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Effects of Water Hyacinth (*Eichhornia crassipes* [mart.] solms) Compost on Growth and Yield Parameters of Maize (*Zea mays*)

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Authors' contributions

This work was carried out in collaboration of all the authors. Authors JMM, JOM and OO designed the study and supervised the greenhouse and field experiments. Author DM was involved in supervision of field experiments. Author AA supervised the soil and compost analysis, authors NO and MM carried out the greenhouse and field experiments, collected the data, performed the statistical analysis and wrote the first draft of the manuscript. Authors OO and JMM read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: To evaluate the effects of water hyacinth compost prepared with various cultures on growth and yield parameters of maize.
Study Design: Randomized Complete Block Design.
Place and Duration of Study: Field experiments were carried out at Otonglo Division in Kisumu County and greenhouse trials were carried out at Kenyatta University from November 2011 to August 2012.
Methodology: The water hyacinth compost was prepared using effective microorganisms

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(EM) solution, cow manure and molasses separately as starter cultures for composting. The compost was applied on maize (H513) on separate growth pots in the greenhouse and plots in the field. The treatments applied included compost prepared with EM (8.84 g/pot), compost prepared with cow manure (8.84 g/pot), compost prepared with molasses (8.84g/pot), diammonium phosphate (DAP) fertilizer (70.7 mg N/pot) and control (without fertilizer). For the field experiments, water hyacinth compost was applied at a rate of 5000 kg ha^{-1} and DAP at 40 kg N/ha. The experiments had five treatments and three replications for each treatment in the greenhouse and four treatments replicated four times in three farmers' fields.

Results: Application of water hyacinth compost and DAP significantly influenced positively ($P \leq 0.05$) the growth attributes of maize. Among the various treatments of the compost, water hyacinth compost prepared with EM (WHE) performed better in most parameters evaluated including plant height, shoot dry weight, root dry weight and root collar diameter. Yield parameters such as 100 seed weight and grain yield were not significantly ($p > 0.05$) influenced by various treatments.

Conclusion: Water hyacinth which is locally available and in large quantities (especially in lake Victoria) can be composted to prepare organic fertilizers and effectively used as an organic soil amendment to restore soil and increase maize production.

Keywords: Water hyacinth; compost; maize; growth parameters; yield.

ABBREVIATIONS

ANOVA	*Analysis of Variance*
C	*Carbon*
Ca	*Calcium*
CAN	*Calcium Ammonium Nitrate*
cm	*Centimetre*
DAE	*Days After Emergence*
DAP	*Di Ammonium Phosphate*
EM	*Effective Microorganisms*
G	*Gram*
Ha	*Hectare*
K	*Potassium*
kg	*Kilogram*
m	*Metre*
mm	*Millimetre*
N	*Nitrogen*
P	*Phosphorus*
RCD	*Root Collar Diameter*
SPSS	*Statistical Package for Social Sciences*
WHC	*Water hyacinth compost prepared using cattle manure treatment*
WHE	*Water hyacinth compost prepared using EM treatment*
WHM	*Water hyacinth compost prepared using molasses treatment*

1. INTRODUCTION

Recent census report on the population of the Lake Victoria Basin shows that about 80% of the population is engaged in agricultural production [1]. These farmers continuously cultivate their land leading to a reduction in soil fertility and reduced crop productivity [2]. Chemical fertilizers which are currently being used by farmers in the region are expensive; cause eutrophication hence algal blooms emerge and increase the overall greenhouse gases such as the oxides of carbon and nitrogen leading to global climate change and environmental destruction [3]. The economic and environmental costs as a result of the use of the chemical fertilizers together with their negative impacts to the environment are now of global concern hence there is need to shift to sustainable organic farming practices such as the use of fertilizers produced from locally available organic materials [4]. The use of organic fertilizers from unexploited natural resources perceived as weeds, such as the water hyacinth, would be a better alternative to improve soil fertility and increase crop yield.

Water hyacinth (*Eichhornia crassipes* [Mart.] *Solms*) is a free floating macrophyte (in the family Pontedericeae, Liliales) that grows in fresh water, but may be rooted in the mud, from where it draws all its nutrients directly. Water hyacinth has been recognized as the most harmful aquatic weed in the world due to its negative effects on people's livelihoods and waterways [5]. Efforts to control the weed through chemical, physical and biological methods have met with little success [6]. However, there is a continued theme from some researchers that there is significant benefit to be obtained from seeing water hyacinth a resource rather than a rogue plant [6,7,8]. The weed is considered a valuable source of macronutrients such as phosphorus, nitrogen and potassium that are essential for plant nutrition [9,10,11]. Due to the availability of water hyacinth in Lake Victoria in large quantities; it can be used as a material for production of organic fertilizer. The compost could then be applied to plants as a source of nitrogen, phosphorus and potassium (NPK) which are the macro nutrients that limit crop growth [12,13].

