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A greenhouse experiment to evaluate compost derived from household and market crop wastes

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Abstract

Urban peasants in Uganda frequently cultivate soils with low intrinsic fertility status (low pH, low organic matter and nutrient contents), which restricts high crop production. A greenhouse study was conducted at Kabanyolo Research Station, Makerere University to evaluate how compost (CO) compares with commercial fertilizers as a soil fertility amendment. The aims included improvement of crop productivity, while reducing environmental pollution with the wastes. The treatments, each of which had two replicates, comprised a control, 5 and 10 t CO ha^{-1} applied singly or in combination with 40 and 80 kg urea-N ha^{-1} and 9 and 18 kg triple superphosphate-P (TSP) ha $^{-1}$. The test crop maize (*Zea mays* L.) plants were harvested, 39 days after sowing, and dry matter (DM) yields were recorded and analyzed for plant tissue contents of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). In the single applications, effectiveness measured in terms of average DM yields increased in the order: Control < N < P < CO. Also in the single applications, DM yields increased along with increasing compost application rates. The combined applications produced significantly higher DM yields than the control and single applications. Of the amendments, CO5 + N40 + P18 was the best treatment, increasing DM yields over control by 629%. Notwithstanding that best performance, however, the CO5 + N40 + P9 treatment, which increased DM yields by 571%, seemed to be more affordable for the peasants concerned. The combined applications generally enhanced uptake of N, P, K and S. The average utilization efficiency (UE) of compost-N, -P, -K and -S was about 11, 3, 11 and 3%, respectively. When the compost was applied together with fertilizers, UE varied from 13 to 98% for N; 2 to 40% for P; 11 to 30% for K and 3 to 11% for S.

Key words: Maize, soil fertility, urban peasants, utilization efficiency, waste

Introduction

Cities in Africa are today struggling with many expanding problems within their urban boundaries. Among these problems are increasing waste production, land degradation and rapid population growth, demanding improved food security. One consequence of rapid population growth is the production of large amounts of wastes, which society cannot handle properly. The Kampala population of about 1.2 million produces about 900 metric tonnes of solid waste daily, with only 45% is being collected. The solid wastes consist of organic matter (OM), paper, plastics and inorganic wastes (Mwesigye and Sabano, 2003). When wastes are not managed properly, they can cause serious health and environmental risks.

Some of the management options are dumping into landfills, burning, heaping in market places (or elsewhere), use as animal feed and/or direct application to agricultural land to improve soil fertility. Disposals by heaping, dumping in landfills and burning are not environmentally friendly options. Landfills are often non-existent or not managed properly in African cities. The first two options are also associated with repulsive odours and leaching of contaminants into the groundwater and surface water. Burning produces greenhouse gases, such as SO_2 and CO_2 and other volatile compounds. Similarly, use of at least some of the wastes on agricultural land may affect the soils negatively since the wastes can transmit toxic substances into the environment including soils and crops. However, as urban soils are depleted of intrinsic fertility with a subsequent reduction in crop production, use of household crop wastes as soil fertility amendment is viable option. The overall goal of municipal waste management is to improve and safeguard public health and welfare, reduce waste generation, increase waste recycling and protect environmental quality.

The present study was undertaken to evaluate how compost (CO) compares with commercial fertilizers as a soil fertility amendment. The aims were to explore ways of improving crop productivity and reducing environmental pollution with the wastes.

Materials and methods

The pot experiment was performed in a greenhouse at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK). A clay loam soil was used. About 500 kg of bulk soil was collected from an undisturbed field that had not been cultivated and fertilized for two years. The soil was crushed a passed through a 5 mm sieve, homogenised and used in the pot experiment. A small amount of the soil was air-dried for analysis of soil properties. The compost investigated was prepared from household and market place food wastes. Some soil and CO characteristics are presented in Table 1.

The main treatments (Table 2) each one of which had two replicates, comprised a control, 5 and 10 t CO ha^{-1}, 40 and 80 kg urea-N ha^{-1} and 9 and 18 kg triple super phosphate-P (TSP) ha^{-1} (Table 2). Compost and fertilizers were applied singly and in compost-fertilizers combinations. There were 28 treatments altogether. The test crop maize (*Zea maize* L. variety Longe 4) plants were harvested 39 days after sowing, dry matter (DM) yields recorded and the plant material was milled for analysis of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) tissue contents. The utilization efficiency (UE) of compost-N, -P, -K and –S was calculated as follows:

UE = {[(Nutrient uptake in amended treatment) – (Nutrient uptake in Control)] / Nutrient rate}∗100.

