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Evaluation of the Performance of Different Organic Fertilizers on Maize Yield: A Case Study of Kampala, Uganda

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Abstract

In Kampala city about 60% of animal manure generated is discarded leading to health and environmental challenges. However about 30% of this manure is used as fertilizer mainly in the form of stored animal manure. The manure could also be vermicomposted or anaerobically digestated and used in crop production. However, it has not yet been clearly established which of these options would be most beneficial in producing better crop yields when applied to soils in Kampala. This study evaluated the performance of different organic fertilizers namely vermicompost, digestate and stored cattle manure and unfertilized control on growth and yield of maize (*Zea mays* spp). The experiment was carried out at Makerere University Agricultural Research Institute Kabanyolo for two seasons (October 2013 to February 2014 and March to June 2014). No significant difference ($P > 0.05$) in the different organic fertilizers was noted in both the growth and yield of maize in each season. However a significant difference ($P < 0.05$) in both crop growth and yield was noted when the organic fertilizers were compared with the control. In addition when the different seasons were compared, the growth and yield of maize in season two was generally found to be better ($P > 0.05$) than that of season one. The interviews conducted with farmer groups showed they generally preferred using stored manure and vermicompost. It can thus be concluded that these fertilizers are best for Kampala thus should be promoted by the municipal authorities to address the rampant poor disposal of animal manure in Kampala.

Keywords: animal manure, crop production, vermicompost, crop growth, digestate, nitrogen

1. Introduction

Between 1950 and 2007, the population in East Africa increased five-fold, from 50.5 to 247.2 million and is projected to reach 422.3 million by 2030, with the urban population anticipated to comprise 30.5% of the total population. The rapidly increasing urban population, annual growth rate of which is estimated to be 3.98%, causes social, economic and spatial problems that urgently need to be addressed (UN-HABITAT, 2008). Unlike in other places of the world, urbanization in East Africa is not predominantly driven by economic growth, but rather by a poverty-based survival strategy where poor rural people seek economic survival in urban areas (Parnell & Walawege, 2011). This has led to rising urban poverty and an associated increase in the occurrence of slums and a reduction in the quality of urban life (UN-HABITAT, 2008). It has been reported that the poverty levels, health risks and food security in some slum areas are often worse than in stressed rural communities (Prain, Karanja, & Lee-Smith, 2010).

In an effort to alleviate their poor economic status, some of the urban poor have turned to urban agriculture to increase their levels of food security and improve their nutrition (Prain et al., 2010). According to Zezza and Tasciotti (2010), an average of 35% of households in sub-Saharan African cities engage in some form of urban agriculture, of which 13% engage in livestock production. However, urban livestock production results in other challenges, as animal waste in many of these cities is poorly managed. For instance in Kampala city, Uganda, Komakech, Banadda, Gebresenbet, and Vinnerås (2014) established that over 60% of the waste generated from livestock production is dumped, mainly into drainage channels where it is carried off by water. This waste eventually finds its way into Lake Victoria, where it contributes to eutrophication (Komakech, Sundberg, Jönsson, & Vinnerås, 2015). At the same time, the yields from urban crop farming have been declining, mainly due to intensive cropping with resulting soil degradation. Each season, nutrients are lost from the soil through crop harvests, with no replacement (Mubiru, Tenywa, Romney, & Halberg, 2007). A remedy to this problem could be to encourage use of animal waste as fertilizer on the soil to improve its fertility and increase crop yields.

Animal waste can be used as a fertilizer in many different forms, with the most common being direct use. Alternatively, the manure can be vermicomposted, anaerobically digested or stored/composted before use. Vermicomposting is a process by which worms are used to convert organic wastes into a humus-like substance called vermicompost, which can also be used as a fertilizer and soil conditioner (Munroe, 2007; Rajesh, Reddy, Naidu, & Ramavatharam, 2003). In anaerobic digestion, organic residues such as animal manure are transformed into biofuel (biogas), while the resulting effluent (digestate) can be reused in agriculture to improve the physical properties of soil and supply vital plant nutrients (Smith et al., 2014). Composting is a simple method of controlled aerobic degradation of manure to produce a stable, soil-like substance. Storage through heaping is the most common method used by urban crop farmers in Kampala (Komakech et al., 2014).

It is an undisputed fact that application of treated animal manure would increase crop yields in urban farming and thus enhance livelihoods, as well as improving health through better nutrition. However, it has not yet been clearly established which of these options would be most beneficial in producing better crop yields when applied to soils in Kampala. The objective of this study was thus to evaluate the performance of different organic fertilizers, namely vermicompost, digestate and stored cow manure, on maize yields. The hypothesis was that the yields from vermicompost would be highest, since it is reported to be higher in nitrates, a more plant-available form of nitrogen, than other organic fertilizers (Atiyeh et al., 2000). According to Bayite-Kasule (2009), this information is vital if farmers are to be encouraged to apply organic fertilizers in their crop fields. This study therefore aimed at providing scientific evidence, as a first step in promoting the use of animal manure in urban agriculture. In field experiments, the fertilizer performance of vermicompost, digestate and stored cattle manure in increasing yield of maize (*Zea mays*) was studied during two different seasons. As phosphorus and potassium are not limiting factors in central Uganda soils (Bayite-Kasule, 2009), the experiments only evaluated the effect of nitrogen.