Maize (*Zea mays*) is the most important staple food in Kenya providing about 40% of the populations' caloric requirements and forming the major component of meals. Kenya produces an average of 30 million bags of maize annually most of which is from smallholder farms with an average of 1.5-2.5 acres per household [14]. At smallholder farmer level, yields are low averaging 1.5 tons/ha compared to research centre yields of 6-8 tons/h [15]. The yield of maize could improve as a result of improved soil fertility management through compost application [16]. No research has been carried out and documented on the effects of application of water hyacinth compost on maize especially within the Lake Victoria Basin. The objective of the study was therefore to assess the effectiveness of the organic fertilizer from composted water hyacinth on growth and yield of maize (*Zea mays*).

2. MATERIALS AND METHODS

2.1 Study Site

The field experiments for the study were conducted at Korando sub location, Otonglo Division, Kisumu County in Lake Victoria Basin from November 2011 to August 2012. The three farms used in maize production (designated as farm A, B and C) lie within latitude 0^o 05' S and 0^o 06' S and longitude 34^o 41' E and 34^o 43' E at an elevation between 1115 M and 1133 M above the sea level. Planting was done during the long rain season between April and July. Greenhouse and laboratory experiments were carried out at the Department of Plant and Microbial Sciences in Kenyatta University from January 2012 to March 2012.

2.2 Preparation of Water Hyacinth Compost

Water hyacinth was harvested manually, sun-dried and chopped into small pieces of about 5 cm. Above ground closed aerobic heap design was used to prepare the compost for fifty days. The water hyacinth compost was prepared using effective microorganisms (EM) solution, cow manure and molasses separately as starter cultures for composting. The physical characteristics of the compost were observed and its chemical composition was assessed in terms of the total nitrogen, organic carbon, total phosphorus, total potassium and pH.

2.3 Greenhouse Experiments

Clean plastic pots measuring 15 cm diameter and 20 cm height were used. The pots were filled with soil and moistened by applying water until all the soil was thoroughly wet. Various fertilizer treatments were applied to each soil per pot and thoroughly mixed. Five viable maize seeds per pot of uniform size and shape were sown at a depth of 3 cm and one week after emergence, they were thinned to three seedlings per pot. The treatments administered were as follows: Maize and water hyacinth compost prepared with EM (WHE), maize and water hyacinth compost prepared with cattle manure (WHC), maize and water hyacinth compost prepared with molasses (WHM), maize and nitrogen fertilizer (DAP at 70.70 mg N/pot), maize with no fertilizer (Control). Water hyacinth compost was applied at the rate of 8.84 g/pot. Watering of the pots was carried out by adding 100 ml of water on alternate days to each pot. Each treatment was replicated thrice on separate blocks and the pots arranged in a Randomized Complete Block design. Sampling of plants was done at 15, 30 and 45 days after emergence (DAE). The root collar diameter and height of the maize plant sampled was measured and recorded. The shoots and the roots of the plants were also separated, oven dried at 60ºC to constant weight and their dry weights measured and recorded. Each greenhouse experimental set up was terminated after 45 days. The experiment was repeated three times.

2.4 Field Experiments

At the field, three researcher managed farmers' fields were prepared by disc ploughing followed by harrowing. Soil was sampled and taken to the laboratory for physical and chemical analysis [17]. Each field was then demarcated into four main blocks with four plots separated by 1 m paths to minimize inter-plot interference. Viable and uniform seeds for maize were planted in the plots in the field at the onset of rains in April, 2012. Two seeds per hole were planted with various treatments and two weeks after germination, they were thinned to one plant per hole after the first weeding. An inter-row spacing of 0.75 m and intra-row spacing of 0.3 m was used. Twenty eight maize plants per plot were retained after thinning. First weeding was carried out in all the farms at two weeks after emergence, after which the plants were top dressed using CAN fertilizer (CAN at 40 kg/ha) for those plots that had been planted with nitrogen fertilizer. Second weeding was carried out four weeks later. The layout in each field was a Randomized Complete Block design with four blocks hence four replications for each treatment. The treatments administered were the same as the greenhouse treatments excluding WHM. Water hyacinth compost was applied at the rate of 5000 kg/ha while DAP (NPK ratio was 18:46:0) was applied at the rate of 40 kg N/ha. CAN (26% N) was applied at the rate of 40 kg N/ha to those plots that had been treated with DAP fertilizer.

2.5 Soil and Compost Analysis

Particle size of the soil samples, pH and composition of nutrients for both soil and compost samples were determined. The particle size was determined by the hydrometer method [17] while the pH was determined using a calibrated Fieldscout pH meter, IQ150 from Spectrum technologies, in aqueous extracts of 1:10 ratio using distilled water. Nutrients such as total nitrogen (Kjedahl method), nitrate – nitrogen (colorimetric method), available phosphorus (Olsen's method), potassium (flame photometry), exchangeable calcium (atomic absorption photometry), organic carbon (Walkey and Black method) and sodium (flame photometry) were all analyzed [17].

