Improving small-scale composting of apple waste

S.F. BARRINGTON[1], K. EL MOUEDDEB[1] and B. PORTER[2]

[1]*Macdonald Campus of McGill University, 21111 Lakeshore, Ste Anne de Bellevue, QC, Canada H9X 3V9; and* [2]*Basco-Tech Inc., Hemmingford, QC, Canada J0L 1H0.* *Received 21 December 1994; accepted 18 November 1996.*

Barrington, S.F., El Moueddeb,K. and Porter, B. 1997. **Improving small-scale composting of apple waste.** Can. Agric. Eng. 39:009-016. Small-scale composting operations of interest to fruit and vegetable processors use tractor-operated compost turners. The mixing and aeration performance of such compost turners were investigated by monitoring the composting of apple residues mixed with sawdust. The results suggested: 1) incorporating liquids into sawdust by passing it through the turner two or three times and using an overdose of the liquid to be absorbed; 2) mixing compounds in stages and in equal proportions to obtain uniform pH, TKN, and dry matter; 3) using a porosity of 35 to 40% and a C:N of 20 to 25 to reach temperatures of 60 °C; 4) bulking the residues with a mixture of sawdust and straw to maintain compost structure while increasing the available C thus reducing N losses.

Les usines de transformation de fruits et légumes s'intéressent aux petits postes de compostage qui utilisent un retourneur d'andain traîné par un tracteur de ferme. Des essais furent effectués pour suivre la performance de ces retourneurs d'andains. Des restes de pommes furent compostés avec de la sciure de bois et les résultats suggèrent de: 1) incorporer les éléments par étapes en utilisant des quantité égales; 2) incorporer les liquides au compost en deux à trois étapes et en utilisant une quantité excessive de liquide; 3) utiliser une porosité de 35 à 40% et un C:N de 20 à 25 pour atteindre des températures de 60 °C; 4) utiliser un mélange de sciure de bois et de paille pour un compost de bonne structure, un meilleur taux de C disponible et moins de pertes de N.

INTRODUCTION

To process organic wastes as organic fertilizers rather than disposing into landfills, fruit and vegetable processing plants have demonstrated some interest in small-scale composting operations using the turned windrow system. The wet and acidic residues generated by the industry are not readily accepted by solid waste disposal sites because of the acid leachate they produce. Small-scale compost operations using the turned windrow system are economical to set up and operate while the low volume processed limits the intensive labour and large space required. The residues are composted in small windrows exposed to exterior conditions and are mixed and aerated by means of a tractor-driven compost turner. The efficiency of such equipment has never been tested.

A project was, therefore, undertaken to evaluate the mixing and aeration performance of compost turners used by small-scale composting operations and to formulate recommendations for their most effective use. Thus, the project followed the evolution of the properties of apple waste compost for 69 days to establish how well, with each successive pass of the compost turner:

1) sawdust was wetted with apple wastewater;
2) amendments and bulk materials were mixed together;
3) oxygen was introduced into the compost at three different levels of dry matter (d.m.).

The composting process was evaluated for 69 days by:

1) monitoring the compost temperature with a metal stem thermometer;
2) monitoring the windrow O_2 with such a probe, to establish the need for turning;
3) establishing the best porosity and dry matter level required to compost apple wastes with sawdust by testing in triplicate three levels of dry matter;
4) evaluating visually the compost quality at 69-day;
5) measuring nitrogen (N) losses during composting by monitoring the evolution of the carbon to nitrogen ratio (C:N).

LITERATURE REVIEW

Except for space, small-scale composting operations using the turned window system require little investment. A compost turner operated by a 60 kW farm tractor is the only equipment required for both mixing and aerating. This tractor-operated turner costs Can $15 000 to $20 000 as opposed to at least Can$200 000 for a commercial self-propelled unit (Diaz et al. 1993). As opposed to the commercial unit which turns 6.0 m wide windrows, the tractor operated turner straddles 3.0 m wide windrows which triples the land base required for the same composting capacity. Nevertheless, the required land base is limited because of the small volume processed.