2. Materials and Methods

2.1 Establishment of Field Experiments

The field experiments were established at Makerere University Agricultural Institute, Kabanyolo (MUARIK), which is located about 21 km north of Kampala city at coordinates 0°27′03.0″N and 32°36′42.0″E. MUARIK has a dairy farm, which was the source of the animal manure that was used in experiments. The vermicompost was obtained from the vermicompost reactor at MUARIK, details of which can be found in Lalander et al. (2015). The digestate was obtained from continuous flow, farm-scale mesophilic floating drum anaerobic digesters fed with cattle manure, also located at MUARIK. The stored cattle manure was obtained from the MUARIK dairy unit manure heap. The soil at the experimental site is a Kandiudalfic Eutrudox, a ferrasol with sandy loam texture (Yost & Eswaran, 1990). The experiment started with land preparation. This was done by ploughing a 30 m × 30 m field (Note: Selection of the field was done in such a way to ensure that it was not at the borderline) using a tractor (Massey Fergusson MF 275) and then harrowing it manually by hoe. An experimental area of 20 m × 25 m was marked off and divided into four blocks of equal size. The blocks were sub-divided into five plots of 5 m × 3 m in a randomised complete block design, as shown in Figure 1. Five replicates of each of four treatments (vermicompost, digestate, stored cattle manure, and a control) were allocated to these 20 plots, with a 1.0 m path between plots and between blocks in both seasons.

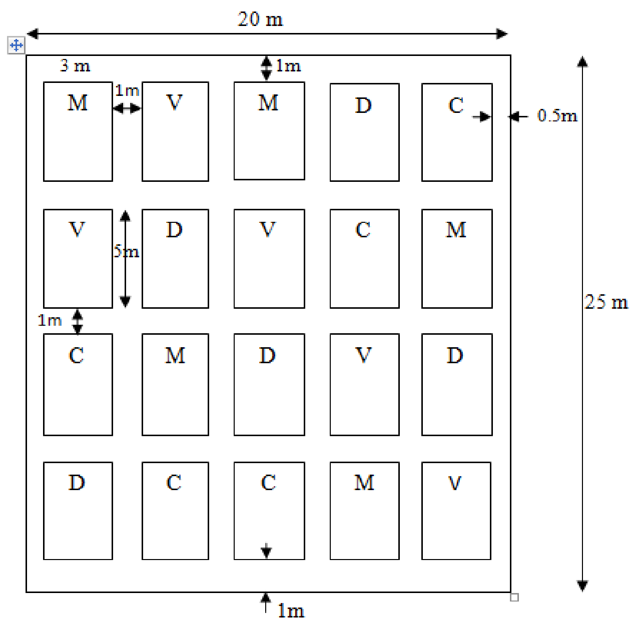

Figure 1. Experimental layout in field experiments with four treatments (t1-t4)

Note. M – Stored cattle Manure; V – Vermicompost; D – Digestate; C – Control.

The seeds of a hybrid variety of maize (Longe 5) were sown manually at a planting depth of 2-3 cm below the surface using a hand hoe and stick, at a spacing of 75 cm × 30 cm and with one seed per hole. The seeds were planted on 12 October 2013 in the first season and on 6 March 2014 in the second season. The plots were weeded twice using a hand hoe, with the first weeding being performed three weeks after seedling emergence and a second weeding in week 7. The experiment in the first season ran from October 2013 to February 2014 and that in the second season from March to June 2014. In both seasons, the maize was harvested by hand after 17 weeks when the moisture content of the kernels was around 30%.

2.2 Laboratory Analyses

The samples of vermicompost, digestate and stored cattle manure used for this study were collected from the vermicompost unit, biogas digester and dairy unit manure heap at MUARIK. Ten 20 g samples of each manure type and a 1 L sample of digestate were collected each season, in labelled polythene bags and a plastic bottle, respectively. For soil sampling, three sampling points were randomly selected in the experimental area. At every sampling point, a disturbed sample at 0.6 m depth was taken using a hand hoe. All soil and organic fertilizer samples were then transported to Makerere University soil laboratory for analysis of nitrogen content. The analysis followed the following procedure: Samples (1 g), dried in an oven to reduce the moisture content were then milled. To determine total nitrogen, the milled samples were acid digested using sulfuric acid and the total nitrogen concentration was determined by a distillation–titration method (Komakech et al., 2014). The procedure as described by Okalebo, Gathua, and Woomer (2002) was followed for for both the acid digestion and the distillation–titration procedure.

