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Agronomic effectiveness of water hyacinth-based composts

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Because water hyacinth-based compost contains substantial amounts of nitrogen (N), phosphorus (P) and potassium (K) its application can boost crop production. We evaluated the agronomic performance of water hyacinth - based composts using field experiments and five treatments which were; water hyacinth compost made using cattle manure (WH+CM), poultry manure (WH+PM), molasses (WH+MO), water hyacinth alone (WH alone) and the control. The composts were applied at two rates of 3 and 6 t ha^{-1} using maize (LONGE 4) as a test crop. 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 were the highest in the experiment. The highest harvest index and agronomic nitrogen efficiency were obtained at 3 t ha^{-1} from WH+PM (4.57) and WH+MO (42.6 kg kg^{-1}) respectively. Compost formulation WH+PM applied at 3 t ha^{-1} was the most effective as measured in terms of grain yield and is recommended for application by farmers for good yields of maize crop.

Key words: Nitrogen, phosphorus and potassium, water hyacinth-based composts, effective application rate, maize grain yield.

INTRODUCTION

Crop production in sub-Saharan Africa is greatly hindered by low soil fertility (Tully et al., 2015). A study by Nkonya et al. (2008) revealed that nutrient levels for most soils in Uganda are below the critical levels for most crops grown in the country. Most soils in Central Uganda are Ferralsols that are highly weathered and leached, with

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low cation exchange capacity, low pH and low organic matter (Aniku, 2001). The soils also have high contents of sesquioxides and a problem of phosphorus fixation and aluminium toxicity. Very high nutrient losses occur due to poor farming practices in most farming communities. Soil erosion alone was found to contribute up to 24, 59 and 33% of total N, P and K losses respectively from the soils in the Lake Victoria crescent region of Uganda (Nkonya et al., 2008). This implies that farming practices used by famers are not sustainable and calls for use of feasible soil fertility management practices to boost crop production. As a result, most fields have negative nutrient balances due to leaching, denitrification and soil erosion (Ebanyat, 2009).

Use of inorganic fertilizers would be the quickest entry point for elevating agricultural productivity and production (Sanchez et al., 2009). However, mineral fertilizer use in Sub Saharan Africa where Uganda lies is still low at 10 kg ha^{-1} (FAO, 2017). Furthermore, studies show that on farms where mineral fertilizers are used, there are low nutrient use efficiencies (Ebanyat, 2009) and this has been partly attributed to low organic matter content (Vanlauwe et al., 2015). Organic matter increases fertilizer use efficiency by supplying the secondary and micronutrients required in the uptake and utilization of macronutrients supplied from mineral fertilizers. Musinguzi et al. (2016) established a range of 1.9-2.2% carbon as the critical concentration for crop response to mineral fertilizer inputs. However, most soils in Uganda have carbon levels below this range (Nkonya et al., 2008). Addition of organic matter would help to improve soil organic carbon stocks but there are limited sources of manure especially in regions where animals are not part of the farming system. Organic resources in most African farming systems have competing uses on the farm (Rufino et al., 2011). Bekunda (1999) revealed that crop residues from maize and beans are mainly put in banana plantations and a result cause soil mining in annual cropping fields. Moreover, the natural means of managing soil fertility like use of fallows have broken down due to land scarcity as a result of increased population pressure on land (Ebanyat, 2009). As a result, most farmers who have continued to get low crop yields due to continued soil nutrient depletion without affordable means of replenishing the lost nutrients to maintain the soil fertility. Therefore, any strategy for improving crop yields should consider building organic matter to levels that can improve the soils' response to fertilizer inputs. This can be achieved by sole or combined application of organic matter with mineral fertilizers and providing farmers with readily available organic matter sources. In this study, we focus on the use of water hyacinth as a potential source of manure for crop production.

