430 **DOI:** 10.1002/jpln.200900292 *J. Plant Nutr. Soil Sci.* 2011, *174,* 430–436

Effectiveness of crop-waste compost on a Eutric Ferralsol

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Abstract

Lack of environmentally safe handling of garbage is a growing problem in urban sub-Saharan Africa (SSA). Composting the garbage for soil-fertility management presents an opportunity for reducing the risks of environmental pollution. This study aimed at evaluating the agronomic effectiveness and nutrient-utilization efficiency of urban market crop-waste compost on a Eutric Ferralsol. The study was conducted in central Uganda with treatments including compost applied at 0, 5, and 10 t ha^{-1} (d.w. basis); inorganic N fertilizer at rates of 0, 40, and 80 kg ha^{-1} and inorganic P fertilizer at 0, 9, and 18 kg ha^{-1}. Maize (*Zea mays* L.), variety Longe 4 was used as the test crop. The nutrient quality of the compost was medium with total N of 0.9% and total P of 0.45%. Compost significantly increased plant height, LAI, stover weight, and grain yield; however, there were no significant differences between the 5 and 10 t ha^{-1} rates. Nitrogen also had a significant effect on LAI and stover yield, though there was no significant difference between the 40 and 80 kg ha^{-1} rates. Likewise, P increased plant height with no significant difference between the 9 and 18 kg ha^{-1} rates. Mineral N at 40 kg ha^{-1} led to the highest increase in N uptake by plants (76%) above the control. Nitrogen- and P-utilization efficiencies for the 5 t ha^{-1} compost rate were more than twice that of the 10 t ha^{-1} rate. The highest P-utilization efficiency (69%) was obtained where 9 kg ha^{-1} P was applied with 40 kg ha^{-1} N, while the highest N-utilization efficiency (48%) was obtained with the 5 t ha^{-1} compost applied together with N at 40 kg ha^{-1}. From the above studies, it is clear that effectiveness of the 5 t ha^{-1} compost rate is the most promising.

Key words: nitrogen / phosphorus / nutrient-utilization efficiency / uptake / sub-Saharan agriculture

Accepted July 30, 2010

1 Introduction

Declining soil fertility is a growing threat to food security in sub-Saharan (SSA) (*IFDC*, 2006) where most communities are dependent on agriculture. This is largely due to low inherent nutrient stocks and uncontrolled losses through inappropriate human activities (*Omotayo* and *Chukwuka*, 2009). Intense crop removal, runoff, and soil erosion are key players in the process of soil-fertility decline. Unfortunately, the bulk of the farmers is unable to mitigate or compensate for these losses especially because of prohibitive of inorganic-fertilizer costs. Nitrogen and P are the most limiting nutrients to viable crop production in SSA (*Smithson* and *Giller*, 2002; *van der Eijk* et al., 2006; *IFDC*, 2006), and thus form the critical entry-point for meaningful intervention efforts. Phosphorus is particularly limiting in the highly P-fixing Ferralsols that dominate the soils of the region (*IFDC*, 2006).

The immediate alternative option for addressing the soil-fertility crisis in SSA is the use of materials of plant origin, especially crop wastes, which are easily available to farmers but are not widely appreciated as resources. The other resource of great potential is crop waste especially in urban markets which is invariably disposed of as garbage. Urban-market wastes reportedly contain up to 97% materials of plant origin (*Ssendawula* et al., 1997; *Anikwe* and *Nwobodo*, 2002). Moreover, the landfill which is the primary disposal method, is invariably inadequate yet often only 40%–60% is disposed of due to urban logistical constraints (*Ekere*, 2009). Unfortunately, the composition of urban crop wastes (UCW) in SSA is widely variable, thus, its use as a soil-fertility input calls for systematic agronomic studies particularly when targeting soils of unique nature such as Ferralsols. Therefore, this study was conducted to optimize utilization of N and P using crop wastes and inorganic sources for crop production in a Eutric Ferralsol in Uganda.

2 Materials and methods

2.1 Study-site description

The study was conducted at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) for three cropping seasons (2003 to 2004). The Institute is located 32°37′ E and 0°28′ N, 17 km N of Kampala City at an altitude between 1250 and 1320 m asl (*Yost* and *Eswaran*, 1990). Mean annual rainfall is 1250 mm with a bimodal distribution. Daily minimum and maximum temperatures are 21°C and 27°C, respectively. The site soil was classified as Kandiudalfic Eutrodox (*Yost* and *Eswaran*, 1990), equivalent to Eutric Ferralsol (*FAO-UNESCO*, 1977).

