5 COMPOSTING PROCESS MONITORING

5.1 INTRODUCTION

Composting of putrescible organic waste is a spontaneous, aerobic and exothermic microbial degradation process (Haug, 1980a). Heat is a by-product of the microbial breakdown of the product and gas exchange facilitates aerobic decomposition. Temperature and gas composition measurements therefore provide information on the nature of the biochemical decomposition processes operating within home compost bins. This chapter examines the temperature and gas composition analysis measurements undertaken during the 2 year Study Trial. The stability and value of composted materials as soil amendments for improving plant growth can be assessed based on chemical quality information and this chapter also presents the results from chemical determination measured in composted residues collected at the end of the first and second years of the home composting study (Section 3).

5.2 TEMPERATURE INVESTIGATIONS

5.2.1 Monitoring by homeowners

The temperature of materials in the compost bins undergoing decomposition was monitored throughout the Study Trial by homeowners using a horticultural thermometer In addition, temperature profiling was undertaken on a further 6 occasions during the 2 year monitoring period (Section 3). The temperature of material in the compost bins recorded by homeowners is shown in Figure 5.1.

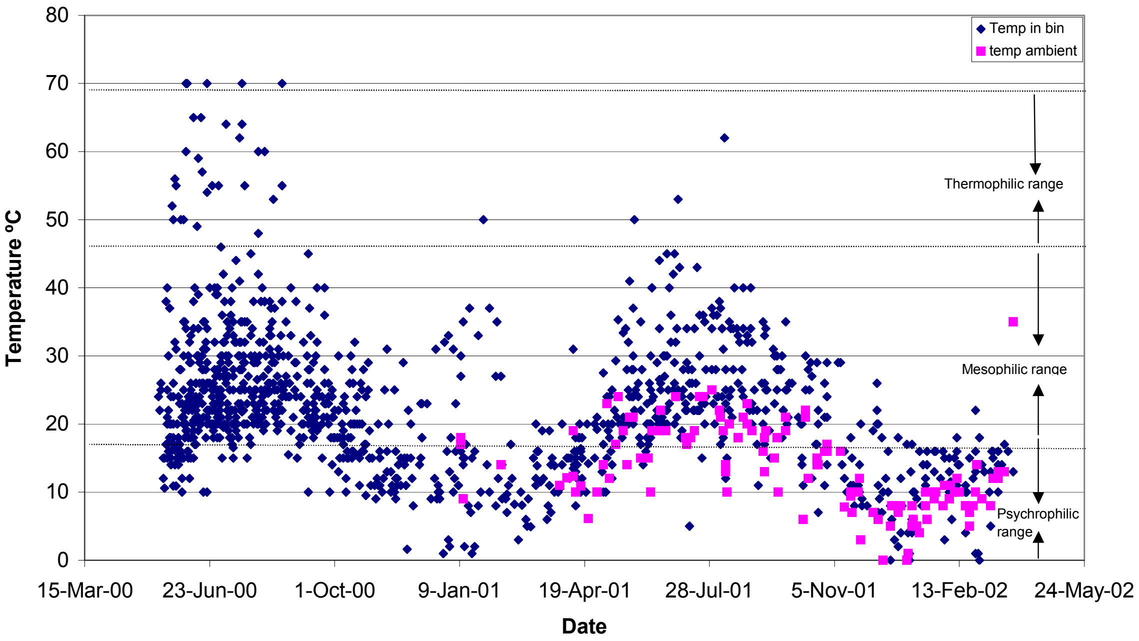


Figure 5.1 **Compost temperatures recorded during the Home Composting Study Trial by participants between May 2000 and March 2002**

The temperatures recorded by homeowners were highly variable and there was an underlying seasonal trend that reflected ambient air temperature (Figure 5.1). In general, temperature conditions were in the mesophilic range (15 - 45 °C) indicating active microbial biodegradation during the composting process (Snell, 1957; McKinley and

Vestal, 1984). However, in some cases, temperatures >45 ºC were measured, particularly during warmer periods (May-September) and these would be associated with thermophilic microbial activity (Suler and Finstein, 1975; Macgregor *et al*., 1981). During the winter period of the study (December-February) cool ambient air and compost temperatures (0 - +5 °C) were recorded. The temperature conditions in the second year of the home composting study were consistent with the trends observed during the first year.

5.2.2 Profile monitoring

Temperature profiles of individual compost bins were also measured using an electronic temperature probe in 4 quadrants, at 10 cm intervals from the surface of the waste (Section 3) in July and December 2000, March, September and December 2001 and March 2002. The mean data for each depth is presented in Figure 5.2.

The home compost was in the temperature range: 6 – 30 ºC, and overall the majority of data was greater than the ambient temperature and within the mesophilic range. Pooled data from all bins showed that there was little variation in mean temperature with depth. Warmer conditions were measured in the most recently deposited waste (upper 10-30 cm layer), which is associated with high rates of microbial activity and temperatures declined with increasing depth in more stabilised material.

Seasonal variability was observed with average temperature profiles. The winter (December 2000 and 2001) temperature data were in the range 9 – 16 °C (Figures 5.2 (b) and (e)) and similar temperatures (8 – 12 °C) were recorded during spring 2001 (Figure 5.2 (c)). However, the following years spring temperatures (Figure 5.2 (f)) were marginally warmer (10 – 23 °C). As expected, the greatest mean temperatures were measured in the summer, in July 2000 this was in the range: 17 – 30 °C and in September 2001: 20 – 24 °C (Figures 5.2 (b) and (e), respectively). The effect of temperature on the composting process is related to microbial activity, during cool conditions such as in winter, active waste degradation will be maintained but at a slower rate compared to the summer when warmer temperatures prevail.

5.2.3 Main treatment effects on compost temperature profiles

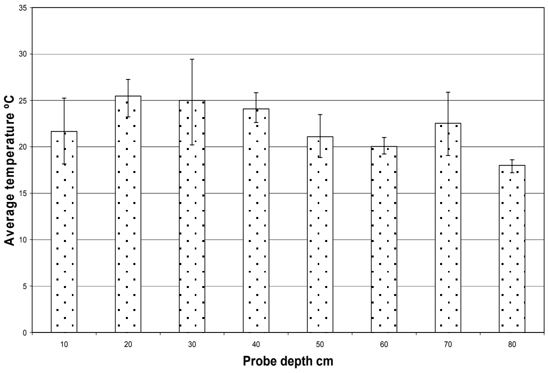
The main effects of compost management factors: garden size, mixing, earthworm inoculum, and accelerator addition on compost temperature profiles were examined by analysis of variance (ANOVA) (Table 5.1).

There was no statistically significant effect of garden size or earthworm inoculum at any of the sample depths or during any of the monitoring periods. This was most likely attributable to the variance in depth of organic matter between homeowner compost bins. Accelerator addition had a significant effect on temperature during the final monitoring period March 2002 at 3 depths and was likely to be associated with the substitution of Biotal formulation for Garrota during this time.

