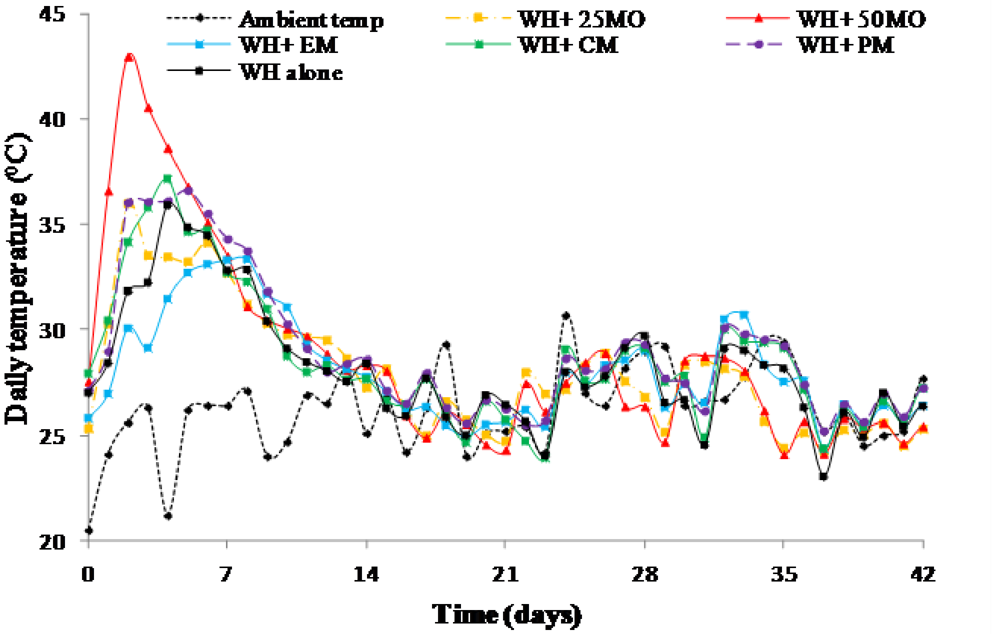

Figure 1. Changes in daily temperature during composting.

dried for five days, sieved with 2 mm sieves, packed and transported to field experimental sites.

The experiments were set out in Randomized Complete Block Design (RCBD) with three replicates and nine treatments which were: four water hyacinth-based composts: WH+PM, WH+CM, WH+MO and WH alone applied at rates of 3 and 6 t ha^{-1} and the control where no compost was applied. Chemical characteristics of compost used are shown in (Table 3).

LONGE 4 maize variety which is high yielding, early maturing (95-115 days) and drought tolerant was used as test crop and planted at a spacing of 75 x 30 cm (one plant per hill). Plots of 3 x 3 m were used and spacing of one and two metres was left between the plots and blocks respectively.

Grain yield data was collected at harvesting from a net plot area of 2.25 m^2. Grain samples were collected from each plot, taken to the laboratory for moisture correction to 12%. The grain yield was then expressed in tonnes per a hectare.

Data analysis

Data were analysed using GenStat discovery 10th edition for windows. Data on pH were converted into [H$^+$] by log transformation before analysis. Analysis of variance test was run to establish effect of treatments on compost maturity, nutrient concentrations and grain yield. Significant means were separated using Fishers protected LSD at 5% significance.

RESULTS

Temperature

The highest temperatures were determined in the first week (Figure 1). In all treatments, temperature rapidly increased from the initial values of 26°C to peaks ranging

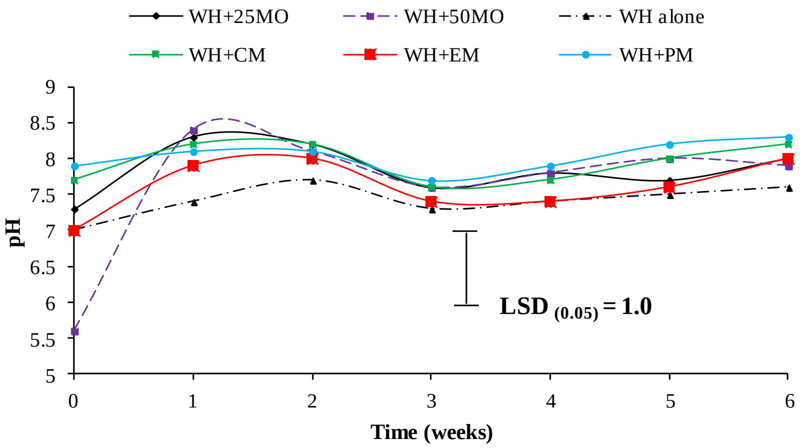

Figure 2. Changes in compost pH during composting.