The turned windrow system also requires more energy and labour than the static system which aerates the compost by ventilating the mass with a fan and a duct system. The turned windrow system incorporates air into the compost by regularly turning and mixing the entire mass, thus using much energy and time and often leading to over-mixing and cooling of the compost. Again, this additional use of labour and energy is limited by the small volume processed by the tractor-driven compost turner.

Sawdust or peat as bulking agent can minimize the frequency of windrow overturning by giving the compost a more porous structure. The pore space of the compost helps store and diffuse oxygen to the microbes (Diaz et al. 1993) and is influenced by the structural strength of the bulking agent. Wood shavings, sawdust, and peat moss offer good structural strength even at humidity levels of 75% while straw and paper residues tend to collapse when wet (Zhan et al. 1992; Mathur et al. 1990). Thus, compost containing sawdust should require less overturning to maintain an oxygen level above 5% within the compost (Midwest Plan Service 1985).

Sawdust as bulking agent leads to high N losses because of its high lignin content and low C bio-degradability. While a compost C:N of 20 to 35 is preferred (Rodrigues et al. 1995; Martin et al. 1993), soil microbes possess a C:N of approximately 8 (Alexander 1977) and lose 60% of the C consumed as CO_2 (Henis 1986). Thus, no N will be lost with a compost possessing a C bio-degradability of 100% and a C:N of 20 because after loosing 60% of the C as CO_2, the final C:N of 8 corresponds to the biomass requirements of the microbes. A compost with a C:N of 30 will conserve all of its N only if at least 66% of its C is bio-degradable (Barrington 1994). When composed mostly of lignin which has a C bio-degradability of 7% (Russell 1973), sawdust compost with an initial C:N of 30, may offer a C bio-degradability of 15% to 25%, and thus, lose 80 to 60% of its N, respectively. A C:N of 20 to 30 is still required early in the composting process otherwise slower composting activity may be expected (Diaz et al. 1993). Thus, sawdust as a bulking agent inevitably leads to high N losses despite its better structure and porosity reducing the need for turning.

Because composting is a controlled aerobic decomposition process converting biodegradable solid organic matter into stable humus (Parent 1983), the performance and timely use of the compost turner is critical. The following criteria can establish the composting performance of the system:

1) temperatures of 60 to 65°C should be reached within 3 to 7 days to efficiently stabilize the residues (Diaz et al. 1993; Lau et al. 1991);
2) the final product should be dark in colour, odourless and well decomposed, except for the wood residues (Mustin 1987; Lo et al. 1993);
3) the compost should have conserved the highest level of nutrients (Lo et al. 1993);
4) the compost O_2 level should be above 5% at all times (Midwest Plan Service 1985).

When such criteria are not achieved, the composting process and the physical and chemical composition of the compost mixture requires correction. These criteria were used to evaluate the mixing and aeration efficiency of compost turners and to recommend guidelines for their most effective use.

METHODOLOGY

The experimental material

Apple pulp and apple wastewater were composted with sawdust used as a bulking agent (Tables I and II). The apple residues were produced by an apple sauce and pie filling manufacturer in Franklin, QC. The sawdust was purchased from a local saw mill cutting mainly maple, hemlock, and oak.

Table I: Chemical properties of the experimental material

Properties	Material		
	Apple pulp	Apple wastewater	Sawdust
d.m. (%)	15.3 (1.77)[3]	1.44 (0.058)	64.6 (0.040)
pH	3.3 (0.14)	4.0 (0.01)	5.9 (0.01)
Ash (%[1])	3.7 (0.50)	20.0 (2.36)	0.6 (0.04)
C (%[2])	53.5	44.4	55.2
TKN (g/kg)	27.3 (1.502)	0.97 (0.025)	7.65 (0.103)
NH4-N (mg/kg)	5.0 (0.01)	17.3 (1.83)	0.9 (0.03)
P total (mg/kg)	1571 (767.6)	3700 (236.2)	256 (113.7)
K total (mg/kg)	340 (52.6)	870 (109.3)	171 (56.4)
C:N	20	460	720

[1] All properties are expressed on a d.m. basis.
[2] Expressed on a d.m. basis and calculated by dividing the organic matter content by 1.83. The organic matter content is equal to one minus the ash content.
[3] The values in parentheses are the standard deviations.