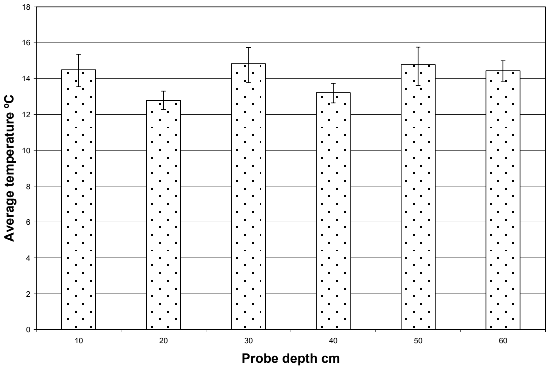
Nevertheless, mixing of the compost demonstrated a significant effect on temperature compared to non-mixed compost material during December 2001 and March 2002, which were the final 2 sampling periods of the temperature profiling trial. This indicated that mixing might not have had a significant effect during the initial stages of the trial due to the early nature of material decomposition process.

Despite the absence of a significant relationship between the majority of management treatments and temperature (Table 5.1), consistent declines in mean temperature with depth with mixing management were observed. However, the temperature variation of the profiles was marginal with depth.

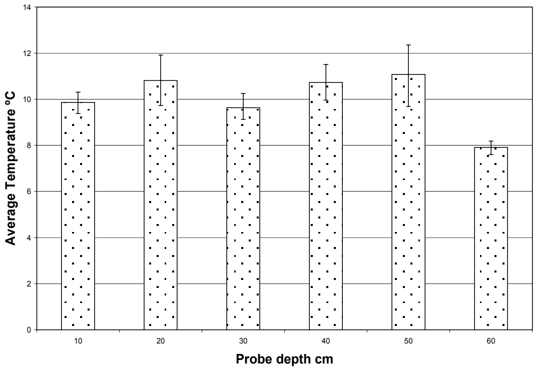
(a) July 2000



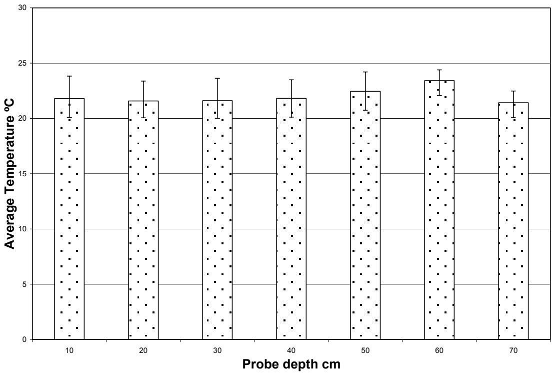
(b) December 2000



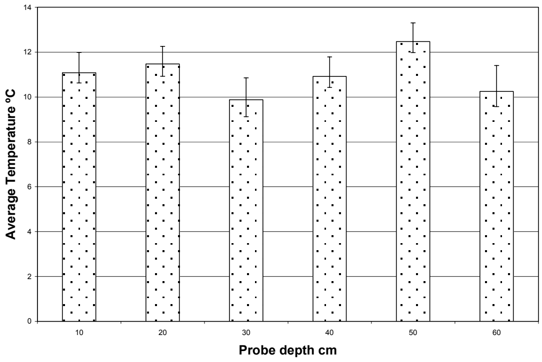
(c) March 2001



(d) September 2001



(e) December 2001



(f) March 2002

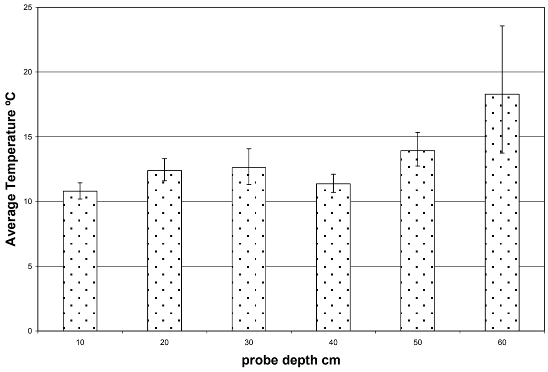


Figure 5.2 Mean compost temperature in relation to probe depth (vertical bars represent minimum and maximum values)

Table 5.1 F probabilities and mean values (temperature profiles)

Monitoring period and depth (cm)	Garden size			Mixing			Earthworm inoculum			Accelerator		
	Large mean	Small mean	F. Prob	No mean	Yes mean	F. Prob	No mean	Yes mean	F. Prob	No mean	Yes mean	F. Prob
July 2000												
10 cm	24.3	24.7	0.75	24.7	24.3	0.71	25.2	23.8	0.26	24.7	24.3	0.68
20 cm	24.8	24.7	0.90	24.8	24.7	0.93	25.2	24.3	0.46	25.1	24.5	0.62
30 cm	23.9	24.0	0.95	24.2	23.7	0.65	24.2	23.7	0.63	23.8	24.1	0.77
40 cm	23.2	22.5	0.45	23.2	22.5	0.45	22.6	23.1	0.55	23.0	22.7	0.76
December 2000												
10 cm	14.6	15.0	0.65	14.9	14.6	0.78	14.7	14.8	0.88	14.4	15.1	?????
20 cm	14.6	15.1	0.59	14.8	14.8	0.98	14.8	14.9	0.90	14.5	15.1	0.54
30 cm	14.2	14.7	0.62	14.4	14.4	0.98	14.3	14.5	0.87	14.2	14.7	0.61
40 cm	13.5	13.8	0.69	13.6	13.7	0.95	13.6	13.7	0.96	13.4	13.9	0.54
March 2001												
10 cm	11.7	11.4	0.78	11.0	12.1	0.21	11.9	11.2	0.42	11.5	11.6	0.88
20 cm	10.9	10.8	0.92	10.3	11.5	0.12	11.3	10.5	0.31	10.9	10.9	0.99
30 cm	10.1	10.1	1.00	9.6	10.7	0.12	10.5	9.8	0.26	10.1	10.2	0.99
40 cm	9.6	9.5	0.90	9.0	10.1	0.05	10.0	9.2	0.23	9.5	9.7	0.72
September 2001												
10 cm	23.8	23.2	0.67	23.6	23.6	0.88	22.2	24.8	0.06	23.0	23.9	0.49
20 cm	22.7	22.8	0.98	22.6	22.9	0.81	21.7	23.8	0.09	22.4	23.1	0.51
30 cm	21.1	21.6	0.64	21.0	21.7	0.45	20.6	22.1	0.13	20.9	21.7	0.42
40 cm	19.8	20.6	0.34	19.7	20.7	0.21	20.2	20.2	1.00	20.2	20.2	0.97
December 2001												
10 cm	12.2	11.4	0.24	**10.9**	**12.7**	**0.01**	11.6	12.1	0.46	11.9	11.7	0.84
20 cm	11.8	11.1	0.23	**10.7**	**12.2**	**0.01**	11.2	11.7	0.37	11.4	11.5	0.93
30 cm	11.3	10.7	0.27	**10.4**	**11.5**	**0.04**	10.7	11.2	0.34	10.9	11.0	0.83
40 cm	10.6	10.4	0.54	10.0	10.9	0.06	10.3	10.7	0.32	10.4	10.5	0.83
March 2002												
10 cm	14.0	14.1	0.96	**11.9**	**16.2**	**<0.01**	13.6	14.5	0.33	**12.7**	**15.3**	**0.01**
20 cm	13.1	13.1	0.98	**11.3**	**15.0**	**<0.01**	12.7	13.5	0.29	**12.1**	**14.1**	**0.01**
30 cm	11.8	11.8	0.92	**10.3**	**13.4**	**<0.01**	11.6	12.0	0.40	**11.2**	**12.4**	**0.02**
40 cm	11.1	11.0	0.80	**9.9**	**12.1**	**<0.01**	10.9	11.1	0.48	10.8	11.2	0.29

5.2.4 Compost temperature in relation to waste inputs

The mean compost temperature per month recorded by householders was calculated and the relationships between average compost temperature and the total monthly inputs of food, paper and garden waste were examined and are shown in Figures 5.3 (a – c).