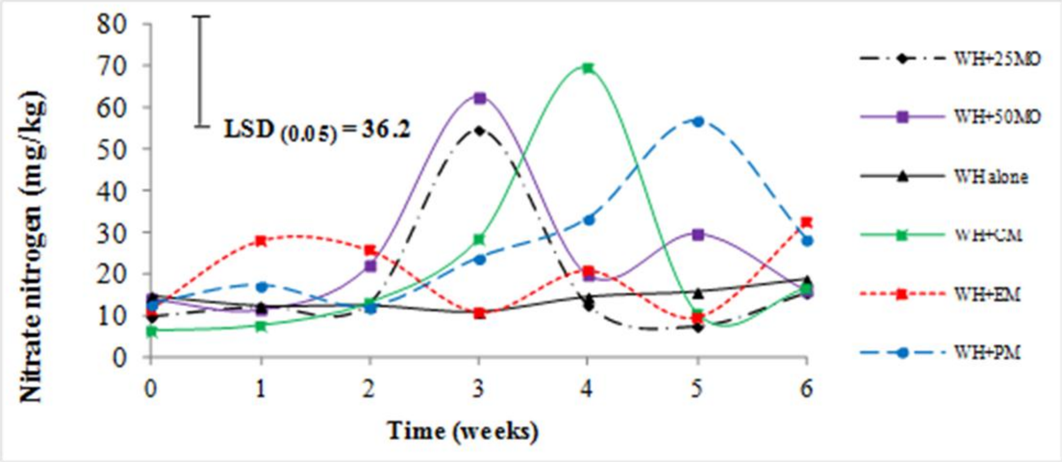

Figure 3. Changes in nitrate concentration during composting.

between 30 and 43°C before beginning to slope to about 25°C throughout the third week. Thereafter, temperature changes were minimal up to the end. Treatment WH+50MO had the highest peak temperature increasing from an initial value of 28 to a peak value of 43°C on the second day and decreasing sharply on the eighth day (Figure 1).

Compost pH

There were significant differences ($p < 0.05$) in pH between treatments and weeks (Figure 2). Compost pH increased within the first week of composting then declined between the second and third week before rising again through compost maturity except for treatment WH+50MO where pH declined in the last week. The highest pH was observed in WH+50MO in the first week. The final pH from all treatments was between 7.6 and 8.3 observed in WH alone and WH+PM treatments respectively.

Nitrate concentration

There was a significant ($p < 0.05$) difference in nitrate nitrogen (NO_3^- - N) between the different treatments during the composting period (Figure 3). At the start of composting, the NO_3^- - N concentration was low in all treatments. Treatments WH+25MO and WH+50MO reached peak nitrate levels earliest in the third week, followed by WH+CM with the highest concentration (69.5 mg kg^{-1}) in the fourth week. Treatments WH+PM and WH+EM reached peak nitrate levels in the fifth and sixth weeks respectively. Changes in NO_3^- - N for treatment WH alone were minimal and statistically similar