The water hyacinth is an aquatic weed present on Lake Victoria and other water bodies in Uganda and spreads rapidly due to its high productivity rate (Amoding et al., 1999). It is considered a menace on aquatic resources but, it accumulates nutrients like nitrogen (N), phosphorus (P), potassium (K) and micronutrients which may be recovered for use to boost agricultural productivity. Amoding et al. (1999) reported that water hyacinth absorbs about 99 kg N ha^{-1}, 8 kg P ha^{-1} and 182 kg K ha^{-1} within a week. However, the study did not go ahead to produce water hyacinth compost and determine the effect of such compost on crop production. In this study, the water hyacinth was co-composted with locally available materials like poultry manure, cattle dung and molasses to fortify its nutrient levels. We assessed the comparative performance of water hyacinth-based compost on crop production using field experiments to determine the most effective water hyacinth-based compost formulation and application rate for crop production.

MATERIALS AND METHODS

Preparing the composts

In order to hasten compost maturity, the water hyacinth was composted using the above ground pile method in boxes of 1.5 m length × 1.5 width × 1.5 m height as described in Beesigamukama et al. (2018). The experiment had four treatments: (i) Water hyacinth co - composted with cattle manure (WH+CM), (ii) Water hyacinth co - composted with poultry manure (WH+PM), (iii) Water hyacinth composted with molasses (WH+MO) and (iv) the control where the water hyacinth was composted alone (WH alone). Table 1 shows selected characteristics of water hyacinth and other materials used in composting. Molasses had a total sugar content of 54.6%, which was determined phenol sulphuric acid method (AOAC International, 2003). The experiment was managed using standard composting procedures (Epstein, 1997) and compost from all treatments was mature in six weeks. The mature compost was harvested and used in the field experiment. Table 2 presents the chemical characteristics of the composts that were used in the experiment. Fortification of water hyacinth with poultry manure produced compost with highest concentration of N, P and K while the unfortified compost had least nitrogen and potassium.

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''), 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 3 shows selected soil characteristics of the sites. The soils are acidic in nature with low nitrogen, phosphorus, organic matter and calcium levels, moderate potassium, and sufficient magnesium. 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 experiments were set out in 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 two rates of 3 and 6 t ha^{-1} and the control where no compost was applied. 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 × 30 cm (one plant per hill). Plots of 3 × 3 m were used and spacing of one and two metres was left between the plots and blocks respectively.

Table 1. Characteristics of raw materials used in composting.

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

TOC= Total organic carbon, TON= Total organic nitrogen.

Table 2. Characteristics of the water hyacinth compost formulations used in experiment.

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 alone	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, TON=Total organic nitrogen, TOC= Total organic carbon.

Table 3. Selected soil physical and chemical characteristics of the sites.

Sites	pH (1:2.5 water)	TON		SOM	Av. P	Ex. cations (cmol/kg)		Textural class
		(%)		(mg/kg)	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)
TON= Total organic nitrogen, SOM= soil organic matter, Av. P= available phosphorus, Ex. cations = Exchangeable cations.

Data collection

Data were collected on plant height, number of leaves and leaf area. Plant heights were determined by measuring the height of the selected plants from the ground level up to the base of the fully opened youngest leaf. Number of leaves was determined by counting while leaf area was calculated as a product of leaf length and width that were measured using a tape measure. Leaf area, number of leaves and a correction factor of 0.71 were used to calculate leaf area index (LAI) using the formula by Edje et al. (1987) below.

$$\text{LAI} = \frac{\text{Number of leaves} \times \text{leaf area}}{\text{Land area}} \quad (1)$$

Grain and stover yield data were collected at harvesting from a net plot area of 2.25 m^2. Grain samples were collected from each plot, taken to the laboratory and oven dried at 70°C for 72 h to determine total dry matter by correcting to a moisture content of 12%. The grain yield was then expressed on a hectare basis. Grain and stover yields obtained were used to calculate harvest index as a ratio of grain yield to biological yield. The grain yield from each treatment was used to determine the additional amount of economic yield per unit N supplied from each treatment by calculating agronomic efficiency (AE) according to (Baligar et al., 2001).

$$\text{AE (kg kg}^{-1}) = \frac{(Yield_F - Yield_C)\, kg}{(Quantity\ of\ nutrient\ applied,\ kg)} . \quad (2)$$

Data analysis

Data were analyzed using GenStat discovery 10th edition for windows. Analysis of variance test was done to generate means for leaf area index, plant height, yield and agronomic nitrogen efficiencies. Correlation analysis was run to establish the relationship between maize growth parameters and grain yield. Significant means were separated using Fishers protected LSD at 5% significance.