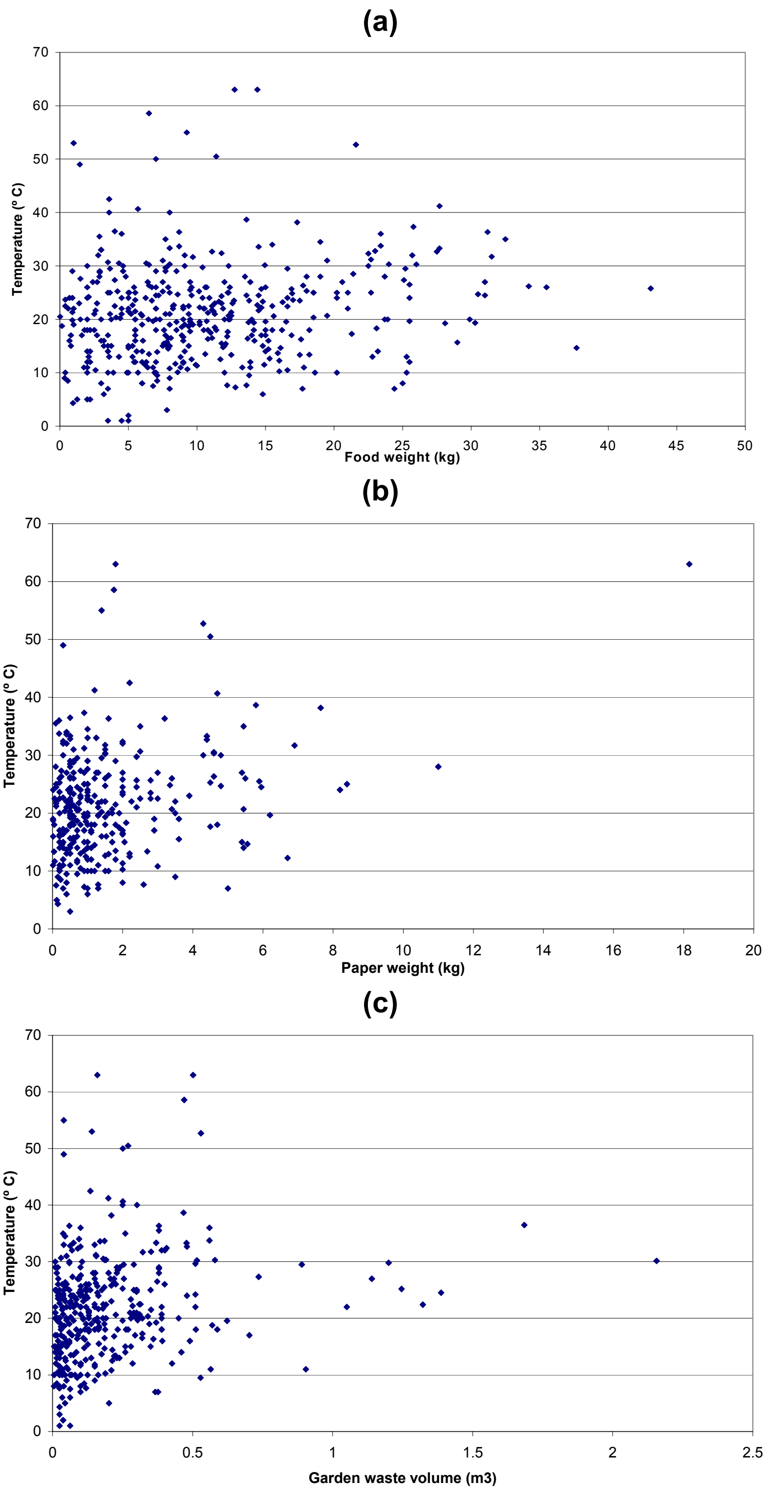


Figure 5.3 Mean monthly compost temperature in relation to the monthly total (a) food (b) paper and (c) garden waste weights per household deposited in compost bins, May 2000 – March 2002

There was no apparent correlation between temperature evolution and different putrescible materials when complex mixtures of food, paper and garden waste were added to small-scale compost bins. This suggested that waste biodegradation processes appear to be relatively well-buffered and are maintained by regular inputs of complex waste mixtures.

5.2.5 Summary

Temperature is a critical factor influencing composting because of the effect on microbial metabolic rates and population structure. For any individual microbial population, growth rates increase within the optimum temperature range, but decline rapidly above this. Temperature measurements during December and March of each monitoring year were below 20 °C. Microbial activity is low at these temperatures and an appreciable lag period may have occurred. As temperature exceeds 20 °C, microbial activity increases, since enzyme activity rates generally double with each 10 °C rise in temperature. Generally, temperatures in this investigation have indicated that composting proceeds through the mesophilic temperature range in home composters (Figures 5.1 and 5.2).

The majority of composting management factors investigated during this study did not appear to have an effect on compost temperature. However, mixing was a significant factor related to temperature depth compared to undisturbed compost bins. Furthermore, compost temperatures in small-scale systems were independent of food, paper and garden waste added to the compost bins.

5.3 GASEOUS PHASE INVESTIGATIONS

Concentrations of oxygen (O_2), carbon dioxide (CO_2) and methane (CH_4) were measured in the interstitial gas of the compost bins at different time periods and at increasing depths to reflect the differing decomposition regions within the bins (Section 3).

5.3.1 Oxygen concentrations

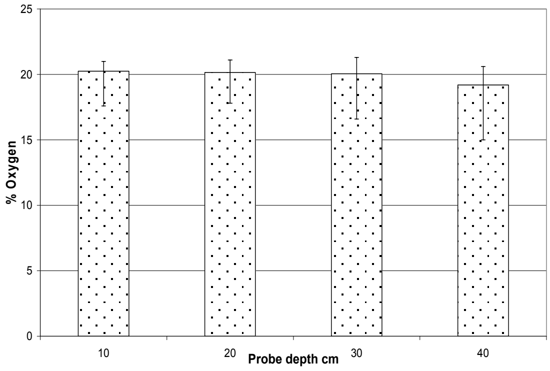
The minimum recommended O_2 concentration in interstitial gas for optimal composting is 5 % (Finstein *et al*., 1985b). The mean O_2 values measured during the gaseous investigation were in the range: 16 – 21 % (Figure 5.4), which indicated that the process of waste biodegradation in the compost bins was aerobic.

There was little variation in mean compost O_2 concentrations between the 10, 20, 30 and 40 cm sample depths. However, a marginal decline in O_2 was observed with depth and the lowest concentration (15 %) was recorded at 40 cm. Nevertheless, in all cases, the mean O_2 concentration was significantly higher than the suggested minimum (5 %) necessary for supporting aerobic composting activity.