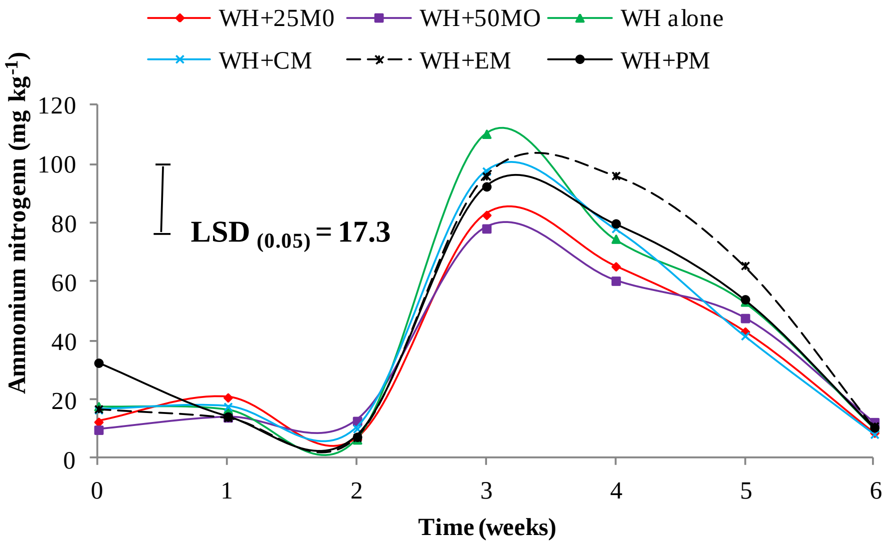

Figure 4. Changes in ammonium concentration during composting.

throughout the experiment even though it followed an increasing trend from the third week up to the end of experiment. There were significant increases ($p < 0.05$) in NO_3^- - N up to peak levels in the third week for WH+25MO and WH+50MO, fourth week for WH+CM and fifth week for WH+PM. However, NO_3^- - N significantly reduced for WH+25MO and WH+50MO in fourth week, fifth week for WH+CM and sixth week for WH+PM (Figure 3).

Ammonium concentration

There was a significant difference ($p < 0.05$) in ammonium concentration between treatments during composting (Figure 4). The ammonium concentration significantly ($p < 0.05$) increased to peak values in the third week for all treatments except WH+EM which reached its peak concentration (96.2 mg kg^{-1}) in the fourth week. Thereafter, ammonium concentration decreased significantly ($p < 0.05$) in fourth week for all treatments except WH+EM and, continued to decrease for all treatments up to the end of composting to less than 12.4 mg kg^{-1}. There was no significant ($p \geq 0.05$) difference in ammonium concentration between the treatments in the mature compost.

Total nitrogen

There were significant differences ($p<0.05$) in total nitrogen concentration between the treatments over the six weeks of composting (Figure 5). Treatment (WH+CM) had the highest initial N concentration (2.5%) which was significantly higher than those of other treatments except (WH+PM) and (WH+25MO). Composting reduced N concentration for all treatments but the trends taken were different for each treatment. The nitrogen concentrations for (WH+CM) and (WH+25MO) decreased significantly ($p<0.05$) in the third week but there were no significant ($p\geq0.05$) changes in N concentration from the third to sixth week for all treatments. Treatments (WH+PM) and (WH+CM) had the highest total N levels which were 38 and 29% higher than the control (WH alone) respectively. With the exception of (WH+PM), N concentration in the mature compost of rest of the treatments was statistically similar to that of the control (WH alone).

Ratios of C/N NH_4^+/NO_3^- - N and WSC/TON

Ratios of C/N NH_4^+/NO_3^- -N, WSC/TON generally followed a decreasing trend throughout the experiment (Table 4). Ratios of C/N decreased throughout the experiment and final values were between 5.9 and 7.5. Changes in WSC/TON ratio also followed a decreasing trend with (WH+CM), (WH+PM) and (WH+EM) having equal ratios at three weeks (0.01) which remained constant up to the end of experiment. WSC/TON ratio of other treatments increased slightly at six weeks but all treatments had final values of below 0.1 with (WH alone) having the highest ratio of 0.05. The NH_4^+/NO_3^- - N ratios for all treatments reduced during the experiment with slight increases from week three to six but final NH_4^+/NO_3^- -N ratios were below 1. Treatment WH+50MO had the highest NH_4^+/NO_3^--N ratio (0.91) while WH+PM had the least (0.39).