2.3 Application of Fertilizer

The average fertilizer application rate for maize fields in central Uganda is 90 kg of nitrogen per hectare, according to Bayite-Kasule (2009). This value was used in calculating the amount of nitrogen fertilizer to apply, taking into consideration that in organic fertilizer only 30% of the nitrogen is plant-available (Hansen, Bhander, Christensen, Bruun, & Jensen, 2006). The amounts of fertilizer applied per plot in the different treatments and seasons are shown in Table 1. The fertilizer was applied 3 weeks after planting, when all maize plants had fully emerged from the soil. According to Shisanya, Mucheru, Mugendi, and Kung'u (2009), potential nitrogen losses due to leaching are higher in the first few weeks after sowing, when evapotranspiration is low and also during this period plant roots are not sufficiently well developed to take up the available nitrates (Prasad, Hochmuth, & Boote, 2015). The fertilizer was spread, or sprayed in the case of digestate, in a ring around the plant and then covered with soil.

2.4 Data Collection

Data on plant height were collected as follows: Four plants per plot were sampled randomly from four corners of the plot and their height measured from the ground to the top of the plant using a tape measure on a weekly basis for 5 weeks after application of the fertilizer. The plant height measurements were taken from the first week of fertilizer application to week 8 of plant growth, after crop tasselling. Average final plant height was then computed for all 20 plots.

The maize was manually harvested from the different plots at 17 weeks in both seasons, when it was ripe and dry enough for harvesting. The maize cobs were placed in polythene bags for weighing on a digital scale and the data were recorded for analysis. This was repeated for all 20 plots in the experiment.

2.5 Data Analysis

The data were analysed using two-way ANOVA and the Tukey test in R statistical software to determine whether there was any difference in maize yield between the different treatments and seasons. Box plots were also generated using the R statistical software. All analyses followed the procedures specified in Venables, Smith, and Team (2012).

3. Results and Discussions

3.1 Nitrogen Content of Fertilizer

The total nitrogen content of the different organic fertilizers investigated in the first and second seasons is shown in Table 1.

Table 1. Total nitrogen (N) concentration in the organic fertilizers used in field experiments on maize and the volumes applied in the first and second growing season

Organic fertilizer	First season		Second season	
	Concentration of N available (g/kg DM)	Quantity applied	Concentration of N available (g/kg DM)	Quantity applied
Stored cattle manure	18.5	24 kg	19.6	23 kg
Digestate	1.5	474 L	1.4	489 L
Vermicompost	21.4	21 kg	12.7	35 kg

The vermicompost used in the second season had lower nitrogen content than that in the first season. The latter had been stored for a longer period and nitrogen had probably leached/ volatilised out of the material during storage. The efficient use of nitrogen is hindered by among other things leaching, denitrification and ammonia volatilization (Chintala et al., 2015; Fageria & Baligar, 2005). During the longer storage period, the vermicompost could also have undergone further aerobic degradation, which can significantly reduce the nitrogen content (Ndegwa & Thompson, 2001). The nitrogen in the stored cattle manure in both seasons was lower than the average nitrogen content in fresh manure (Lalander et al., 2015). That treatment aimed to represent the common manure use practice in Uganda, where according to Komakech et al. (2014) most farmers first store the manure before applying it in their crop fields. This practice is associated with reduction in the nitrogen content of the manure, as can be seen in Table 2. Similar loss of nutrients in stored manure was reported by Shisanya et al. (2009). These losses can be attributed to ammonia volatilization, leaching, and nitrous oxide emissions and can amount to up to 50% of the nitrogen present, depending on the type of animal manure (Petersen, Lind, & Sommer, 1998). The level of nitrogen in the digestate was within the range reported by Möller and Müller (2012).

3.2 Plant Height

Maize plant height in the weeks after fertilizer application in the first and second season is shown in Tables 2 and 3, respectively.

Table 2. Height (cm) of maize plants after fertilizer application in the first season, October-February (mean ± standard deviation)

Treatment	Weeks after fertilizer application (3 weeks after sowing)				
	1	2	3	4	5*
Stored cattle manure	56.0 ± 6.6	95.1 ± 3.9	138.1 ± 2.5	161.5 ± 35.2	183.5 ± 17.8
Digestate	56.4 ± 3.9	101.3 ± 1.7	143.8 ± 18.2	168.6 ± 9.5	189.9 ± 12.7
Vermicompost	56.6 ± 6.5	107.4 ± 7.4	144.6 ± 5.4	173.9 ± 11.7	194.5 ±42.8
Control	50.7 ± 15.7	90.5 ± 7.2	127.5 ± 5.8	151.6 ± 8.3	170.2 ± 14.3

Note. *No significant growth in Longe 5 maize variety after 60 days or eight weeks (Kasozi, 2010).