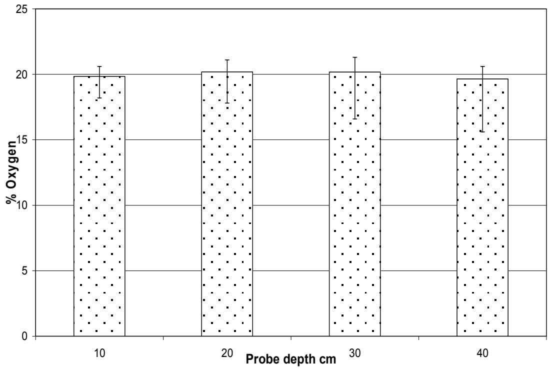
There was also little variation between sampling periods, which suggested that gaseous evolution from the aerobic decomposition of materials was unrelated to climatic seasonal variability.

During December 2000, mixing the compost had a significantly increased O_2 concentration by approximately 0.4 % at the 10 and 20 cm depth compared to the non-mixed material. The addition of an earthworm inoculum also significantly decreased O_2 by 1.3 % during this sampling period at the 40 cm depth compared to the compost without inoculum (Table 5.2). These effects, though statistically significant, were probably of only minimum biological consequence as O_2 concentrations were relatively close to ambient. There was no significant effect of either garden size or accelerator addition.

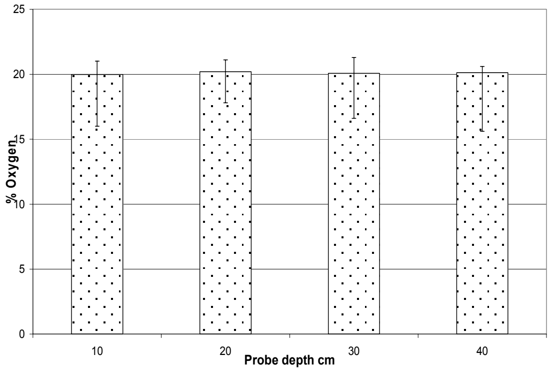
(a) December 2000



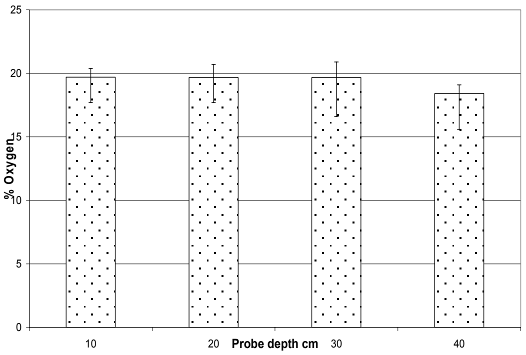
(b) March 2001



(c) September 2001



(d) December 2001



(e) March 2001

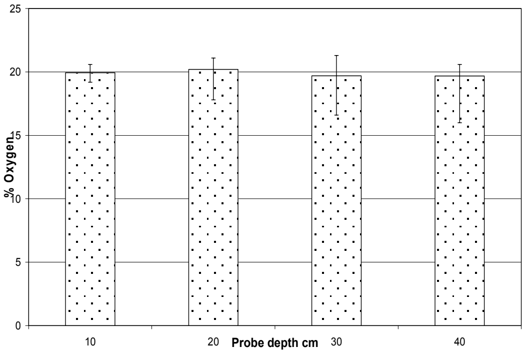


Figure 5.4 Average compost oxygen concentrations in relation to probe depth (vertical bars represent minimum and maximum values)

In March 2001, measurements represented the presence of waste materials for almost one year. Mixing had a marginally significant effect at the 30 cm depth increasing O_2 concentrations by 0.3 % compared to the unmixed compost. There were no statistically significant effects of other management factors on O_2 concentrations of composting materials.

During September 2001, earthworm or accelerator addition did not effect O_2 concentrations at any of the sampling depths. Garden size significantly decreased mean O_2 at the 10 cm depth, which represented the freshest waste layer, but not at the 20, 30 or 40 cm measurements. Similarly, to March 2001, O_2 concentrations were significantly increased with mixing, however in this case at depths of 20 and 30 cm of the compost bin (Table 5.2).

Table 5.2 F probabilities and mean values (O_2 concentrations)

Monitoring period and depth (cm)	**Garden size**			**Earthworm inoculum**			**Mixing**			**Accelerator**		
	Large mean	**Small mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**
December 2000												
10 cm	20.2	20.3	0.22	20.2	20.3	0.81	**20.1**	**20.39**	**0.02**	20.2	20.3	0.33
20 cm	20.2	20.1	0.73	20.1	20.2	0.54	19.9	**20.38**	**0.01**	20.1	20.2	0.29
30 cm	20.1	20.0	0.55	20.0	20.1	0.94	19.9	20.19	0.11	20.0	20.1	0.62
40 cm	19.1	19.3	0.68	**19.9**	**18.6**	**<0.01**	19.4	19.02	0.19	19.3	19.1	0.68
March 2001												
10 cm	19.9	19.8	0.59	19.8	19.9	0.78	19.9	19.81	0.21	19.8	19.9	0.37
20 cm	20.2	20.2	0.73	20.2	20.3	0.43	20.1	20.31	0.07	20.1	20.3	0.37
30 cm	20.1	20.2	0.35	20.2	20.2	0.83	**20.0**	**20.31**	**0.05**	20.2	20.2	0.90
40 cm	19.9	19.4	0.14	19.8	19.5	0.30	19.5	19.78	0.44	19.6	19.7	0.62
September 2001												
10 cm	**20.3**	**19.6**	**<0.01**	20.1	19.9	0.11	19.9	20.0	0.47	19.9	20.0	0.39
20 cm	20.2	20.2	0.96	20.2	20.2	0.65	**20.0**	**20.3**	**0.02**	20.2	20.2	0.54
30 cm	20.0	20.1	0.35	20.1	20.0	0.30	**19.9**	**20.3**	**0.01**	20.1	20.1	0.92
40 cm	20.2	20.1	0.64	20.1	20.1	1.00	20.1	20.2	0.75	20.0	20.2	0.48
December 2001												
10 cm	**19.5**	**19.9**	**<0.01**	**19.5**	**19.9**	**<0.01**	19.7	19.7	0.95	19.6	19.8	0.19
20 cm	**19.4**	**20.0**	**<0.01**	19.6	19.7	0.65	19.6	19.7	0.46	19.7	19.7	1.00
30 cm	**19.3**	**20.0**	**0.01**	19.6	19.7	0.78	19.6	19.7	0.75	19.7	19.7	0.92
40 cm	**17.7**	**19.1**	**<0.01**	18.4	18.4	0.83	18.4	18.4	1.00	18.4	18.4	0.70
March 2002												
10 cm	**20.0**	**19.8**	**<0.01**	19.9	20.0	0.05	19.9	20.0	0.13	**19.9**	**20.0**	**0.01**
20 cm	20.2	20.2	0.73	20.2	20.3	0.43	20.1	20.3	0.07	20.1	20.3	0.37
30 cm	**20.1**	**19.3**	**<0.01**	19.9	19.5	0.06	19.2	**20.2**	**<0.01**	19.8	19.6	0.44
40 cm	**19.9**	**19.4**	**0.05**	19.8	19.5	0.30	19.6	19.8	0.50	19.6	19.7	0.70

The O_2 concentrations at the four depths were significantly associated with garden size in December 2001, indicating that input from the smaller gardens significantly increased O_2 in the range of 0.4 – 1.4 % compared to the large garden size (Table 5.2). This garden size group potentially increased O_2 due to the addition of more fibrous material. Furthermore, earthworm inoculum was found to have a significant effect at 10 cm increasing O_2 by 0.4 % compared to the material without this addition. Although earthworms generally reside in lower regions of the compost bin, their movement may have created discreet air pockets that could increase concentrations at specific depths. Neither mixing the compost nor adding accelerator had a significant impact on O_2 concentrations in the bin profile.