Because the apple residues were acid and the sawdust had a high C:N of 720, dehydrated lime ($Ca(OH)_2$) and urea (46%) were used to correct the pH to 7.0 and the C:N to 30. A C:N of 30 instead of 20 was selected to reduce N losses and minimize amendment costs while still respecting the recommended ratio. The required quantity of lime was established in the laboratory by measuring the buffer capacity of the apple residues.

Apple pulp and apple processing wastewater as primary composting materials offered excellent testing conditions for:

1) mixing as their acidity requires correcting with limited quantities of limestone;
2) aeration as their high humidity reduces the porosity of the mass and increases the need for aeration.

The experimental equipment

The test compost turner (Model 1012, Sittler Inc., Linwood, ON) consisted of a 3.66 m-long rotating drum with knives

Table II: Physical properties of the experimental materials

Properties	Material		
	Apple pulp	Apple wastewater	Sawdust
Particle density (kg/m)	0.83 (0.086)*	- -	1.05 (0.112)
Bulk density (kg/m^3)	1.00 (0.002)	1.00 (0.002)	0.68 (0.021)
Particle size (%)	22.6 (7.00)	-	7.7 (0.26)
> 4.76 mm	29.5 (12.34)	-	15.0 (1.61)
4.76 - 2.36 mm	9.6 (0.42)	-	60.3 (1.38)
2.36 - 0.42 mm	3.9 (0.28)	-	15.4 (1.12)
0.42 - 0.25 mm	0.9 (0.54)	-	1.4 (0.13)
0.25 - 0.075 mm	33.5 (6.54)	-	0.2 (0.09)
< 0.75 mm			

* the values in parenthesis are the standard deviations.

held at 300 to 600 mm above ground level and powered by the power-take-off of a 60 kW farm tractor. The drum is rotated while being moved through the compost and heavy rubber mats on both sides of the housing direct the thrown material to shape a windrow while protecting the tractor and driver.

The temperature of the compost was measured by inserting a long metal-stem compost thermometer to a depth of 800 mm within the windrows. The oxygen level of the windrows was measured by pumping the compost's air against an oxygen sensor (Sensitron Inc., Readings, PA) by means of a rigid PVC (polyvinyl chloride) tube, perforated at its tip and inserted into the windrows to a depth of 800 mm. This PVC tubing could be unscrewed from the sensor for cleaning when necessary.

The methodology

Eighteen exterior windrows were built to test in triplicates for three sawdust to apple pulp ratios and three sawdust to apple wastewater ratios (Table III). Three levels of dry matter (d.m.), and thus porosity, were tested for each residue. The windrows measured 3.0 m in width and 1.5 m in height and were built outside in unprotected straight rows spaced 5.0 m apart. The windrows were built by dumping 3 wet tonnes of sawdust in a row and topping it with the apple residues. The pH and C:N of the compost were corrected by manually spreading over the crest of the windrows the required amount of lime and urea. All the ingredients then were mixed by overturning the piles twice with the compost turner.

The wastewater was applied to the sawdust using a technique adopted by most small-scale composting operations. The sawdust windrows were manually trenched at their crest to receive the wastewater from a hose attached to the compost turner in operation. Then, the lime and urea were manually spread over the windrows and mixed using the compost turner. All sawdust and wastewater windrows were sampled immediately after incorporation to establish the level of liquid absorption.

The windrows were composted from September 25 to December 3, 1992. The temperature and oxygen level of all windrows were measured early in the morning, every four days from day 0 to 32 and once a week thereafter. The windrows were turned once every 7 to 10 days. From day 20 to 30, the frequency was changed to once a day to measure the effect of additional overturning on windrow temperature and oxygen level.

The mixing performance of the compost turner was measured by sampling all windrows on days 3, 11, 41, and 69. The variation in pH, TKN, and dry matter among four samples taken within the same windrow served as an indication of mixing efficiency for the lime, urea, and apple residues. The level of wetting of the sawdust with the wastewater was observed from the variation in dry matter of samples taken immediately after mixing the windrows.

