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Composting of selected organic wastes from peri-urban areas of Harare, Zimbabwe

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Abstract

Background: The composting process of peri-urban household wastes, changes that occur during composting, and the properties of the composting products that are of importance for use as soil amendments were studied. Seven different composting mixtures were made in large piles consisting of fallen tree leaves and fresh vegetable leaves mixed with grass or maize straw (0%, 10%, 30% and 50% *w/w*), wastes common in peri-urban areas of Harare.

Results: The highest temperature peaks of the mixtures with 0% and 10% straw were in the range of 68°C to 72°C. Mixtures with 30% straw had temperature peaks of 50°C (maize) and 52°C (grass). The mixture with 50% grass straw reached a peak of 50°C, while the corresponding mixture with maize straw did not reach thermophilic temperatures. pH ranged from between 6.2 and 6.8 before composting to between 7.4 and 7.8 after composting. The ammonium concentration peaked at various times but declined to negligible concentrations at day 140. The concentration of nitrates increased with composting up to day 97 and decreased gradually thereafter. There was a general increase in nitrogen concentration from 0.9% to 2.3% as composting progressed. Decreases in organic C% and C/N ratio with composting were also observed, signifying mass loss.

Conclusion: The results of this study indicated that household wastes with 50% straw or less can be composted but with measures being taken to achieve temperatures greater than 55°C for at least 3 days to destroy weed seeds and pathogens. The composts with 30% straw mixture had the greatest potential as a soil amendment in peri-urban areas of Harare as they effectively reduced nitrogen losses.

Keywords: Composting; N mineralisation; Organic waste recycling; Peri-urban organic wastes

Introduction

Rapid urbanization, expansion of urban and peri-urban agriculture and escalating waste disposal costs have resulted in widespread interest in composting as a strategy for managing urban and peri-urban household wastes (Kapetanios et al. 1993; El-haggar et al. 1998; Eklind 1998). Recycling of organic wastes provides an environmentally sound method of reducing the problems of land degradation, atmospheric pollution, soil health, soil biodiversity and sanitation (Misra et al. 2003). Compost is an important source of organic matter. Soil organic matter improves physico-chemical and biological properties and can supply crops with nutrients (Kokkora et al. 2008). Organic amendments such as compost can therefore be used as soils amendments. Smallholder farmers in developing countries use compost materials as soil amendments as these are a cheaper alternative when compared to commercial fertilizers. Peri-urban areas of developing countries in particular have high population densities, lack waste management facilities for handling and disposing of waste and rely on agriculture as a source of livelihood. Composting as a waste management strategy has multiple benefits for peri-urban agriculture considering the scarcity of animal manures among small holder farmers as highlighted by Nzuma and Murwira (2000) and the rapid organic matter mineralization associated sub-Saharan Africa. Clear guidelines on which readily available materials to be used by smallholder farmers, the mixtures and the procedures to follow require scientists to dedicate

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resources in order to come up with site-specific recommendations.

It is not possible to produce household waste compost with a specific fertilizer value (Ozores-Hampton et al. 1998) because household waste is heterogeneous and varies in composition with place and season (Kirchmann and Widen 1994). The composting substrate, methods and environmental conditions determine the quality of the composting product. Little research has been done on composting in the less-developed countries. In Zimbabwe, local work on composting has focused on effects of methods of treating or storing cattle manure with a major thrust on quality and nutrient release patterns (Murwira and Kirchmann 1993; Nzuma and Murwira 2000).

The formulation of composting mixtures has to balance the substrate composition to meet the nutrient (C, N and to some extent P), aeration and moisture requirements of the microbial decomposer community. Basic requirements of rapid composting are a C/N ratio near 30%, 30% air-filled porosity and 50% to 55% moisture content (Jeris and Regan 1973). The success of the composting process is evaluated by monitoring such parameters as temperature, pH, organic matter and N transformations as well as changes in microbial activity (Chefetz et al. 1996). Successful composting is typified by a temperature profile rising to thermophilic temperatures (Haug 1980).

In this study, the composting process of selected components of peri-urban organic wastes was studied. The effect of using varying proportions of grass and maize straw as bulking material, with periodical manual mixing, on performance of the composting process of selected peri-urban organic waste comprising tree leaves and green wastes was investigated. This study therefore sought to identify for the benefit of resource poor peri-urban farmers, mixtures of readily available wastes that if composted, have the potential of being used as soil amendments.

Methods

Raw materials and composting mixtures

Grass, maize straw, dry tree leaves and fresh vegetable leaves were used as raw materials (Table 1). Grass straw mainly *Hyparrhenia* spp. was collected from the University of Zimbabwe campus grounds where senesced grass had just been cut. Maize straw was obtained from the University Crop Science Department after the harvesting of their commercial crop. Peri-urban farmers were requested to retain all the fallen leaves mainly of avocado (*Persea* spp.) and mango (*Mangifera indica* L.) fruit trees that they collected as yard sweepings. All materials were shredded to 5 to 10 cm by chopping with cane knives. Leaves were crushed by hand after they had been left in the sun to dry. Fresh vegetable leaves were obtained from a commercial vegetable peri-urban farming plot in Harare. Vegetable waste comprised *Brassica* spp., mainly rape, cauliflower, cabbage and carrot leaves (*Daucas carota*). Tree leaves and vegetable leaves mixed in the proportion 6:1 were further mixed with maize or grass straw to make seven different composting mixtures consisting of 0%, 10%, 30% and 50% straw (Table 2). Mixing was done manually on a tent sheet measuring 6 m × 6 m. Mixing was done systematically from one corner of the tent sheet to the centre by lifting the four corners of the tent sheet simultaneously to enhance uniform mixing at the centre of the sheet. This was followed by mixing with a garden fork, and the process was repeated several times to ensure that the materials were uniformly mixed. Mixed dry wastes were moistened 1 day before composts were set up. Composting was done in bins (2.2 m × 1.2 m × 1 m), each partitioned across its length into cells separated by 10 cm of open space. The cells provided three replicates for each of the mixtures. Composts were set up over 4 weeks, as vegetable waste material became available.