2.6 Data Handling

The data obtained from measurement of various growth and yield parameters was analyzed using one way ANOVA with SPSS computer software version 11.5 for Windows. Means were separated using Tukey's honest significant difference at 5% level.

3. RESULTS

3.1 Shoot Dry Weight

The treatments had a significant effect on the shoot dry weight of maize on the 30th DAE (P = .000) and 45th DAE (P = .000) but not on the 15th DAE (P = .565). Plants grown on soils amended with DAP and WHM had a mean shoot dry weight of 0.79 g, followed by WHC treatment with a mean shoot dry weight of 0.73 g, WHE treatment with a mean shoot dry weight of 0.68 g and the least mean dry weight of 0.54 g was recorded among plants grown on soil with no added fertilizer (control) on the 15th DAE. Soils amended with DAP led to plants with a mean shoot dry weight of 3.06 g which was the highest mean weight on the 30th DAE and significantly different from plants treated with WHC and the control that produced a mean shoot dry weight of 1.48 g. The shoot dry weight of plants grown on soils amended with WHE and WHM was also significantly different from the control on the 30th DAE weighing 2.41 g and 2.56 g respectively. Soils amended with DAP led to plants with a mean shoot dry weight of 11.07 g on the 45th DAE which was the highest mean weight and significantly different from all other treatments while control produced a mean shoot dry weight of 2.19 g per plant on the 45th DAE (Table 1).

Table 1. Mean shoot dry weight (g) of maize grown in the greenhouse under different soil amendments

	Mean shoot dry weight (g)		
Treatment	**15 DAE**	**30 DAE**	**45 DAE**
WHC	0.73±0.13^{aX}	2.16±0.21^{abX}	4.24±0.41^{aX}
WHE	0.68±0.09^{a}	2.41±0.19^{bc}	5.72±0.59^{a}
WHM	0.79±0.09^{a}	2.56±0.15^{bc}	4.01±0.10^{a}
DAP	0.79±0.18^{a}	3.06±0.29^{c}	11.07±2.11^{b}
Control	0.54±0.08^{a}	1.48±0.13^{a}	2.19±0.28^{a}

DAE- Days after emergence.

^{X}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHC - Water hyacinth compost prepared using cattle manure treatment; WHE - Water hyacinth compost prepared using EM treatment; WHM - Water hyacinth compost prepared using molasses treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

Soil amendments significantly influenced the shoot dry weight of maize plants in farm A at tasseling stage (*P* = .00). Plants grown on the soil amended with DAP and WHC had a mean shoot dry weight of 448.50 g and 401.00 g respectively which were significantly higher compared to WHE and control that recorded a shoot dry weight of 281.00 g and 251.00 g per plant respectively (Table 2). Soil amendments had a significant effect on the shoot dry weight of maize at farm B (*P* = .00). Plants grown on soil amended with DAP had a mean shoot dry weight of 398.00 g and performed significantly better compared to all other treatments.

Amendment of the soil with WHE yielded plants with a mean shoot dry weight of 260.25 g followed by WHC and control whose plants had a weight of 225.00 g and 199.75 g respectively (Table 2). Various soil amendments significantly affected the shoot dry weight of maize at farm C (*P* = .00) at tasseling stage. Plants grown on soils amended with DAP and WHE had a significantly higher mean shoot dry weight compared to those grown on soil amended with WHC and control treatments. Amendment of soil with DAP, WHE, WHC and control led to plants with a mean shoot dry weight of 435.75 g, 248.25 g, 248.75 g and 170.50 g respectively (Table 2).

Table 2. Mean shoot dry weight of maize at tasseling grown in four farms under different soil amendments at Korando B during the long rain season of 2012

	Mean shoot dry weight (g		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	281.00 ± 16.65^{aX}	260.25 ± 7.32^{aX}	248.25 ± 28.65^{bX}
WHC	401.00 ± 13.21^{b}	225.00 ± 13.12^{a}	248.75 ± 8.29^{a}
DAP	448.50 ± 16.35^{b}	398.00 ± 18.64^{b}	435.75 ± 22.53^{b}
Control	251.00 ± 15.85^{a}	199.75 ± 16.69^{a}	170.50 ± 12.36^{a}

[x]*Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle* manure *treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.*

3.2 Root Dry Weight

The root dry weight of maize grown under different soil amendments was significantly different on the 30^{th} and 45^{th} day after emergence (*P* = .000 on the 30^{th} DAE and *P* = .000 on the 45^{th} DAE). The control had the lowest mean root dry weight of 0.14 g on the 15^{th} DAE, 0.42 g on the 30^{th} DAE and 1.05 g on the 45^{th} DAE (Table 3). The highest mean root dry weight, 0.18 g on the 15^{th} DAE, was recorded when the soil was amended with WHM compared to other treatments although there was no significant difference (Table 3). Roots from soil amended with WHE, DAP and WHC had a mean dry weight of 0.17 g, 0.16 g and 0.15 g respectively on the 15^{th} DAE. The mean root dry weight of maize plants grown in soil amended with WHM was 0.93 g on the 30^{th} DAE which was significantly higher compared to that of plants grown on soil amended with DAP that weighed 0.55 g (Table 3). Maize roots from plants grown on the soil amended with WHC had a mean weight of 0.77 g while those from WHE weighed 0.70 g on the 30^{th} DAE. Plants obtained from soil amended with DAP had the highest mean root dry weight of 3.50 g on the 45^{th} DAE which was significantly different from all other treatments (Table 3).

