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Enhancing maize (*Zea mays* l.) growth and nutrient uptake via application of water hyacinth (*Eichornia crassipes* [Mart.] Solms) compost and inorganic nutrients

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ABSTRACT

A soil culture experiment was conducted in the screenhouse to assess the growth response of maize to water hyacinth compost application rates and their residual effects. Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) compost, namely, 2.5 t ha^{-1}(W1) and 5.0 t ha^{-1} (W2) with and without fortification with fertilizer, F [N (25 kg ha^{-1} as urea) and P (26 kg ha^{-1} as SSP)] were mixed with portions of 5 kg soil and used to grow maize. At eight weeks after planting in each of two consecutive cropping, plant heights, biomass dry weight and their nutrient contents were determined. Soil was also sampled from each pot for chemical analyses. Compared with the control, available P and exchangeable K were increased ($p<0.05$) by W2F (27%) and W2 (43%), respectively. Similarly, W2F and W2 increased SOM by 86 and 107% ($p<0.05$), respectively, while W2F, W2 and W1F increased exchangeable Ca between 8 and 10% ($p<0.05$). Treatments W2F, W2 and W1F increased plant heights by 35–40% while W2 and W2F increased the dry matter yield by 72 and 75% ($p<0.05$), respectively. Further, sole compost or its organo-mineral form increased the tissue contents of N (98–141%), and K and Mg (103–280%). The tissue content of Ca was also increased ($p<0.05$) by W2F. Residual effects of the soil amendments were also significant on most tested soil and plant parameters. It was concluded that soil nutrient status, maize agronomic and nutrient uptake parameters were improved by the application of water hyacinth compost with and without inorganic N and P. The rate of 5.0 t ha^{-1} of the sole compost and its organo-mineral form proved superior in enhancing maize growth and soil nutrient status.

1.Introduction

Globally, agriculture (comprising crop and pasture) constitutes significant land use (Howden et al., 2007) totaling about 5 billion hectares (FAOSAT, 2014). The practice in traditional agriculture involves employing crop rotation with regular fallow periods, and animal manure or plant residue application to maintain soil fertility and health, thereby supporting crop production. However, the ever-increasing demand for food occasioned by rapid growth in human population has necessitated the replacement of these traditional methods with the application of mineral fertilizers. Despite some of the advantages of commercially available mineral fertilizers such as high solubility, facilitating the nutrient uptake by plants and better means of storage and handling (Jensen et al., 2011), their increasing inputs can lead to soil and environmental degradation, and loss of biodiversity. For example, contamination in many regions has made groundwater unfit for human consumption (Jiang and Yan, 2010; Khan et al., 2018). The environmental and increased economic costs associated with the use of chemical fertilizers are now of global concern. Hence, there is need to shift to more sustainable and environmental-friendly practices such as the use of fertilizers produced from locally-available organic materials (Mahanta et al., 2012; Gonfa et al., 2018; Nurhidayati et al., 2018). Globally, substantial quantities of organic amendments (OAs) such as plant residues (3.8×109 Mg/yr), biosolids (10×107 Mg/yr), and animal manures (7×109 Mg/yr) are generated (Thangarajan et al., 2013). Recycling these OAs in agriculture has several advantages such as improving plant growth, yield, soil carbon content, and microbial biomass and activity (Fraser et al., 1988; Vinten et al., 2002; Thangarajan et al., 2013).