Table 1 Chemical characteristics of wastes used as composting raw materials

Raw material	Dry matter (% of fresh weight)	Percent of dry matter			C/N
		Ash	C	N	
Vegetable leaves	20	14	48	4	12
Tree leaves	73	13	44	0.45	98
Maize straw	75	8	51	0.7	74
Grass straw	75	9	46	0.5	102

A 60-cm-long type T thermocouple probe (Thermo Works, Lindon, UT, USA), and a dual logging Digi-sense thermocouple thermometer (Eutech Instrument Pte Ltd, Singapore, Singapore), was used to measure the internal temperature of the composts. Temperature measurements were made in the centre of the compost in three different positions along the middle of the cell at equal intervals four times a day during the first 2 weeks constituting the active composting phase. Thereafter, temperature measurements were made twice daily up to 30 days after which readings were taken once daily. The ambient temperature was also recorded. Mixing was done on days 0 and 3 and thereafter at weekly intervals. Samples were taken after thorough mixing on days 0, 3, 11, 19, 27, 41, 69, 97 and 140 by pooling five sub-samples from random positions in the compost. Moisture adjustments were timed to coincide with mixing and were based on the findings of the previous sampling. When the moisture content fell to 55%, additional water (5 to 10 L) was added at the next mixing. At 140 days of composting, composts were removed from the bins and allowed to dry further in bags.

Table 2 Amount of fresh and dry matter (kg per pile), lignin content and C/N ratio of the mixtures of the household waste used in the composting trials

Mixture	Straw	Tree leaves	Vegetable leaves	Total mass	Lignin%	C/N ratio
No straw	0 (0)	28 (21)	172 (34)	201 (55)	9.5	33
10% grass	23 (17)	29.5 (22)	177.5 (36)	230 (74)	11.0	41
30% grass	87 (65)	29.1 (21)	194 (39)	290 (125)	12.9	60
50% grass	116 (87)	16.5 (12)	99 (20)	232 (119)	11.6	87
10% maize	23 (17)	30 (22)	178 (36)	291 (75)	12.6	41
30% maize	78 (56)	25 (18)	150 (30)	253 (104)	13.9	58
50% maize	116 (87)	16.5 (12)	99 (20)	232 (119)	14.5	78

Chemical analyses

Analysis for the moisture content and extraction of samples for mineral N was done in triplicate on fresh samples within 4 h of sampling. Mineral N was extracted from compost samples with acidified 1 M KCl. Mineral N was determined by steam distillation of NH_4^+-N into 2% boric acid followed by titration with dilute HCl (Mulvaney 1996). Magnesium (MgO) was added to an aliquot of the sample extract alone to obtain NH_4^+-N and with Devarda's alloy to obtain combined NH_4^+-N and NO_3^--N. The concentration of NO_3^--N was obtained by difference. Total N, carbon, pH and electrical conductivity were determined on air-dried samples. Electrical conductivity and pH were determined on water extracts (1:5 compost/water) as outlined by Anderson and Ingram (1993). Moisture content was determined gravimetrically on oven drying samples (70°C for 48 h). The salicylic acid-modified Kjeldahl method followed by distillation and titration was used to determine total N. Ash and volatile solid content were obtained after dry ashing in a furnace at 550°C for 12 h. The lignin and C content were determined as described by Anderson and Ingram (1993).

Data analysis

The data of the measured final compost parameters were subjected to analysis of variance using Genstat version 12 software. Where there were significant differences in the measured compost parameter, the treatment means were separated using LSD or standard error of difference (SED) ($p < 0.05$). Graphs were plotted using Sigmaplot version 12.1.

Results

Temperature patterns

Temperatures for both grass and maize straw composts peaked within 2 days from the onset of composting (Figure 1). For the composts containing 0%, 10%, 30% and 50% grass straw, temperature peaks were at 75°C, 70°C, 52°C and 50°C, respectively. The equivalent maize straw composts had similar peaks with the exception of the 50% straw compost, which failed to rise to thermophilic temperatures peaking at 32°C (Figure 2). There was a second peak in temperature after the composts were mixed on day 3. The active composting phase was very short with temperatures dropping to ambient within 12 days of composting for both the maize and the grass straw-based composts (Figures 1 and 2). In all of the composts, internal temperatures fell below 55°C within 3 days.

Changes in the moisture content of composts

Both the grass and maize straw composts with 0% and 10% straw had initial moisture contents above 65% (Figure 3). Moisture adjustments for the no straw mixture became necessary after 6 weeks of composting while the 10% straw mixtures both for grass and maize straw needed moisture to be added within the first 4 weeks of composting. Moisture adjustment was essential within the first fortnight of composting for the 30% and 50% maize straw composts. This might have been due to higher moisture losses due to excessive aeration as a result of the more open structure of the maize straw composts when compared with the grass straw composts as well as differences in the starting moisture content. Pieces of maize straw were generally larger than pieces of grass straw. At 140 days of composting, moisture contents were approaching 50%, indicating gradual drying relative to the initial moisture contents of the mixtures.

Changes in electrical conductivity and pH

The trends of electrical conductivity and pH were similar in grass and maize composts. Both compost types showed fluctuations in electrical conductivity (Figure 4). In general, electrical conductivity increased with composting and significant changes ($P < 0.05$) in electrical conductivity were detected around day 97. Electrical conductivity was higher in maize composts than in grass composts ($P < 0.05$). Differences in electrical conductivity were not significant between the no straw and the 10% straw mixtures or between the 30% and the 50% composts but significant differences were observed between the two resulting groups ($P < 0.05$).