The final O_2 concentration sampling in March 2002 showed further and sporadic significant associations between compost depth and main treatment factors (Table 5.2). At depths of 10, 30 and 40 cm, O_2 concentrations were highly significant with garden size. Indeed, the data showed that mean concentrations were reduced in the range 0.2 – 0.8 % in the small garden compost compared to the material from the larger gardens. At the 10cm depth, oxygen concentrations were significantly increased with accelerator and earthworm addition, and at the 30cm depth, mixing significantly increased O_2 concentrations by 1 % compared to non-agitated compost (Tables 5.2).

Overall, the data has shown a varied and inconsistent relationship between management factors and O_2 concentrations, which further emphasises the varied biodynamic activity occurring within the small-scale composters during the study period.

Generally mixing was shown to marginally increase O_2 concentrations above those of the un-mixed system. However, results were likely to have a significant impact as the difference between the mean O_2 data were small and concentrations in unmixed compost remained close to ambient and above the minimum threshold recommended for optimum composting activity. Garden size also had an effect on O_2 rates. In December 2001, smaller garden size appeared to significantly increase concentrations whereas in March 2002, the reverse was true and compost from large gardens had a greater mean O_2 value than from the smaller gardens. The other management treatments, e.g. earthworm and accelerator addition had marginal effects on O_2 concentrations.

Transport of O_2 is *via* diffusion to materials in the compost bin and is assisted by natural convection. However, this may be limited to the upper and outer parts of the pile. The protruding spike (Figure 5.5) built into the compost bin was designed to facilitate gas exchange in the central potential anaerobic zone and O_2 concentrations within the lower depths, which corresponded to this region were slightly depressed indicating that this component may have assisted gas exchange.

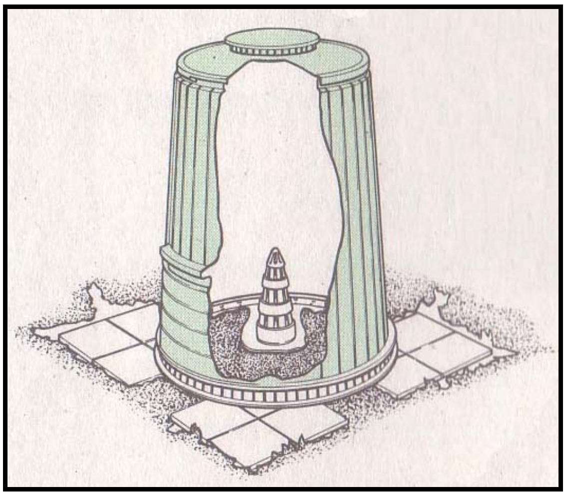


Figure 5.5 **Protruding spike inside Milko compost bin (Straight Recycling Ltd, Leeds)**

5.3.2 Carbon dioxide concentrations

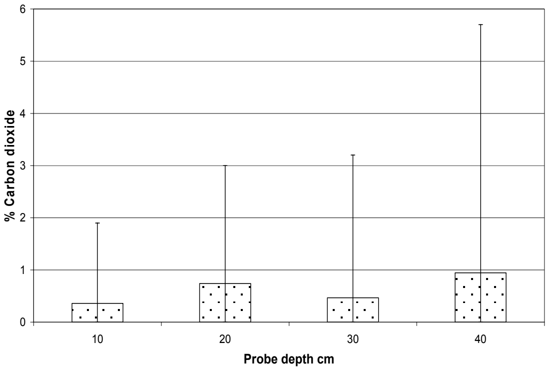
The CO_2 concentration of the interstitial gas of individual bins were in the range: 0 – 6 % and generally increased with increasing sampling depth (Figure 5.6). Overall, the range of CO_2 concentrations within the compost bins were greater during the initial monitoring periods (December 2000 and March and September 2001) compared to December 2001 (Figure 5.6 (a – c) and (d)). However, the CO_2 levels measured in March 2002 (Figure 5.6 (e)) were similar to the preliminary results. The partial depletion in O_2 and the increase in CO_2relative to ambient values were indicative of significant biological activity in lower regions of the compost bins.

During the December 2000 monitoring period, garden size had a statistically significant effect on CO_2 concentrations at the 10 cm sampling depth (Table 5.3). The mean CO_2 value was 50 % greater in the bins situated in the larger garden compared to that measured in the smaller garden size group. A possible explanation was that fresh deposits of nitrogenous green waste by the large garden sized group increased CO_2 concentrations. Agitation of the compost during mixing significantly decreased the mean CO_2 between 0.36 and 0.57 % compared to the material that remained unmixed. This indicated the presence of active aerobic activity within the bins. Earthworm and accelerator addition did not significantly affect CO_2 data.

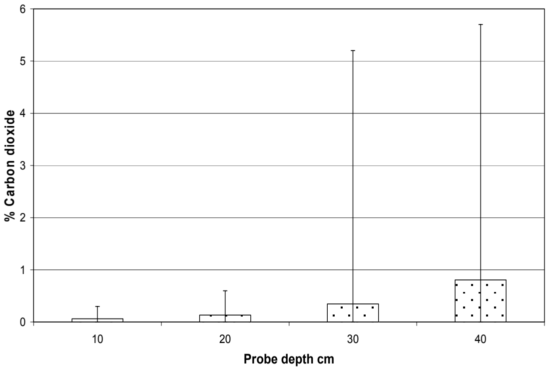
Measurements taken during March 2001 were from material that was almost one year old and included the first grass cuttings of the year. At almost all depths (20, 30, and 40 cm), CO_2 concentrations were affected by garden size (Table 5.3) and at the lower depths, CO_2 was greater from the larger sized gardens than the small gardens. As was the case in December 2000, mixing significantly lowered the CO_2 values, and inoculation with accelerator and earthworms did not effect concentrations of interstitial CO_2.

Addition of accelerator in September 2001 was again unrelated to CO_2. However, earthworms did significantly increase mean concentrations of CO_2 (0.2 %) at the 10 cm depth compared to materials without this factorial addition. The statistically significant effects of garden size and mixing observed in the previous sampling time periods were observed here.