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2.2 Study-soil characterization

Soil samples taken at a depth of 0–20 cm for site characterization were air-dried at room temperature for 7 d and then ground to pass through a 2 mm sieve. They were analyzed for pH, organic C (OC), total N, available P, exchangeable base cations, and texture; pH was determined in water (1:2.5) using the pH electrode technique while OC was determined using the *Walkley* and *Black* (1934) method. Total N was analyzed using the Kjeldahl technique (*Anderson* and *Ingram*, 1993), after the soil sample was digested in hot concentrated sulfuric acid. Available P was determined using the Bray-1 method (*Okalebo* et al., 2002), while soil texture was determined using the BOUYOUCOUS or hydrometer method, K^+ using flame photometry, and Ca^{2+} and Mg^{2+} using AAS (*Page* et al., 1982).

2.3 Compost making

The compost used was prepared in open windrows, each with cemented wall bricks and dimensions of 4 m × 2 m × 1.5 m, covered with slanting corrugated iron sheets. Garbage loads for composting were collected from markets in Kampala City and its suburbs. The garbage was over 90% crop wastes of different types, but largely banana peels and leaves, maize husks, and vegetables. The materials were freed of nonbiodegradables before composting. Four windrows were used in a sequence of garbage transfer, with an interval of 3–4 weeks between windrows till compost maturity. Compost was transferred manually between the windrows using forked spades and hand-hoes. The mature compost was further freed of visible nonbiodegradables using a sieve before sampling for laboratory characterization.

Two compost samples of ≈ 20 g were oven-dried at 105°C for 24 h to determine dry weights as a basis for achieving dependable compost rates. Additionally, compost pH, OC, N, and P were analyzed. pH was determined using a pH probe in a 1:10 garbage–to–distilled water suspension ratio. This mixture was then shaken for 1 h in a mechanical shaker before measurement. Compost OC was analyzed using the Walkley and Black method, total N by the Kjeldahl method, and total P by Bray and Kurtz No 1 method as described by *Page* et al. (1982) and *Anderson* and *Ingram* (1993).

2.4 Treatment design and plant analysis

Treatments included compost, mineral N and P applied at 0, 5, and 10 t ha^{-1} (d.w. basis); 0, 40, and 80 kg ha^{-1}; 0, 9, and 18 kg ha^{-1}; respectively. The compost rates yielded 0, 45, and 90 kg N ha^{-1} and 0, 22.5, and 45 kg P ha^{-1}. Mineral N and P were applied as urea (46% N) and triple superphosphate (46% P_2O_5), respectively. The experiment was laid out in randomized complete block design, in a factorial arrangement. The plot sizes were 5 m × 5 m. Treatments were replicated three times, and the plots were separated by 1 m alleys.

The experimental crop was *Zea mays*, var. Longe 4. This was planted at a spacing of 75 cm × 30 cm (*Kikafunda-Twine* et al., 2001). The compost and P fertilizer were applied at planting, while urea was applied in two splits, one dose (50%) at 2 weeks after planting (WAP) and the rest at 6 WAP to minimize leaching losses. Compost was hand-applied and spread evenly on the surface before being incorporated in the soil using hand-hoes. Nitrogen and P fertilizers were applied in furrows along the plant rows and covered lightly with soil.

Parameters measured included plant height, leaf-area index (LAI), stover, cob, and grain weights. Plant height was determined at 4, 6, 8, 10, and 12 WAP using a measuring tape, from the base of the stem to the youngest fully expanded leaf (3rd leaf from the top). Simultaneously, LAI was determined from the length and width of the widest part of the same leaf. The number of leaves per plant was recorded. Leaf-area index was calculated using the linear procedure (*Levy* and *Jarvis*, 1999). Maize cobs and stover were harvested concurrently using a 3 m × 3 m quadrate. All the quadrate-enclosed plants were harvested and counted. Stover and cobs were weighed separately before the latter were further dried under the sun to a moisture content of 14%. The cobs were hand-threshed within their respective samples and weighed using a spring balance.