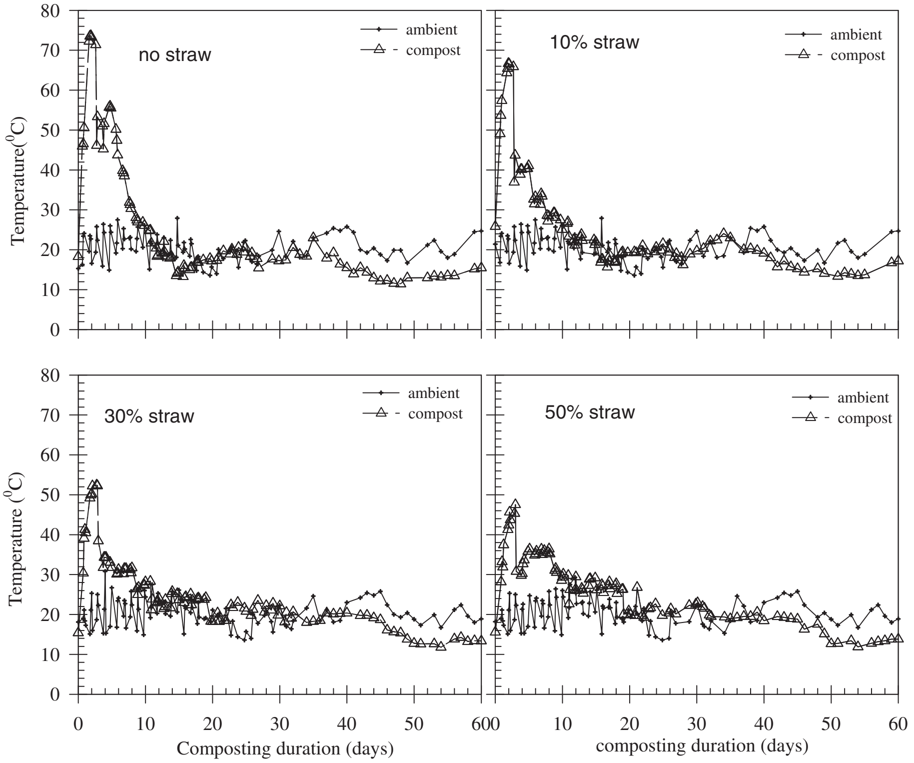

Figure 1 **Temperature profiles for compost mixtures with 0°C, 10°C, 30°C and 50% grass straw as bulking material.**

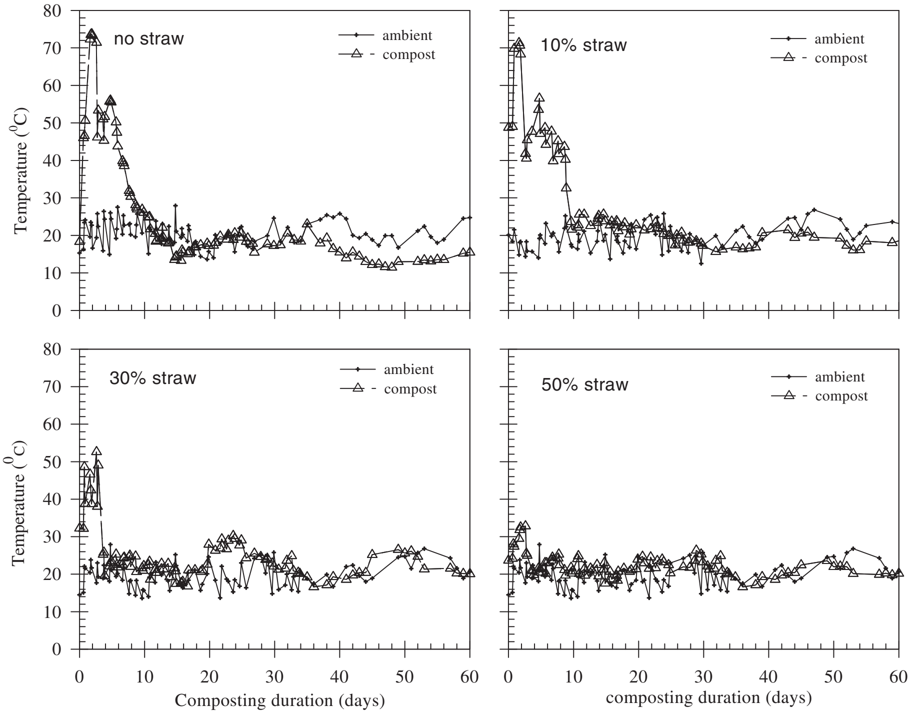

Figure 2 **Temperature profiles for compost mixtures with 0°C, 10°C, 30°C and 50% maize stover as bulking material.**