Table 3. Mean root dry weight (g) of maize grown in the greenhouse under different soil amendments

	Mean root dry weight (g)		
Treatment	**15 DAE**	**30 DAE**	**45 DAE**
WHC	0.15±0.04^{aX}	0.77±0.08^{bcX}	2.13±0.22^{aX}
WHE	0.17±0.04^{a}	0.70±0.02^{bc}	2.06±0.30^{a}
WHM	0.18±0.04^{a}	0.93±0.08^{c}	1.85±0.08^{a}
DAP	0.16±0.05^{a}	0.55±0.03^{ab}	3.50±0.53^{b}
Control	0.14±0.04^{a}	0.42±0.04^{a}	1.05±0.09^{a}

DAE- Days after emergence.

^{X}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHC - Water hyacinth compost prepared using cattle manure treatment; WHE - Water hyacinth compost prepared using EM treatment; WHM - Water hyacinth compost prepared using molasses treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

Soil amendments significantly influenced the root dry weight of maize plants in farm A at tasseling stage (*P* = .008). Plants grown on soils amended with WHC and DAP had a mean root dry weight of 100.00 g and 99.00 g respectively which was significantly higher compared to the control that recorded a mean root dry weight of 51.00 g. Soil amendments had a significant effect on the root dry weight of maize at farm B at tasseling (*P* = .000). Plants grown on soil amended with DAP had a mean root dry weight of 100.25 g which was significantly higher compared to all other treatments. Amendment of the soil with WHE yielded plants with a mean root dry weight of 49.50 g whereas WHC and control treatments had plants whose roots had a mean dry weight of 49.25 g and 50.50 g respectively (Table 4). Various soil amendments significantly affected the root dry weight of maize at farm C (*P* = .000) at tasseling stage. Plants grown on soils amended with WHC and DAP had roots that had a significantly higher root dry weight compared to those of plants from WHE treatment and control (Table 4). WHC, DAP, WHE, and control had plants with a mean root dry weight of 67.25 g, 50.50 g, 24.00 g and 18.50 g respectively.

Table 4. Mean root dry weight of maize at tasseling grown in four farms under different soil amendments at Korando B during the long rain season of 2012

	Mean root dry weight (g)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	88.50±11.35^{abX}	49.50±5.61^{aX}	24.00±2.38^{aX}
WHC	100.00±9.44^{b}	49.25±3.71^{a}	67.25±8.36^{b}
DAP	99.00±8.68^{b}	100.25±5.02^{b}	50.50±5.33^{b}
Control	51.00±6.12^{a}	50.50±4.41^{a}	18.50±1.85^{a}

^{x}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

3.3 Plant Height

Maize plants had significant differences in their height under various treatments in the greenhouse on the 30th and 45th day after emergence (*P* = .049 and *P* = .000 respectively) while there was no significant difference on the 15th DAE (*P* = .073). The least mean plant height on the 15th DAE, 13.42 cm, was recorded for the maize plants from the soil which had not been amended with fertilizer (control) while the highest mean height of 16.95 cm was recorded in plants grown on soil amended with DAP (Table 5). A mean height of 26.58 cm was recorded as the highest on the 30th DAE for plants obtained from soil amended with DAP which was not significantly different from those plants grown in the soil amended with WHM, WHE and WHC that had a mean height of 23.82 cm, 23.58 cm and 22.08 cm respectively (Table 5). The control had a significantly lower plant height compared to DAP on the 30th DAE. The highest mean plant height of 36.87 cm was recorded on the 45th DAE for plants grown on soil amended with DAP which was significantly different from those plants grown in the soil amended with WHM, WHC and the control with a mean plant height of 28.87 cm, 26.17 cm and 23.67 cm respectively (Table 5).

Table 5. Mean height (cm) of maize plants grown in the greenhouse under different soil amendments

	Mean plant height (cm)		
Treatment	**15 DAE**	**30 DAE**	**45 DAE**
WHC	15.57 ± 0.56^{aX}	22.08 ± 0.97^{abX}	26.17 ± 1.19^{aX}
WHE	16.32 ± 0.47^{a}	23.58 ± 0.72^{ab}	32.98 ± 2.05^{bc}
WHM	15.50 ± 1.15^{a}	23.82 ± 1.53^{ab}	28.87 ± 1.69^{ab}
DAP	16.95 ± 1.26^{a}	26.58 ± 2.09^{b}	36.87 ± 1.96^{c}
Control	13.42 ± 0.43^{a}	20.32 ± 1.27^{a}	23.67 ± 0.79^{a}

DAE- Days after emergence.

