2. GENERAL MATERIALS AND METHODS

2.1 <u>Quantitative waste diversion assessment</u>

2.1.1 Experimental design and rationale

The impacts of HC and kerbside recycling on landfill disposal of household waste were quantified by a novel research approach using an advanced weighing technology (SULO MGB Ltd, High Wycombe, UK) to directly measure residual waste arisings from individual households in the Borough of Runnymede. The wheeled bins of 324 households participating in the monitoring programme were fitted with a passive read/write microchip to uniquely recognize the characteristics of each property. The weighing system was fitted to the mechanical lifter of the refuse collection vehicle (RCV) and weighed the containers before and after emptying providing an accurate measure of the net weight of residual waste. An antenna on the RCV identified the microchip and transmitted the household identification information to the vehicle's on board computer. The weight data were stored on a RAM card, which was then transferred to an office computer for data manipulation.

The households were selected either from a database of properties with one or more compost bins held by RBC, or from the electoral roll. These were allocated into four treatment groups depending on whether the households were involved in kerbside recycling, or home composting or both types of activity, as follows:

1. – Recycling bin, – Compost bin (Control treatment group)
2. + Recycling bin, – Compost bin (Recycling-only treatment group)
3. – Recycling bin, + Compost bin (Composting-only treatment group)
4. + Recycling bin, + Compost bin (Recycling+composting treatment group)

A questionnaire was designed to canvass participation and obtain socio-demographic information about participants. Two questionnaires were produced: (a) for householders who had already participated in the RBC composting scheme and (b) householders who did not appear on the RBC database and were randomly selected from the electoral roll (Appendix I). Homeowners who did not respond to the questionnaire were interviewed by telephone.

2.1.2 Questionnaire survey

A number of selection criteria, mainly based on geographical data and the socio-demographic characteristics of the local population, led to the decision to locate the HC trial in the Hythe and Egham areas of the Borough of Runnymede. These areas were served by two waste collection rounds (round 3 and 6). Further statisitics and data regarding waste generation and management in RBC are presented in Appendix II. Householders that were identified from the RBC HC database were allocated to the HC treatment groups. The current composting status of the selected householders was confirmed by telephone or through a postal survey, which also provided opportunity to update the socio-demographic and property data for the group.

The questionnaire and a stamped addressed envelope were posted on 15 March 2004 to 278 householders who were identified as owning a compost bin (Home Composting questionnaire). A modified version of the questionnaire (Waste Management questionnaire) was sent to 173 residents selected randomly from the electoral roll from the same area to form the Recycling-only and the Control treatment groups. The total number of homeowners that responded to the questionnaire and agreed to participate in the Study was 214, equivalent to 48% of the households in the survey. Table 2.1 shows the total number of responses obtained for the households and there allocation to the different treatment groups.

Table 2.1 Total responses to the questionnaire survey

Treatment group allocation	No. of replies	% of total
Control	9	4.2
Composting-only	9	4.2
Recycling-only	71	33.2
Recycling+composting	125	58.4
Total	**214**	**100**

A notional target was to obtain at least 150 replicate households in the Recycling+composting group, to allow various support measures to be tested (see later), and 50 households in each of the other treatment groups. Additional participants were therefore sought by contacting those homeowners who had not responded to the questionnaire by telephone where this was possible. A total number of 82 homeowners agreed to be interviewed by telephone and provided information about how they dispose of their waste. These additional households augmented the Recycling+composting, and Recycling-only treatment groups, but only a few households were identified for inclusion in the Composting-only and Control groups.

A further attempt to increase the number of households within the Control and Composting-only treatment groups was by direct home visits in the Study Area. This raised the number of households in the Control group to 47, close to the target value of 50. However, relatively few households were identified that only composted their waste as most homeowners engaged in HC also participated in the kerbside recycling scheme operated by RBC.

The total number of households participating in the Study was 324, distributed amongst the experimental treatment groups as follows:

- Control: 47
- Recycling-only: 92
- Composting-only: 19
- Recycling+composting (no support): 64
- Recycling+composting (+ leaflet): 51
- Recycling+composting (+ leaflet + home visits): 51
- TOTAL: 324

2.1.3 Promotional support methods

The Study was also designed to quantify the effects of promotional activities on the impact of HC on diversion of biodegradable waste from landfill disposal. An advisory leaflet (Appendix III) was designed providing essential information for homeowners on HC, including, for example, recommendations on the suitability of different types of waste for composting, management techniques to improve the composting process, and solutions to potential problems and difficulties that may arise. The leaflet was distributed to 102 households of the Composting+recycling group during 1-15 August 2004.