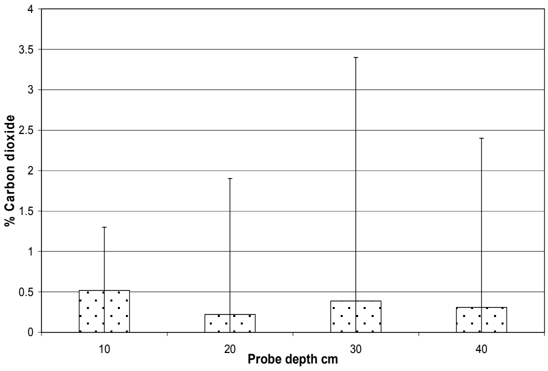
(a) December 2000



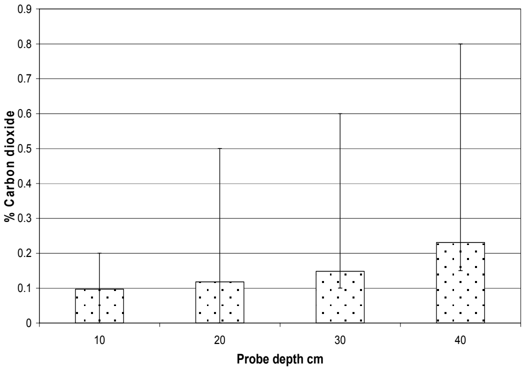
(b) March 2001



(c) September 2001



(d) December 2001



(e) March 2002

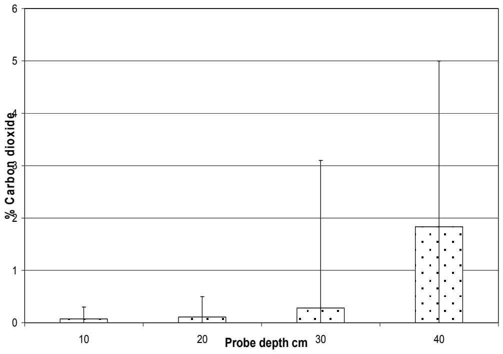


Figure 5.6 **Average compost carbon dioxide concentrations in relation to probe depth (vertical bars represent maximum and minimum values)**

Table 5.3 F probabilities and mean values (CO$_2$ concentrations)

Monitoring period and depth (cm)	**Garden size**			**Earthworm inoculum**			**Mixing**			**Accelerator**		
	Large mean	**Small mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**	**No mean**	**Yes mean**	**F. Prob**
December 2000												
10 cm	**0.48**	**0.24**	**0.01**	0.40	0.32	0.32	**0.54**	**0.18**	**<0.01**	0.35	0.37	0.84
20 cm	0.74	0.74	0.97	0.79	0.69	0.59	**0.98**	**0.50**	**0.01**	0.75	0.73	0.89
30 cm	0.48	0.45	0.86	0.48	0.45	0.83	**0.75**	**0.18**	**<0.01**	0.47	0.46	0.95
40 cm	0.81	1.08	0.33	0.87	1.02	0.59	**1.19**	**0.70**	**0.08**	1.04	0.85	0.48
March 2001												
10 cm	0.08	0.05	0.08	0.07	0.06	0.80	**0.08**	**0.05**	**0.01**	0.07	0.06	0.80
20 cm	**0.08**	**0.18**	**0.02**	0.14	0.13	0.72	0.13	0.14	0.83	0.13	0.14	0.72
30 cm	**0.69**	**0.00**	**<0.01**	0.33	0.37	0.80	**0.64**	**0.05**	**<0.01**	0.37	0.33	0.80
40 cm	**1.39**	**0.22**	**<0.01**	0.66	0.95	0.25	**1.20**	**0.41**	**0.01**	0.88	0.73	0.56
September 2001												
10 cm	**0.32**	**0.72**	**<0.01**	**0.42**	**0.62**	**<0.01**	0.53	0.50	0.60	0.51	0.52	0.89
20 cm	**0.44**	**<0.00**	**<0.01**	0.24	0.20	0.57	**0.44**	**<0.01**	**<0.01**	0.23	0.21	0.81
30 cm	**0.77**	**<0.00**	**<0.01**	0.50	0.27	0.10	**0.58**	**0.20**	**0.01**	0.46	0.32	0.30
40 cm	0.32	0.30	0.86	0.30	0.32	0.86	**0.48**	**0.14**	**0.02**	0.32	0.30	0.89
December 2001												
10 cm	0.09	0.11	0.10	0.10	0.10	1.00	0.10	0.09	0.58	0.09	0.11	0.10
20 cm	0.12	0.12	0.93	0.11	0.13	0.31	0.13	0.11	0.22	0.12	0.12	0.83
30 cm	0.17	0.13	0.11	0.14	0.15	0.75	0.16	0.13	0.22	0.15	0.14	0.75
40 cm	**0.26**	**0.20**	**0.02**	0.23	0.23	0.91	0.23	0.24	0.69	0.23	0.23	1.00
March 2002												
10 cm	0.08	0.07	0.72	0.07	0.08	0.25	0.08	0.06	0.17	0.08	0.07	0.51
20 cm	0.10	0.12	0.33	0.11	0.11	0.98	0.13	0.09	0.15	0.09	0.13	0.14
30 cm	**0.56**	**<0.00**	**<0.01**	0.26	0.30	0.67	**0.51**	**0.05**	**<0.01**	0.27	0.29	0.78
40 cm	**2.65**	**1.02**	**<0.01**	**1.53**	**2.13**	**<0.01**	1.93	1.73	0.30	1.70	1.97	0.16

There were very few significant effects of experimental management factors during the final sampling periods (December 2001 and March 2002). During December 2001, only garden size at the 40 cm sampling depth had a significant impact on CO_2 concentrations. Whereas at the lower depths (30 and 40 cm) in March 2002, garden size and mixing were associated with a significant decrease in CO_2 and earthworm inoculum significantly increased CO_2 above the mean concentrations measured in the bins without this biological input.

Consistent increases of CO_2 concentration with increasing depth were observed with mixing and large garden size management practices. The presence of large deposits of nitrogenous green waste from the large garden size group may have increased composting activity and CO_2 concentrations, which is a by-product of the process.

5.3.3 Methane concentrations

In general, CH_4 concentrations measured within the compost bins during the Study Trial were relatively consistent. Small concentrations were detected and the mean CH_4 values were in the range: 0.1 – 0.2 % and the maximum value was 0.5 %, which indicated aerobic activity (Figure 5.7). However, the data from December 2001 and March 2002 showed that CH_4 marginally increased with increasing depth (Figure 5.7 (d) and (e)).

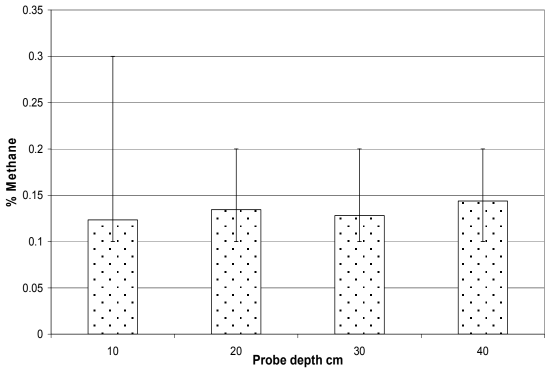
Garden size had a statistically significant effect on CH_4 concentrations and the mean data showed that CH_4 values measured in the compost bins from the larger gardens were greater than in the material produced from the smaller gardens. However, this was variable with depth. For example, during December 2000 there was a significant difference between concentrations at the 10 cm sampling depth only whereas in December 2001 this occurred in the lower depths (30 and 40 cm). This difference was attributed to the greater green waste deposits by the large garden sized group.