Table 3. Height (cm) of maize plants after fertilizer application in the second season, March-June (mean ± standard deviation)

Treatment	Weeks after fertilizer application (3 weeks after sowing)				
	1	2	3	4	5*
Stored cattle manure	49.0 ± 3.6	89.1 ± 1.5	132.4 ± 4.2	175.6 ± 13.0	205.3 ± 12.4
Digestate	45.6 ± 2.2	85.2 ± 5.7	131.3 ± 6.3	173.6 ± 15.9	201.9 ± 10.3
Vermicompost	44.0 ± 6.8	79.9 ± 2.3	127.7 ± 16.4	166.6 ± 11.4	198.2 ± 29.6
Control	41.0 ± 4.4	64 ± 5.4	115.6 ± 4.0	155.6 ± 12.0	185.6 ± 16.2

Note. *No significant growth in Longe 5 maize variety after 60 days or eight weeks (Kasozi, 2010).

The results showed that plant height increased across the treatments during the different stages of plant growth, with the increase generally higher for all the organic fertilizers compared with the control. Two-way Anova analysis revealed a significant difference ($P < 0.05$) in plant height between the different treatments and seasons. Further statistical analysis using the Tukey test showed a significant difference ($P < 0.05$) in plant height for plots treated with organic fertilizers compared with the control from week 2 to week 5 in both seasons. This shows the potential importance of nitrogen-rich organic fertilizers in enhancing maize growth for poor farmers who currently cultivate their crops with no fertilizer application. It also confirms the limited nitrogen supply capacity of Central Ugandan soils. According to Roth and Fox (1990), a higher content of nitrogen in the soil stimulates plant growth. Thus the nitrogen supplied by the organic fertilizers may also have stimulated faster growth than in the control. Similar results have been obtained in field trials conducted in Pakistan (Nogales, Cifuentes, & Benitez, 2005). In that study, the presence of phytohormones in the organic fertilizers was reported to stimulate plant growth. It is thus likely that phytohormones could be the cause of the taller plants in the organic fertilizer treatments compared with the control in the present study. This could explain why there was no significant difference ($P > 0.05$) in plant height between plots treated with the different organic fertilizers. Smith et al. (2014) found that untreated manures provide high inputs of available nutrients, resulting in an initial flush in crop growth. However, this effect seems not to have been manifested in the present study, as no significant difference ($P > 0.05$) in crop growth was observed on comparing manure and other organic fertilizer treatments.

The results also showed a significant difference ($P < 0.05$) in plant growth between the different seasons, with growth being greater in the second season than in the first. According to Hernández et al. (2010), composts are slow releasers of nitrogen fertilizer, with only a small fraction of the total nitrogen being mineralized per crop cycle. Lynch, Voroney, and Warman (2004), on the other hand, reported that following incorporation of compost and manure, net nitrogen immobilization can occur in the first season, followed by mineralization in the second season. Thus the improved plant growth in the second season could be explained by greater release of the nitrogen in the fertilizers through improved mineralization.

3.3 Crop Yields

The maize yields obtained in the different treatments differed between treatments and during the two growing seasons studied (Tables 4 and 5).

Table 4. Maize yield (kg) in fields of size 15 m^2 subjected to different organic fertilizer treatments in the first season (Oct.-Feb.)

Treatment	R1	R2	R3	R4	R5	Mean
Stored cattle manure	20.09	15.26	16.27	19.37	7.94	15.79 ± 4.83
Digestate	24.78	17.62	18.93	17.1	15.54	18.79 ± 3.56
Vermicompost	28.32	20.86	23.54	17.23	19.42	21.87 ± 4.27
Control	6.4	3.75	3.7	5.66	8.05	5.51 ± 1.85

Table 5. Maize yield (kg) in fields of size 15m^2 subjected to different organic fertilizer treatments in the second season (March-June)

Treatment	R1	R2	R3	R4	R5	Mean
Cattle manure	52.18	35.62	52.46	30.05	48.17	43.70 ± 10.25
Digestate	42.02	48.92	53.56	36.05	39.2	43.95 ± 7.17
Vermicompost	43.58	53.28	49.66	28.75	30.38	41.13 ± 11.13
Control	11.45	11.42	9.15	13.26	18.82	12.82 ± 3.66

Two-way Anova statistical analysis showed a significant difference ($P < 0.05$) in maize yield for the different treatments and seasons. On average, yields were higher for the organic fertilizer treatments compared with the control (Figure 2).