Analyses

Soil and compost pH_{aq} was measured using a wt:vol ratio of 1:5. The concentrations of the elements P, K and S in plant tissues were obtained by digesting the tissues in conc. HNO_3 and and analysed the solution obtained in an ICP spectrometer. Total contents of N and carbon (C) were determined by dry combustion on the LECO CNS-2000 Analyzer. Inorganic N was measured in fresh compost and bulk soil through extraction with 2 M KCl and thereafter calorimetrically assayed on the Auto-Analyzer TRAACS 800. The SAS software package (SAS Institute, 1999-2000) was used for statistical analyses. Means were separated by the *t*-test ($LSD_{0.05}$).

Results

DM yields

DM yields are presented in Table 3. All the treatments impacted on DM yields, but the magnitude of the effects was usually not similar. Thus, the yields were significantly larger in the single CO applications than in the corresponding N and P applications and control. The combined applications of CO and commercial fertilizers generally increased DM yields above the single application levels. By contrast, combinations of N and P were not as effective even though DM yields were higher than their corresponding single applications. Of the amendments, CO5 + N40 + P18 was the best treatment, increasing DM yields over control by 629%. Figure 1 shows the impact of selected treatments on DM production.

Plant tissue contents of nitrogen, phosphorus, potassium and sulphur

Plant tissue analytical data are presented in Table 4. Of the nutrient contents, K varied generally widely (11.89 to 67.64 with a mean of 46.67 mg g^{-1} DM). N tissue contents were accentuated in treatments receiving urea alone or in combination with CO and TSP (~4%) compared with treatments not amended with urea (<3%). The trend of events was similar for tissue P contents. The tissue K contents were significantly higher in treatments amended with CO than those without CO. Sulphur tissue contents were evenly distributed in all treatments (range 1.55-2.14, average 1.82 mg g^{-1} DM).

Utilization efficiency (UE) of nutrients by plants

Utilization by maize plants of nitrogen, phosphorus, potassium and sulphur supplied by C was on average 11, 3, 11 and 3%, respectively (Table 5). Plant UE of N was markedly elevated in treatments receiving urea, especially in CO40 + P18 where nearly all urea applied was utilized (UE = 98%). In the N40 treatment UE (43%) was nearly twofold higher than the UE in the combined treatments of CO5 + N40 and CO10 + N40 (27 and 23%, respectively) and more than about threefold higher than in CO5 + P18 and CO10 + P18 (13%). When CO5 was applied in combination with urea (N40) and TSP (P18), UE was about 51%, whereas when CO rate raised 10 t ha^{-1}, UE was 24. The results indicated that CO supplemented plant requirement of N.

The UE for P showed an extreme and inconsistent pattern: 7.0% in P18, 10.85% in N40 + P18, 5.0% in CO5 + N40 + P18 and 37.5% in CO10 + N40 + P18 compared with 7.0% determined P18. By contrast, combined applications of CO and fertilizers increased utilization of compost's K particularly in CO10 + N40 + P18 (37.48%) compared with 11% in single applications of CO (11%). A similar pattern was recorded for S.

Soil analytical data

Soil analytical data are presented in Table 6. As expected CO applied singly substantially increased soil pH from 5.46 in control to 5.58 and 6.16 in CO5 and CO10, respectively. Without addition of CO, urea decreased pH, whereas combined applications of CO, urea and TSP pH was above that in the control. TSP alone did not affect pH. The C/N ratios were relatively stable.

Discussion

Evaluated on the basis of its low pH, contents of OM, total N and Bray1-P, the soil used in this study was not fertile. The recommended fertilizer application rate for maize in Uganda is 60 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1} (Kikafunda-Twine et al., 2001). That P_2O_5 rate translates into 19 kg P ha^{-1}, implying that 4 t of the compost (P content 0.478% DM) would be needed to supply this level. If compost with C:N wider than 10:1 is applied to the soil demand of plants for N will be high due to competition with microorganisms (Follet et al., 1981). The compost investigated in this study had C:N ratio of 12:1, implying that N was not limiting plant

Table 1. Selected soil and compost properties

Property	Unit	Compost	Soil
Sand	%	-	47
Clay	%	-	41
Silt	%	-	12
OM	% DM	n.d	2.88
Moisture	%	20.1	16.8
pH		9.85	5.54
Total C	%	8.662	2.132
Total N	%	0.729	0.17
NH_4-N	%	0.0026	0.0202
NO_3-N	%	0.0818	0.0031
Total mineral N	% of Tot-N	11.58	13.71
Organic N	% of Tot-N	88.42	86.29
C/N ratio		11.9	12.5
Bray1-P	mg g^{-1}	n.d	0.007
Total P	mg g^{-1}	4.78	0.48
Total K	mg g^{-1}	21.76	0.34
Total S	mg g^{-1}	2.08	0.23