Organic fertilizers could be produced from less exploited natural resources perceived as weeds, such as the water hyacinth (*Eichhornia crassipes* [Mart.] Solms) (Osoro, 2014). Water hyacinth is a free-floating macrophyte (in the family Pontedericeae) that grows in fresh water, but may be rooted in the mud, from where it draws all its nutrients. It has been recognized as the most harmful aquatic weed in the world due to its adverse effects on people's livelihoods and waterways (Wilson et al., 2005; Mbula, 2016). If left uncontrolled, water hyacinth can form continuous sheets of hundreds to thousands of hectares (Albright et al., 2004). There is no simple answer to the problem of water hyacinth and efforts currently focused on the removal of the obnoxious weed by hand, mechanically, using chemical pesticides and biological control (Mayo and Hanai, 2017). All these efforts have achieved only little success (Abdelsabour, 2010), with chemical control capable of causing environmental and health hazards in the long run (Mbula, 2016). However, the weed is considered a valuable source of macronutrients such as phosphorus (P), nitrogen (N) and potassium (K) that are essential for plant nutrition (Woomer et al., 2002). Due to the abundant availability of water hyacinth in the creeks across Nigeria's waterways, it can be used as a material for the production of organic fertilizer (Gashamura, 2009) which will improve soil N, P and K which are the macronutrients that limit most crop growth (Wasonga et al., 2008). Hence, the present investigation seeks sustainable utilization of water hyacinth waste resource as its way of management. Osoro (2014) found that cow-manure- and molasses-fortified water hyacinth compost enhanced the growth parameters of maize. However, to make the process of composting water hyacinth practicable to the peasant farmers who might not have access to some of the additives used in the previous study, we adopted pure aerobic composting without any external treatment or fortification during the process. In investigating the effectiveness of water hyacinth compost as a source of plant nutrients, in this current study, maize was selected as the test crop. Maize, the world's third most important crop after wheat and rice (Rasheed et al., 2004) is the most important cereal crop in sub-Saharan Africa (SSA). It serves as a staple food for more than 1.2 billion people in SSA and Latin America (IITA, 2014). All parts of the crop can be used for food and non-food products. Maize accounts for 30−50 % of low-income household expenditures in Eastern and Southern Africa (IITA, 2014). The grains are rich in vitamins A, C and E, carbohydrates, and essential minerals, and contain 9 % protein. They are also rich in dietary fiber and calories which are a good source of energy. The requirements of maize for macronutrients (NPK) are very high compared to those of other cereals. The maize plant needs 100 to 150 kg ha^{-1} of N, 40 to 60 kg ha^{-1} of phosphoric acid and 100 to 150 kg ha^{-1} of potassium oxide during the vegetative growth period (Singh, 1998). Some tropical soils can generally not meet more than 20 to 35 % of maize requirements for N, P and K due to the inherently low fertility status of the soils (Gashamura, 2009). Ultisol, being a soil formed from Amphibolite, and reflects the kaolinitic and oxide clay mineralogy, is inherently low in potassium (K). This soil has broad coverage in Nigeria. The objective of this study was to assess the effects of water hyacinth compost application with and without N and P on soil nutrient contents and growth response of maize on this soil type. Because water hyacinth is rich in K, we hypothesized that its compost application on this soil could make the soil more productive while cutting on inorganic fertilizer use. Hence, halves the recommended rates of N and K required for maize growth in the south-western Nigerian soils were adopted in the current study.

2.0 Materials and methods

2.1 Soil sample and compost

The screenhouse soil culture experiment was carried out at the Obafemi Awolowo University, Ile-Ife in Southwestern Nigeria. Topsoil (0-15 cm) portion of Itagunmodi series (an Ultisol) was obtained from an uncultivated plot, bulked, air-dried, pulverized and sieved using 2 mm sieve, to remove extraneous materials. The choice of the soil was based on its inherently low potassium (K) content, being a soil formed from Amphibolite, and which reflects the kaolinitic and oxide clay mineralogy. Water hyacinth *(Eichhornia crassipes)* was harvested, chopped into smaller pieces and composted aerobically (in sacks) over a period of 3 months with regular turning.

2.2 Soil and compost analysis

Soil physical and chemical properties were determined using standard methods: particle size distribution using the hydrometer method (Bouyoucos, 1962); water holding capacity and bulk density using the core sampling method (Blake and Hartge, 1986); soil pH, potentiometrically in a soil-solution ratio of 1: 2 in 0.01 M $CaCl_2$ using a glass electrode pH meter (Peech et al., 1953); available phosphorus using the Bray-1 method (Bray and Kurtz, 1945) and read after the development of the molybdenum blue colour; exchangeable cations extracted with 1 N ammonium acetate (NH_4OAc) at pH 7, and contents of sodium (Na), calcium (Ca) and K read with flame photometer while magnesium (Mg) was determined using the ethylenediamine tetraacetic acid (EDTA) titration method (Page et al., 1982). The total nitrogen (N) was determined using micro-Kjeldahl digestion and distillation process (Bremner and Mulvaney, 1982). Samples of fresh and composted water hyacinth were digested using concentrated H_2SO_4 and 30 % H_2O_2, and the contents of cations were read: K, Na, and Ca with flame photometer; Mg and heavy metals (Cd, Pb, Zn, As, and Cu) with Atomic Absorption Spectrophotometer (AAS). The organic carbon (OC) and total N contents of the compost were also determined using chromic acid digestion method of Allison (1965) and micro-Kjeldahl digestion and distillation process (Bremner and Mulvaney, 1982), respectively.