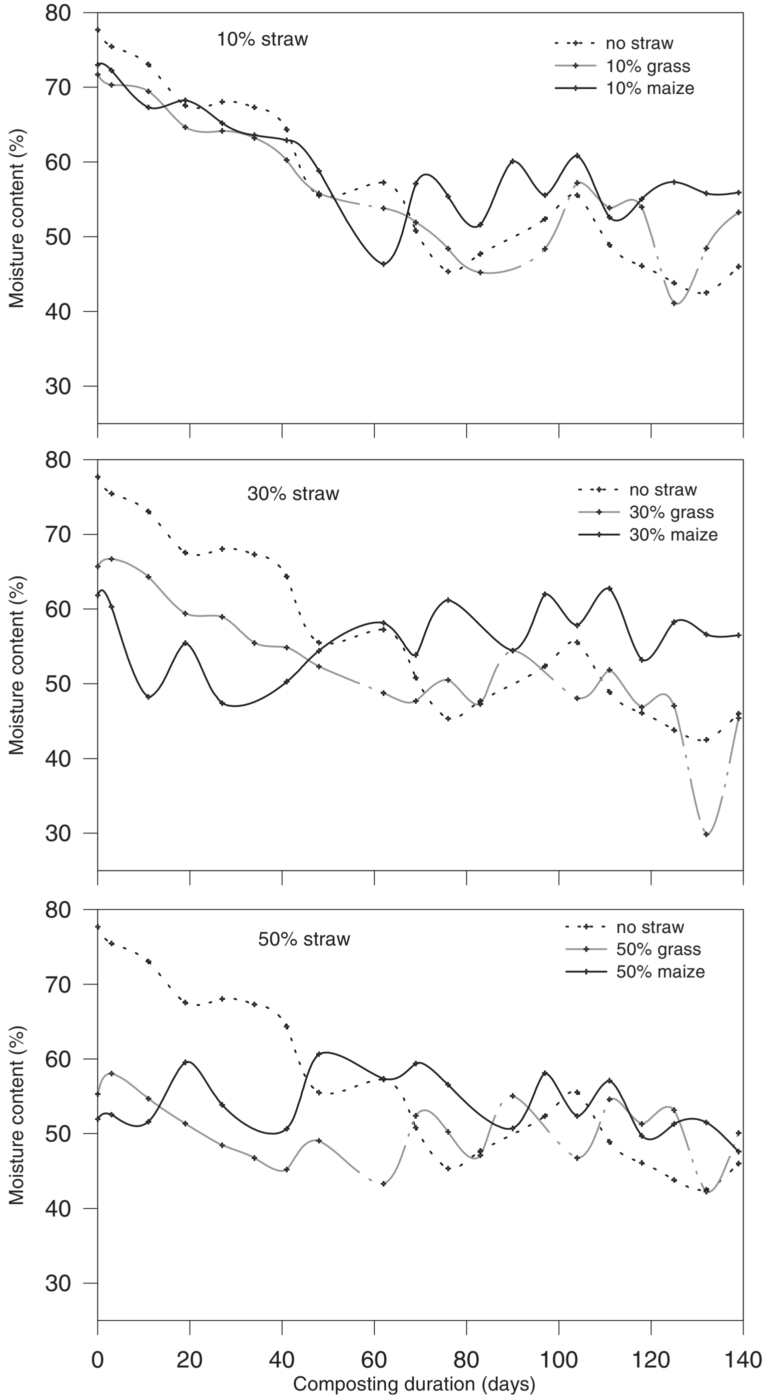

Figure 3 Changes in moisture content during composting of selected peri-urban household wastes.

There was an initial increase in pH with composting followed by a drop in pH to near neutral (Figure 5). No differences existed between grass and maize composts ($P < 0.05$) but significant differences occurred due to varying proportions of straw in composts. During the first 3 weeks of composting, pH (water) exceeded eight for the compost without straw or exceeded 7.5 in the 10%, 30% or 50% straw composts. The appearance of pH peaks was delayed for composts containing high proportions of straw. At the end of the composting period, there were no significant differences between the 0% and 10% straw grass composts, or the 30% and 50% grass composts, but differences were significant between these two groups of grass composts. The final pH of composts

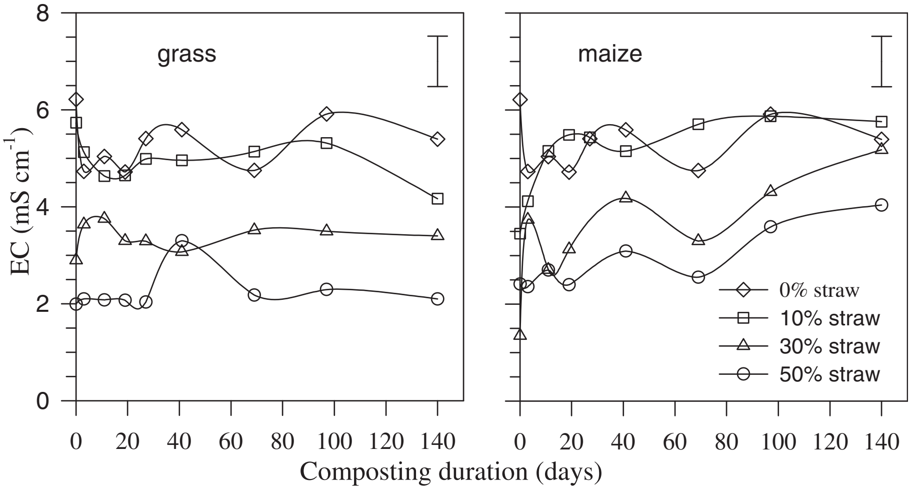

Figure 4 Changes in electrical conductivity of grass and maize stover compost mixtures with composting time. Data points are a mean of three readings. Bars represent SED (*n* = 3).

was such that pH was highest for the no straw mixtures and lowest for the mixtures with the highest proportion (50%) of straw (Figure 5) and higher in maize than grass composts. Higher values of pH were obtained in 0.01 M $CaCl_2$ than in water.

N mineralisation

The effect of the proportion of straw on ammonium and nitrate concentrations in composts was highly significant ($P < 0.001$). Significant interactions occurred with composting between the type and proportion of straw present in composts (Figure 6). Concentrations of ammonium increased to their maximum within 4 weeks in all maize composts except the 50% maize compost, which reached a maximum on day 97 (Figure 6). The highest concentration of ammonium was obtained in the composts without straw (1.8 gkg^{-1} dry matter). Concentrations of ammonium were generally small for most of the time. The peak concentrations of ammonium decreased with increasing straw contents in composts and were delayed and spread out over time in grass relative to maize composts (Figure 6). Maize composts had higher concentrations of ammonium than the equivalent grass composts ($P < 0.05$). After day 97 of composting, the ammonium concentration had dropped significantly, in all composts. Only traces of ammonium were detectable on day 140 of composting. Traces of nitrates were present in the composts from the onset of composting