The results also showed that CH_4 measured in home compost that had not been agitated by mixing was greater than in the mixed material. The data was again inconsistent and varied between sampling depths during the monitoring periods. Nevertheless, the overall trend indicated that CH_4 decreased with depth.

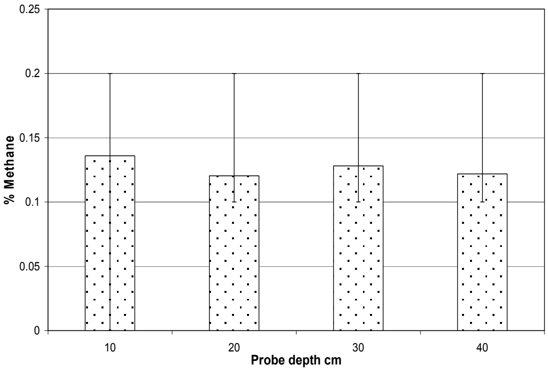
Small numbers of sampling periods also showed a significant difference between bins with and without accelerator addition and earthworm inoculum. However, the majority of data indicated that these management factors did not a significant effect on CH_4 evolution.

Overall, concentrations of CH_4 were very low during the Study Trial and in general increased with compost bin depth. A significant relationship was observed between increasing CH_4 concentrations and large garden size and this was associated with a larger proportion of green waste input compared to the small garden group. As previously observed in O_2 and CO_2 investigations, mixing was significantly associated with CH_4 and this management treatment decreased CH_4 concentrations.

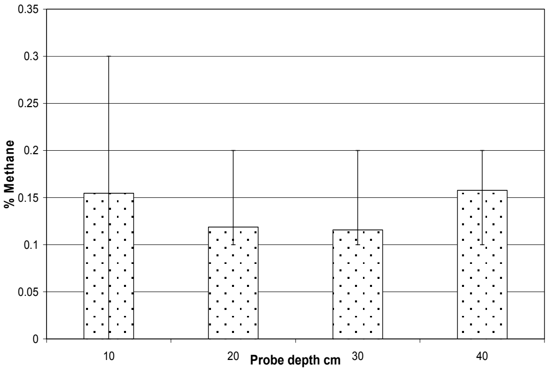
(a) December 2000



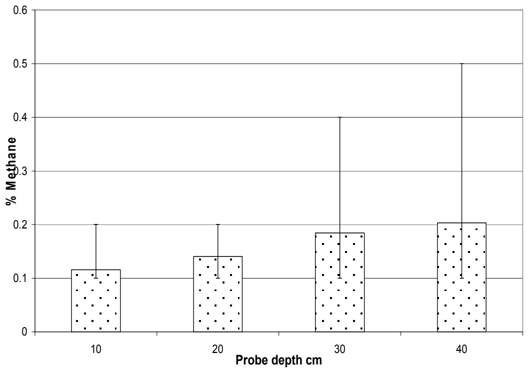
(b) March 2001



(c) September 2001



(d) December 2001



(e) March 2002

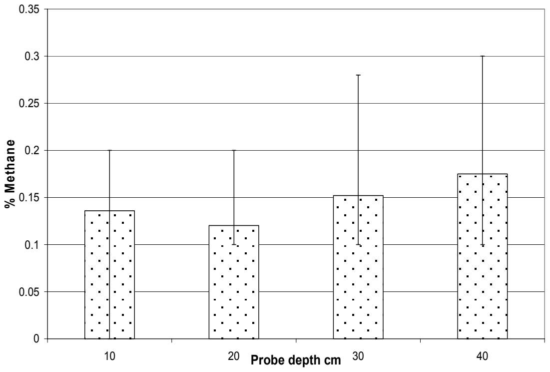


Figure 5.7 **Average compost methane concentrations in relation to probe depth in (a) December 2000, (b) March 2001, (c) September 2001, (d) December 2000 and (e) March 2002 (vertical bars represent maximum and minimum values)**

Table 5.4 F probabilities and mean values (CH_4 concentrations)

Monitoring period and depth (cm)	Garden size			Earthworm inoculum			Mixing			Accelerator		
	Large mean	Small mean	F. Prob	No mean	Yes mean	F. Prob	No mean	Yes mean	F. Prob	No mean	Yes mean	F. Prob
December 2000												
10 cm	**0.13**	**0.11**	**0.02**	**0.14**	**0.11**	**<0.01**	**0.14**	**0.11**	**<0.01**	0.13	0.12	0.73
20 cm	0.13	0.13	1.00	**0.13**	**0.13**	**<0.01**	0.15	0.12	1.00	0.13	0.13	1.00
30 cm	0.13	0.13	1.00	0.13	0.13	1.00	**0.14**	**0.11**	**0.01**	0.13	0.12	0.24
40 cm	0.14	0.14	1.00	0.15	0.14	0.61	**0.16**	**0.13**	**0.01**	0.15	0.14	0.61
March 2001												
10 cm	0.14	0.13	0.29	0.13	0.14	0.29	0.14	0.13	0.83	0.14	0.13	0.52
20 cm	**0.13**	**0.11**	**0.02**	0.13	0.11	0.02	0.12	0.12	0.73	**0.11**	**0.13**	**0.02**
30 cm	**0.15**	**0.11**	**<0.00**	0.13	0.13	1.00	**0.14**	**0.12**	**0.01**	0.13	0.13	1.00
40 cm	**0.14**	**0.10**	**<0.00**	0.12	0.13	0.28	**0.14**	**0.10**	**<0.01**	0.13	0.12	0.28
September 2001												
10 cm	**0.13**	**0.18**	**<0.01**	0.15	0.16	0.75	0.16	0.15	0.34	0.16	0.15	0.75
20 cm	**0.13**	**0.10**	**<0.01**	0.12	0.12	0.42	**0.13**	**0.10**	**<0.01**	0.12	0.12	1.00
30 cm	**0.13**	**0.10**	**0.01**	0.12	0.11	0.13	**0.13**	**0.10**	**0.01**	0.12	0.11	0.44
40 cm	**0.18**	**0.14**	**<0.01**	0.15	0.16	0.24	0.16	0.15	0.24	**0.17**	**0.17**	**0.01**
December 2001												
10 cm	0.12	0.12	1.00	0.11	0.13	0.03	0.12	0.11	0.46	0.12	0.11	0.46
20 cm	0.15	0.13	0.24	0.14	0.14	0.56	**0.17**	**0.12**	**<0.01**	0.15	0.13	0.24
30 cm	**0.21**	**0.16**	**<0.01**	0.19	0.18	0.18	**0.23**	**0.13**	**<0.01**	0.18	0.18	1.00
40 cm	**0.29**	**0.12**	**<0.01**	0.22	0.19	0.16	0.21	0.20	0.57	0.20	0.20	1.00
March 2002												
10 cm	0.14	0.13	0.29	0.13	0.14	0.29	0.14	0.13	0.83	0.14	0.13	0.52
20 cm	**0.13**	**0.11**	**0.02**	0.13	0.11	0.02	0.12	0.12	0.73	0.11	0.13	0.02
30 cm	0.15	0.15	0.70	0.15	0.16	0.49	**0.18**	**0.13**	**<0.01**	0.15	0.15	0.83
40 cm	**0.19**	**0.16**	**0.03**	0.17	0.18	0.65	0.18	0.17	0.37	0.18	0.17	0.37

5.4 DISCUSSION

5.4.1 Temperature in relation to composting activity

Under aerobic conditions, temperature is an important environmental variable during composting because it influences the composition and density of the microbial population as well as microbial metabolic activities (Finstein and Morris; 1975; Finstein *et al*., 1986; Namkoong and Hwang, 1997; Joshua *et al*., 1998). Increasing temperature within composting materials is a function of initial temperature, metabolic heat evolution and heat conservation (Miller 1992a). A minimum temperature of at least 40^oC is necessary to facilitate a substantially high rate of decomposition for effective composting (Finstein and Morris; 1975; Finstein *et al*., 1986; Miller 1992a). During this Study Trial, temperatures measured in the home composting bins were highly variable, but were generally above ambient and within a mesophilic range. Temperatures during December and March of each monitoring year were below 20 °C and this indicated that microbial activity would be low and therefore the composting processes slow due to an appreciable lag period (Mosher and Anderson, 1977).