2.3 Amendment of soil samples

Five kilograms (5 kg) portions of soil were amended with water hyacinth compost with or without N (25 kg N ha^{-1} as urea) and P (26 kg P ha^{-1} as SSP). The treatments comprised:

1. Soil only (Control)
2. Soil + 2.5 t ha^{-1} water hyacinth compost (W1)
3. Soil + 5.0 t ha^{-1} water hyacinth compost (W2)
4. Soil + W1 + N (25 kg ha^{-1}) + P (26 kg ha^{-1}) (W1F)
5. Soil + W2 + N (25 kg ha^{-1}) + P (26 kg ha^{-1} (W2F)
6. Soil + N (25 kg ha^{-1}) + P (26 kg ha^{-1}) (F)

Where, W = water hyacinth compost, F= Inorganic N and P; 1 = 2.5 t/ha; 2 = 5.0 t/ha.

2.4 Greenhouse experiment

Water hyacinth compost (with or without N and P) was thoroughly mixed with 5 kg portions of soil at the rate of 0, 2.5, 5.0 t ha^{-1} on polyethylene sheets and later transferred to plastic pots perforated and plugged with cotton wool at the bottom to allow free water drainage and air exchange. The treatments were replicated three times while the pots were arranged in a completely randomized design (CRD) and watered every other day. Four maize seeds were sown per pot and thinned to two at two weeks after planting (WAP). The plants were harvested at 8 WAP and the pots replanted to evaluate the residual effects of the amendments.

2.5 Harvesting

At harvest (8 WAP), the plant heights were taken using meter rule, and the shoots and the roots were carefully harvested. The fresh weights of the shoots and the roots were taken and later oven-dried in paper bags at 65 ^oC to constant weight. The oven-dried plant tissues were weighed for the determination of the dry matter yields and later ground in a micro-hammer stainless steel mill in preparation for chemical analyses. The ground samples were analyzed for tissue contents of K, Ca, Mg and N using standard procedures as done for the fresh and composted water hyacinth.

2.6 Data analyses

The data generated were analyzed using analysis of variance (ANOVA) technique and means were separated using Duncan's New Multiple Range Test (DNMRT) at 5 % level of probability with the SAS Software Package (SAS, 1990).

3.0 Results and discussion

3.1 Properties of the soil and organic amendments

The physical and chemical properties of the soil are shown in Table 1. The textural classification of the soil was clay. The pH (0.01 M $CaCl_2$) of the soil showed an acidic reaction (4.1). The soil according to Sobulo and Adepetu (1987) and Adepetu (1990) was within the medium soil fertility range having OC of 11 g kg^{-1}. The total N (5.8 g kg^{-1}) of the soil was higher than the critical minimum (1.1 g kg^{-1}) for Nigeria soils (Adepetu and Adebusuyi, 1985; Adepetu, 1990) while the available P (21.34 mg kg^{-1}) was also within the high fertility range. A P content of 10-16 mg kg^{-1} is considered critical for crop production by Sobulo and Osiname (1981) and Adeoye and Agboola (1985). The exchangeable cation contents of the soil had the following values in cmol kg^{-1}: 5.1 Ca, 0.21 K, 3.21 Mg and 0.28 Na. Based on the critical contents of 2.5 and 0.2 – 0.4 cmol kg^{-1} Ca and Mg, respectively (Akinrinde and Obigbesan, 2000; Adeoye and Agboola, 1985), the soil was in the high fertility range. The exchangeable K content of 0.21 cmol kg^{-1} was, however, in the medium fertility range as the critical minimum value is 0.16 – 0.25 cmol kg^{-1} (Adeoye and Agboola, 1985).The chemical properties of the fresh and composted water hyacinth are presented in Table 2. The water hyacinth (W) compost contained 15.3 % OC and was, therefore, a good source of OC to the soil. The compost also showed the following analyses: N 1.05 %; P 0.67 %; K 4.81 %; Ca 0.67 %; Mg 0.02 % and Na 0.48 %. The compost was higher in virtually all nutrients determined than the fresh material. The compost in addition had low C: N ratio of 15:1 which is not up to C: N ratio of 30:1, above which N immobilization sets in (Olayinka, 2001; Flavel and Murphy, 2006). Hence, mineralization of nutrients is made possible and faster. The heavy metal and some toxic elemental contents (Cd, Pb, Zn, As, and Cu) of the compost were also analyzed (Table 2). The heavy metal contents were lower than the maximum permissible levels in sewage sludge used in agriculture (Lixandru et al., 2010), and thus qualifies as a suitable organic amendment for crop production.