^{X}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHC - Water hyacinth compost prepared using cattle manure treatment; WHE - Water hyacinth compost prepared using EM treatment; WHM - Water hyacinth compost prepared using molasses treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

Soil amendments had no significant effect on the height of maize plants in farm A at tasseling stage (*P* = .064). Amendment of the soil with WHC led to the production of the tallest plants with a mean height of 262.00 cm while the control had the shortest plants with a mean height of 232.67 cm (Table 6). Plants grown on soil amended with WHE measured 258.50 cm whereas DAP plants had 253.08 cm as their mean height. Addition of compost and DAP to the soil had a significant effect on the plant height of maize at farm B during tasseling (*P* = .000). Plants grown on soil amended with WHC had a mean height of 211.00 cm which was the highest followed by those on soil amended with DAP, WHE and the control that had plants with a mean height of 206.67 cm, 203.75 cm and 166.58 cm respectively (Table 6). Various soil amendments significantly affected the root dry weight on maize at farm C (*P* = .01) at tasseling stage. The mean plant height of the plants grown on the soil amended with WHC was significantly lower compared to WHE, DAP treatments and the control. The tallest plants were recorded from soils amended with WHE with a mean height of 257.00 cm whereas WHC treatment had the shortest plants at tasseling with a mean height of 173.75 cm (Table 6).

Table 6. Mean plant height of maize at tasseling grown in four farms under different soil amendments at Korando B during the long rain season of 2012

	Mean plant height (cm)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	258.50±9.56^{aX}	203.75±6.07^{bX}	257.00±7.72^{bX}
WHC	262.00±8.48^{a}	211.00±8.52^{b}	173.75±3.73^{a}
DAP	253.08±5.02^{a}	206.67±4.43^{b}	237.92±7.51^{b}
Control	232.67±8.76^{a}	166.58±9.19^{a}	229.00±16.19^{b}

^{x}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

3.4 Root Collar Diameter (RCD)

The various treatments had a significant effect on the root collar diameter of maize plants on the 15th DAE (P = .002), 30th DAE (P = .000) and 45th DAE (P = .000). DAP treatment had plants with the highest mean root collar diameter of 10.42 mm on the 30th and 11.02 mm on the 45th DAE while soil amended with WHM led to plants with a mean root collar diameter of 7.51 mm on the 15th DAE. Plants under the control experiment had the lowest mean root collar diameter of 5.50 mm, 6.92 mm and 6.00 mm on the 15th, 30th and 45th DAE respectively. The root collar diameter on the 15th DAE of the soil which was not amended was significantly lower compared to those plants grown in soil amended with DAP, WHC and WHM whose plants measured 7.25 mm, 7.50 mm and 7.51 mm respectively (Table 7). Plants grown in soil with no added fertilizer (control) had a mean root collar diameter which was significantly lower compared to plants grown on soils treated with WHC, WHE and WHM that recorded a mean root collar diameter of 9.33, 9.50 mm and 9.58 mm respectively on the 30th DAE. Plants grown in soil amended with WHE compost had a higher and significantly different root collar diameter of 9.23 mm compared to the control unlike WHC and WHM treatments that had 7.28 mm and 7.67 mm respectively on the 45th DAE (Table 7).

Table 7. Mean root collar diameter (mm) of maize grown in the greenhouse under different soil amendments

	Mean root collar diameter (mm)		
Treatment	**15 DAE**	**30 DAE**	**45 DAE**
WHC	7.50±0.18^{bX}	9.33±0.48^{bX}	7.28±0.21^{abX}
WHE	6.67±0.21^{ab}	9.50±0.48^{b}	9.23±0.72^{bc}
WHM	7.51±0.18^{b}	9.58±0.20^{b}	7.67±0.49^{ab}
DAP	7.25±0.66^{b}	10.42±0.30^{b}	11.02±0.57^{c}
Control	5.50±0.22^{a}	6.92±0.33^{a}	6.00±0.20^{a}

DAE - Days after emergence.

^{X}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHC - Water hyacinth compost prepared using cattle manure treatment; WHE - Water hyacinth compost prepared using EM treatment; WHM - Water hyacinth compost prepared using molasses treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

Soil amendments had a significant effect on the root collar diameter of maize plants in farm A at tasseling stage (P = .002). Amendment of the soil with DAP and WHE led to the production of plants with a statistically higher root collar diameter of 3.46 cm and 3.10 cm respectively compared to those plants grown on soils amended with WHC (3.03 cm) and control (2.82 cm) in farm A (Table 8). Amendment of the soil with DAP had maize plants with the highest root collar diameter (3.51 cm) at farm B which was significantly different (*P* = .000) compared to all other treatments (Table 8). Plants grown on soil amended with WHC had a mean height of 2.67 cm whereas WHE and control treatments had plants with a mean root diameter of 2.56 cm and 2.39 cm respectively. Various soil amendments significantly affected the mean root collar diameter of maize plants at farm C (*P* = .01) at tasseling stage. Plants grown on soils amended with DAP recorded the highest root collar diameter of 2.73 cm which was significantly different from the control and WHC that had a mean of 2.52 cm and 2.44 cm respectively. WHE treatment had plants with a mean root collar diameter of 2.71 cm which was not significantly different from DAP treatment (Table 8).