Table 4. Effect of water hyacinth-based composts on maize leaf area index.

Compost type	Rates (t ha^{-1})	Leaf area index at different growth periods		
		6 weeks	8 weeks	10 weeks
Control	0	2.01	2.80	2.81
WH+MO	3	2.33	3.88	3.14
WH+CM	3	2.12	3.23	2.85
WH+PM	3	2.13	3.54	3.05
WH alone	3	2.26	3.43	2.99
WH+MO	6	2.31	3.64	2.17
WH+CM	6	2.30	3.59	3.05
WH+PM	6	2.28	3.66	3.10
WH alone	6	2.19	3.57	3.35
LSD$_{(0.05)}$		**0.36**	**0.43**	**0.43**
CV (%)		**22.3**	**16.9**	**19.4**

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; 3 and 6 t ha^{-1} are compost application rates.

Table 5. Maize height at six weeks and increases in height at 8 and 10 weeks after application of water hyacinth-based composts.

Compost type	Rates (t ha^{-1})	Plant height at 6 weeks	Increase from 6th to 8th week	Increase from 8th to 10th week
		(cm)		
Control	0	32.1	49.7	75.2
WH+MO	3	45.7	70.2	70.1
WH+CM	3	41.1	61.4	76.4
WH+PM	3	41.0	62.6	69.6
WH alone	3	41.0	60.6	69.1
WH+MO	6	44.4	64.3	70.0
WH+CM	6	43.1	60.5	76.3
WH+PM	6	45.4	67.0	69.9
WH alone	6	43.6	61.7	73.1
LSD$_{(0.05)}$		**6.9**	**7.5**	**16.2**
CV (%)		**22.5**	**41.6**	**37.9**

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; 3 and 6 t ha^{-1} are compost application rates.

RESULTS

Maize leaf area index (LAI)

Compost treatments had significant ($p<0.05$) effect on leaf area index at eight and ten weeks after planting (Table 4). Leaf area index for all treatments increased up to eight weeks and started reducing beyond eight weeks. Compost formulations applied at 6 t/ha produced higher LAI than those applied at 3 t ha^{-1} but the differences were statistically similar. However, the largest LAI of 3.88 was recorded from (WH+MO) applied at 3 t ha^{-1}, and this was significantly higher than that of control. At 10 weeks, LAI for (WH alone) at 6 t ha^{-1} was significantly ($p<0.05$) higher that of control by 19%.

Maize plant height

All compost treatments irrespective of the rates produced significantly higher plant heights ($p<0.05$) than the control at six weeks (Table 5). Similar trends of events were observed in the eighth and tenth week. Similarly, increases in plant height after compost application were significantly ($p < 0.05$) higher than those of the control from the sixth to eighth week irrespective of the rates. At the tenth week, increases in plant height were not significantly different ($p≥0.05$), indicating slowdown in

Table 6. Effect of water hyacinth-based composts on maize yield.

Compost formulations	Rates ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Harvest index	N_{AE} ($kg\ kg^{-1}$)
Control	0	4.4	0.45	
WH+PM	3	6.5	0.47	25.3
WH+MO	3	6.5	0.42	42.6
WH+CM	3	6.3	0.43	29.8
WH alone	3	6.0	0.39	41.5
WH+CM	6	6.8	0.45	19.7
WH+MO	6	6.6	0.42	19.0
WH alone	6	6.1	0.42	20.8
WH+PM	6	5.8	0.41	11.0
LSD		**1.1**		**19.4**
CV (%)		**25.7**		**77.1**

Key: N_{AE} = agronomic nitrogen efficiency; 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; 3 and 6 t ha^{-1} are compost application rates.

vertical growth. The highest increases in maize plant heights from the sixth to eighth week were recorded from (WH+MO) at 3 t ha^{-1} while (WH+CM) at both rates recorded the highest increase from eight to ten weeks. The least increases in plant height were observed in the control treatment (no input) at both sampling weeks (Table 5).