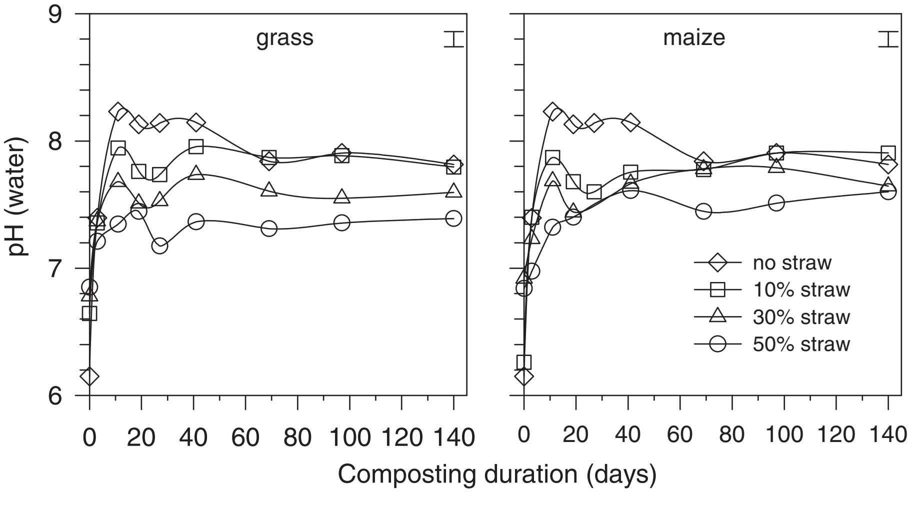

Figure 5 Changes in pH of grass and maize stover composts with composting time. Data points are a mean of three readings. Bars represent SED (*n* = 3).

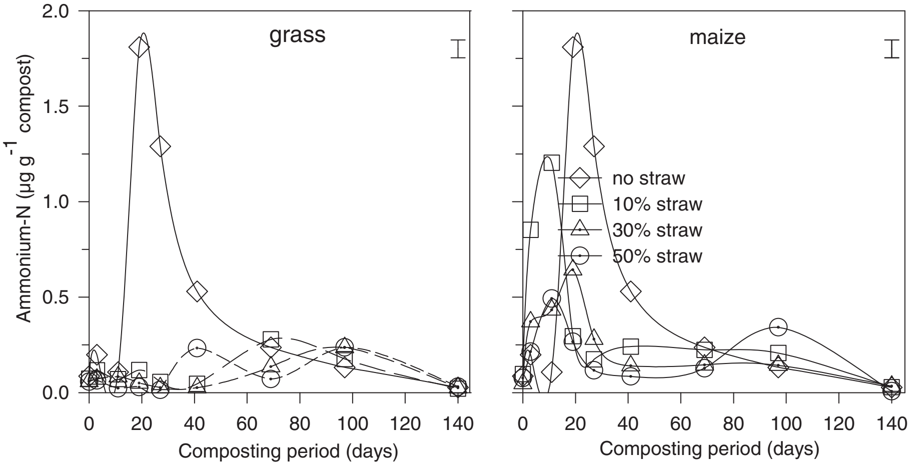

Figure 6 Changes in the concentration of ammonium with composting time. Bars represent SED (*n* = 3).

and concentrations increased significantly as composting proceeded (Figure 7). The highest concentration of nitrate in grass composts was observed on day 97. In maize composts, the peak nitrate concentrations were observed at various times between days 41 and 140. The largest nitrate peaks were found in the 0% and 10% grass or maize composts and smaller peaks in the 30% and 50% composts. The compost nitrate concentration decreased significantly between days 97 and 140 in all except the 30% maize compost. The peak nitrate-N concentrations were almost the same as the corresponding ammonium-N concentrations for the no grass or maize compost, suggesting a stochiometric conversion of nitrate to ammonium.

Changes in compost C/N ratio

The N concentration of composts increased significantly with composting and with decreasing proportions of straw ($P < 0.001$) (Table 3). Significant differences in the N concentration of grass or maize composts were observed between the 30% and 50% straw composts, but there were no significant differences between the 0% and 10% straw composts. At the end of the composting period, the compost N content was higher in the maize composts with more than 30% of the bulking material relative to the grass composts.

The organic matter and percent carbon content both decreased with time of composting ($P < 0.001$; Figure 8). The C content of maize composts was higher than that of the grass composts ($P < 0.001$). After 140 days of composting, there were no significant differences in the C content of the 0% and the 10% nor between the percent C of the 30% and 50% straw composts. The C/N ratios (Figure 9) generally decreased with composting time. However, there were no significant changes in the C/N ratio of the no straw and the 10% maize compost.

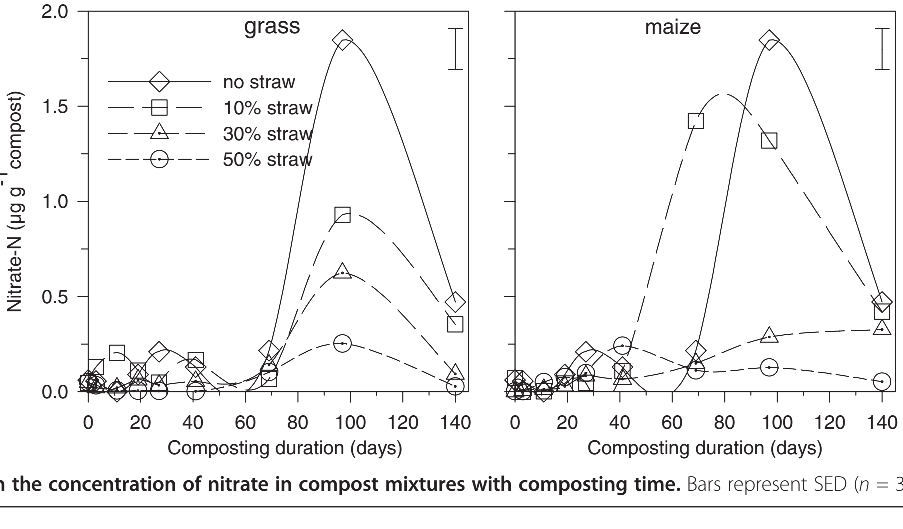

Figure 7 Changes in the concentration of nitrate in compost mixtures with composting time. Bars represent SED (*n* = 3).