Phosphorus

There was a significant difference ($p<0.05$) in total P

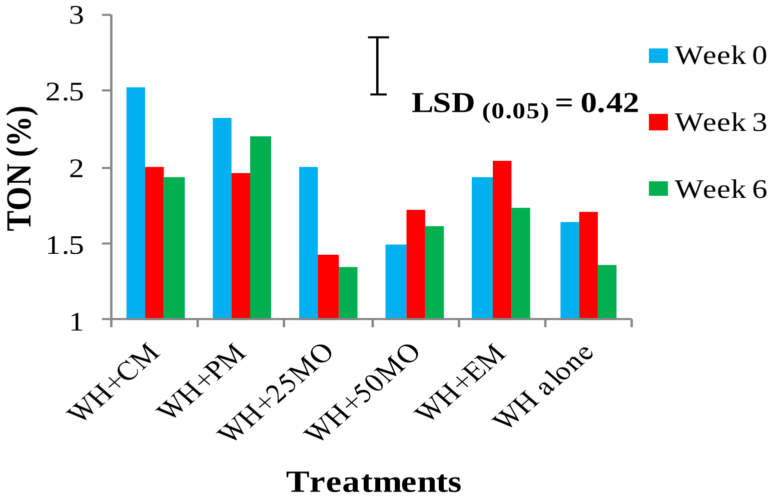

Figure 5. Changes in total nitrogen during composting.

Table 4. Ratios of C/N, WSC/TON and NH_4^+-N/NO_3^--N at selected days during composting.

Ratios	Days	Treatments					
		WH+CM	**WH+PM**	**WH+25MO**	**WH+50MO**	**WH+EM**	**WH**
C/N	0	16.4	17.7	18.5	19.2	19.3	19.4
	21	7.3	8.2	6.0	7.7	8.5	6.3
	42	7.5	7.5	5.9	6.6	6.4	6.3
WSC/TON	0	0.45	0.50	1.63	3.17	0.69	1.75
	21	0.01	0.01	0.01	0.02	0.01	0.04
	42	0.01	0.01	0.02	0.04	0.01	0.05
NH_4^+-N/NO_3^- -N	0	1.34	1.49	1.21	1.38	1.68	1.89
	21	0.06	0.14	0.12	0.18	0.12	0.13
	42	0.54	0.39	0.58	0.91	0.41	0.76

Key: C/N= ratio of total organic carbon to total organic nitrogen, WSC= water soluble carbon, TON= total organic nitrogen, NH_4^+-N= ammonium nitrogen, NO_3^-N= nitrate nitrogen, WH+CM = water hyacinth co - composted with cattle manure, WH+PM = water hyacinth co - composted with poultry manure, WH+25MO = water hyacinth composted with molasses at 25% total sugar content, WH+50MO = water hyacinth composted with molasses at 50% total sugar content, WH+EM = water hyacinth composted with effective microorganisms and WH = control where the water hyacinth was composted alone.

concentration between treatments. The highest (1.49%) initial P concentration was recorded in treatment (WH+PM) and this was significantly ($p<0.05$) higher than those of other treatments. Treatment (WH+25MO) had the least initial P concentration of 0.32% (Figure 6). There were minimal changes in P concentration for all treatments throughout the study. However, treatment (WH+PM) experienced a significant reduction ($p < 0.05$) in total P concentration in the third week but, it maintained significantly higher ($p<0.05$) P concentration than the rest of the treatments throughout the composting period. After composting, highest (1.36%) and least (0.31%) P concentrations were observed in treatments were recorded in (WH+PM) and (WH+25MO) respectively and these were significantly ($p<0.05$) different (Figure 6).

Potassium

There were significant differences ($p<0.05$) in potassium among treatments within the weeks and amongst treatments across the duration of composting (Figure 7). Treatments (WH alone) and (WH+EM) had the highest (2.4%) and least (1.1%) initial K concentrations respectively which were significantly ($p<0.05$) different. Total K concentrations for (WH alone), (WH+PM) and (WH+25MO) significantly ($p<0.05$) reduced in the third week while that of (WH+EM) increased significantly (p <