A further level of support was provided through home visits to 51 households that also received the advisory leaflet. This provided homeowners the opportunity to discuss their experience with HC and to ask questions about composting and waste management in general. The home visits were completed during the period 1 August – 25 September 2004. The majority of homeowners regularly composted their biodegradable waste, produced compost once a year, and experienced only minor problems with the composting process.

2.1.4 Automatic weighing system

Automatic weighing equipment (SULO MGB Ltd, High Wycombe, UK), utilising radio frequency identification (RFID), was fitted to a refuse collection vehicle (RCV) with a low-level lifter, owned and operated by RBC. RFID technology provides wireless contact between RFID microchips and the reader system with non line-of-sight communication. Microchip transponders (Figure 2.1), holding unique identification data, were fitted to the wheeled bins of participating households (Figure 2.2; Appendix IV). An antenna is fitted to the weighing system and reads the microchip code number and transmitted the information and weight of the bin contents to a computer on the RCV (Figure 2.3). The data were saved on a RAM card and transferred to an office computer. At the end of the weekly waste collection round, the weight data accumulated on the RAM card was downloaded at the RBC depot and transferred electronically to Imperial College. The weighing system was calibrated and the experimental error of the weight measurements is shown in Table 2.2.

Unfortunately, due to many operational problems beyond the control of Imperial College, the automatic weigh system operated only to a limited extent. However, data were obtained from the collection rounds for a two week period: 11-13 and 18-20 October 2005. Also, detailed compositional analysis was completed for the residual waste from selected households and treatment groups collected on 30 June 2004 and 10-11 November 2004. Therefore, the compositional data obtained for the autumn period were cross-referenced to the automatic weight data recorded during the same period. Further details of the experimental procedures involved in the compositional waste analysis are given in Section 3.

Figure 2.1 Microchip with identification number

Figure 2.2 Mounting the micro-chips on wheeled bins

(a) (b)

Figure 2.3 Operation of the automatic weighing system (a) on board computer and (b) low-level lifter

Table 2.2 Calibration weight errors (n=10) of the SULO automatic weighing system fitted to the refuse collection vehicle

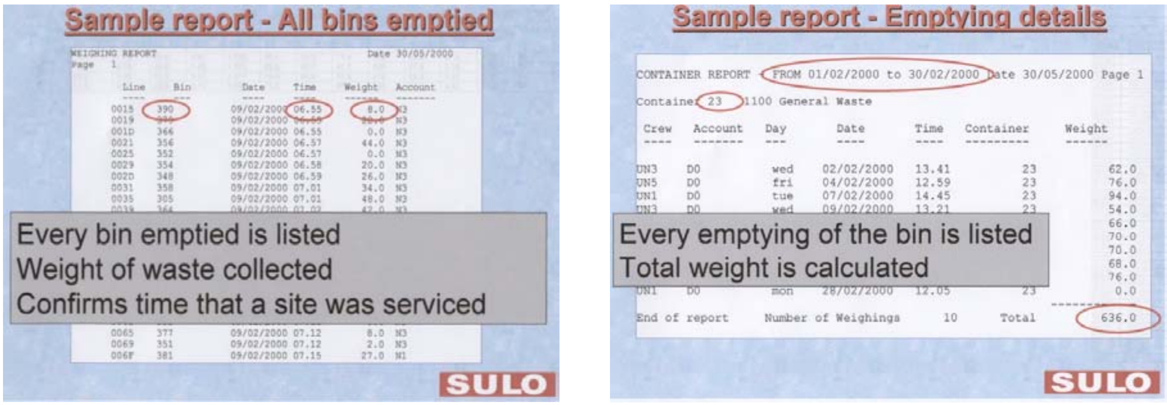
Weighing unit	Weight range (kg)	Error (kg)
	0-25	± 0.5
Left and right unit	26-150	± 1.0
	0-100	± 2.0
Combined unit	101-450	± 5.0