Table 8. Mean root collar diameter (cm) of maize grown in four farms at tasseling stage under different soil amendments at Korando B during the long rain season of 2012

	Mean root collar diameter (cm)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	$3.10{\pm}0.13^{bX}$	$2.56{\pm}0.13^{aX}$	$2.71{\pm}0.04^{bX}$
WHC	$3.03{\pm}0.07^{a}$	$2.67{\pm}0.12^{a}$	$2.44{\pm}0.09^{a}$
DAP	$3.46{\pm}0.11^{b}$	$3.51{\pm}0.06^{b}$	$2.73{\pm}0.09^{b}$
Control	$2.82{\pm}0.11^{a}$	$2.39{\pm}0.06^{a}$	$2.52{\pm}0.04^{a}$

^{x}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

3.5 Maize Grain Yield

Various soil amendments did not have a significant effect on the maize grain yield at farm A (*P* = .61). Plants grown on soil amended with WHE produced the highest mean grain yield of 8622.75 kg/ha while DAP treatment had the least yield of 6047.83 kg/ha in farm A. WHC treatment had a mean grain yield of 6541.28 kg/ha whereas the control had 6169.47 kg/ha (Table 9).

The grain yield at farm B was not significantly influenced by soil amendments (*P* = .148). Amendment of soil with DAP resulted into a mean grain yield of 4568.41 kg/ha at the farm B which was the highest and soil amendment with WHE resulted to plants with the lowest mean yield of 2991.16 kg/ha. The mean grain yield of plants grown on soil amended with WHC was 4440.91 kg/ha whereas the control had 3105.25 kg/ha (Table 9).

There was no significant effect of the soil amendments on the grain yield in farm C (*P* = .349). Plants grown on soil amended with WHE produced the highest mean grain yield of 7759.01 kg/ha followed by DAP, control and WHC that recorded a mean grain yield of 7271.20 kg/ha, 6723.80 kg/ha and 5022.81 kg/ha respectively (Table 9).

Table 9. Mean grain yield of maize grown in the four farms under different soil amendments at Korando B during the long rain season of 2012

	Grain yield (Kg/ha)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	8622.75±2739.1	2991.16±194.43	7759.01±629.39
WHC	6541.28±738.44	4440.91±812.45	5022.81±1447.62
DAP	6047.83±902.09	4568.41±531.54	7271.20±439.47
Control	6169.47±584.87	3105.25±590.43	6723.80±1421.37

WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

Application of various amendments on soil did not significantly affect the weight of one hundred maize grains in the four farms. The mean dry weight of 100 seeds from maize plants grown on soil amended with WHE had the highest mean dry weight of 44.48 g in farm A followed by DAP (43.78 g), the control (42.22 g) and WHC (41.73 g) (Table 10).

Plants grown on soil amended with WHC had grains with the highest 100 seed mean dry weight of 37.96 g in farm B while the control had the least 100 seed mean dry weight of 32.63 g. Plants grown on soil amended with DAP and WHE treatment had grains whose 100 seed mean weight was 35.20 g and 35.17 g respectively (Table 10).

The effect of the soil amendments was not significant in farm C (P = .553). The mean dry weight of 100 seeds from soil amended with WHE of 45.24 g was the highest followed by the control, DAP and WHC which had 100 seed mean dry weight of 43.63 g, 41.36 g and 40.99 g respectively (Table 10).

Table 10. 100 seed mean dry weight of maize grains grown in four farms under different soil amendments at Korando B during the long rain season of 2012

	100 Seed dry weight (g)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	44.48±1.26	35.17±1.52	45.24±1.56
WHC	41.73±0.50	37.96±2.29	40.99±2.85
DAP	43.78±1.72	35.20±1.07	41.36±2.27
Control	42.22±0.99	32.63±2.8	43.63±2.48

WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

3.6 Stover Dry Weight

There was no significant effect of the soil amendments on the stover dry weight of maize (P = .397) in farm A. The heaviest stovers were from plants grown on soils amended with DAP which had a dry weight of 25860.9 kg/ha whereas the lightest stovers which weighed 20406.7 kg/ha were from the soils in which fertilizer was not added (control). Stovers from plants under WHC and WHE treatment recorded a mean stover yield of 22450.0 kg/ha and 20425.1 kg/ha respectively (Table 11). Soil amendments did not have a significant effect on the stover dry weight at farm B (P = .844). Soil amended with DAP led to the production of the heaviest stovers with a mean weight of 20524.9 kg/ha. The control and WHE treatments had a mean stover dry weight of 18930.00 kg/ha and 18612.22 kg/ha respectively whereas WHC treatment recorded the lowest stover dry weight of 15832.00 kg/ha (Table 11). Soil amendments significantly affected the stover dry weight of maize in farm C (*P* = .016). Plants grown on soil amended with DAP had stovers with the highest mean dry weight of 26935.7 kg/ha which was significantly different from WHC treatment that had 9611.9 kg/ha. Plants grown on soil amended with WHE and plants with no added fertilizer had a mean stover dry weight of 21782.5 and 18196.2 kg/ha respectively (Table 11).

