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Chemical and physical composition of household wastes from selected peri-urban areas of Harare

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Abstract

We studied the physical and chemical characteristics of household wastes generated in three peri urban areas bordering the city of Harare in Zimbabwe. Month-long waste surveys involving 252 peri-urban households were conducted during a predominantly wet season and also during the dry season. The objective of the study was to determine waste composition and waste generation rates in target areas. Across all sites, weekly waste generation rates were significantly different for the peri-urban sites studied, being greater during the wet season than during the dry season. Waste generation rates ranged from 4.8 -2.7kg/household/week in the dry season and from 13.6kg to 7.2kg/household per week in the wet season. In both surveys waste components were predominantly organic and non-compostable materials accounted for less than 30% of the waste spectrum. Nitrogen, calcium and phosphorus were the most dominant nutrient elements present in wastes. There was minimal variation in content of essential nutrient elements across sites. Lignin content was low and also varied minimally across sites. Wastes had an average C/N ratio of 30 and were considered to be suitable for composting without the use of any additives.

Key words: *Organic waste; Recycling; composting; Peri-urban wastes; C: N ratio; Waste characterization*

Introduction

One of the major challenges confronting agricultural production in developing countries of the tropics is negative nutrient balances and a general decline in soil fertility (Keerthisinghe, Zapata and Chalk, 2003). According to Woperies, Mando and Vanlauwe, (2008); Omotayo and Chukwuka (2008), strategies for soil fertility management increasingly have to focus on reuse and recycling of organic resources for enhanced sustainabilty of agricultural production. Such nutrient management strategies as composting, should therefore receive increasing focus as a waste management strategy especially in urban and peri-urban areas of cities and towns of most developing countries where the collection and disposal of wastes is a major concern (Mudzengerere and Chinogwenya, 2012; Mangizvo, 2007 and Musademba, Musiyandaka, Muzinda, Nhemachena and Jambwa, 2011). The addition of household wastes to soil helps replace lost organic matter and nutrients while it reduces the problem of waste disposal (Garcia, Hernandez, Costa, Ceccanti, Masciandaro and Gardi, 1992; Allison *et al.*, 1998; Lopez-real, 1998, Omotayo and Chukwuka, 2008). Any characterisation leading to a better utilisation of these wastes is of great importance to agricultural production.

The increasing use of municipal or household wastes in agriculture has resulted in their characteristics being widely studied (Eklind, 1998; Diener *et al.*, 1993, Musademba *et al.* 2011). Household waste has been utilised in its raw form (Rahman, 2010) or after being subjected to some pre-treatment like burning or composting. Composting being cheaper, better able to preserve nutrients like N and organic matter, and more environmentally acceptable with respect to pollution, is preferred to burning or incineration as a waste treatment strategy (Tevera, 1991; Pizano, 1998). Dumping or land filling as a waste disposal strategy is less desirable being less hygienic (Mangizvo, 2010) and linked to ground water pollution among other problems.

Characterisation of waste intended for use in agriculture has mostly focused on parameters that influence its usefulness as a soil amendment either in its raw or composted form (Palczynski, 2002). Such quality parameters as the organic matter, ash, N, lignin, polyphenol content and the C/N ratio have been the focus of most waste characterisation studies. The content of plant macro- and micronutrients has also been reported as an indication of the estimation of gross crop nutrients that can be turned back into the soil (Minich and Hunt, 1979; Muller-Saaman and Kotschi, 1981; Diener *et al.*, 1993, Keerthisinghe *et al.*, 2003).

While quality characteristics of waste are very important in determining their short and long term usefulness as soil amendments, the quantities returned into the soil determine their potential contribution to soil fertility. Numerous studies have been performed in various localities to characterise the domestic or municipal waste stream in terms of the relative quantities of the organic and compostable fractions (Eklind, 1998; Lopez-Real 1995, Musademba et al. 2011). The main obstacles that hinder the utilisation of solid waste in agriculture are a result of its heterogeneous nature. Estimates of organics in household or domestic wastes that can be of agricultural importance are subject to wide variations. The composition can vary with climate, standard of living, method of collection of garbage and season (Chefetz, Hatcher, Hadar and Chen, 1996). Rural localities tend to show more seasonal variation in composition and quantity of household wastes, and have more agricultural waste as indicated for New Hampshire by Ballestero *et al.* (1996). Broad ranges of the contribution of various fractions of the waste stream for Harare City Council (Tevera, 1991) could be due to seasonal variability. Any characterisation of wastes should therefore accommodate local seasonal changes.