Table 1 Physical and chemical properties of the soil used for the study

Property	Value
Sand (g kg^{-1})	310
Silt (g kg^{-1})	230
Clay (g kg^{-1})	460
Textural class	Clay
FMC (%)	22.3
pH (H_2O)	4.4
pH (0.01 M $CaCl_2$)	4.1
Organic carbon (g kg^{-1})	11
Total N (g kg^{-1})	5.8
Available P (mg kg^{-1})	21.34
Exchangeable cations (cmol kg^{-1})	
K	0.21
Ca	5.1
Mg	3.21
Na	0.28

3.2 Soil organic matter content and available phosphorus at the end of the first and second plantings

The SOM contents were increased by W2F (86%) and W2 (107%) ($p<0.05$) at the end of the first planting while at the end of the second planting, there was no difference between the treatments and the control (Fig. 1a). The available P was increased by only W2F over the control at the end of both the first (27%) and second (36%) plantings ($p<0.05$, Fig. 1b). This result showed the capacity of the treatment with sole, but a higher rate of compost (W2) and fortified with N

Table 2: Chemical properties of fresh and composted water hyacinth (dry weight bases) used for the study.

Chemical properties	Water hyacinth		Maximum permissible levels (mg kg^{-1} dried substance)		
	Fresh	Compost	Romania (Ord. 344/2004)	EU86/278/ECC	USA (EPA 503/1999)
Carbon (%)	37.44	15.31			
Nitrogen (%)	0.84	1.05			
Phosphorus (%)	0.92	0.67			
Potassium (%)	2.25	4.81			
Calcium (%)	0.28	0.67			
Magnesium (%)	0.02	0.02			
Sodium (%)	1.14	0.48			
Carbon: Nitrogen	45	15			
Cadmium (mg kg^{-1})	5.13	6.50	10	20-40	85
Lead (mg kg^{-1})	30.00	31.25	300	750-1200	840
Zinc (mg kg^{-1})	27.50	48.00	2000	2500-4000	7500
Asenium (mg kg^{-1})	6.88	7.50	10	-	-
Copper (mg kg^{-1})	72.25	72.50	500	1000-1750	4300

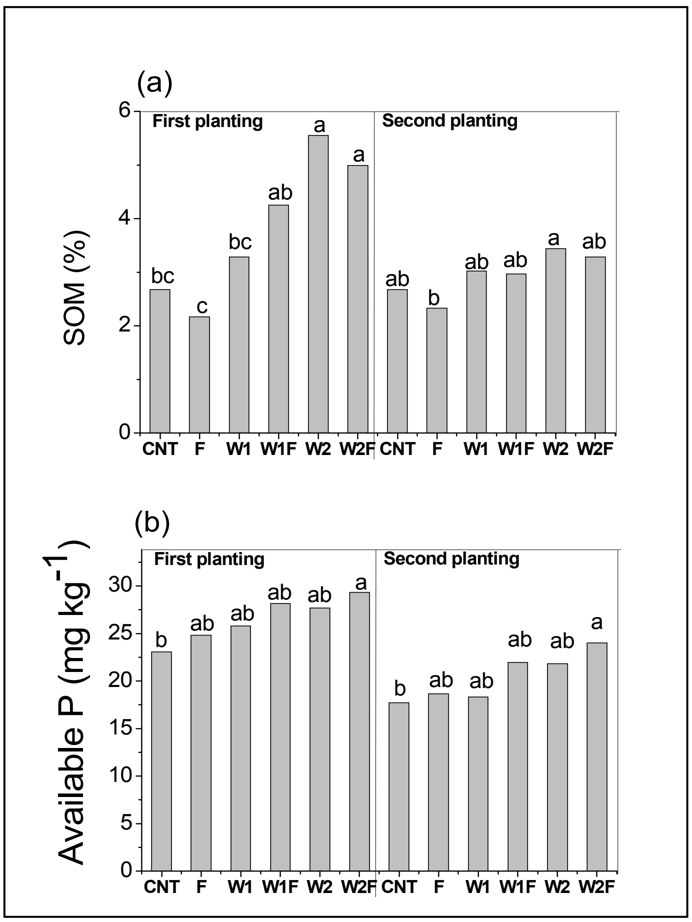

Fig. 1: Soil organic matter (SOM) (a) and available P (b) at the end of the first and second weeks of growth of maize (*Zea mays* L.). Means across treatments with similar letter(s) are not significantly different ($p<0.05$) from each other. CNT: control; F: fertilizer; W: water hyacinth compost; 1: 2.5 t ha^{-1}; 2: 5.0 t ha^{-1}.

and P (W2F) to increase the SOM as well as release more P into the soil through mineralization. Beneficial effects of applications of sole organic amendments or its organo-mineral forms on soil organic matter and other physical and chemical properties have been reported by many authors (Balesdent et al., 2000; Guo et al., 2016). Also, organic residues have been found to reduce P sorption capacity of soils and increase crop yields in P limiting soils (Nziguheba et al., 1998).