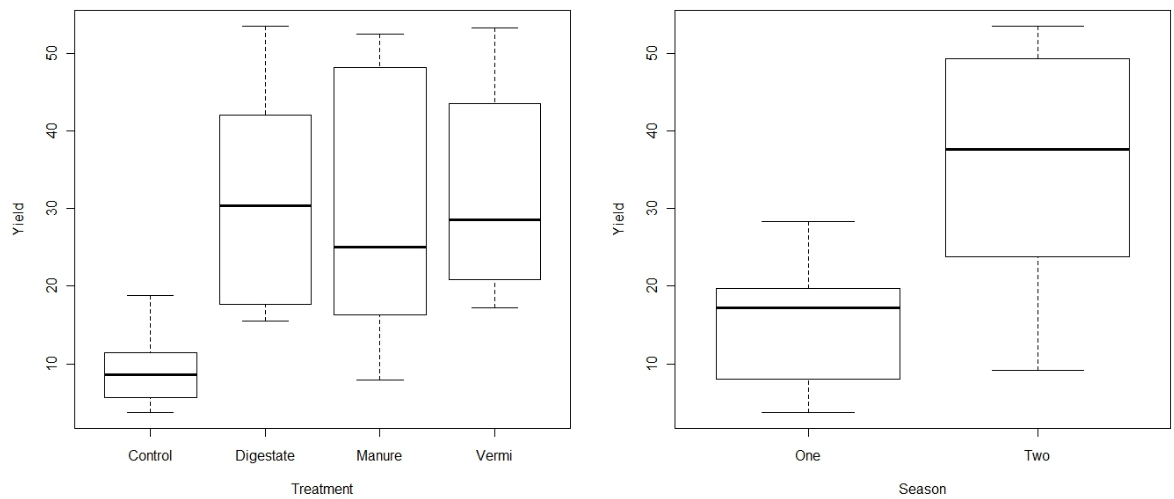

Figure 2. Statistical comparison (Tukey test) of maize yields in the different organic fertilizer treatments compared with the control

Further statistical analysis using the Tukey test showed that there was a significant difference ($P < 0.05$) in maize yield between the plots treated with the organic fertilizers and the control. The average yield increase relative to the control was 252±134% for stored cattle manure, 290±130% for digestate and 320±160% for vermicompost. However, the Tukey test showed no significant difference ($P > 0.05$) in maize yield between these three organic fertilizers. Wopereis et al. (2006), who investigated the effect of organic fertilizer inputs on maize in West Africa, established that nitrogen was the major yield-limiting nutrient and that phosphorus had a non-significant effect. The effect of phosphorus on maize yield was not investigated in the present study. However, it is reported to be present in low concentrations in animal waste generated in Kampala, Uganda (Lalander et al., 2015), so nitrogen is probably the major yield-limiting nutrient in Ugandan soils.

The statistical analysis also showed that maize yield was significantly greater ($P < 0.05$) in the second season than in the first. Wopereis et al. (2006) found that rainfall amount played a critical role in determining the kind of crop yield obtained, with better yield being associated with higher amounts. This factor seemed to have an impact on maize yield in the present study too, as the rainfall amount in the first season (400 mm) was 20% less than that in the second season (500 mm). According to Shisanya et al. (2009), nitrogen from organic inputs must first decompose and mineralize before it is made available to the crop and this process is directly proportional to the amount of rainfall received. Thus it is also probable that the improved maize yield in the second season could be explained by the release of more of the nitrogen from the organic fertilizers through improved mineralization. Similar findings have been reported in previous studies (Hernández et al., 2010; Lynch et al., 2004). In maize trials in Kenya, Shisanya et al. (2009) reported that application of cattle manure alone increased soil nitrogen content, and attributed this to the manure increasing nitrogen availability either by directly alleviating aluminium toxicity or by producing organic acids. In addition, the manure treatment maintained soil pH (Shisanya et al., 2009). This is important, as nitrates are more susceptible to leaching losses in acidic soils (Chintala et al., 2013; Ryan, Graham, & Rudolph, 2001)