Table 2. Rates of compost (CO) and fertilizers

Treatment	Field rate (ha^{-1})	Greenhouse rate (field rate x 5)	Converted into g pot^{-1} (4 kg dry soil)
Control			
CO5	5 t	25	62.2 DM
CO10	10 t	50	124.4 DM
N40	40 kg	200	0.86 (urea)
N80	80 kg	400	1.7 (urea)
P9	9 kg	45	0.45 (TSP)
P18	18 kg	90	0.90 (TSP)

Table 3. Mean DM yields (g ± standard deviation)

Treatment	Absolute DM (g)	Relative DM (100%)
Control	1.22 ± 0.27	100
CO5	3.18 ± 0.09	260
CO10	4.83 ± 1.39	396
N40	1.58 ± 0.16	130
N80	1.20 ± 0.71	98
P9	2.09 ± 0.04	171
P18	1.73 ± 0.21	142
CO5 + N40	4.20 ± 0.76	344
CO10 + N40	6.53 ± 1.87	535
CO5 + N80	4.11 ± 0.54	336
CO5 + N80	6.17 ± 1.59	505
CO10 + N80	6.18 ± 2.30	506
CO5 + P9	4.46 ± 1.07	365
CO10 + P9	6.37 ± 0.88	522
CO5 + P18	4.83 ± 0.04	395
CO10 + P18	6.03 ± 0.25	494
N40 + P9	3.05 ± 0.93	250
N40 + P18	2.57 ± 0.42	211
N80 + P9	3.00 ± 0.13	245
N80 + P18	3.55 ± 1.65	291
CO5 + N40 + P9	6.97 ± 1.94	571
CO10 + N40 + P9	6.76 ± 1.42	554
CO5 + N80 + P9	7.29 ± 1.49	597
CO10 + N80 + P9	5.38 ± 0.23	441
CO5 + N40 + P18	7.67 ± 1.00	629
CO10 + N40 + P18	6.75 ± 1.05	553
CO5 + N80 + P18	7.38 ± 1.24	605
CO10 + N80 + P18	7.58 ± 3.35	621
$LSD_{(0.05)}$	1.35	

Table 4. Mean (g ± standard deviation) plant tissue contents of N, P, K and S

Treatment	N (% DM)	P (mg g^{-1} DM)	K (mg g^{-1} DM)	S (mg g^{-1} DM
Control	2.8 ± 0.44	1.68 ± 0.31	28.78 ± 5.69	1.82± 0.26
CO5	2.7 ± 0.12	3.18 ± 0.67	63.08 ± 17.1	1.91 ± 0.32
CO10	2.9 ± 0.87	3.61 ± 0.79	67.64 ± 15.8	2.06 ± 0.55
N40	4.3 ± 0.08	1.76 ± 0.11	23.25 ± 1.69	2.00 ± 0.16
P18	2.3 ± 0.52	2.80 ± 0.30	19.68 ± 5.40	1.62 ± 0.00
CO5 + N40	4.2 ± 0.19	2.82 ± 0.24	61.22 ± 10.2	2.10 ± 0.20
CO10 + N40	4.0 ± 0.11	2.53 ± 0.34	59.19 ± 4.51	1.77 ± 0.08
CO5 + P18	1.9 ± 0.16	2.97 ± 0.15	58.69 ± 0.98	1.59 ± 0.19
CO10 + P18	2.5 ± 0.17	2.63 ± 0.01	55.97 ± 2.87	1.65 ± 0.02
N40 + P18	4.4 ± 0.05	2.49 ± 1.29	11.89 ± 4.66	1.51 ± 0.76
CO5 + N40 + P18	4.0 ± 0.24	2.98 ± 0.09	60.72 ± 2.52	2.14 ± 0.02
CO10 + N40 + P18	4.1 ± 0.14	2.53 ± 0.09	53.47 ± 2.79	1.76 ± 0.08
$LSD_{(0.05)}$	0.86	1.11	17.52	0.68

Comparisons are made by columns.