The best dry matter level was selected as that from the compost demonstrating temperatures closest to 60 - 65°C, developing a dark colour, having no odour, and maintaining the highest level of nutrients (Lo et al. 1993). The effectiveness of the O_2 meter in predicting the aeration needs of the compost was tested by comparing O_2 level in the windrows with its final visual qualities. The level of N conservation during composting was evaluated by comparing the initial and final C:N. The level of C bio-degradability of the sawdust and apple pulp was estimated by assuming that 60% of the bio-degradable C was lost as CO_2 and an average biomass C:N biomass requirement of 8.

Sampling and analytical procedures

The apple residues and the sawdust were randomly sampled four times from piles stored outside. The apple wastewater samples were collected after agitating the contents of the plant storage tank. These samples were analyzed for particle density and size distribution, dry matter, TKN, NH_4-N, NO_3-N, pH, and ash. The ash content was used to calculate organic matter as (1- ash, expressed as a fraction) and C as (organic matter / 1.83) according to Lo et al. (1993) and Jiménez and Garcia (1992).

Standard methods were used to analyze the samples (APHA 1990). Dry matter was determined by drying at 80°C for 23 hours and one hour at 103°C. Particle density was determined on oven dried samples by soaking in kerosene (Parent and Caron 1993). Particle size was determined by sieving dried samples using standard sieves with opening sizes ranging from 75 m to 4.76 mm. TKN was determined after digestion with sulphuric acid and hydrogen peroxide using an ammonia-selective electrode connected to a voltage meter. Ammonium and pH were measured using an ammonia-selective and pH electrodes, respectively, connected to a voltage meter.

Table III: The experimental treatments

Treatment	Compost composition			Compost properties	
	Residue t/t*	Lime kg/t	Urea kg/t	C:N	D.M.
Apple pulp					
A-1	0.75	3.00	36	30	45
A-2	1.50	6.10	38	30	40
A-3	3.75	15.4	43	30	30
Apple wastewater					
W-1	2.50	0.50	35	34	30
W-2	5.00	0.60	35	34	18
W-3	8.50	1.0	35	36	12

* element per ton of sawdust on a d.m. basis

The porosity of the compost was measured by excavating the windrow to a depth of 600 to 800 mm and taking a core volume. This procedure was repeated three times for each windrow. The mass of each volume was weighed wet and after oven drying. The particle density of the compost was measured and the porosity was calculated by:

$$P = (V_p + V_w) / V_t \qquad (1)$$

where:

V_p = M_p/D_p = volume of oven dried compost particle in the core sample (m^3),
V_w = volume of water in the core sample (m^3),
V_t = total volume of the core sample (m^3),
M_p = oven dried mass of compost particles in the core sample (kg), and
D_p = density of the compost particles (kg/m^3).

The compost pile samples were analyzed for particle density and size distribution, dry matter, TKN, NH_4-N, NO_3-N, pH, and ash.

The mixing performance of the compost turner was calculated from the variation in compost pH, TKN, and dry matter (Larson 1978):

$$C_v = 100\, s / x \qquad (2)$$

where:

C_v = coefficient of variation (%),
s = standard deviation of the element within the samples, based on the normal curve,
x = mean value of the concentration of the element among the samples.

RESULTS AND DISCUSSION

Sawdust absorption of wastewater

The initial dry matter of the wastewater windrows was higher than that calculated (Table III) because the slow absorption rate of the sawdust produced ground runoff during mixing. Treatments W-1, W-2, and W-3 should have possessed initial dry matter of 30, 18, and 12%, respectively, whereas the values obtained were 58.9, 46.5, and 40.1%. Since the windrows absorbed 1.20, 3.20, and 9.08 m^3 of wastewater when 4.85, 9.7, and 16.5 m^3 was applied, the level of wastewater absorption for treatments W-1, W-2, and W-3 was 25, 33, and 55%, respectively. To improve sawdust wetting, the wastewater should be applied in quantities exceeding that required and repeating the procedure with the collected runoff until the desired dry matter is reached. Adding large volumes of liquid improves the level of absorption. Treatments W-2 and W-3 were designed to exceed the sawdust absorption capacity of 3 times its weight as most bulking agents reach their limit at a dry matter of 25% (Midwest Plan Service 1983).