When the maize yield in the present study was converted to tonnes per hectare, with a 37% deduction for husks removed, average cob yield in the first season was 6.6, 7.9, 9.2 and 2.3 tonnes per hectare for cattle manure, digestate, vermicompost and the control, respectively. In the second season, the corresponding values were 18.4, 18.5, 17.3 and 5.4 tonnes per hectare, respectively. The increased yield in the second season was similar to that experienced in the wider central region of Uganda as a result of a favourable rainfall pattern. According to FAO (2014), the increased yields of maize in that season caused a 40-45% decline in the average price of maize, despite the sustained demand for exported maize from neighbouring Kenya, South Sudan, the Democratic Republic of Congo and Rwanda. Bayite-Kasule (2009) reported that when 90 kg per hectare of nitrogen as mineral fertilizer were applied to soils in central Uganda, maize yield was between 5 and 8 tonnes per hectare. The yield obtained in the present study was generally higher than that level in both seasons. The discrepancy can be explained by various factors. First, the maize varieties used by Bayite-Kasule (2009) were probably local varieties, while in the present study Longe 5, an improved variety, was used. According to Mugisha and Diiro (2010), the yield from these improved varieties is about twice that achievable with local varieties. Second, Bayite-Kasule (2009) reported results of experiments carried on farmer's fields. According to Snapp, Mafongoya, and Waddington (1998), these are degraded soils where the soil total nitrogen and carbon levels are about one-third of the levels found at research stations, as indicated by the yield in the control being quite satisfactory in the present study. It is thus possible that this factor played a role in the unusually high yields obtained here. Third, the conversion factor for husks assumes that the field is homogeneous. This is not necessarily the case in practice, since fertility levels may vary across fields due to features such as termite hills and sandy patches (Wopereis et al., 2006). Therefore the actual yield may be lower than the calculated values reported here due to the non-homogeneity of fields. Furthermore, according to Chivenge, Vanlauwe, and Six (2011), agricultural productivity in sub-Saharan Africa is often limited by the low organic matter content of the soils. In addition, according to Lal (2004), carbon sequestered as soil organic matter leads to an increase in crop yield. It is therefore probable that a combination of factors such as addition of organic matter and nitrogen from the organic fertilizers may have contributed to the pronounced improvement in maize yield observed in this study.

There was no significant difference ($P > 0.05$) between the different organic fertilizers. According to Smith et al. (2014), the anaerobic digestion process concentrates plant nutrients (nitrogen) through release of carbon in the form of methane, reducing the carbon to nitrogen ratio. Bradbury, Whitmore, Hart, and Jenkinson (1993) and Chintala et al. (2014) reported that when this is ratio is < 8:1, the organic material tends to easily release nitrogen into the soil, while higher ratios tend to immobilise the nitrogen. Thus anaerobic digestion causes the organic material to have a higher content of easily released nitrogen (Smith et al., 2014). As regards vermicompost, Atiyeh et al. (2000) reported that it tends to have a higher content of nitrates (the more plant-available form of nitrogen), while Munroe (2007) confirmed that vermicomposted animal manure had a higher available nitrogen content than stored manure. Thus because of these advantages vermicompost and digestate have over stored manure, maize yield from these could have been expected to be greater than from the stored manure. However, no significant difference was noted between these different organic fertilizers in the present study. Further studies are required to ascertain why this is the case.

Although the majority of animal farmers in Kampala dump their animal manure, about one-third use the manure to fertilize their crop fields (Komakech et al., 2014). Most of the latter category first stores the manure in a heap/pit before application to the soil. Based on the results obtained in this study, crop yield would not be significantly improved if those farmers were to adopt vermicomposting or anaerobic digestion technology. Thus they would have no motivation to adopt these technologies from a fertilizer production point of view.

When a group of small-scale crop farmers in the Kampala region was asked to list the most important attribute of a fertilizer and to rank the three fertilizers tested in this study, the following results were obtained (Table 6):

Table 6. Ranking of organic fertilizers, according to a sub-set of farmers in the Kampala region

Attribute	Percentage of farmers in favour	Fertilizer score (3 for best, 1 for worst)		
		Vermicompost	Stored manure	Digestate
Good nutrient content	80%	3	2	1
Odourless	10%	3	2	1
No weed seeds	10%	2	3	1
Low volume	50%	3	2	1
Low cost	40%	1	3	2
Availability	30%	1	3	2
Ease of storage	10%	2	3	1
water content	10%	2	2	3
Total fertilizer score		5.5	5.7	3.3

The most favourable fertilizer from the point of view of the small-scale farmers surveyed appeared to be the stored manure and vermicompost, while the least favourable was the digestate. It is therefore important that these technologies be promoted amongst small-scale farmers to improve crop yields. It should be noted, however, that vermicompost and anaerobic digestion have other useful by-products, namely energy in the case of anaerobic digestion and animal protein in the case of vermicomposting, that go a long way towards making these organic wastes attractive. If these technologies were to be actively promoted, the incidence of animal farmers dumping animal manure generated would most probably be greatly reduced, resulting in economic, social, health and environmental benefits for the different stakeholders involved in urban animal agriculture in Kampala and other similar cities.

4. Conclusions

This study found no significant differences in maize growth and yield when the soil was treated with vermicompost, digestate or stored cattle manure. However, treatments with any of these products performed significantly better than the unfertilised control, showing how valuable organic fertilizers are in improving crop yield. A survey of small-scale farmers in the region revealed that various factors are important to them when assessing organic fertilizers and they considered stored cow manure and vermicompost to be the most desirable organic fertilizers. Overall, the use of animal waste as a fertilizer in crop fields improves the management of animal manure in urban agriculture compared with dumping it and leaving it to cause environmental and health problems. Use as a fertilizer should therefore be encouraged by the authorities. Further studies should also be conducted on similar organic fertilizers from municipal waste and on the effect of applying organic fertilizer before sowing.