This study aimed at investigating the waste stream in Domboshawa, Porta Farm and Epworth, peri-urban areas bordering the city of Harare. Taking into account seasonal variability, this study determined the quantities and chemical characteristics of wastes produced in these peri-urban areas.

Materials and Methods

Study sites

Three peri-urban sites Epworth, Domboshava and Porta Farm squatter camp were selected for the study on the basis of their proximity to the city of Harare and the absence of solid waste management services.

Domboshava is predominantly rural but population growth and contact with the city is creating more and more pressure for land. Domboshava farmers are actively involved in market gardening. Epworth is a former mission farm, handed to the government for resettlement purposes. Movement of people from the city to Epworth in search of affordable rented accommodation is a continuous feature. Most of the residents of Porta Farm were former squatters of Epworth or the City of Harare awaiting resettlement elsewhere. Residents had limited access to land and cultivated small patches of land between their closely clustered houses. All three sites relied on refuse pits for disposal of household wastes.

Selection of households, source separation and collection of waste

Surveys of domestic waste were carried out twice in the year 1999. The first survey was carried out at the end of the wet season during the period April to May (Waste Survey I) and the second at the end of the dry season during the period November to December (Waste Survey II). Sampling times were aimed at capturing maximum variation in waste composition due to seasonal changes. Random sampling was done using lists of residents at Epworth. At Porta Farm sampling was achieved by selecting ten households at equal intervals on a transact of the settlement. At Domboshawa only one village participated in the waste surveys. For Waste Survey I, 100 households were selected to participate at Epworth and Porta Farm while only 52 households could take part at Domboshawa. During Waste Survey II, 30 households were selected at each of the sites.

Members of the household active in the disposal of waste were identified and invited to decide on the criteria for the preliminary separation of wastes at disposal. Selected households were each issued with four refuse bags for waste disposal. Categories of separation were identified as fresh vegetable and fruit wastes; dry plant residues; non-compostable materials and food scraps. Newsprint and other decomposable paper were put along with the dry plant residues. Each of the four refuse bags was labelled accordingly.

Household wastes were collected once every two days for a week (Waste Survey 1) or once every week for a month (Waste Survey II). After collection, household wastes were further separated into five categories as follows:

- Food scraps: all remains of cooked or processed food etc
- Fresh leaves: fruit or vegetable peels and trimmings, egg shells etc
- Paper: cardboard and newsprint paper etc
- Dry plant residues: grass, leaves etc
- Non-organic matter: plastics, textiles, ceramics, metals, glass etc

Each of the categories was weighed separately and the mass noted. In waste survey II after being weighed, wastes were remixed, shredded by hand and spread thinly. By quartering and discarding half the wastes in opposite quarters repeatedly a sixteenth of the wastes was retained as a sub sample (Anderson and Ingram, 1993). A composite sample was obtained for each site and week by pooling all the sub-samples at the end. The composite sample was spread thinly and air-dried. Dried samples were then ground (1mm), sieved and stored for chemical analyses.

Physicochemical analyses of household wastes

The dried samples were analysed for pH in a 1:5 suspension of waste in 0.01M $CaCl_2$ or water. Ash and organic matter content were determined as the residual mass after weight loss on ignition at 450^0C for 12 hrs. Total N content was determined using wet oxidation based on the Kjeldahl digestion method whereby organic N in the wastes was oxidised to NH_4^+ by concentrated sulphuric acid. The NH_4^+-N was then distilled in a strongly alkaline solution and released as ammonia which was captured in 2% boric acid. Standard dilute HCl was used to titrate the ammonia trapped in boric acid against screened methyl orange indicator. After dry ashing 1 gram of ground waste material, the residue or ash was dissolved in 50% sulphuric acid and evaporated to dryness, then in 25% nitric acid and again evaporated to dryness before being dissolved in 50% HCl and diluted to 100 ml. The elements Ca, Mg, K, Na and P were determined on the diluted solution of ash. The heavy metals Mn, Cr, Pb, Cu and Zn and the macro nutrient elements Ca and Mg were determined by atomic absorption; K and Na by flame photometry and P by colorimetry using the modified Olsen method. Methods of the above analyses were as outlined by Anderson and Ingram (1993). Organic carbon was calculated from weight loss on ignition as follows:

$$\%C = \frac{weight\ loss\ on\ ignition}{1.8}\ x\ 100$$

(Haug, 1980)