Performance of the compost turner

Mixing The C_v (Eq. 2) for the compost pH, TKN, and dry matter (Figs. 1,2, and 3) served as an indication of the mixing performance of the compost turner with respect to the lime, urea, and apple residues. Initially, the C_v was quite high but decreased with time to reach its lowest value at 41 days, after 15 passes of the compost turner.

After two passes with the compost turner (day 3), the lime and urea were not effectively mixed as the C_v of the pH and TKN was 10 times that on day 41. The compost turner was better able to mix the residues and the sawdust since the dry matter C_v was only 2 to 3 times that on day 3 than on day 41.

The major factors influencing mixing uniformity are (Larson 1978; Weeden and Norrish 1981):

1) Compound density and moisture, where compounds denser than 400 kg/m^3 mix easier because of higher

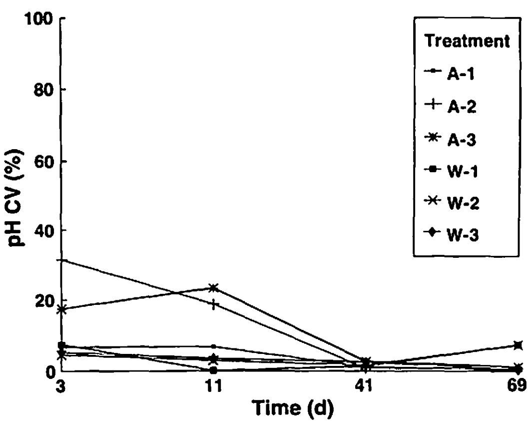

Fig. 1. Coefficient of variation of the compost pH with time.

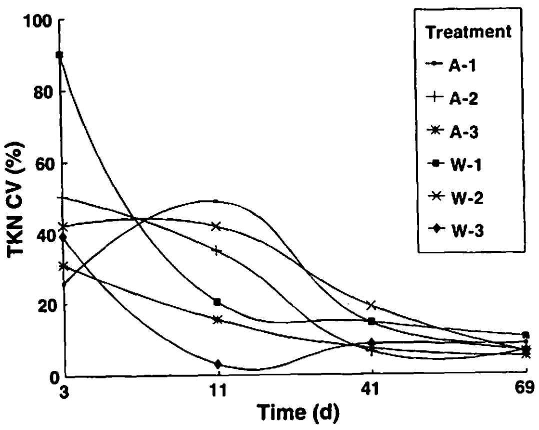

Fig. 2. Coefficient of variation of the compost TKN with time.

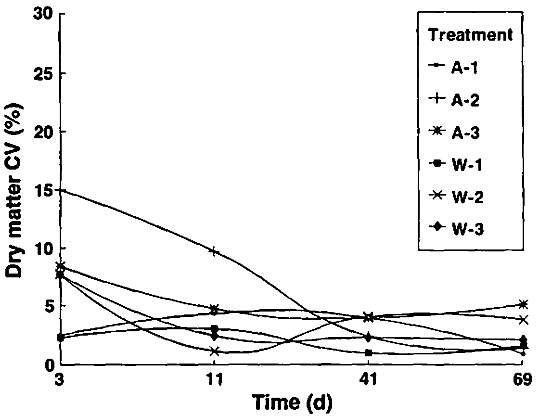

Fig. 3. Coefficient of variation of the compost dry matter with time.

frictional and shear forces leading to more particle interaction;

2) The mass proportions, where the probability of finding an ingredient in a sample is related to its presence within the mix. Proper mixing is more likely when incorporating two compounds of equal weight;

3) Particle dimension, where particles of smaller sizes segregate by moving and falling through the larger ones in the mix;

4) The mixing time, where a long mixing time segregates the particles, while a short time leads to non-uniform mixing.

The blending effectiveness of the compost turner can, therefore, be improved by mixing the compounds in stages, depending upon their mass. Mixing of the bulk materials should be carried out at near equal proportions. For example, 3.75 t of apple pulp can be composted with 1.0 t of sawdust by initially mixing 1.5 t of apple pulp to 1.0 t of sawdust and then, 2.0 t of apple pulp to the 2.5 t mixture. The amendments should be added to 100 kg of residue and then incorporated to the rest of the residues before mixing with the bulking agent.