Other parameters included plant N, P, and K content at 50% bloom (10 WAP) and at final harvest. For this purpose, four plants were randomly selected and harvested from each plot at 10 WAP and at final harvest. The plant samples were oven-dried, ground into powder, and analyzed for N and P contents. Total N was analyzed using the Kjeldahl technique (*Anderson* and *Ingram*, 1993) and total P using colorimetry, after the plant sample was digested in hot concentrated sulfuric acid (*Anderson* and *Ingram*, 1993).

Nutrient-utilization efficiency (NTUE) was computed focusing on UCW compost which was the primary subject of this study. Nevertheless, N rates were also considered as elaborated in the formula below:

$$NTUE = \frac{NU_1 - NU_0}{X} \times 100,$$

where: NU_1 = nutrient uptake in a given treatment; NU_0 = nutrient uptake in control; and X = nutrient applied.

Experimental data were subjected to analysis of variance (ANOVA) using the Genstat statistical package (*Payne* et al., 2009).

3 Results

3.1 Soil characteristics and compost characteristics

Soil pH was slightly below the critical level, while total N, available P, and exchangeable Ca^{2+} were insufficient (Tab. 1). Soil organic matter (SOM) was moderate, and exchangeable K^+ and Mg^{2+} were marginally above the critical values. The compost used was strongly alkaline but had OC, total N and P, and C : N ratios within the common range for mature composts (Tab. 2).

Table 1: Soil characteristics of the experimental site at MUARIK *versus* their respective critical values.

Item	pH (H_2O)	SOM[a]	Total N	Avail. P	K^+	Ca^{2+}	Mg^{2+}	Na^+	Textural class
		/ %		/ mg kg^{-1}	(exchangeable) / cmol kg^{-1}				
Site value	5.4	3.2	0.08	4.75	0.50	3.3	1.4	0.3	Sandy clay
Critical value[b]	5.5	3	0.25	15	0.22	4.0	0.30	<1	

[a] SOM = soil organic matter; [b] *Okalebo* et al. (2002)

Table 2: Chemical composition of UCW compost used in the crop-waste study in Uganda.

Item	pH (H_2O)	OC	N	P	C : N ratio
		(total) / %			
Compost used	10.0	11.9	0.9	0.45	13.2
Common compost range[a]	6–8	8–40	0.7–1.0	0.3–0.5	10–25

[a] Sources: *Negro* et al. (1999); *Sullivan* and *Miller* (2001); *Saebo* and *Ferrini* (2006)

Table 3: Response of maize-plant height and LAI to application of UCW compost and N and P fertilizer in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	Height / cm	LAI	N / kg ha^{-1}	Height / cm	LAI	P / kg ha^{-1}	Height / cm	LAI
0	87.1	2.004	0	91.5	2.019	0	91.2	2.078
5	95.8	2.182	40	94.5	2.134	9	94.2	2.145
10	97.2	2.162	80	94.1	2.195	18	94.8	2.125
$LSD_{0.05}$	3.28	0.09	$LSD_{0.05}$	ns[a]	0.109	$LSD_{0.05}$	2.87	ns

[a] ns = not significant (p > 0.05)

3.2 Maize response to soil-fertility treatments

Growth response. Compost application significantly ($p < 0.05$) increased plant height and LAI at both 5 and 10 t ha^{-1} rates (Tab. 3), though there was no significant difference ($p > 0.05$) between these rates. Application of N also had a significant effect on LAI, though there was no significant difference between 40 and 80 kg ha^{-1} N rates. Application of P significantly increased plant height, but again there was no difference between 9 and 18 kg P ha^{-1}.

Maize yield components. There were no significant effects of P-fertilizer rate on maize stover, cob, and grain yield, hence only the main effects of compost and N that significantly ($p < 0.05$) influenced these components are presented (Tabs. 4–6). For all these components, yield response was higher at 5 and 10 t ha^{-1} compost than in the control, although the 5 and 10 t ha^{-1} rates did not differ significantly ($p > 0.05$). With regard to N rates, both applied rates (N_{40} and N_{80}) significantly increased ($p < 0.05$) maize stover and cob yield above the control, but the two N treatments did not differ significantly, while for grain yield, the 40 and 80 kg N ha^{-1} rates significantly increased grain yield above both the control, however, the 80 kg ha^{-1} rate also led to a significantly higher yield than the 40 kg ha^{-1} (Tab. 6).