Maize yield and agronomic nitrogen efficiency

All compost treatments irrespective of the rates produced significantly ($p<0.05$) larger maize grain yields than the control (Table 6). 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. However, the highest harvest index and agronomic nitrogen efficiencies were recorded at the lower rate of 3 t ha^{-1}, and the control treatment performed better than WH alone in terms of harvest index at the same rate. With the exception of WH+CM, increasing compost application rate to 6 t ha^{-1} reduced agronomic nitrogen efficiencies by more than 50%.

Correlation between growth parameters and maize grain yield

There was generally strong positive correlation between plant heights at all growth periods and grain yield (Figure 1). The strongest relationship of all was obtained at six weeks ($r=0.8$) while weakest was obtained at eight weeks. Of all the three stages, plant height affected yield significantly only at 10 weeks ($p<0.05$). The correlation between maize grain yield and leaf area index (LAI) varied greatly but strongest at eight weeks ($r=0.8$) and weakest at 10 weeks ($r=0.49$) (Figure 2). However, LAI did not significantly affect grain yield for all the three growth periods ($p\geq0.05$).

DISCUSSION

Effect of water hyacinth composts on maize growth

It was noted that all compost treatments produced significantly ($p<0.05$) higher plant heights than the control, and that compost treatments applied at 6 t ha^{-1} produced higher plant heights than those applied at 3 t ha^{-1} (Table 5). The higher mean plant heights associated with 6 t ha^{-1} compared to the 3 t ha^{-1} rate can be attributed to the supply of enough nutrients (N, P and K) that are essential for maize growth. The tallest plants height observed throughout the experiment for (WH+PM) applied at 6 t ha^{-1} were because (WH+PM) had higher nitrogen and phosphorus concentrations (Table 2). Phosphorus is important in root growth and development and therefore nutrient uptake; while nitrogen is important in photosynthesis and protein formation hence fast growth in terms of height and leaf expansion (Hawkesford et al., 2012).

The higher increases in maize plant height associated with treatment (WH+MO) applied at 3 t ha^{-1} at six, eight and ten weeks (Table 5) are because this treatment was able to supply just enough nutrients required for plant growth without excesses. The same trend was observed on leaf area index (Table 4). There, were therefore, little or no cases of antagonism or toxicity due to excess nutrient supply that could have affected plant growth. The

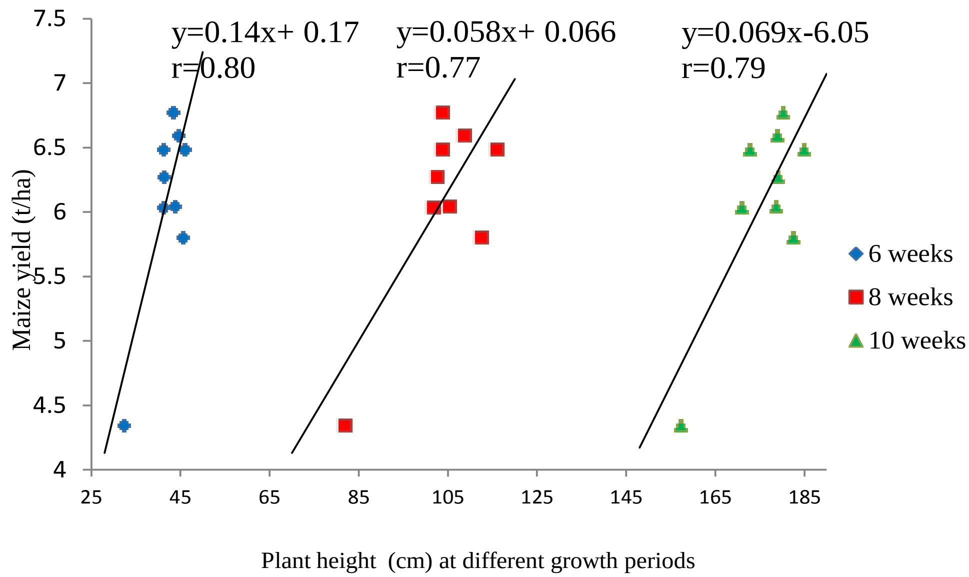

Figure 1. Relationship between maize grain yield and plant height after application of water hyacinth-based composts.