2.1.5 Software development for the manipulation of weight data

A database (Appendix V) was designed to scrutinise the weight data collected from the RCV. The data were examined according to specific criteria as follows:

Property characteristics: refers to the type of property (detached/semi-detached/terrace/bungalow/flat), number of residents living in the household, type and size of the garden;
Employment status: denotes the type of employment of the householder (fully employed/part-time employed/unemployed/student/home maker/retired);
Waste management practices: includes participation in kerbside collection and HC schemes as well as use of local civic amenity sites and recycling banks;
Size and number of bins: the capacity of the wheeled bins in the Study Area was 240 l or 120 l and data on the number and size (290 or 330 l) of compost bins was also included.

The software generated weighing reports listing the amounts of residual waste collected associated with individual microchip code numbers and the times of waste collection. For example, Figure 2.4a provides a report showing the emptying of bins on the scheduled collection date and time and identifies any bins that were omitted from collection on the round. Figure 2.4b shows the total amount of waste generated and recorded by the weighing system for selected time intervals.



(a) (b)

Figure 2.4 Weighing reports (a) confirming the emptying of bins and (b) showing monthly waste generation

2.2 Controlled home composting investigation

2.2.1 Experimental design and installation

A controlled HC field trial was established at the Imperial College Field Station at Silwood Park, Ascot to assess the effects of the waste input regime on degradation rates and maximum waste treatment potential of small-scale home composters. The experiment was established on 8 February 2005 and was completed on 6 March 2006, after a period of 392 days. The experimental design included six treatment conditions with different relative inputs of garden, kitchen and paper waste, listed in Table 2.3, to 290 l compost bins (Milko, Straight Recycling Ltd, Leeds). The waste input regime in Treatment 4 was replicated in an alternative bin type of 330 l capacity (Blackwall, Straight Recycling Leeds). Both compost bin types are shown in Figure 2.5. There were three replicate bins per treatment at a spacing of 2 m x 2 m, arranged as randomized blocks (Figure 2.6).

Table 2.3 Final percentage inputs (fresh mass) of waste materials to compost bins

Treatment	Garden waste (%)	Kitchen waste (%)	Paper waste (%)
Treatment 1	100	0	0
Treatment 2	40	60	0
Treatment 3	20	80	0
Treatment 4	40	58	2
Treatment 5	40	56	4
Treatment 6	20	78	2
Blackwall	40	58	2

(a) (b)

Figure 2.5 Compost bin types used in the experiment (a) 290 l Milko bin and (b) 330 l Blackwall bin

Figure 2.6 Compost bins arranged in randomised blocks at the field site

The Milko standard compost bin was selected for the main part of the investigation as this model had been distributed by the RBC HC scheme and was used in the previous investigation by Jasim and Smith (2003). The Milko bin was green in colour and constructed from recycled plastic with dimensions: height 963 mm, base diameter 800 mm, and lid diameter 525 mm. It was fitted with a hinged lid with air vents. The bin has a perforated base with a ventilation spike in the centre designed to encourage gaseous exchange and the maintenance of aerobic conditions within the compost. A sliding hatch is fitted at ground level to permit access to the compost at the base of the bin. The alternative Blackwall bin type evaluated in the experiment is currently promoted by RBC and was of simpler construction than the Milko standard bin. Also produced from recycled plastic, the bin was black in colour with dimensions: height 1000 mm, base diameter 800 mm, and lid diameter 300 mm. The capacity of the bin (330 l) was approximately 14 % larger than the Milko type (290 l). The Blackwell bin was fitted with a removable lid without ventilation and an access hatch at the base, but, in contrast to the Milko model, there was no base to the bin and composting materials were, therefore, in direct contact with the soil. The surface soil was cleared to a depth of 2 cm and leveled beneath the base of the bins to provide close contact with the ground and facilitate the migration of soil fauna into the waste materials.