Table 3 Changes in selected compost parameters and mass loss from the different compost mixtures over the composting period

			Grass composts			Maize composts		
		No straw	**10%**	**30%**	**50%**	**10%**	**30%**	**50%**
Dry matter (kg)	Initial	55	74	125	119	75	104	119
	Final	44	50	79	69	60	65	55
N (%)	Initial	2.3	1.6	1.1	0.9	1.7	1.5	1.3
	Final	2.3	2.1	1.7	1.3	1.7	2.3	2.2
Lignin (%)	Initial	9.5	11	11.6	13.9	12.9	12.6	14.5
	Final	23.3	18.3	19.5	22.7	19.5	22.1	20
Volatile solids (OM) (%)	Initial	78.6	69.8	77	69.4	82.8	87.7	89.1
	Final	69.8	54.6	55.1	48.9	58.9	66.6	71.0
Mass loss (%)		20	32	37	42	20	37	54
N loss (%)		20	11.3	2.3	17	20	3	22

Concentrations of organic matter showed a gradual decrease (Figure 8) accompanied by increases in C/N ratio, and a decline in lignin content of composted wastes (Table 1). Lignin content in raw wastes ranged from 69% to 73% in grass mixtures to 83% to 89.1% in maize mixtures. The no straw mixture had an OM content of 78%. Thus, volatile solids and lignin were higher in maize composts than the grass composts although the grass composts had higher starting C/N ratios. These results compare very well with findings by Mupondi et al. (2006).

Significant interactions occurred between the composting duration, type of straw and the proportion of straw in the various compost mixtures. Mass loss due to decomposition varied from 20% to 54% and was highest in the mixtures with high straw content (Table 3). Losses in total nitrogen ranged from 2.3% to 22% being highest in the mixture with 50% maize straw. Mixtures with 30% straw exhibited the lowest losses of N; 2% and 3% for the grass and maize straw composts, respectively.

Discussion

Temperature profiles of composts

Generally, the temperature profiles obtained in the composting experiments showed a short initial mesophilic stage before attaining thermophilic temperatures. The themophilic stage was very short and followed by rapid cooling period (Figures 1 and 2). Failure to stay hot might be attributed to various factors such as excessively high moisture levels in some cases, low ambient temperature and excessive cooling due to small size of the compost piles. The recalcitrant nature of the composting substrate could also have resulted in slow generation of heat in comparison to losses to the surroundings. High temperatures are necessary for effective composting (de Bertoldi et al. 1983). Respiration of micro-organisms decomposing the organic substrate is responsible for the generation of heat (Garcia-Gomez et al. 2002; Adediran et al. 2003).

Results obtained in this study compared well with those obtained in the composting of household wastes

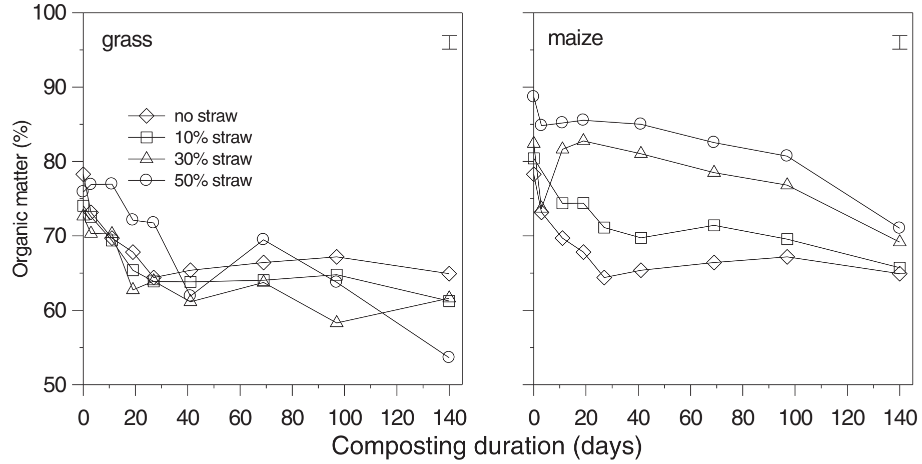

Figure 8 Changes of organic matter in compost mixtures with composting time. Bars represent SED (*n* = 3).

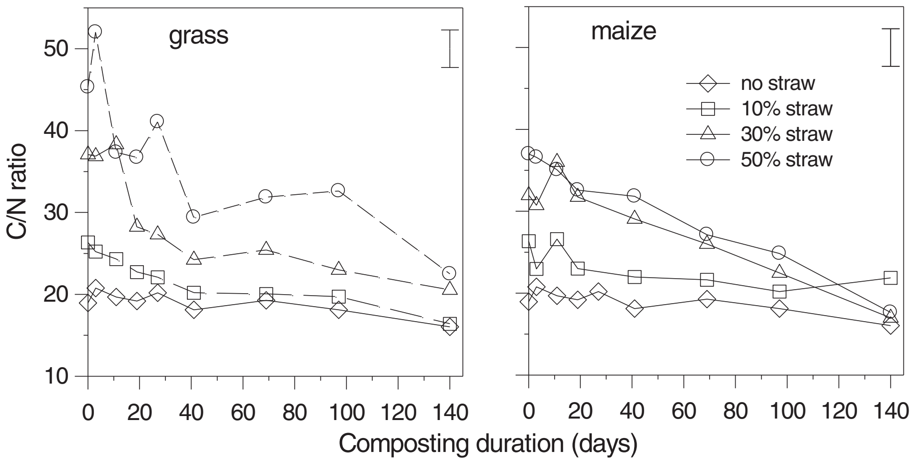

Figure 9 Changes in the C/N ratios of compost mixtures with composting time. Bars represent SED (*n* = 3).