3.3 Plant nitrogen and phosphorus contents

There were no significant ($p > 0.05$) treatment interactions on N and P contents in the maize plants. Even among the main

Table 4: Response of maize stover yield to application of UCW compost, N and P fertilizer in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	Stover yield / t ha^{-1}	N / kg ha^{-1}	Stover yield / t ha^{-1}	P / kg ha^{-1}	Stover yield / kg ha^{-1}
0	6.88	0	6.91	0	7.43
5	7.55	40	7.61	9	7.51
10	7.93	80	7.84	18	7.43
$LSD_{0.05}$	0.46	$LSD_{0.05}$	0.39	$LSD_{0.05}$	ns[a]

[a] ns = not significant (p > 0.05)

Table 5: Response of maize cob yield to application of UCW compost and N and P fertilizer in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	**Cob yield** / t ha^{-1}	**N** / kg ha^{-1}	**Cob yield** / t ha^{-1}	**P** / kg ha^{-1}	**Cob yield** / kg ha^{-1}
0	10.3	0	9.67	0	10.62
5	10.89	40	11.15	9	11.02
10	11.16	80	11.53	18	10.70
LSD$_{0.05}$	0.53	LSD$_{0.05}$	0.68	LSD$_{0.05}$	ns[a]

[a] ns = not significant ($p > 0.05$)

Table 6: Response of maize grain yield to application of UCW compost and N and P fertilizer in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	**Grain yield** / t ha^{-1}	**N** / kg ha^{-1}	**Grain yield** / t ha^{-1}	**P** / kg ha^{-1}	**Grain yield** / t ha^{-1}
0	5.71	0	5.47	0	6.01
5	6.22	40	6.12	9	6.09
10	6.10	80	6.45	18	5.94
LSD$_{0.05}$	0.32	LSD$_{0.05}$	0.23	LSD$_{0.05}$	ns[a]

[a] ns = not significant ($p > 0.05$)

effects, only plant N uptake was significantly ($p < 0.05$) influenced (Tabs. 7 and 8). Application of compost led to a significant increase in N uptake in the plant at tasselling (10 WAP). The 10 t ha^{-1} compost rate led to a superior N content, representing an increase of 29% above the control; however, there was no significant difference between 5 and 10 t ha^{-1} rates (Tab. 7). At final harvest, only N application significantly increased N uptake above the control. In this case, the 40 kg N ha^{-1} rate led to superior N uptake (Tab. 8), representing an increase of 76% above the control, although this was not significantly different from N uptake where 80 kg N ha^{-1} was applied.

3.3 Nitrogen- and phosphorus-utilization efficiencies

Table 9 presents data on N- and P-utilization efficiencies in the field. In terms of compost, the N-utilization efficiency (NUE) for the 5 t ha^{-1} compost rate was higher than that for the 10 t ha^{-1} rate, whereby the 5 t ha^{-1} value was more than twice that obtained for the 10 t ha^{-1} rate. Similarly, the P-utilization efficiency (PUE) for the 5 t ha^{-1} compost rate was again more than twice that of the 10 t ha^{-1} rate. Furthermore, N or compost applied in combinations with P gave relatively higher values than in the other treatments. The highest PUE value was obtained where 9 kg P ha^{-1} was applied with 40 kg N ha^{-1} (69%), while the highest NUE (48%) was obtained with the 5 t ha^{-1} compost applied together with N at 40 kg ha^{-1}.

4 Discussion

The suboptimal levels of total N and available P in the study soil (Tab. 1) are typical of the continuously cultivated nutrient nonreplenished soils of the sub-Saharan region (*Smithson* and *Giller*, 2002). Indeed, crop response to N and P inputs on these soils has been reported as phenomenal (*Tenywa* et al., 1999). Thus, for viable crop production, N and P should form the foundation nutrient in the recommendations. The presence of inadequate exchangeable Ca^{2+} and barely adequate levels of exchangeable K^+ and Mg^{2+} is typical of humid tropical soils (*Sanchez* et al., 2003), which are intensely weathered and leached. Regular monitoring of the depletion front of