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References

Atiyeh, R., Subler, S., Edwards, C., Bachman, G., Metzger, J., & Shuster, W. (2000). Effects of vermicomposts and composts on plant growth in horticultural container media and soil. *Pedobiologia, 44*(5), 579-590. http://dx.doi.org/10.1078/S0031-4056(04)70073-6

Bayite-Kasule, S. (2009). *Inorganic Fertilizer in Uganda: Knowledge Gaps, Profitability, Subsidy, and Implications of a National Policy*. International Food Policy Research Institute (IFPRI).

Bradbury, N. J., Whitmore, A. P., Hart, P. B. S., & Jenkinson, D. S. (1993). Modelling the fate of nitrogen in crop and soil in the years following application of 15N-labelled fertilizer to winter wheat. *The Journal of Agricultural Science, 121*(03), 363-379. http://dx.doi.org/10.1017/S0021859600085567

Chintala, R., Mollinedo, J., Schumacher, T. E., Papiernik, S. K., Malo, D. D., Clay, D. E., ... Gulbrandson, D. W. (2013). Nitrate sorption and desorption in biochars from fast pyrolysis. *Microporous and Mesoporous Materials, 179*(0), 250-257. http://dx.doi.org/10.1016/j.micromeso.2013.05.023

Chintala, R., Owen, R., Schumacher, T., Spokas, K., McDonald, L., Kumar, S., ... Bleakley, B. (2015). Denitrification kinetics in biomass- and biochar-amended soils of different landscape positions. *Environmental Science and Pollution Research, 22*(7), 5152-5163. http://dx.doi.org/10.1007/s11356-014-3762-2

Chintala, R., Schumacher, T. E., Kumar, S., Malo, D. D., Rice, J. A., Bleakley, B., ... Gu, Z. R. (2014). Molecular characterization of biochars and their influence on microbiological properties of soil. *Journal of Hazardous Materials, 279*(0), 244-256. http://dx.doi.org/10.1016/j.jhazmat.2014.06.074

Chivenge, P., Vanlauwe, B., & Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant and Soil, 342*(1-2), 1-30. http://dx.doi.org/10.1007/s11104-010-0626-5

Fageria, N. K., & Baligar, V. C. (2005). Enhancing Nitrogen Use Efficiency in Crop Plants. *Advances in Agronomy, 88*, 97-185. http://dx.doi.org/10.1016/S0065-2113(05)88004-6

Hansen, T. L., Bhander, G. S., Christensen, T. H., Bruun, S., & Jensen, L. S. (2006). Life cycle modelling of environmental impacts of application of processed organic municipal solid waste on agricultural land (EASEWASTE). *Waste Management & Research, 24*(2), 153-166. http://dx.doi.org/10.1177/0734242X06063053

Hernández, A., Castillo, H., Ojeda, D., Arras, A., López, J., & Sánchez, E. (2010). Effect of vermicompost and compost on lettuce production. *Chilean Journal of Agricultural Research, 70*(4), 583-589. http://dx.doi.org/10.4067/S0718-58392010000400008

Komakech, A. J., Banadda, N. E., Gebresenbet, G., & Vinnerås, B. (2014). Maps of animal urban agriculture in Kampala City. *Agronomy for Sustainable Development, 34*(2), 493-500. http://dx.doi.org/10.1007/s13593-013-0164-7

Komakech, A. J., Banadda, N. E., Kinobe, J. R., Kasisira, L., Sundberg, C., Gebresenbet, G., & Vinneras, B. (2014). Characterization of Municipal Waste in Kampala, Uganda. *Journal of the Air & Waste Management Association, 64*(3), 340-348. http://dx.doi.org/10.1080/10962247.2013.861373

Komakech, A. J., Sundberg, C., Jönsson, H., & Vinnerås, B. (2015). Life cycle assessment of biodegradable waste treatment systems for sub-Saharan African cities. *Resources, Conservation and Recycling, 99*(0), 100-110. http://dx.doi.org/10.1016/j.resconrec.2015.03.006

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *science, 304*(5677), 1623-1627. http://dx.doi.org/10.1126/science.1097396

Lalander, C. H., Komakech, A. J., & Vinnerås, B. (2015). Vermicomposting as manure management strategy for urban small-holder animal farms – Kampala case study. *Waste Management, 39*(0), 96-103. http://dx.doi.org/10.1016/j.wasman.2015.02.009

Lynch, D., Voroney, R., & Warman, P. (2004). Nitrogen availability from composts for humid region perennial grass and legume–grass forage production. *Journal of Environmental Quality, 33*(4), 1509-1520. http://dx.doi.org/10.2134/jeq2004.1509

Möller, K., & Müller, T. (2012). Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. *Engineering in Life Sciences, 12*(3), 242-257. http://dx.doi.org/10.1002/elsc.201100085

Mubiru, S. L., Tenywa, J. S., Romney, D., & Halberg, N. (2007). Manure application as an option for improving nutrient balances, yields and income from major crop patterns in Uganda. *8th African Crop Science Society Conference, El-Minia, Egypt, 27-31 October 2007*, pp. 1703-1707.