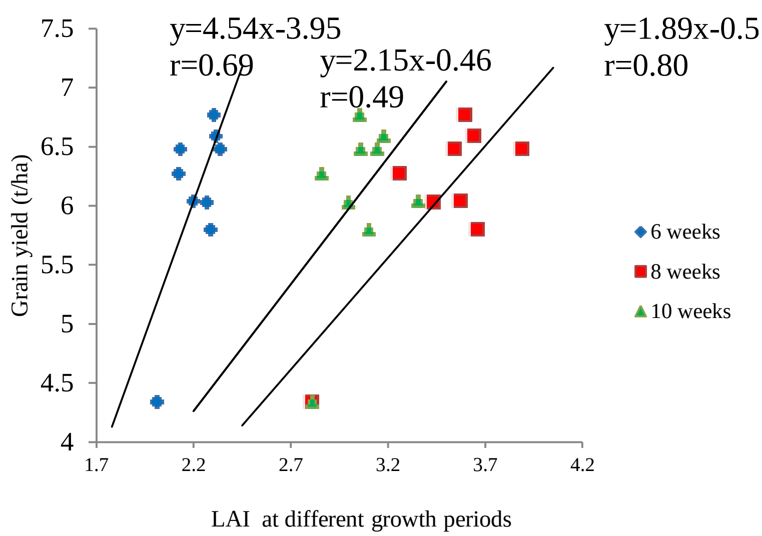

Figure 2. Relationship between maize grain yield and LAI after application of water hyacinth-based composts.

non-significant difference ($p \geq 0.05$) in maize height between 3 and 6 t ha^{-1} implies that the plant had absorbed enough of the nutrients it required at 3 t ha^{-1}. Therefore, most nutrients that were absorbed beyond 3 t ha^{-1} were not utilized in the plant growth and development processes hence no significant difference ($p \geq 0.05$) in growth parameters like height between the two rates even though 6 t ha^{-1} produced higher means. High plant and leaf area index are important in positioning the plant to trap photosynthetically active radiation to make enough assimilates important for grain formation. This is confirmed by the strong correlation of growth parameters with grain yield (Figures 1 and 2).

Effect of water hyacinth compost on maize grain yield

The control treatment (no input) realized the least grain yield yet there was no significant ($p \geq 0.05$) difference between grain yield at 3 and 6 t ha^{-1} (Table 5). The significant difference ($p < 0.05$) in grain yield observed between different water hyacinth compost formulations and the control has been reported in other studies

(Evanylo et al., 2008; Rutonesha, 2009; Osoro et al., 2013). The significantly ($p<0.05$) higher grain yields of compost formulations compared to the control could be because of the higher nutrient contents of the compost formulations 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. Ming-Mang et al. (2008) reported similar corn uptake of N, P and K in compost but significantly higher ($p<0.05$) than those in the control treatment, hence giving higher grain yield than the control. 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}, higher harvest indices and agronomic nitrogen efficiencies obtained using lower application rate of 3 t ha^{-1} indicate the role of fortified composting in compost quality improvement. With a nutrient rich compost, a small amount is required to satisfy crop nutrient demands. The two fold reduction in agronomic efficiency at 6 t ha^{-1} means that the plant had taken up enough nutrients 3 t ha^{-1} and there was luxury consumption beyond this rate. The higher harvest indices recorded at 3 t ha^{-1} mean that enough nutrients were taken up and converted into economic yield.

Conclusion

This study has demonstrated that the compost derived from water hyacinth is a good soil conditioner to enhance maize grain yields in soils of Uganda, with acidic pH. Application of water hyacinth-based compost at higher rate of 6 t ha^{-1} produced higher maize grain yield, leaf area index and plant height than the rate of 3 t ha^{-1} but highest agronomic nitrogen efficiencies and harvest index were obtained at lower rate of 3 t ha^{-1}. The most effective dose of water hyacinth-based compost in enhancing grain yields is 3 t ha^{-1} and the compost should be made using poultry manure. Future studies should determine the effect of water hyacinth-based composts on soil physical, chemical and biological properties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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