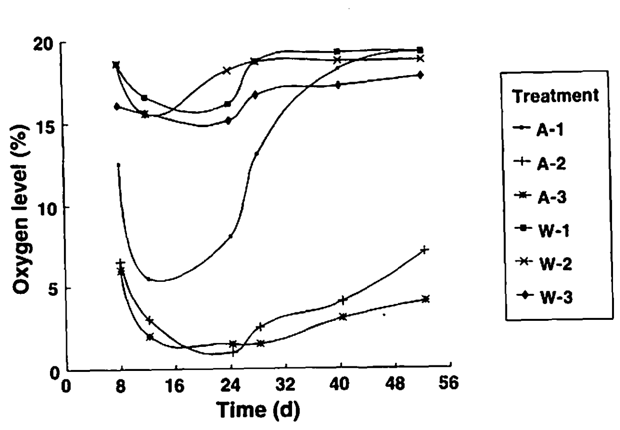

Fig. 4. Oxygen concentration level in the compost with time.

Aeration At the onset of composting, turning once a week was insufficient in maintaining O_2 levels above 5% for all treatments with less than 34% d.m. or 50% porosity (Fig. 4, Tables IV and V). For treatments A-2 and A-3 with 27.8 and 22.7% d.m. or 30.8 and 20.2% porosity, respectively, O_2 levels fell below 5% and temperatures did not exceed 45°C (Fig. 5). Turning once a day, from day 20 to day 30 in A-2 and A-3, increased O_2 levels and temperatures by 1 to 2% and 10 to 20°C, respectively.

For treatment A-1 with 34.0% d.m. and 50.6% porosity, turning once a week maintained O_2 levels above 5% at all times while turning once a day had the negative effect of decreasing its temperature either because of:

1) the cooling effect of frequent turning, since the exterior temperatures were low and the windrows had subsided to a small size, or;

2) less active microbe activity after an earlier, more active composting period (higher O_2 levels and temperatures than the other treatments for day 0 to 20) leading to the depletion of bio-degradable C or available N.

For treatments W-1, W-2, and W-3, with a dry matter exceeding 35% and a porosity of 60%, turning frequency had no marked effect on O_2 levels which stayed above 15%.

The oxygen probe was effective in indicating a lack of compost O_2. Also with treatments A-2 and A-3, turning once a day was insufficient in maintaining the necessary O_2 levels and forced aeration should have been used.

The composting process

Temperature evolution and final visual quality No treatment reached the desired temperatures of 60 to 65°C (Fig. 5) because of:

1) a lack of bio-degradable C, in the case of the wastewater treatments;

2) excess cooling because the windrow size reduced after subsidence to a height of 1.0 m and a width of 2.0 m and because night temperatures below 0°C left frost on the windrow surfaces by morning;

Table IV: Final chemical properties of the compost

Properties[1]	Treatment					
	A-1	A-2	A-3	W-1	W-2	W-3
d.m. (%)	34.0 (0.3)[3]	27.8 (0.3)	22.7 (1.2)	38.4 (0.6)	36.8 (1.4)	35.7 (0.8)
pH	7.9 (0.03)	8.2 (0.06)	7.4 (0.08)	8.2 (0.11)	8.5 (0.1)	8.7 (0.03)
TKN (g/kg)	4.7 (0.35)	7.2 (0.40)	10.2 (0.42)	4.2 (0.39)	4.4 (0.23)	4.1 (0.22)
P (mg/kg)	471 (15)	1294 (142)	1564 (274)	284 (22)	282 (52)	280 (37)
K (mg/kg)	121 (5)	236 (5)	344 (37)	91 (6)	77 (29)	84 (33)
Ash (%)	4.9 (0.05)	4.6 (0.3)	2.0 (0.5)	1.2 (0.3)	1.2 (0.3)	1.5 (0.1)
C:N[2]	53	74	117	130	126	133

[1] All properties are expressed on a d.m. basis.
[2] The C is expressed on a d.m. basis and is calculated by dividing the organic matter content by 1.83. The organic matter content is equal to one minus the ash content.
[3] The values in parenthesis are the standard deviations.