Mugisha, J., & Diiro, G. (2010). Explaining the adoption of improved maize varieities and its effects on yields among smallholder maize farmers in Eastern and Central Uganda. *Middle-East Journal of Scientific Research, 5*(1), 6-13.

Munroe, G. (2007). Manual of on-farm vermicomposting and vermiculture. *Organic Agriculture Centre of Canada*, 1-56.

Nogales, R., Cifuentes, C., & Benitez, E. (2005). Vermicomposting of winery wastes: a laboratory study. *Journal of Environmental Science and Health Part B, 40*(4), 659-673. http://dx.doi.org/10.1081/PFC-200061595

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory Methods of Soil and Plant Analysis: A working Manual* (2nd ed.). TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Parnell, S., & Walawege, R. (2011). Sub-Saharan African urbanisation and global environmental change. *Global Environmental Change, 21, Supplement 1*(0), S12-S20. http://dx.doi.org/10.1016/j.gloenvcha.2011.09.014

Petersen, S. O., Lind, A.-M., & Sommer, S. G. (1998). Nitrogen and organic matter losses during storage of cattle and pig manure. *The Journal of Agricultural Science, 130*(01), 69-79. http://dx.doi.org/10.1017/S002185969700508X

Prain, G., Karanja, N., & Lee-Smith, D. (2010). *African urban harvest. Agriculture in the cities of Cameroon, Kenya and Uganda*. Spring Street, New York, NY 10013, USA: Springer, Science + Business Media. http://dx.doi.org/10.1007/978-1-4419-6250-8

Prasad, R., Hochmuth, G. J., & Boote, K. J. (2015). Estimation of nitrogen pools in irrigated potato production on sandy soil using the model SUBSTOR. *Plos One, 10*(1), e0117891. http://dx.doi.org/10.1371/journal.pone.0117891

Rajesh, C., Reddy, K. S., Naidu, M., & Ramavatharam, N. (2003). Production and evaluation of composts and vermicomposts from solid organic wastes. *Asian Journal of Microbiology Biotechnology and Environmental Sciences, 5*(3), 307-311.

Roth, G., & Fox, R. (1990). Soil nitrate accumulations following nitrogen-fertilized corn in Pennsylvania. *Journal of Environmental Quality, 19*(2), 243-248. http://dx.doi.org/10.2134/jeq1990.00472425001900020008x

Ryan, M. C., Graham, G. R., & Rudolph, D. L. (2001). Contrasting Nitrate Adsorption in Andisols of Two Coffee Plantations in Costa Rica. *J. Environ. Qual., 30*(5), 1848-1852. http://dx.doi.org/10.2134/jeq2001.3051848x

Shisanya, C. A., Mucheru, M. W., Mugendi, D. N., & Kung'u, J. B. (2009). Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. *Soil & Tillage Research, 103*, 239-246. http://dx.doi.org/10.1016/j.still.2008.05.016

Smith, J., Abegaz, A., Matthews, R. B., Subedi, M., Orskov, E. R., Tumwesige, V., & Smith, P. (2014). What is the potential for biogas digesters to improve soil fertility and crop production in Sub-Saharan Africa? *Biomass and Bioenergy, 70*(0), 58-72. http://dx.doi.org/10.1016/j.biombioe.2014.02.030

Snapp, S. S., Mafongoya, P. L., & Waddington, S. (1998). Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agriculture, Ecosystems & Environment, 71*(1-3), 185-200. http://dx.doi.org/10.1016/S0167-8809(98)00140-6

UN-HABITAT. (2008). *The state of African cities 2008. A framework for addressing urban challenges*. Nairobi, Kenya: United Nations Human Settlements Programme (UN-HABITAT).

Venables, W., N.,, Smith, D., M.,, & Team, R. C. (2012). *An Introduction to R. Notes on R: A programming environment for data analysis and graphics*. Version 2.15.1 (22-06-12).

Wopereis, M. C. S., Tamelokpo, A., Ezui, K., Gnakpenou, D., Fofana, B., & Breman, H. (2006). Mineral fertilizer management of maize on farmer fields differing in organic inputs in the West African savanna. *Field Crops Research, 96*, 355-362. http://dx.doi.org/10.1016/j.fcr.2005.08.004

Yost, D., & Eswaran, H. (1990). *Major land resource areas of Uganda*. World Soil Resources, Soil Conservation Service, USDA, Washington D.C.

Zezza, A., & Tasciotti, L. (2010). Urban agriculture, poverty, and food security: Empirical evidence from a sample of developing countries. *Food Policy, 35*(4), 265-273. http://dx.doi.org/10.1016/j.foodpol.2010.04.007