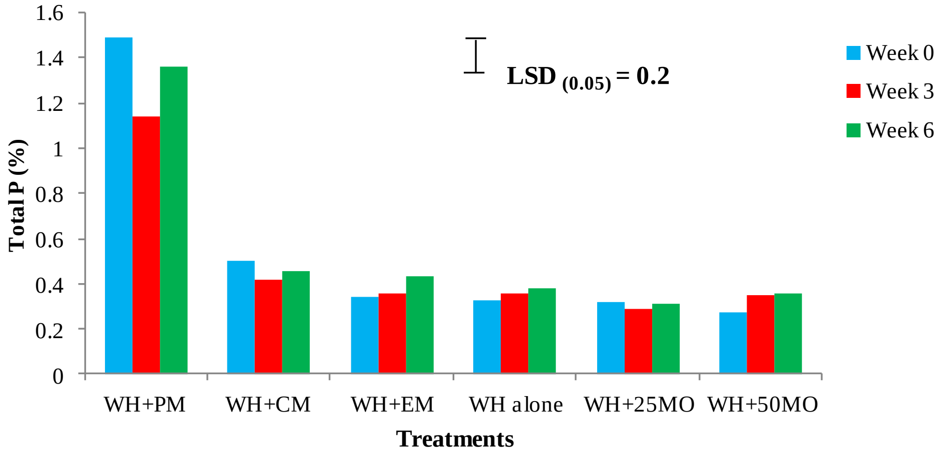

Figure 6. Changes in phosphorus concentration during composting.

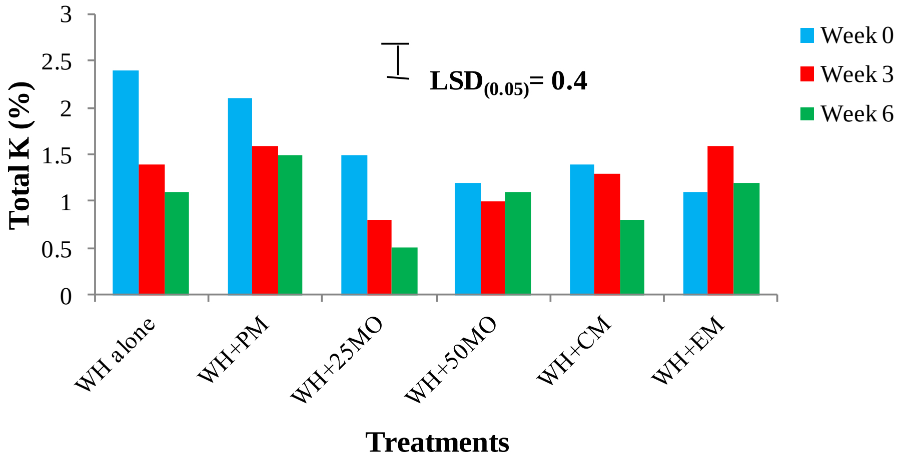

Figure 7. Changes in potassium concentration during composting.

0.05) (Figure 7). In the third week, (WH+EM) and (WH+PM) had the highest and equal concentrations of K (1.6%) which were significantly ($p<0.05$) higher than those of (WH+50MO) (1%) and (WH+25MO) (0.8%). Total K concentration declined for all treatments in the sixth week except (WH+50MO). After composting, the treatment (WH+PM) had the highest (1.5%) final K concentration which was significantly ($p<0.05$) higher those of (WH+CM) and (WH+25MO). Treatment (WH+25MO) had the least (0.5%) final K concentration which was significantly lower ($p<0.05$) those of other treatments except (WH+CM) (Figure 7).

Effect of water hyacinth-based composts on maize yield

All compost treatments irrespective of the rates produced significantly ($p<0.05$) higher maize grain yields than the control (Figure 8). With the exception of (WH+PM), all compost treatments applied at 6 t ha^{-1} produced higher grain yields than at 3 t ha^{-1} but the differences were statistically similar. Treatments (WH+PM) and (WH+CM) produced the highest grain yields at 3 and 6 t ha^{-1} respectively and were higher than that of the control by 32% and 35% respectively.