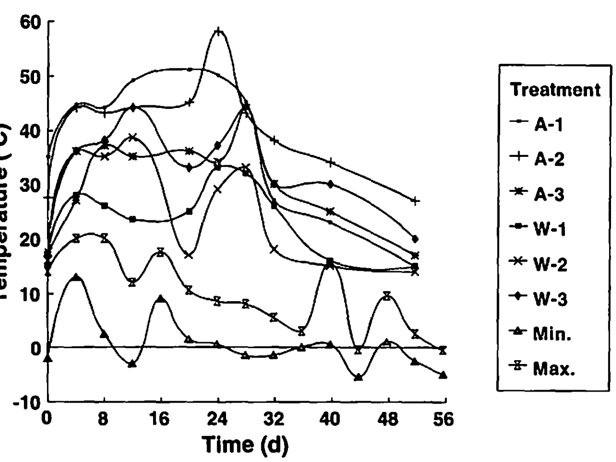

Fig. 5. Temperature of the compost with time.

3) depletion of bio-degradable C and N where a C:N of 20 would probably have improved microbial activity, despite N losses.

Despite low O_2 levels from day 8 to 40, treatment A-2 demonstrated the best final compost properties after 69 days based on its lack of odour, dark brown colour, and no longer distinguishable apple residues. Treatments W-1, W-2, and W-3 produced a mass of sawdust with little colour change because of the low dry matter of the wastewater. Treatment A-1 developed a light brown colour but lacked structure besides the sawdust. Treatment A-3 was too wet to decompose properly. Among other factors, O_2 levels below 5% for treatment A-2 had the drawback of preventing temperatures from reaching to 60°C. Considering the performance of A-2, the ideal sawdust and apple pulp compost mixture should give a porosity between 30% and 50%, probably in the range of 35 to 40%, and a C:N lower than 30, probably between 20 to 25.

Nitrogen losses All treatments demonstrated a high N loss as the final C:N ranged between 52 and 133 (Fig. 6). The initial C:N varied from that corrected with urea to 30 because of poor mixing.

From day 11, N losses were obvious as all windrows smelled of ammonia indicating that the urea was being degraded into ammonia, which in turn, was being volatilized. Only treatments A-3 and W-1 demonstrated little ammonia smell during the experiment because, for A-3, a high moisture content helped dissolved the ammonia and created anaerobic conditions which slowed the degradation of urea and, for W-1, a low moisture content slowed the microbial activity degrading urea (Alexander 1977).

The final C:N of 52 to 133 indicated N losses ranging from 40 to 80%, respectively. The final C:N would have been lower if the bulking agent had offered more bio-degradable C. The final C:N (126 to 133) in the apple wastewater treatments indicated that the sawdust had a C biodegradability of 10 to 15% while that of the apple pulp treatments (52 to 117) indicated that the apple pulp had a C biodegradability of 30

Table V: Final physical properties of the compost

Property	Treatment					
	A-1	A-2	A-3	W-1	W-2	W-3
Wet density						
- bulk (kg/m^3)	0.58	0.74	0.84	0.46	0.48	0.49
	(0.04)[1]	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)
- particle (kg/m^3)	1.05	0.98	1.02	1.11	1.10	1.09
	(0.05)	(0.04)	(0.03)	(0.04)	(0.06)	(0.04)
Compost porosity (%)	50.6	30.8	20.2	66.4	64.9	65.7
Particle size distribution (%)						
> 4.76 mm	34.7	19.2	17.0	8.6	10.6	13.5
	(3.2)	(2.1)	(2.0)	(1.5)	(1.2)	(0.7)
2.36-4.76 mm	29.9	41.1	42.5	42.6	50.7	47.5
	(8.2)	(5.9)	(1.4)	(7.0)	(7.3)	(6.7)
0.84-2.36 mm	17.8	17.0	28.2	40.7	31.1	30.4
	(6.8)	(5.9)	(3.5)	(2.8)	(8.5)	(7.6)
0.25-0.84 mm	10.1	9.0	3.7	1.6	4.2	4.2
	(2.1)	(1.8)	(0.6)	(1.2)	(0.6)	(0.9)
0.075-0.25 mm	0.4	0.4	0.5	6.5	3.4	4.4
	(0.2)	(0.3)	(0.3)	(1.3)	(2.4)	(2.1)
< 0.075 mm	7.1	13.3	8.1	0	0	0
	(1.3)	(3.0)	(2.6)			

[1] The values in parenthesis are the standard deviations.