2.2.2 Waste input materials

Three types of biodegradable waste were added to the compost bins, including: garden waste, kitchen waste, and waste paper. The composition of the garden waste inputs followed normal seasonal variations in supply. Thus, in the late autumn and winter period, garden waste consisted of tree leaves collected from woodland areas adjacent to the experimental site. Grass clippings from lawn mowing were deposited in the bins during the spring, summer and early autumn. Food waste was collected fortnightly from a local supermarket (Sainsbury's, Bagshot Rd, Bracknell) and provided a representative surrogate material for household kitchen waste. The main types of food waste were fruit, vegetable and bakery wastes. As would be expected, the types of fruit and vegetable wastes varied according to season and availability. Shredded paper waste was provided from the office buildings at Silwood Park. Typical garden, kitchen and paper waste input materials are shown in Figure 2.7.

Figure 2.7 Typical biodegradable waste input materials: garden (winter sample), kitchen and paper waste

Garden waste was added to the bins at intervals of approximately 25 days. The final addition of garden waste occurred on 6 December 2005, 302 days from commencement of the experiment. The supply of kitchen waste was maintained throughout the period of the experiment and this waste type was added to the bins at a frequency of 17 days on average. Paper waste was supplied at intervals of approximately 28 days. Inputs of garden and kitchen waste varied depending on the quantities available, whereas paper waste was provided in relatively consistent amounts. The overall mean additions of garden, kitchen and paper waste to the bins estimated on a per month and per week basis are presented in Table 2.4. These normalised rate values allow the experimental conditions to be compared directly with waste input data recorded from trials monitoring HC undertaken directly by homeowners. For example, the monthly weighted average inputs of garden, kitchen and paper waste by homeowners to home compost bins measured by Jasim and Smith (2003) over a two year period were: 21.5, 9.0 and 0.8 kg, respectively. Thus, the quantities of the different waste types supplied to the bins were within generally representative ranges of normal HC conditions.

An inoculum of mature compost (5 kg), obtained from an established home composter treating a mixture of garden, kitchen and paper waste, was added to each bin to provide a culture of microorganisms and macrofauna adapted to the degradation of household organic wastes (Figure 2.8). Water was supplied to the bins when waste materials were dry and the low moisture content was limiting the composting process. The total volumes of water added to the different experimental treatments are listed in Table 2.5. Treatments 1 and 5 required the largest volumes of water overall due to the low moisture content of the garden waste and the high rate of paper addition, respectively.

Table 2.4 Average amounts of waste material deposited into compost bins for the different experimental treatments normalized to monthly and weekly frequency basis

	Garden waste (kg)		Kitchen waste (kg)		Paper waste (g)	
Treatment	**Monthly**	**Weekly**	**Monthly**	**Weekly**	**Monthly**	**Weekly**
1	13.4	3.4	-	-	-	-
2	10.0	2.5	12.5	3.1	-	-
3	7.5	1.9	25.0	6.3	-	-
4	10.6	2.7	12.8	3.2	433	36.1
5	9.7	2.4	11.4	2.8	867	72.2
6	7.7	1.9	24.9	6.2	650	54.2
Blackwall	10.6	2.7	12.8	3.2	433	36.1

Figure 2.8 Addition of mature compost inoculum at start of experiment

Table 2.5 Total volume of water added to the different experimental treatments

Treatment	Volume per bin (l)
1	55
2	30
3	20
4	30
5	40
6	20
Blackwall	30

2.2.3 Mass balance analysis

A mass balance was produced for each compost bin at the mid-point and at the end of the experimental period on 26-27 July 2005 and 6 March 2006, respectively. The bins were dismantled (Figure 2.9) and the contents were weighed in plastic buckets using a hanging scale. In the case of the initial assessment, the waste materials were spread on a plastic sheet, mixed thoroughly with a fork and a representative composite sample was collected to determine the moisture content of the wastes. The mixed materials were returned to the compost bin. For the final mass balance, the waste mass was recovered from the bins in three distinctive layers (A, B, C – refer to Section 2.2.5). Representative samples were collected from each layer to determine the moisture content.

Figure 2.9 Compost bin dismantling to determine the mass balance

2.2.4 Sample preparation and laboratory analyses

Sub-samples of the input waste materials (garden, kitchen and paper waste) were collected and the moisture and organic matter contents were determined using standard laboratory techniques (BSi, 1994; BSi, 2000a,b; BSi, 2001). The raw waste materials were finely chopped manually and mixed prior to oven drying. Oven-dried material was ground in a laboratory mill to pass a 1 mm mesh size. The same procedures were followed for samples collected from the home compost bins.