Lignin and Cellulose were determined in a sequential extraction using the acid detergent fibre method (Wine and Van Soest, 1967).

Results

Waste generation rates

In both surveys waste generation rates (Figs. 1 and 2) were different ($p<0.001$) for the three sites studied. In the period April-May the weekly averages of the weight of wastes produced was 13.6 kg; 7.2 kg and 10.2 kg for Domboshava, Porta Farm and Epworth respectively. During November-December averages had dropped to 4.2 kg, 2.7 kg and 4.8 kg for the three sites respectively (Fig. 2). There was much variation in households' waste generation rates (cv = 76%).The distribution of households by the quantity of wastes produced per week by an average household is shown in Figs. 1 (a) and (b)). There was a drop in the highest amounts of wastes generated by a single household in all three sites and there was a general shift from the higher (>10 kg household^{-1} week^{-1}) rates to the lower rates of waste generation (<10 kg household^{-1} week^{-1}). This trend was more pronounced for Porta Farm and Domboshawa than for Epworth. In the second survey, over 40% (Fig. 1) of the households in all the three sites produced less than or equal to 5 kg of waste per week. In the dry season the number of households who produced in excess of 10 kg waste per week fell by 19%, 15% and 16% at Domboshawa, Porta Farm and Epworth respectively.

The mean waste generation rates are summarised in Fig. 2. The three sites generated an average waste volume of 3.9 kg per household per week in the dry season and 9.8 kg of wastes per week in the wet. The greatest decline in the quantity of wastes generated by an average household per week in the dry season was at Domboshawa and approximated to 60%. More wastes ($p<0.001$) were disposed of in the wet season than in the dry season at all the three sites.

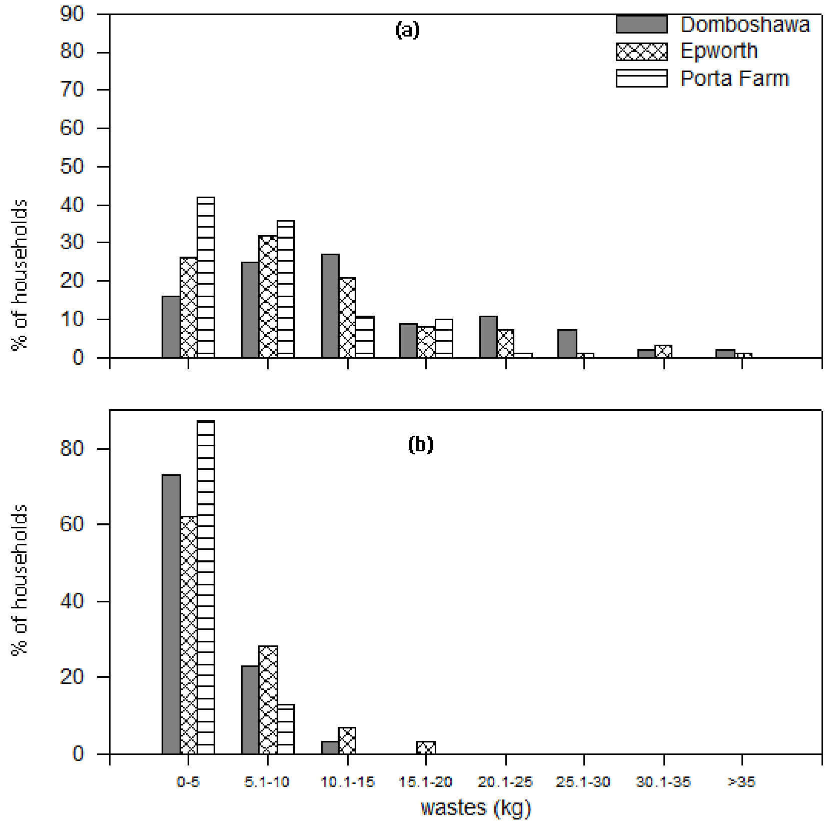

Figure 1 : Relative quantities of physical constituents of waste discarded by a single household at peri-urban sites. Data was collected in a survey of wastes during April-May and November-December 1999