Table 7: Nitrogen uptake in maize aboveground biomass at 10 WAP in response to compost and N and P applications in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	**Plant N uptake** / kg ha^{-1}	**N** / kg ha^{-1}	**Plant N uptake** / kg ha^{-1}	**P** / kg ha^{-1}	**Plant N uptake** / kg ha^{-1}
0	64.0	0	74.9	0	66.8
5	77.9	40	71.6	9	79.0
10	82.7	80	78.1	18	78.9
LSD$_{0.05}$	15.1	LSD$_{0.05}$	ns[a]	LSD$_{0.05}$	ns

[a] ns = not significant ($p > 0.05$)

Table 8: Nitrogen uptake in maize aboveground biomass at final harvest in response to compost and N and P applications in a Eutric Ferralsol in Uganda.

Compost / t ha^{-1}	**Plant N uptake** / kg ha^{-1}	**N** / kg ha^{-1}	**Plant N uptake** / kg ha^{-1}	**P** / kg ha^{-1}	**Plant N uptake** / kg ha^{-1}
0	63.0	0	51.0	0	75.0
5	69.0	40	90.0	9	75.0
10	89.0	80	80.0	18	71.0
$LSD_{0.05}$	ns[a]	$LSD_{0.05}$	24.6	$LSD_{0.05}$	ns

[a] ns = not significant ($p > 0.05$)

Table 9: Utilization efficiency of compost and fertilizer N and P by maize plants grown in a Eutric Ferralsol in Uganda.

Treatment / t ha^{-1}	**NUE**[a] / %	**PUE**[b] / %
Control	na[c]	na
C_5	19	17
C_{10}	9	4
N_{40}	28	na
P_9	na	4
$C_5 + N_{40}$	48	15
$N_{40} + P_9$	27	69

[a] NUE, nitrogen-utilization efficiency; [b] PUE, phosphorus-utilization efficiency; [c] na = not applicable

these nutrients is necessary to deter the advancement to critical limiting levels.

Overall, the compost used in this study (Tab. 2) can be rated of average nutrient quality based on the range reported by various researchers (*Sullivan* et al., 2002; *Risse* and *Faucette*, 2005). The concentration of 0.9% N in this compost implies that the 5 t ha^{-1} compost rate used in this and other studies (*Kihanda* et al., 2004; *Micheni* et al., 2004) would practically yield 45 kg N ha^{-1}. This makes market-waste compost a competitive input particularly at the small-scale farmer level, where the cost of mineral fertilizer is largely prohibitive to their use. Similarly, the presence of 0.45% P in the compost had a potential of yielding 22.5 kg ha^{-1} P, which would be adequate for viable small-scale farmer crop production. On the other hand, compost pH was quite high (Tab. 2). This, however, might be nonconsequential for normal crop production since the material is normally applied in proportions of < 0.5% of the actual mass of topsoil. In addition, the application of mature composts to soils will seldom substantially alter the soil pH, since compost buffer capacity in the rates applied is insignificant relative to the buffer capacity of the recipient soil (*Saebo* and *Ferrini*, 2006).

The significant response of plant-growth parameters, namely, plant height and LAI, and the yield components, namely, stover, cob, and grain yield, to compost and N (Tabs. 3–6) is further testimony that soil fertility is a hinderance to crop production at the study site. However, the lack of a significant difference between the 5 and 10 t ha^{-1} compost rates signals the adequacy of nutrient supply by the former and the lack of need for the extra quantities supplied by the latter. This directly links stover, cob, and grain yield to the effect of the 5 t ha^{-1} compost rate on plant height and LAI (Tab. 3), implying that the physiological gains from this nutrient resource are directly transformed into the successive growth stages. The statistically similar performance of the 40 and 80 kg N ha^{-1} rates for LAI, stover, cob, and grain yield also indicates the adequacy of the lower rate. *Kaizzi* et al. (2006) also evaluated the effect of N at 40 and 80 kg ha^{-1} on maize in E Uganda. They recommended a management package with 40 kg N ha^{-1} as a principal component.