DISCUSSION

Temperature

For all treatments, temperatures were highest in the first week, then declined up to fourth week and slightly rose in the fifth week (Figure 1). The highest temperatures

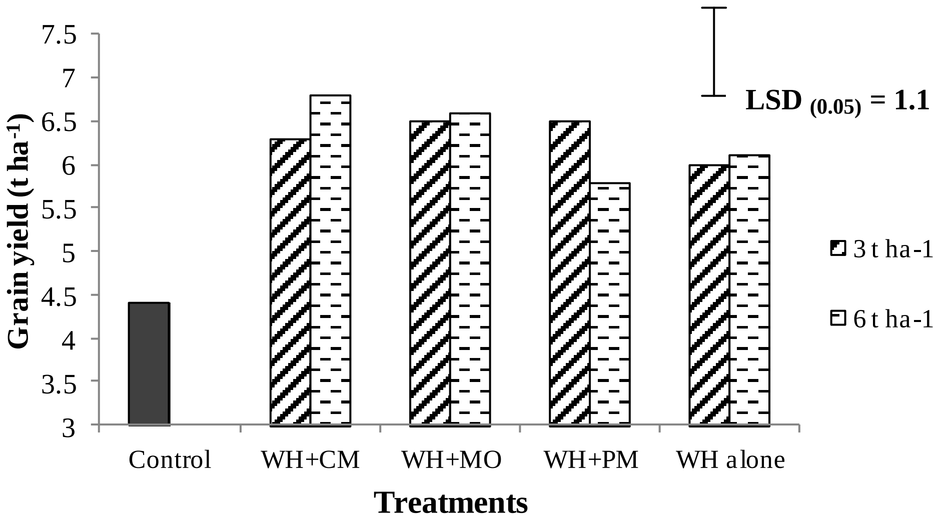

Figure 8. Effect of water hyacinth- based composts on maize grain yield.

observed in the first week were because in the initial stages of composting, there are high amounts of easily broken down proteins and carbohydrates that act as a source of energy for rapid action by microorganisms. The increase in temperature demonstrates microbial activity. This trend in temperature changes has also been reported in other studies (Prasad et al., 2013; Raj and Antil, 2011; Tumuhairwe et al., 2009). The highest temperatures associated with treatment (WH+50MO) are because molasses have high quantities of sugars that are an important energy source for microorganisms. The increase in temperature in the fourth and fifth weeks coincided with increases in ammonium nitrogen (Figure 4); implying that rapid mineralization had resumed (Bernal et al., 2009). In terms of maturity, changes in daily temperatures from all treatments fell below ambient temperature (25°C) after two weeks (day 16). However, this did not mean that the compost was mature because other parameters like WSC (Figure 2), nitrate nitrogen (Figure 3), ammonium nitrogen (Figure 4) and mineral nitrogen ratio (Table 2) had not yet reached the recommended ranges of maturity (Bernal et al., 1998; Bernal et al., 2009).

Compost pH

There were significant differences in compost pH and the trends observed (Figure 5) have been reported in earlier studies (Dhal et al., 2012). The highest initial and final pH associated with (WH+PM) could be attributed to the high salt content in the chicken feeds and droppings. The pH for treatment (WH+PM) and other treatments generally reduced after week one because as composting takes place especially the thermophilic phase, some of the cations are precipitated and removed from solution. Furthermore as composting proceeds, most of the easily decomposable materials had been depleted and there were not enough energy and carbon sources for the microbes to continue rapid nitrification. This leaves a few microbial populations, mainly fungi that are efficient in breaking down recalcitrant materials like roots and stolons which cannot be easily broken down by bacteria and archaea. It is for this reason that pH for (WH+EM), (WH+PM) and (WH+CM) continued to increase even after the fourth week (Figure 2). The EM culture has organisms effective in breaking recalcitrant materials while treatments (WH+PM) and (WH+CM) still had some carbon as energy source for the indigenous microbes to continue decomposing the materials. Ammonification leads to eventual rapid release of ammonium ions from breakdown of organic nitrogen and release of other cations that consequently increased pH (Aparna et al., 2008). Therefore, increases in pH for WH+25MO and WH+50MO from four to weeks were due to release of ammonium ions from stolons and roots. Final pH values were in the range of 7.6 to 8.3 and they fall in a range of 6-8 that was recommended by (Janakiram and Sridevi, 2010) for mature compost.