3.3 Exchangeable cations at the end of the first and second plantings

The exchangeable K was increased only by W2 over the control at the end of both the first (by 43%) and second croppings (by 77%) ($p<0.05$, Table 3). Whereas at the end of the first cropping, the exchangeable Ca was increased between 8 and 10% by W2F, W2 and W1F over the control, it was only increased by W2 (77%) at the end of the second cropping ($p<0.05$). The treatments, however, showed no significant effects on exchangeable Mg and Na at the end of each cropping. Higher rate (5.0 t ha^{-1}) of application of the compost with and without N and P improved the exchangeable K and Ca due to its enrichment of soil organic matter which acts as the soil nutrient (especially the exchangeable cations) reserve. Increases in the contents of exchangeable cations with the applications of organic wastes applied singly or combined with inorganic fertilizers were reported by Olayinka and Adebayo (1983), Olayinka (1990), Balesdent et al. (2000), Odedina et al. (2007), Ayeni (2008, 2010), and Oladipo et al. (2010).

3.4 Agronomic parameters of maize at the end of the first and second cropping

Table 3 The exchangeable cation contents of soils at the end of the first(a) and second (b) consecutive 8-week periods of maize cropping in the screenhouse.

	K	Ca	Mg	Na
Treatments	--------------------	cmol kg^{-1}	-----------------	
(a)				
Control	0.14bc*	3.53b	1.18	0.16
Fertilizer(F)	0.12c	3.33ab	1.52	0.17
W1	0.17ab	3.63ab	1.69	0.19
W1F	0.15bc	3.83a	1.35	0.21
W2	0.20a	3.87a	2.03	0.19
W2F	0.18ab	3.80a	2.37	0.22
			NS	NS
(b)				
Control	0.09b	2.57b	1.01ab	0.16
Fertilizer(F)	0.08b	2.37b	0.74b	0.18
W1	0.10ab	2.70b	1.08ab	0.17
W1F	0.10ab	2.73b	1.08ab	0.18
W2	0.16a	3.27a	1.29a	0.18
W2F	0.12ab	2.90ab	1.35a	0.18

*Means in a column with similar letter(s) are not significantly different ($p>0.05$). Where, W = water hyacinth compost; 1= 2.5 t ha^{-1}; 2 = 5.0 t ha^{-1}.

At the end of the first planting, W1F, W2 and W2F increased plant heights by 35–40% while the remaining treatments were not different from the control ($p<0.05$, Fig. 2a). A similar trend was obtained at the end of the second planting. The maize dry matter yield was increased by W2F (75%) and W2 (72%) at the end of the first planting, and by W2F (56%), W2 (35%) and W1F (40%) at the end of the second planting (($p<0.05$, Fig. 2b). Considering the richness of the water hyacinth compost in plant nutrients, especially N, P and K (Table 2), and its low C: N ratio of 15, nutrients were available for the plant uptake. The presence of inorganic fertilizer also ensured early nutrient release for plant uptake while the compost slowly releases its nutrient. Therefore, due to the release of considerable amounts of nutrients, especially nitrogen and phosphorus, to the plant that was utilized during photosynthesis, there was better plant development (Kamanu et al., 2012). The improved seedling growth of *Brassica juncea* (Indian mustard) had been observed with the application of 100 % water hyacinth compost and 50 % water hyacinth compost + 50 % garden soil (Lata and Veenapani, 2011). Some other studies confirmed the superior effects of combined applications of organic manure and mineral fertilizers in terms of improved soil fertility, balanced plant nutrition (Uyovbisere and Elemo, 2000; Makinde et al., 2001; Ayeni, 2008) and maize agronomic parameters (Laekemariam and Gidago, 2013; Adams et al., 2015) .