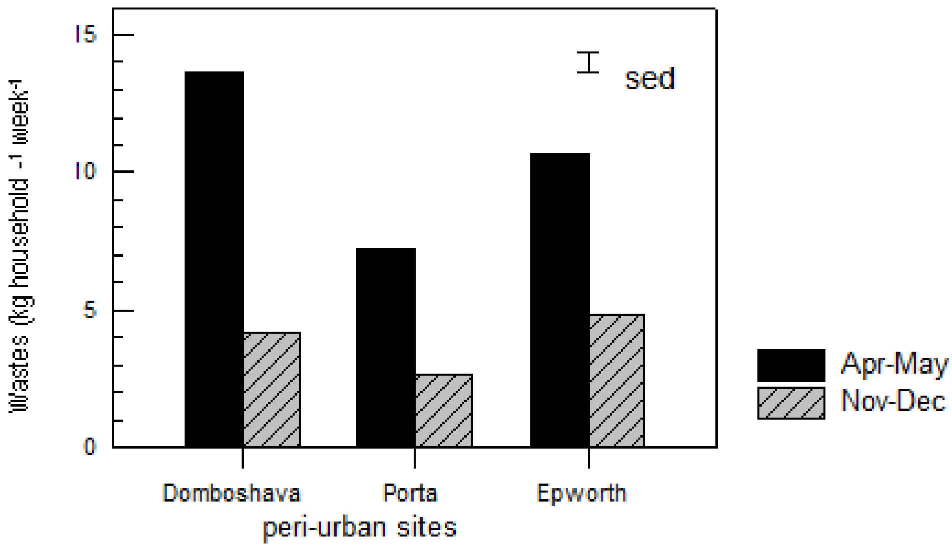

Figure 2: Quantity of waste discarded by an average peri-urban household during April-May and November-December 1999

Waste Composition

In both surveys waste components were predominantly organic and non-compostable materials accounted for less than 30% of the waste spectrum. The highest content of non-organic materials (27 %) was noted at Porta Farm during the dry season (Table 1). The next highest content of 20% non-organic matter in household wastes was recorded at Epworth occurring during April-May. Waste categories that constituted the greatest proportion of household wastes for Domboshava were dry plant remains and fresh vegetable waste in both surveys. Epworth participants discarded more food scraps and fresh vegetable wastes than all other types of waste in each of the surveys. More dry plant remains and food scraps were discarded than all other waste categories at Porta Farm. Paper content was highest at Epworth (6-7%) but was negligible (<1%) at the other two sites.

Table 1: Composition of wastes from the peri-urban areas Domboshawa, Epworth, and Porta Farm. Results of a study carried out in April-May and November-December 1999

Waste category	%			
	Domboshava	Epworth	Porta Farm	Overall
Food scraps	11.5	31	26	23
Green wastes	26	27	14	22
Paper (khaki, newsprint etc)	0.5	7	6	4.5
Dry plant remains	48	19	33	33
Total Compostable	86	84	79	83
Non compostable (Plastics, metal, glass, textiles rubber, bones, etc)	14	16	21	17
Total	100	100	100	100

Chemical properties of wastes

Analysis of the household waste showed low variation of most parameters within and across sites. Potassium and magnesium are the nutrient elements that showed considerable variability with coefficients of variation of 55 % and 20 % respectively. No definite trends were evident in the changes in concentration of the various nutrients over the four weeks of survey in the dry season. The pH ($CaCl_2$) of the wastes averaged 5.6. The lowest pH of waste was recorded at Domboshawa and the highest at Porta Farm (Table 2).