by Eklind (1998) and Smith and Hughes (2002) with the highest temperature peak at 70°C followed by one or two other smaller peaks. Up to three peaks were obtained at around 65°C to 70°C in the composting of racetrack manure and grass clippings (Warman and Temeer 1996) by the pile method. In the latter study, however, compost piles were larger resulting in the temperature staying hot for longer periods of time; the compost temperature remained above 40°C for even longer when compost leachate was returned into the compost which suggests that microbial activity was increased possibly by the replenishment of nutrients like nitrates which could have been lost in the leachate (Warman and Temeer 1996). It may therefore be anticipated that addition of N to the composts in our study could have lengthened the active composting phase, although no leachates were produced from our composts as the water contents were not too excessive. Swinker et al. (1997) added more N as ammonium sulphate on day 37 of composting of a variety of horse bedding materials comprising phone book paper, wheat straw or saw dust to keep the process active.

In the trial by Eklind (1998), composting was performed indoors at 25°C in 125-L drums, and mixing was achieved by rotating the drums. Results obtained in our study indicate that there was a marked drop in temperature when composts were turned on day 3 of composting. Excessive heat losses could have occurred at the time of mixing which entailed emptying the bins, heaping the composting material on a tent sheet before mixing with garden forks. Heat losses could have been exacerbated by the small pile size of composts. Piles started off being just equivalent to 1 m^3 but ended up much smaller as decomposition progressed. In the composting of mixed garden wastes in long windrows, temperatures remained above 50°C for at least 23 days (Keeling et al. 1995). Where composting of unsorted municipal solid was done utilising perforated 1-m^3 plastic boxes, it took 8 weeks for the compost temperature to drop to ambient. This seems to suggest that the type of temperature profile obtained in this study may not be explained by the small size of the compost heaps. The extent of perforation or insulation on the boxes could have been such that losses were minimal while this study utilised boxes made from 76-mm slats separated by 40 mm. The material for composting consisted of particles less than 5 cm in length, which is similar to the chopped straw used in this study.

The chemical composition of the waste composted by Keeling et al. (1995) was not specified. Slow decomposition can result in gradual generation of heat so that where heat losses to the environment are large energy losses will exceed accumulation (Hankin et al. 1976). The initial rapid rise in temperature in our study was presumably due to the rapid decomposition of the green vegetable leaves also observed by Smith and Hughes (2002) in South Africa using similar materials. The lack of available C in the grass straw probably limited the rate of composting. The drop in temperature could signify the point where readily available carbohydrates or proteins became exhausted. Adediran et al. (2003) points out that a good source of N for microbial protein synthesis is important in composting. Thus, heat generation was highest in the no straw mixture and least in the mixture containing only 43% of wet weight as fresh vegetable leaves. Mixtures with 10% or no straw could also have been affected by high moisture content (Figure 3). These mixtures had moisture contents in excess of 70% and would require to be turned at least twice a week to ensure adequate aeration.

The optimum moisture content for composting manure on the basis of studies by Senn as cited by Haug (1980) is in the range of 55% to 60%. Misra et al. (2003)

also cites the optimal moisture content as lying in the range of 40% to 65%, depending on the openness and water holding capacity of the composting substrate.

This moisture range was achieved for compost mixtures with 30% and 50% straw. Failure of the compost with 50% maize straw to heat up to thermophilic levels may indicate that the rather low moisture content (50%) may have limited microbial activity in the mixture. It is also possible that excessive aeration because of the larger (thicker diameter) pieces of maize straw contributed to lower temperatures. Hence, where there are problems of too high compost temperatures, forced ventilation is recommended so as to lower temperature (de Bertoldi et al. 1983; Paredes et al. 2000).

Variation in compost moisture

Adjustment of moisture at weekly intervals resulted in considerable variation in the moisture content of composts. Moisture content fell to a minimum after day 97 for all the grass composts. This might account for the changes in the nitrate concentration that fell after day 97 (Figure 7). Nevertheless, the variation of moisture content was maintained within the desired range (close to 50% *w*/*w*) for the greater part of the composting period (Figure 3). Starting moisture contents were rather high for mixtures without or with 10% straw. Higher moisture contents have been used in some studies, especially in the composting of manure slurries and with frequent turnings to improve aeration and reduce moisture (Wang et al. 2004).

Chemical changes during composting

Trends in electrical conductivity changes were similar for both the composts containing grass and those with maize straw for each of the mixtures. Trends were more distinct in the composts containing maize stover whereby electrical conductivity increased significantly with increasing straw contents of composts. Mupondi et al. (2006) and Manios (2004) also observed an increase in electrical conductivity with composting time for different compost mixtures. This highlights the role of carbonaceous amendments in moderating the increases in concentration of salts that accompany composting. As composting progresses, components of organic matter mineralize into their soluble forms and become more concentrated with drying. High electrical conductivity of composts has been cited as one of the factors that inhibit seedling germination in some composts (Eklind 1998), hence seedling germination is used as a test for maturity and quality of composts (Wang et al. 2004; Nakasaki and Marui 2011). Addition of straw up to 10% by weight of the composting mixture does not seem to alter the electrical conductivity of the compost water extracts significantly (Figure 4) as indicated by the electrical conductivities ranging from 3 to 8 mS/cm and 2 to 6.2 mS/cm for the no straw and 10% straw mixtures, respectively. Findings by Manios (2004) were also in the range of 3.6 to 6.8 for various solid waste mixtures containing olive leaves. These results suggest that, on the basis of the electrical conductivity, composts mixtures with high (30% or 50%) straw are better suited for use in agriculture as soils amendments.