3.5 Tissue contents of N, P and cations (K, Ca, and Mg) at the end of the first and second plantings

Maize tissue content of N was increased between 98 and 141% ($p<0.05$) by the sole or fertilizer-based compost (W2F, W2, W1F and W1) over the control at the end of the first cropping, and W2F and W2 at the end of the second cropping (Table 4). While at the end of the first cropping, tissue K and Mg were not significantly affected by the treatments, they were increased between 103 and 280% ($p<0.05$) by the sole or fertilizer-based compost at the end of the second cropping. The tissue Ca was only increased ($p<0.05$) by W2F at the end of the first cropping while it followed a similar trend as K and Mg in the second planting. The tissue content of P was, however, not significantly affected at the end of either of the two croppings. The applications of 5.0 t ha^{-1} water hyacinth compost with and without N and P were effective in enhancing the tissue contents of cations of the maize due to the fact that more mineralized nutrients were available for the plant uptake at higher rates of compost application. The trend observed in this study was in accord with earlier reports. Improved nutrient uptake by maize was recorded when compost, poultry manure or their combinations with NPK fertilizer was applied, as opposed to the sole application of NPK (Makinde, 2007; Ayeni et al., 2012; Hossain et al., 2013).

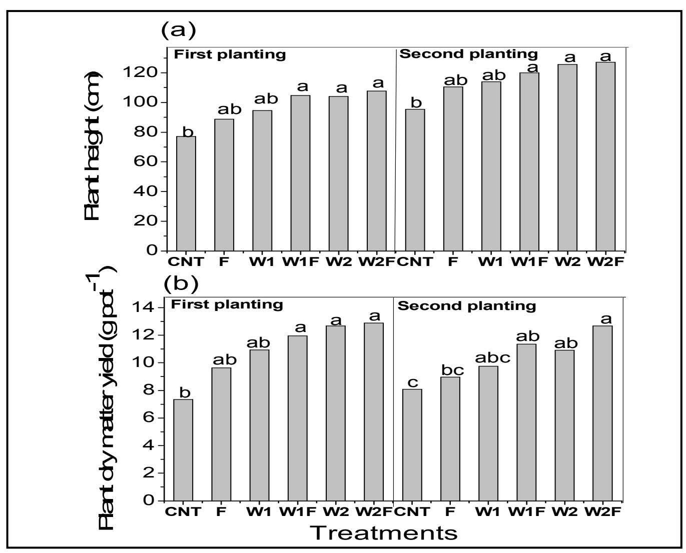

Fig. 2 Maize plant height (a) and Dry matter yield (b) at treatments with similar letter(s) are not significantly different ($p<0.05$) from each other. CNT: control; F: fertilizer; W: water hyacinth compost; 1: 2.5 t ha^{-1}; 2: 5.0 t ha^{-1}.

Table 4: Tissue contents of nitrogen, phosphorus and cations at the end of the first (a) and second (b) croppings of maize in screenhouse.

(a)

Treatments	Total N	P	K	Ca	Mg
	%	N			
Control	0.54b*	0.60	1.48ab	0.13b	0.22
Fertilizer(F)	0.77ab	0.67	1.35b	0.133b	0.20
W1	1.07a	0.67	1.75a	0.16b	0.24
W1F	1.19a	0.70	1.73ab	0.15b	0.23
W2	1.21a	0.70	1.81a	0.18ab	0.27
W2F	1.30a	0.72	1.73ab	0.25a	0.26

(b)

Control	1.03b	0.59	0.75c	0.03c	0.05c
Fertilizer (F)	1.04b	0.60	0.85bc	0.03c	0.07c
W1	0.18ab	0.65	1.57a	0.05b	0.13b
W1F	1.17ba	0.65	1.52ab	0.05b	0.13b
W2	1.25a	0.78	1.69a	0.08a	0.19a
W2F	1.24a	0.77	1.68a	0.07a	0.18a

*Means in a column with similar letter(s) are not significantly different ($p<0.05$). Where, W = water hyacinth compost; 1= 2.5 t ha^{-1}; 2 = 5.0 t ha^{-1}

4.0 Conclusion

It was concluded that agronomic and nutrient uptake parameters of maize, and soil nutrient status were improved by the application of water hyacinth compost with and without inorganic N and P. The rate of 5.0 t ha^{-1} of the sole compost and its organomineral form (fortified with N at 25 kg/ha and P at 26 kg ha^{-1}) proved superior in enhancing maize growth and soil nutrient status. Therefore, the obnoxious weed 'water hyacinth' could find alternative use as a source of nutrients to crop s (maize in this study) if composted.

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