Mineral nitrogen

The significant differences among treatments ($p < 0.05$) on nitrate nitrogen reported in this study have been reported in other studies (Tumuhairwe et al., 2009; Benito et al., 2003). The significant differences ($p < 0.05$) in NO_3^--N in weeks three and five (Figure 3) could be attributed to turning. Turning increases oxygen circulation in the pile which is necessary for the fast action of aerobic decomposers. Treatments (WH+25MO) and (WH+50MO) reached peak concentration earlier (third week) compared to (WH+CM) (fourth week) and (WH+PM) (fifth week) because molasses had initially high simple sugar levels which were released in the first three weeks of composting. The sugars are a source of energy for the action of microorganisms and so helped to fasten nitrogen mineralization and fast release of nitrates. However, reaching peak nitrate levels earlier could also mean that these treatments did not reach full nitrogen mineralization levels compared to (WH+CM) and (WH+PM) whose nitrate concentration increased gradually and reached their peak nitrate concentration later, implying that nitrogen mineralization was complete in these treatments. The significant differences ($p < 0.05$) in ammonium concentration and the trends observed are normal and have been reported in other studies (Prasad et al., 2013; Tumuhairwe et al., 2009; Zhu, 2007). The increase in ammonium concentration from the fourth to fifth week could be due to break down of recalcitrant parts of water hyacinth like the stolons and roots. However, reduction in ammonium concentration after the fourth week was not followed by an equal increase in nitrate levels. This could be attributed to the high pH observed during composting (Figure 2) that might have caused ammonia loss through volatilization (Bernal et al., 2009). Furthermore, beyond three weeks, the C/N ratio for all compost treatments had greatly reduced (Table 4). At low C/N ratio, microorganisms transform nitrogen rapidly and this contributes to ammonia volatilization. Therefore, in order to conserve more nitrogen use of materials such as struvite and lime which precipitate ammonia and those that adsorp ammonia like peat and biochar (Sánchez, et al., 2017) should be explored. Nevertheless, with final ammonium levels of below 0.04%, ammonia/ nitrate ratio of less than 1 and WSC/TON of below 0.55, the compost was already mature at six weeks according to established indices (Antil et al., 2013; Bernal et al., 2009).

Nitrogen, phosphorus and potassium

The significant differences ($p<0.05$) in N, P and K concentration between and within treatments and the trends observed during composting are consistent with previous studies (Goyal et al., 2005; Barrington et al., 2002). The higher N, P and K concentration in mature compost reported for (WH+PM) and (WH+CM) signify the role of fortified composting. The significantly ($p < 0.05$) higher nitrogen concentrations (Figure 5) observed in treatments (WH+CM) (1.94%) and (WH+PM) (2.21%) could be attributed to their role in composting. This is consistent with (Raj and Antil, 2011) who reported that addition of poultry and cattle manure improved ammonification and nitrification by maintaining aeration for decomposers. Besides, the use of additives like effective microorganisms and molasses in composting accelerated decomposition but, provided no sink for soluble minerals hence increasing their losses (Figure 5). The final total N concentrations obtained in this experiment were between 1.4 and 2.2% and are comparable with those of (Padmavathiamma et al., 2008; Goyal et al., 2005) who obtained final total N values of 2.08 and 1.70% respectively. However, higher compost N levels than those reported in this study have been obtained in studies where more than one additives have been combined with water hyacinth (Dhal et al., 2012). Therefore in order to further reduce nitrogen and potassium losses, higher amounts of cattle manure, poultry manure or a combination should be used during composting. The significantly high total P concentration (Figure 6) observed for treatment (WH+PM) could be attributed to the initially high total P concentration (Table 1). The consistent trend and least variability in P concentration observed could be attributed to behavior of phosphorus. Phosphorus as orthophosphate ions during composting is less mobile in compost and soil media. The orthophosphate ions form complexes with organic matter ligands and cations and thus little P is lost. Dhal et al. (2012) reported high P values where cattle manure was added during water hyacinth composting. On the other hand, potassium is a very mobile ion during composting since it is not a structural element. As soon as the cell wall is raptured, K^+ ions are released into the solution within the composting medium and lost through leaching. This explains the decreasing concentration of K during composting (Figure 7). Given that the water hyacinth biomass had the highest concentration of K (Table 1) and high moisture content, it therefore decomposed faster releasing the K^+ ions. Additives that enhanced decomposition would, therefore, experience further leaching of K^+ ions as observed in (Figure 7). The significant differences ($p>0.05$) in final total K concentration between (WH+25MO) and (WH+CM), (WH+EM), (WH+50MO) and (WH+PM) and also between (WH+CM) and (WH+PM) ($p<0.05$) could be attributed to the initial characteristics of the materials in terms of K concentrations and moisture contents of the materials used in the experiment (Table 1).The treatment (WH+PM) had the highest total K concentration (Figure 7); this could be because it had high initial K and other nutrients that sustained microbial activity and ensured full mineralization of K. Even though (WH+EM) and (WH+50MO) had higher percent K recovery (>90%) than (WH+PM) (71.4%) and (WH+CM) (57.1%) the latter had produced matured compost with higher K levels than the former. This can be attributed to additive effect from poultry and cattle manure; in addition to the K contained in water hyacinth biomass, these materials contained their own K which boosted levels in mature compost. The higher percent K recovery observed in (WH+EM) and (WH+50MO) could be attributed to efficiency of introduced microorganisms in breaking down water hyacinth biomass (Mupondi et al., 2006; Wei et al., 2007). Supply of external source of energy improves activity of indigenous microorganisms in composting and this was the case for the molasses treatment (WH+50MO) (Sylvia et al., 2005).