Nitrogen and calcium were the most dominant macronutrients at 1.3% and 0.86% dry matter respectively. The other dominant nutrient was potassium, which averaged 5 g kg^{-1} of dry matter. The content of plant macronutrients was in the order N > calcium >potassium > phosphorus > magnesium.

Table 2: Concentration of macro crop nutrients in household wastes sampled at three peri-urban sites in the months November to December 1999.

	Average for site			
	Domboshava	Epworth	Porta	C.V.
pH	5.3	5.6	6	5.9
N (%)	1.37	1.44	1.19	10.8
Phosphorus (%)	0.23	0.25	0.25	6.1
Potassium (%)	0.83	0.35	0.28	55.6
Sodium (%)	0.19	0.29	0.23	112
Magnesium (%)	0.19	0.17	0.15	20.6
Calcium (%)	0.86	0.92	0.80	5.9
Carbon (%)	39.8	43.7	40.3	8.6
Ash (%)	28.3	21.8	27.8	24.4
Lignin (%)	11.6	8.3	10.9	-
Cellulose (%)	21.4	19.3	23.5	-
C/N	28	30	33	13.9

Sodium content was higher than that of phosphorus and showed the most variation (CV =112%) although no clear trends were observed. Values obtained were similar to those reported by Eklind (1998). Lignin content differed little between sites (8.3 to 11.6%) while the cellulose content ranged from 19.3% to 25%. (Table 3). Both the lignin and cellulose contents were in the order Porta >Domboshava > Epworth. The heavy metal content of wastes was lower lower than those permissible in sludge used in agriculture according to EC regulations (Staneva, 1997).

Table 3: Concentration of some heavy metals in household waste from three peri-urban sites of Harare

Heavy Metal	Peri-urban Sites			PermissibleLimits (EC)
	Domboshawa	Epworth	Porta	
Manganese (µg g^{-1})	0.335	0.18	0.107	75
Chromium (µg g^{-1})	8.6	8.7	8.6	1000-1500
Lead (µg g^{-1})	0.24	0.24	0.24	750-1200
Copper (µg g^{-1})	0.54	0.333	0.59	1000
Zinc (µg g^{-1})	101.8	88.6	145	1000-2500

Discussion

Peri-urban waste generation rates

The waste generation rate is the amount of wastes produced by a given household or community over a period of time (Flintoff, 1976). The amount of wastes generated by a community or household is strongly related to food availability. Porta Farm settlement was a holding camp for people who were previously vagrants or squatters in the city of Harare. Their poverty was reflected in their lower waste generation rates relative to the other peri-urban sites studied. Waste quantities ranged from 2.7 -7.2 kg per household per week compared to 4.2-13.6 kg for Domboshawa or 4.8-10.7 kg for Epworth. From other studies (Eklind, 1998), approximately 50kg of waste would be required for the construction of a compost of at least $1m^3$, which is the minimum requirement for successful composting. Thus, at these waste generation rates, households would require approximately 5-20weeks to accumulate waste volumes adequate for thermophillic composting.

The relative drop in the quantity of wastes discarded by households between the two surveys (Fig. 2) was greater for Domboshawa and Porta than it was for Epworth. This may be expected as Domboshawa and Porta farm are relatively much more rural than Epworth. In urban areas household consumption patterns are influenced by availability of money to purchase food almost all year round although fruits may be more abundant because of season. A greater consumption of food from own produce results in agricultural wastes contributing more to the waste stream in the wet season than in the dry season when food is relatively scarce. This trend could have been more pronounced for Porta residents who being destitute could not have enough money to purchase food in abundance in the dry season. Households are capable of growing their own food through rain-fed agriculture during the wet season. However for Porta Farm the waste grass from thatching and fencing could have compensated for the scarcity of discards in the dry season. Drier weather conditions could have resulted in the significant drop in the weight of wastes produced in the second survey of wastes. A higher proportion of green wastes in the period April-May could have contributed significantly to the higher weight relative to November to December.