2.2.5 Composting process monitoring

2.2.5.1 Temperature investigations

Manual temperature measurements of the decomposing materials were recorded at intervals of 12 days using an electronic thermometer (Hanna Instruments, Leighton Buzzard) fitted with a K-type thermocouple sensor mounted in a penetration probe (10 mm in diameter, 1 m long). The probe was inserted to a depth of 20 cm from the surface at three locations, in the most recently deposited material, and the mean value was calculated. On five occasions (see Table 2.6) during the experimental period, the probe was inserted at increasing depths of 10 cm from the waste surface at three points within each bin to construct the temperature profile of the waste mass.

Over time, the waste materials became stratified into three distinct layers: fresh input waste (layer A), decomposing waste (layer B) and decomposed waste or compost (layer C). The temperature of the three waste layers was continuously monitored automatically using a datalogger (CR23X: PC200W, Campbell Scientific Ltd, Loughborough; Figure 2.10) during two periods of the experiment (Table 2.6). An average reading from 180 temperature values was recorded every half an hour (the datalogger scanned the compost layers every 10 s). There were 16 probes fitted to the datalogger allowing five treatments to be monitored (1, 2, 3, 4 and 6 – see Table 2.3) and the additional probe was set up in an environmental hood to measure ambient air temperature.

2.2.5.2 Gas investigations

Gas measurements (CH_4, CO_2, O_2) were performed following two procedures. Overall emissions of CH_4 and CO_2 from the entire mass of organic material within the compost bins were measured by covering selected treatments (3 and 6, Table 2.3 – bin number 4 and 6) with an emission flux chamber. This was constructed from medium density polyethylene (MDPE) with an internal diameter of 1016 mm and height of 1093 mm (Figure 2.11). A fan mounted at the top of the chamber mixed the air within the void space and accumulative gas concentration measurements were recorded at 30 minute intervals using a portable analyzer (GA2000 Landfill Gas Analyzer, Geotechnical Instruments Ltd, Leamington Spa). The chamber could be used by transferring the entire bin and its undisturbed contents onto a rigid base. However, placing the chamber over the compost bin *in situ* without the base and providing an air seal by burying the lower 2 - 3 cm into the soil surface was equally effective and a more practicable approach as the bins filled with waste. The temperature of the air in the void space and the waste materials was monitored by a thermocouple connected to an electronic thermometer.

Table 2.6 Temperature monitoring schedule for home compost bins

Type of temperature monitoring	Time period
Probe inserted at 20 cm depth in the waste at three points in a fixed triangular pattern	During the experimental period (February 2005 – March 2006)
Datalogger – stratified temperature monitoring	27 July – 04 November 2005, 12 January – 06 March 2006
Probe inserted at increasing depths of 10 cm in the waste at three points in a fixed triangular pattern -Temperature profiles	On five occasions: 12/07/05, 21/09/05, 11/10/05, 12/12/05, 13/02/05

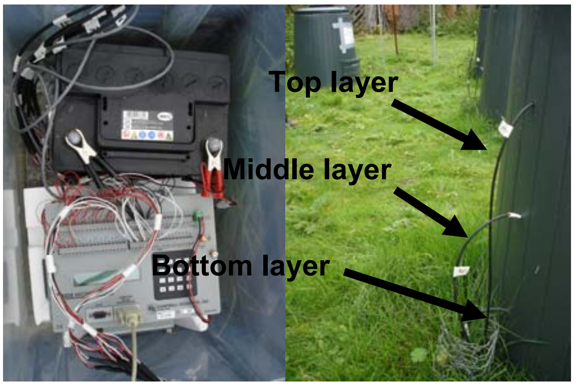


Figure 2.10 Continuous monitoring of three compost layers by temperature probes connected to a datalogger

Measurements of the interstitial gases were also recorded within the composting wastes for all treatments at intervals of 12 days using an insertion probe attached to the gas analyzer (Figure 2.12). The probe was inserted to a depth of 30 cm and the concentrations of CO_2, CH_4 and O_2 were recorded.