Table 11. Mean stover dry weight of maize grown in the four farms under different soil amendments at Korando B during the long rain season of 2012

	Stover yield (Kg/ha)		
Treatment	**Farm A**	**Farm B**	**Farm C**
WHE	20425.1±2784.1^{aX}	18612.22±485.34^{aX}	21782.5±3036.3^{abX}
WHC	22450.0±2242.2^{a}	15832.0±1535.2^{a}	9611.9±738.06^{a}
DAP	25860.9±2419.7^{a}	20524.9±6941.2^{a}	26935.7±3850.1^{b}
Control	20406.7±2590.3^{a}	18930.0±2257.6^{a}	18196.2±4107.1^{ab}

^{X}Means within the column followed by the same letters are not significantly different (p > 0.05) according to Tukey's honest significant difference at 5 % level. WHE - Water hyacinth compost prepared using EM treatment; WHC - Water hyacinth compost prepared using cattle manure treatment; DAP - Diammonium phosphate (Nitrogen fertilizer) and Control - No added fertilizer.

3.7 Soil and Compost Characteristics

Soil analyzed from the three farms had characteristics as tabulated on Table 12.

Table 12. Soil chemical properties for the four experimental farms in Korando B, Kisumu before planting

Characteristic	Farm A	Farm B	Farm C
pH	6.4	5.1	6.5
Texture (% S:L:C)	20:80:0	40:60:0	20:20:60
SOM (%)	1.89	1.21	2.28
N(%)	0.11	0.07	0.12
Av P (mg/kg)	23.7	7.8	42.3
K (cmol kg^{-1})	2.82	0.37	2.12
Ca (cmol kg^{-1})	14.0	5.0	10.0
Na (cmol kg^{-1})	0.09	0.03	0.17

SOM - Soil organic matter; N - Nitrogen; Av P - available Phosphorus; K - potassium; Ca - Calcium; Na - sodium; S:L:C - Sand: Loam: Clay soil.

Compost with the various starter cultures physically turned into a black granular mass with a characteristic pleasant scent after fifty days. The chemical characteristics of compost prepared using different starter cultures were as shown in Table 13.

Table 13. Chemical composition of water hyacinth compost prepared for fifty days with various starter cultures

	Value for samples from various starter cultures		
Element	**Manure**	**EM**	**Molasses**
N (g/kg)	10.74	11.90	12.44
P (g/kg)	3.30	3.09	3.02
K (g/kg)	9.98	14.44	11.90
O.C (%)	12.83	14.95	13.35
pH (1:10)	8.10	7.98	8.13

N - total nitrogen; P - total phosphorus; K - exchangeable potassium ions; O.C - Organic Carbon; manure - Water hyacinth compost prepared using cattle manure; molasses - Water hyacinth compost prepared using molasses; EM - Water hyacinth compost prepared using EM.

4. Discussion

Application of compost and DAP led to a higher shoot biomass compared to the control of maize in the greenhouse probably due to the release of considerable amounts of nutrients, especially nitrogen and phosphorus, to the plant during mineralization that were utilized in chlorophyll formation for photosynthesis hence better plant development [4,18]. The higher shoot dry weight recorded for maize plants grown on soil amended with DAP compared to other treatments in all the farms at tasseling stage could be attributed to the availability of N and P more readily in inorganic fertilizer compared to compost that releases its nutrients slowly.

Compost contains high amounts of organic matter which could have increased the moisture retention of soil, improved dissolution of nutrients particularly phosphorus and soil structure hence better root growth and nutrient uptake [19]. Compost could have contained more microbes compared to the other treatments hence improved the soil aeration thus better root development. DAP also readily provided phosphorus that probably enhanced root development thus the higher dry weight in maize in the greenhouse. A significant increase in the root dry weight of plants with application of DAP has also been reported [18,20,21]. The higher root dry weight of maize plants grown in amended soils in farm A could probably be attributed to the improved dissolution of nutrients availed by the amendments and the high soil organic matter content hence better root growth and development [22]. The readily available phosphorus provided by DAP in soluble form could probably have been absorbed and utilized by maize plants in root development hence significantly increased the root dry weight of plants in phosphorus deficient farm B. The lower mean root dry weight of maize grown on soil amended with compost prepared using EM and DAP in farm C compared to all other farms could probably be attributed to its water logged nature of the soil as a result of the percentage clay abundance in its soil.