The results showed that mixing the compost material significantly reduced compost temperatures. Indeed, in large-scale composting operations, mixing is used to control temperature and to encourage oxygenation and uniformity of material decomposition (De Bertoldi *et al*., 1982; Kuter *et al*., 1985; Finstein *et al*., 1986; Haug, 1993). Bach *et al.* (1984) and McKinley and Vestal (1984) report that optimal decomposition rates occur in the range: 55 to 60 °C. Furthermore, thermophilic systems have been shown to achieve greater pathogen inactivation rates and weed seed destruction, although the evidence is not conclusive (Briddlestone *et al*., 1997; Ten Brummeler, 2000). Nevertheless, mesophilic temperatures promote higher process stability at a low heat demand (Van Santen *et al*., 1998) and a high quality product is still achievable with temperatures in this range (Miller, 1990). Data has also indicated that lower temperatures may even permit greater microbial activity (McKinley *et al*., 1986; Suler and Finstein, 1997).

5.4.2 Gas composition in relation to composting activity

The O_2 content in a composting system reflects the balance between O_2 diffusion rate and material O_2 consumption. Gas exchange is an important component supporting aerobic microbial metabolism, and composting failure is often attributed to lack O_2 (Gray *et al*., 1971; Poincelot, 1975). For solid waste composting systems, free airspace of 30 to 35 % of the total volume has been suggested for sufficient gas diffusion (Schulze, 1961; Haug, 1978).

Oxygen consumption is a function of substrate characteristics such as C/N ratio, carbon bioavailability, moisture and particle size as well as environmental conditions e.g. temperature, moisture, O_2 concentration, and pH. Furthermore, input materials from different sources consume O_2 at different rates, for example rapidly degrading products such as grass clippings or food waste expend O_2 more rapidly than leaves (Finstein and Hogan 1993).

During the Study Trial O_2 concentrations in the compost bins were typically close to ambient values and levels of CH_4 were small, which indicated that waste degradation was predominately aerobic. Concentrations of CO_2 of the interstitial gas of individual bins were in the range of 0 – 6 % and generally increased with increasing probe depth.

5.4.3 Gas composition in relation to management regimes

Continuously mixed compost systems enhances aerobic microbial activity and turning removes large amounts of heat as the material is moved through the air ((Shell and Boyd, 1969; Miller *et al*; 1989). The data presented here demonstrated that incorporation of air through mixing increases O_2 and CO_2 concentrations decreases CH_4 and reduces temperature in the composting mass. Whereas, these variables remained close to ambient within the unmixed systems. However, the data was above the minimum threshold recommended for optimum composting activity. Similar results were demonstrated by Illmer and Schinner (1997) who examined compost turning in 12 small-scale systems receiving 3 different turning treatments (no mixing, manual mixing and mechanical mixing) during a 1 year period. The data showed significant influences of chemical and biological parameters for example speed of degradation, as well as the quality of the end product, were significantly increased through mixing with a mechanical stirrer. Nevertheless, manual mixing produced better compost from static composters, although differences between management factors were less distinct.

Consistent increases of CO_2 concentration and decreasing CH_4 concentration with increasing compost bin depth were observed with the large garden size management practice. The presence of large deposits of nitrogenous green waste from this garden size group may have increased composting activity accounting for changes in gas composition. Composting matrices can contain aerobic and anaerobic microenvironments coexisting within close proximity (Miller *et al.*, 1989) and in the presence of interstitial O_2 products of anaerobic metabolism (such as H_2S or CH_4) will be oxidised. Therefore, mixing may have encouraged oxidation in areas of high CH_4 concentration.

Variation in gas exchange with increasing compost bin depth has been associated with moisture content of the waste composition, as microbial activity appears to be more influenced by moisture content than temperature (Suler and Finstein, 1977; McKinley *et al.*, 1986; Tiquia *et al*, 1998; Liang *et al*, 2002). Microbial cells have a physiological requirement for water, which is also an essential component for the transport of organisms within compost. Low moisture content can therefore inhibit bacteria colonisation due to reduced cell transport (Miller, 1989), although fungi and *Actinomycete* species are less affected by moisture because they can colonize *via* hyphae across air gaps. Research suggests that moisture content in the range: 50 – 60 % is suitable for efficient composting (Suler and Finstein, 1977; McKinley *et al.*, 1986; Tiquia *et al*, 1998). However, a well-colonized compost kept under otherwise favourable conditions still can be active at moisture contents as low as 22 %, but addition of water can renew microbial activity resulting in a more mature compost (Finstein *et al.*, 1983; Stentiford, 1996).

In large scale composting systems, high moisture contents impact the system in two ways; (1) it limits O_2 diffusion within the composting matrix and (2) it increases pliability of the materials, potentially leading to compaction of the compost. These factors reduce air permeability and increase aeration costs. Furthermore, high moisture can cause anaerobic conditions from water logging in the pore spaces impeding the composting processes (Tiquia *et al.*, 1996; Schulze, 1962).

The moisture content from inputs of food waste and grass clippings will be approximately 60 – 70 % and this will collect at the bottom of the bin as leachate during decomposition or will be lost through evaporation. The moisture content will therefore be greater in the lower regions of the composting material compared to those in the top of the bin and this will increase gas diffusion pathways until metabolic demands exceed supply. Oxygen diffuses more slowly in water than in air and larger moisture contents in lower regions will reduce O_2 penetration, which supports the results from the 40 cm sampling depths. In addition, the reduced O_2 concentrations were complemented with increasing CH_4 concentrations, particularly in the large garden size group, reflecting the reduction in O_2 concentration and aerobic activity within the lower depth regions. However, mixing was observed to reduce the CH_4 content and subsequent increases in O_2 and CO_2 were measured implying that this management supports aerobic activity.

5.4.4 Discussion summary

The stabilisation of frequent inputs of small amounts of mixed organic residues in small-scale composters were not observed to follow the normal ecological progression such as those in conventional batch-operated, centralised composting systems. Waste treatment in small-scale composting units is highly biodynamic and organic matter is present at different stages of decomposition, which depends on the activities of invertebrate animals, particularly earthworms. Regular, small inputs of mixtures of different waste types (kitchen, paper and garden waste) to home composting systems provide a relatively stable and well-buffered environment for the biodegradation of putrescible household solid waste. Temperature and gas composition measurements indicate that aerobic processes are the predominant waste degradation mechanism operating in small-scale home compost bins.