2.3 Biodegradation of packaging waste in compost bins

Ten representative packaging materials were selected that are common types available to consumers and may be potentially suitability for composting. The materials included eight uncoated and coated cardboards, a starch-based and poly-lactic acid (PLA) type food packaging (Table 2.7). The compostability of the package was examined by inserting the materials into the degrading waste in the controlled HC experiment (Section 2.2). Degradation was monitored for a maximum period of up to 126 days and was assessed based on the loss in dry matter of specimen sections of the packaging (Section 2.2.5). Small specimens (2.5 x 2.5 cm, 6.5 cm^2) of each packaging type were wrapped within nylon netting (Figure 2.13), to maintain the integrity of the sample, and placed between a mesh screen (Figure 2.14) that was inserted into compost bins representing Treatment 4 (Table 2.3). Eighteen specimens of each material were initially located randomly on the screens and three replicate specimens per material were removed at each sampling time. Six sampling events were carried out during the experimental period and the removal dates are listed in

Table 2.8. The screens were buried between the layer of fresh input material (A) and decomposing material (B) and were in intimate contact with the compost mass.

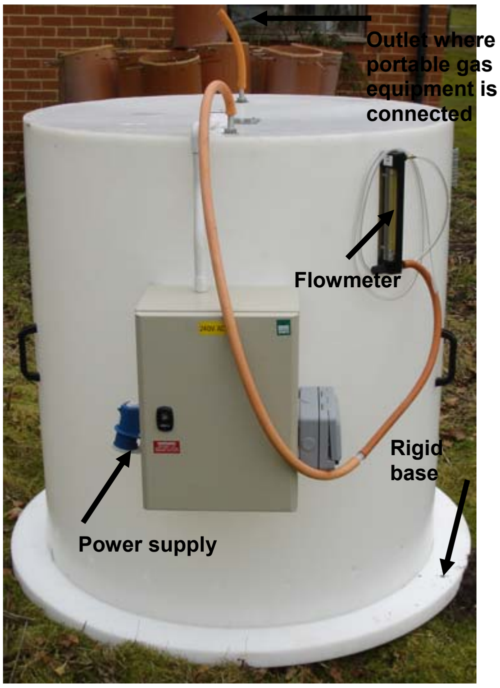


Figure 2.11 Flux chamber for measurement of compost gas emissions

Figure 2.12 Monitoring interstitial gases with portable equipment

Table 2.7 Types of packaging materials tested for biodegradation by home composting

Identification code	Material	Descriptive characterization[(1)]
A	Doughnut cardboard box	Solid bleached board
B	Laundry tablets cardboard box	Heavily waxed corrugated cardboard
C	Sliced cheese cardboard box	Folding boxboard
E	Breakfast cereal cardboard box 1	White line chipboard
H	Packaging cardboard case for bottles	Solid unbleached board
I	Non packaging cardboard (notepad board back)	Uncoated chipboard
K	Breakfast cereal cardboard box 2	White line chipboard
M	Pizza cardboard box	Waxed corrugated cardboard
O	Disposable cardboard plate	Bleached white line chipboard
R	Potato starch tray	-
W	Polylactic acid (PLA) deli-container	-

[(1)]Pro carton Europe (2006)

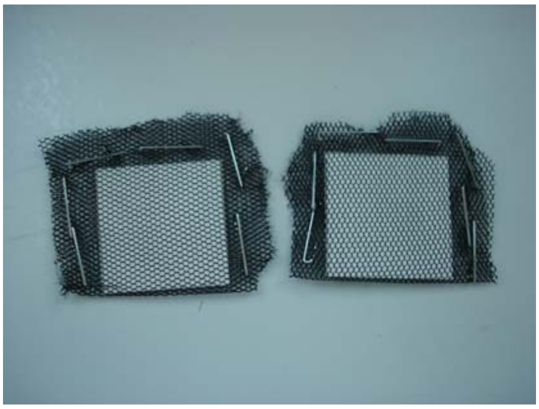


Figure 2.13 Packaging samples (2.5 x 2.5 cm) inserted in nylon netting to maintain sample integrity and allow recovery after home composting treatment

(a)

(b)

Figure 2.14 Specimens of packaging materials located on mesh screens for insertion into home compost bins

Table 2.8 Degradation times and removal dates for packaging samples after treatment in home composting bins

Sampling	Date	Day number
1	31/10/2005	15
2	15/11/2005	32
3	17/12/2005	46
4	01/02/2006	67
5	08/03/2006	112
6	22/03/2006	126