Table 5. Plant utilization efficiency (%) of some nutrients applied in compost and fertilizers

Treatment	N	P	K	S
CO5	11.2	2.7	12.2	3.0
CO10	11.5	2.6	10.8	3.0
N40	43.1	-	-	-
P18	-	7.0	-	-
CO5 + N40	27.07	3.30	16.40	5.09
CO10 + N40	22.82	2.43	12.97	3.61
CO5 + P18	12.64	3.64	18.33	4.22
CO10 + P18	12.88	2.17	11.16	2.98
N40 + P18	98.23	10.85	-	-
CO5 + N40 + P18	51.30	5.04	31.82	10.99
CO10 + N40 + P18	24.32	37.48	12.03	3.72

Table 6. Soil pH and C/N ratios determined after harvesting the maize plants

Treatment	pH_{water}	C/N ratio
Control	5.46	12.8
CO5	5.85	12.9
CO10	6.16	12.5
N40	4.97	12.6
P18	5.44	13.1
CO5 + N40	5.47	12.6
CO10 + N40	6.00	12.7
CO5 + P18	5.83	12.4
CO10 + P18	6.11	12.3
N40 + P18	4.99	12.5
CO5 + N40 + P18	5.59	12.4
CO10 + N40 + P18	5.88	12.1

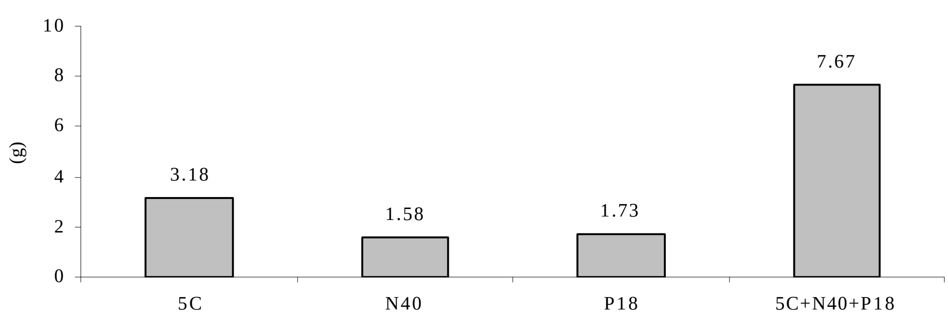

Figure 1. Comparison of DM yields harvested from in some selected treatments.

growth when the compost was applied alone. Indeed, DM response to the single applications of fertility amendments was consistently greater for CO than fertilizers, even though yields were not substantially enhanced. The compost also supplied the nutrients P, K, Ca, S, Mg and Ca and exhibited liming effects. The increase in pH not only increased plant growth, it probably also have increased phosphorus availability. A similar effect was rcorded by Soumaré *et al.* (2003). Moreover, compost also has a structural role is soil, i.e. it improve soil structure and preserves moisture for plants (Cooke, 1975). Also, compost decomposes producing compounds, such as oxalic acid that detoxifies aluminium Feng *et al.*, 1997).

Effectiveness of the compost was reinforced when it was applied in combination with the commercial fertilizers, indicating positive interactions between compost and fertilizers. Such interactions are reported elsewhere (e.g. Cooke, 1975). As was shown in Figure 1 in this study, the highest DM yield of 7.67 g pot^{-1} was harvested in the CO5 + N40 +P18 treatment.

The maize plants poorly responded to both urea and triple superphosphate apparently due to poor balance of available nutrients in soils. Moreover, urea acidified the soils: CO $(NH_2)_2 + 2H_2O$'! $(NH_4)_2CO_3$, with NH_4^+ being oxidized to HNO_3. Both N40 and N80, but especially the latter negatively impacted on DM production apparently due soil acidification. Further more, soil acidification activates soil aluminium ions (Al^{3+}) which, on the one hand, damages plant growth and, on the other hand, it precipitates phosphorus causing P deficiency in plants.

Conclusion

The soil investigated was not fertile. The greenhouse experiment showed that applying urea and TSP singly or in combination did not enhance crop yields markedly. Compost applied alone stimulated plant growth more than the fertilizers. Compost applied together with urea and TSP produced the highest DM yields, with the best treatment being CO5 + N40+ P18 (7.67g), followed by CO5 + N40 + P9 (6.97g, i.e. 10% lower than the former). As fertilisers are expensive, low rates (affordable by small-scale farmers) could be recommended to be applied with compost on the soil tested. From economic pint of view, 5 t compost applied in combination with 40 kg N and 9 kg P ha^{-1} could be recommended for the resource-constrained urban peasants, even though the maximum DM yield was obtained in the CO5, N40, P18 treatment.

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