Chemical fertilizers offer soluble nutrients which are instantly availed to the maize plants hence perform significantly better compared to the control while compost provides the nutrients slowly but steadily and improve the soil's physical properties with time thus better uptake of nutrients by the crop but the effects are not very significant compared to the control especially at early stages of crop development [23]. This was observed in the height of maize grown on soil amended with DAP and compost in the greenhouse on the thirtieth and forty fifth day after emergence. The insignificant difference among treatments on the height of maize plants on the fifteenth day in the greenhouse was probably as a result of the uniform availability of natural nutrients in the potted soils since nutrients from the added fertilizer had not yet fully dissolved. Similar findings have been reported [24,25,26,27]. The insignificant difference among treatments on the height of maize plants in farm A could probably have been due to sufficient organic matter and slightly acidic soil pH that favoured microbial action releasing the nutrients from the soil (Table 12) hence the effect of fertilizer amendments was suppressed. This also explains their taller plants compared to maize plants from other farms for any specific soil amendment. Farm B had the lowest amount of all nutrients and soil organic matter (Table 12) hence the greater height of maize plants grown on amended soil when compared to the control could be attributed to uptake of soluble nutrients from compost and DAP by the maize hence increased growth [28]. Farm C had the highest soil organic matter, pH, nitrogen and available phosphorus compared to other farms but the soil texture that contained a higher percentage of clay soil (Table 12) and caused a high water holding capacity probably led to poor soil aeration hence poor nutrient uptake by maize plants grown on soil amended with compost prepared with cow manure.

DAP significantly increased the root collar diameter of maize plants in the greenhouse and in all farms compared to the control due to the availability of soluble nutrients that were utilized by the plants to build up their dry weights hence producing bigger plants with a statistically higher root collar diameter. Similar findings were reported by [28,29]. Maize plants grown on soil amended with compost had a higher root collar diameter in the greenhouse compared to the control due to the nutrients released by compost slowly and in small amounts with time [30]. Plants grown on soil amended with compost prepared using EM had a higher root collar diameter in farm A and C compared to those grown on soil amended with compost prepared with cow manure and the control probably due to the high organic matter in the soil and lower acidity in addition to the presence of effective microbes in the compost that increased microbial action hence faster release and absorption of nutrients from the compost. The insignificant but higher root collar diameter of plants grown on soil amended with compost prepared with EM compared to the control in farm B could probably be attributed to the high acidity and low soil organic matter in their soil (Table 12) hence reduced microbial action thus slow release of nutrients.

Farm A and C had a higher maize grain yield compared to B probably due to the higher amount of N and P in the soil (Table 12) which are the essential minerals required for plant growth and development thus no significant effect of the soil amendments. The pH in farm A and C was less acidic compared to farm B hence favoured nitrification by soil bacteria and was suitable for the production of maize [31]. In farm B, poor grain yield of maize was recorded compared to farm A and C probably due to lack of sufficient nitrogen in the soil analyzed before planting (Table 12) which stressed the plant especially at the initial growth stages thus poor growth and development. The high acidity of the soil in farm B could have caused phosphorus fixation and reduced microbial action of the available nitrogen and ammonia to absorbable nitrates which made the nutrient unavailable to maize plants hence no significant difference between the treated plots and the control was observed [18,32]. However, compost prepared with cow manure effectively regulated the soil's acidity probably by binding the exchangeable aluminium ions in the acidic soils besides releasing plant nutrients slowly hence equally produced higher maize grain yield compared to the control in farm B [33,34]. Continuous application of compost over time has been reported to produce significantly better results compared to inorganic fertilizer due to its slow but steady release of nutrients but not in the first season of application [30]. The lower yields observed in maize plants grown on soils amended with water hyacinth compost prepared using EM compared to the control in farm B could have been due to reduced nitrification rates and phosphorus fixation in the acidic soil that rendered N and P unavailable for plant uptake [33].

There was no significant difference in the weight of 100 maize seeds among various treatments probably due to the fact that all of them were of the same maize variety. Similar results were reported [27,35]. However, maize grains from Farm A and C had a higher dry weight compared to B probably due to the higher amount of N and P in the soil (Table 12) which are the essential minerals required for grain development.

The stover weight after harvest was higher in maize plants grown in soil amended with DAP compared to other amendments probably due to the release of considerable amounts of nutrients, especially nitrogen and phosphorus, to the plant during mineralization that were utilized for photosynthesis hence better plant development [18].

5. CONCLUSION

Water hyacinth compost increased the growth parameters of maize. This is therefore an indicator of better yields if proper farm management is practiced under favourable environmental conditions. DAP also performs well in crop production but its adverse effects on the soil and the environment makes its use undesirable. Although the field results indicate that maize production without fertilizer application in some farms is possible, there is fear that without replenishment, the macronutrients could be depleted leading to low yields. Therefore, compost from water hyacinth which is locally available, plentiful and cost free can be effectively used as an organic soil amendment for soil restoration and crop production. The effects of water hyacinth compost on soil characteristics will be reported in an independent paper.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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