Physical composition

The high content of compostable organic material (Table 1), with an average C/N ratio of 30 (Table 2), should facilitate successful composting of wastes without the addition of amendments. This trend is as expected since heterogeneous nature of household waste, composed mainly of plant material almost always results in the occurrence of nutrients in proportions that permit degradation by micro-organisms. The high proportion of food scraps at Porta Farm (Table 1) a squatter settlement and therefore predominantly poor, was surprising. Porta farm residents could deliberately have introduced bias in an attempt to hide their poverty and safeguard their pride. At the time of the survey residents of Domboshawa, a predominantly rural area, kept livestock and pets (Govera-Mhindu, 2002). Food scraps would constitute a great part of their animals' diets especially dogs, and therefore a negligible portion of the discards. Epworth and Porta Farm households lacked livestock and therefore had no use for food scraps, guaranteeing availability of food scraps as a component of their waste stream.

A notable presence of paper at Epworth (Table 1) is attributable to the urban nature of Epworth. In urban areas most of the food consumed in the home is purchased and comes wrapped up in several layers of paper, newsprint or plastics. Plastic packaging materials contribute towards the high proportion of non-organic material in the Epworth or Porta Farm waste. Domboshawa is a predominantly rural farming community, which explains the absence of paper and the abundance of plant remains and fresh vegetable waste.

Concentration of crop nutrients and heavy metals

Notable differences were observed in the pH, phosphorus and magnesium levels, which were low relative to those, reported by Eklind (1998) and Kirchmann and Widen (1994) in Sweden. The ash content of the waste was rather high for household wastes that were predominantly of plant origin. The elevated ash content (22%-28%) could be an indication of contamination with soil, which was unavoidable. Ash content of soil is much higher than that of plant matter, which ranges from 10-15% of dry matter. Wastes comprised kitchen wastes as well as yard wastes normally gathered into a heap by sweeping with a broom before being put into the rubbish pit. It may therefore be concluded that the extent of contamination was low.

Other studies of household wastes indicated higher contents of N and hence lower C/N values for source separated household wastes. Kirchmann and Widen (1994) reported a mean C/N ratio of 11.8 and 2.1% N (dm) for source separated household wastes in Europe. Higher N content for these wastes might be due to a greater presence of wastes like lawn and hedge trimmings relative to dry plant remains, since these other studies were performed in affluent urban areas of Europe. Judging by the higher N concentration (1.44%) in wastes at Epworth this argument seems to hold but more because of a lower presence of dry plant residues. A higher consumption of dairy products and eggs in more affluent communities could also account for differences in N, P, Ca and Mg content. Eklind (1998) attributed high concentrations of Ca in household wastes to the consumption of dairy products and low concentration of heavy metals in household wastes to the absence of contamination. No contamination was expected as wastes were separated at source and collected from residential areas with little contact with industrial effluents.

An assessment of the cellulose and lignin content of wastes indicates that wastes from Epworth had the lowest content of both. This implies that residues of mature plants were more abundant at Domboshawa and Porta relative to Epworth. A greater abundance of fallen tree leaves, which was found at Domboshawa, might account for the high concentration of lignin in the Domboshawa wastes. The concentration of cellulose at

Epworth was low relative to Porta Farm probably because the most abundant waste components of the Epworth wastes was food scraps and fresh vegetable waste and not lignified plant remains which was the true for Porta Farm. High lignin content of the wastes from Porta farm might result in slower decomposition of wastes when added to the soil or when composted.

The concentration of K in Domboshawa wastes was more than double that in Porta or Epworth wastes. High potassium concentrations could be associated with a greater presence of fresh vegetable waste in particular tomatoes in the waste from Domboshawa than wastes from either Porta farm or Epworth. Potassium consumption is higher for fresh vegetables and succulent fruits like tomatoes (Havlin, Beaton, Tisdale and Nelson, 2005), and tomato is the most common crop grown by Domboshawa households.

Conclusions

Findings of this study clearly show that though wastes from the selected peri-urban sites were suitable for composting, availability of adequate materials is a major problem. It would take long periods of time before sufficient volumes of waste are generated to make compost heaps large enough for hot composting especially in the dry season. Composting could be done in community groups or using materials collected from urban areas.

Major components of waste have been identified mainly as dry plant residues and fresh vegetable waste that could include weeds removed from gardens. Variation of compost products would have to be dealt with by standardising amounts and types of raw materials for compost mixtures. A possibility remains therefore of producing a range of different types of compost products.

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