The 5 t ha^{-1} compost rate together with 40 kg N ha^{-1} emerged as the most promising management package. This combination reflects the commonly recommended practice of integrating organic and inorganic sources, whereby the organic source in addition to providing nutrients often in suboptimal quantities relative to crop requirements also contributes to improvement of the agronomically desired chemical, physical, and biological properties of the soil (*Cambardella* et al., 2003). The analytical data for crop-waste compost in this study is evidence of this. Inclusion of inorganic nutrient sources supplements the organic nutrient base by providing targeted nutrient quantities in easily available forms.

The increase in stover, cob, and grain yields from the applications of compost and N (Tabs. 4–6) may be linked to the increased supplies of nutrients derived from the treatments. Studies on use of waste compost on maize are not well documented, however, there have been studies on other crops using waste compost. For instance, *Roe* et al. (1997) reported that in green pepper plots amended with waste compost and standard fertilizer, plots with 100% fertilizer *plus* compost gave higher yields and larger fruit sizes than those with only 100% fertilizer. *Smith* et al. (1992) also reported a significantly higher yield of field-grown cabbage (*Brassica oleracaea*) and onion (*Allium cepa*) when fertilized with 25% compost + 75% NH_4NO_3, than with NH_4NO_3 alone.

The significant yield increase with N application underscores the importance of N management for viable crop production in the study area. This observation further supports earlier reports that application of N is necessary to achieve realistic crop yields in Uganda (*Tenywa* et al., 1999). Nitrogen effects are widely known to be dramatic on cereals most especially in N-deficient soils (*Tenywa* et al., 1999), and variable responses to the application of N fertilizer have been observed in maize (*Karlen* et al., 1987) and sorghum (*Muchow*, 1998). Suboptimal availability of nutrients, particularly N, is known to limit crop productivity in many ecosystems (*Smithson* and *Giller*, 2002). However, improved crop growth, following N fertilization, tends to be limited by N dynamics in the soil, the components of which are leaching, denitrification, volatilization, and to a large extent microbial immobilization (*Tripathi* and *Singh*, 1992). Incorporating compost into the soil also influences N availability through mineralization and mobilization of native soil organic matter, as well as the mineralization of its own inherent organic N (*Hadas* et al., 2004). The higher NUE in the field when urea was applied together with compost (Tab. 9) could be attributed to the fact that the compost could have provided the C needed as an energy source for the microorganisms which immobilize the excess N (*Snapp* et al., 1998), hence reducing the losses and leading to a higher NUE.

In the case of compost and fertilizer P (Tab. 9), the higher PUE when P fertilizer was applied with compost and/or N could be explained by the fact that compost has the ability to produce chelating agents that immobilize Al, hence making P more available (*Feike* et al., 2003). In the case of urea, this fertilizer hydrolyzes in soils producing $OH^–$ groups that precipitate Al as $Al(OH)_3$ (*Qing-ru* et al., 2006), thereby releasing the fixed P. However, the lower PUE where P was applied singly could be attributed to factors like P fixation (*Osiname* et al., 2000). In terms of compost rate (Tab. 9), the higher N- and P-utilization efficiencies for the 5 t $ha^{–1}$ compost rate compared to those for the 10 t $ha^{–1}$ rate, may be the reason why there was no significant yield difference between the 5 and 10 t $ha^{–1}$ compost rates. Hence, elevation of available N and P concentrations through external inputs facilitated more efficient transformation of N and P together with other growth factors into grain yield.

It can, therefore, be concluded that the compost obtained from the urban-market garbage is agronomically effective for maize production. Because the 5 and 10 t $ha^{–1}$ compost rates performed similarly, the 5 t $ha^{–1}$ rate would be preferred to minimize the costs involved in compost making and application. However, the best performance in terms of maize yield is when the 5 t $ha^{–1}$ compost rate is supplemented with mineral N and P. With respect to N management, 40 kg $ha^{–1}$ stands out for recommendation, since the yield is not far different from the 80 kg N $ha^{–1}$. However, there is need for economic evaluation of the production process most especially under the farmers' socio-economic framework. Also, there is need to investigate the residual effect of compost application on maize yield. Furthermore, it would be interesting to assess the nutrient-release patterns of urban-market crop-waste compost relative to crop nutrient needs, with the aim of optimizing nutrient uptake and utilization by the crop.

Acknowledgments

This study was funded by *Makerere University (Uganda)* and the *Swedish Government (Sida/SAREC)* under the bilateral grant, Phase I.

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