Maize grain yield

The control treatment realised the least grain yield yet there was no significant ($p \geq 0.05$) difference between grain yield at 3 and 6 t ha^{-1} (Figure 8) of the treatments. The significant difference ($p < 0.05$) in grain yield observed between different water hyacinth compost mixtures and the control has been reported in other studies (Osoro et al., 2014; Evanylo et al., 2008). The significantly ($p < 0.05$) higher grain yields of compost mixtures compared to the control could be because of the higher nutrient contents of the compost mixtures applied. The site characteristics (Table 3) indicated low soil fertility and therefore, there was response to added compost and the rate of 3 t ha^{-1} could have been sufficient. This study did not determine nutrient content in maize tissue but other studies (Renck and Lehmann, 2004) reported highest yield and tissue concentrations of K and P where compost consisting chicken manure was applied. Therefore the higher grain yield observed at 3 tha^{-1} than 6 t ha^{-1} for WH+PM could be because the lower rate was able to satisfy maize nutrient requirements. The slightly higher but non-significant grain yield at 6 than 3 t ha^{-1} obtained using lower rate of 3 t ha^{-1} indicates the role of fortified composting in compost quality improvement. With nutrient rich compost, a small amount is required to satisfy crop nutrient demands. Failure to attain double increase in yield after doubling compost rate to 6 t ha^{-1} means that the plant had taken up enough nutrients at lower rate 3 t ha^{-1}. Therefore, there was luxury consumption beyond 3 t ha^{-1}.

Conclusion

The study has demonstrated that co-composting of water hyacinth with poultry manure, cattle manure, molasses and inoculation with effective microorganisms hastens the composting process and reduces nutrient losses. Composting water hyacinth using pile method shortened the compost maturity period to 42 days compared to 63, 100 and 126 days reported by Osoro et al. (2014), Seoudi (2013) and Lata and Veenapani, (2011) respectively. Co-composting water hyacinth with poultry manure increased N, P and K concentrations in matured compost. The most effective dose of compost in enhancing grain yields was 3 t ha^{-1}. Therefore, in order to reduce nutrient losses and accelerate the composting process, water hyacinth should be composted with poultry manure. Mature water hyacinth-based compost should be applied at 3 t ha^{-1} since it produced maize grain yield that was comparable to that obtained from the higher rate of 6 t ha^{-1}. Future studies should explore options increasing nitrogen recovery during water hyacinth composting for example composting a mixture of water hyacinth, cattle and poultry manures in one pile and adjusting C/N ratio using carbon rich materials like sawdust. Nitrogen fertilizer equivalence of water hyacinth-based composts and effect of applied composts on soil properties should also be determined.

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