Changes in pH (Figure 5) showed a similar pattern for the grass and maize straw composts. The trends in pH changes were typical of changes that take place during composting, a rapid initial rise and a gradual decline to slightly alkaline or near neutral range (de Bertoldi et al. 1983). The mixture with no straw and the one with only 10% straw, maintained high pH (>8) for periods of approximately 1 month. In these mixtures, N losses from ammonia volatilization, especially during the hot phase of composting could have occurred, particularly at the time of mixing (Tiquia and Tam 2000). It may therefore be anticipated that N losses during composting were highest for the zero-straw composts and least for the 50% straw composts as ammonium concentrations were lowest in the 50% straw treatments (Figure 6). The higher C/N ratio of grass resulted in a lower rate of decomposition and hence slower ammonium release. Alternatively in the grass composts, N losses could have been greater following the decomposition of the vegetable waste mainly because of the poor availability of carbon to facilitate microbial N immobilisation. An initially high C/N ratio coupled with readily available carbon that can facilitate microbial assimilation of most of the N released during decomposition of wastes is more desirable. Findings by Mupondi et al. (2006)) reported levels of ammonium as high as 50 mgN/kg as compared to figures in the range of 2 mg NH_4^+-N/kg of compost reported in this study. The relatively low concentration of NH_4^+-N observed in composting mixtures in this study is consistent with low microbial activity as signified by the short thermophilic composting phase.

There was a general increase in nitrate and a decrease in ammonium with composting reflecting the progression of N mineralization with ammonification leading to nitrification in almost equal quantities. There were fluctuations in the nitrate and ammonium concentrations (Figure 7 and 9). This shows the high sensitivity to the shift of equilibrium in the produced or assimilated ammonium or ammonia lost. Data obtained in this study fit the trends observed in other studies (Eklind 1998; Canet and Pomares 1995).

The major difference in the grass and maize composts was reflected in the 10% straw mixtures. The peak ammonium concentration in the maize composts was significantly ($P < 0.05$) higher than its grass equivalent after 3 weeks of composting. This might be indicative of greater N losses through ammonia volatilization in the maize compost especially during the thermophilic phase of composting. It is also worth noting that the appearance of ammonium peaks in grass composts was delayed relative to those in the maize composts suggesting a slower rate of decomposition in the latter. Both compost types showed marked decreases in the nitrate concentration between days 97 and 140 especially for the 0% and 10% mixtures. This could be due to losses as a result of denitrification or leaching. Conditions leading to such losses could have been created when moisture was adjusted on day 97. There is therefore need for further investigation of alternative methods for adjusting compost moisture content.

The N content of the no straw compost apparently remained static despite a reduction in organic matter content through C oxidation and CO_2 evolution that accompanies organic matter decomposition. This is indicative of possible N losses during composting. The decrease in total N indicates greater losses through volatilisation or denitrification of N that could have occurred in the no straw compost. Martins and Dewes (1992) observed that during composting, the greatest nitrogen losses were caused by gaseous emission of NH_3 as well as small amounts of NO_x. The enrichment in N is an indication of the loss of carbon and hence dry matter with composting. A gradual decrease in the organic matter content was evident in all mixtures but was greater for the composts with higher straw contents (Figure 8). A corresponding increase in the ash content was observed. Changes were more rapid in the first month indicating the more active composting stage when more readily decomposable carbon was oxidised by the compost microbial population. The increase in ash content accompanied by a corresponding decrease in organic matter content reflected mass loss in the form of carbon dioxide. Apparently, overall changes in mass loss relative to the starting values were greater in the 30% and 50% straw mixtures. The C/N ratio of the various composts clearly indicated differences in the starting mixtures for the grass composts and the maize straw composts (Figure 9). Grass composts started off at higher C/N ratios (26, 36 and 47) than the corresponding maize straw composts (26, 30 and 35). There was no significant difference at least on the basis of the C/N ratio between the grass (16, 7, 21.7 and 18).and the maize straw (24, 19.5 and 19.8) in the final compost mixtures. The higher C/N ratio of the 10% maize straw compost is explained by the higher N losses observed relative to the equivalent grass composting mixture. This result is supported by Tiquia et al. (2002) who identified the starting C/N ratio as the critical factor affecting N losses after measuring N losses ranging from 37% to 60% of initial N from low C/N ratios (9 to 12) composting mixtures.

The results from this study indicate that the compost mixtures containing 30% or 50% straw reduced N losses during composting. However, these composts did not attain thermophilic temperatures for a long enough period to achieve sanitization. High EC and pH values greater than 4 dS/m and 7, respectively, for most of the final composts suggest the need for further stabilization. Further studies, such as germination tests, degree of humification as indicated by the E4/E6 ratio also need to be done to assess the quality of the final compost products.

Conclusions

Although high temperatures were attained in the no straw and the 10% straw composts during composting, nitrogen losses were, however, high signifying the loss of an important resource. The mixtures with 30% and 50% straw behaved in similar ways with respect to N and C mineralization, but the N losses were less with the composts to which 30% straw were added suggesting that this was the optimal mixture. The pH and EC values of most of the final composts suggest that the compost materials needed more composting time to stabilise. The results of this study indicated that peri-urban organic wastes with 50% straw or less can be composted but with measures being taken to achieve temperatures greater than 55°C for at least 3 days to destroy weed seeds and pathogens. This highlights the potential of composting peri-urban organic materials as a waste disposal method. The composts with 30% straw mixture had the greatest potential as a soil amendment in peri-urban areas of Harare as they effectively reduced nitrogen losses. Further studies are however essential to evaluate the compost quality over a longer period and assess its effect on plant growth.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

RLM was the MPhil student and main author and did the field and laboratory work and drafted the manuscript. MW was supervisor and participated in drawing up the project draft proposal, some field work, statistical analysis and correction of the manuscript. EN was also student supervisor and participated in some field work, preparation of some graphs and in correction of the manuscript. All authors read and approved the final manuscript.

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