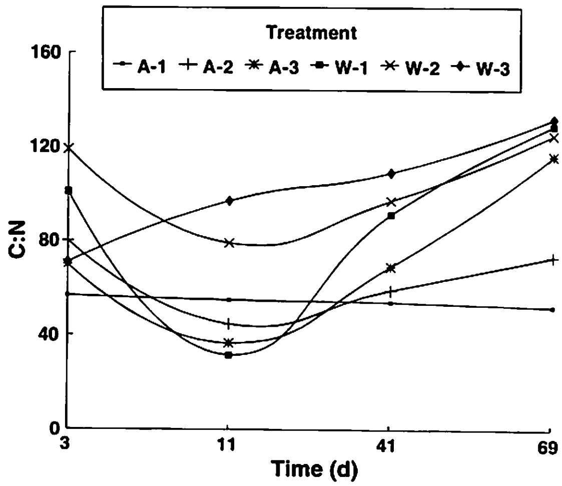

Fig. 6. C:N of the compost with time.

to 35%. The use of straw instead of sawdust would have fixed more N and produced a lower final C:N at the expense of less air exchange.

CONCLUSIONS

Small-scale composting operations use a tractor pulled compost turner to mix and aerate exterior windrows. The project demonstrated that incorporating wastewater to sawdust required the application of liquid two to three times while turning the windrows. The results of this study also indicate that compost turners will be most effective if:

1) the mixing operations are carried out in stages, especially when adding small quantities of amendments;
2) the O_2 levels of the windrows can be monitored with a probe and the frequency of turning can be increased to maintain an O_2 level above 5%.

The compost could have reached temperatures of 60 to 65°C with better aeration by:

1) using an initial compost porosity and dry matter of 35 to 40% and 28 to 34%, respectively;
2) an initial C:N of 20 to 25 to maximize microbial activity;
3) the compost had been turned once a day for the first two weeks and then once a week thereafter.

Dry matter and porosity were found to be just as important as overturning frequency in maintaining proper O_2 levels. Finally, sawdust as bulking agent was found to help maintain a good compost structure through the process but to lead to high N losses. A combination of straw and sawdust should be investigated.

ACKNOWLEDGEMENT

The authors acknowledge the financial contribution of Leahy Orchards Inc., Franklin, QC, the National Research Council of Canada, and the Natural Science and Engineering Research Council of Canada.

REFERENCES

Alexander, M. 1977. *Soil Microbiology*. New York, NY: John Wiley and Sons.

APHA. 1990. *Standard Analysis for Water and Wastewater*. Washington, DC: American Public Health Association, American Waster Works Association, and Water Pollution Control Federation.

Barrington, S.F. 1994. La gestion des engrais de ferme. Cours sur les programmes fertilisation intégrée. LaPocatière, QC: Institut Agricole de LaPocatière.

Diaz, L.F., G.M. Savage, L.L. Eggerth and C.G. Golueke. 1993. *Recycling Municipal Solid Waste*. Boca Raton, FL: Lewis Publishers.

Henis, E. 1986. Soil microorganisms, soil organic matter and soil fertility. In *The Role of Organic Matter in Modern Agriculture*, eds. Y. Chen and Y. Avnimelch. Boston, MA: Martinus Nijhoff Publishers.

Jiménez, E.I. and V.P. Garcia. 1992. Relationship between organic carbon and total organic matter in municipal solid wastes and city refuse compost. *Bioresource Technology* 41:265-272.

Larson, F.D. 1978. Mixing fundamentals. In *International Feed Milling Production and Grain Processing Seminar*. Winnipeg, Manitoba: Underwood McLellan Ltd.

Lau, A.K., K.V. Lo, P.H. Liau and J.C. Yu. 1992. Aeration experiments for swine manure composting. *Bioresource Technology* 41:145-152.

Lo, K.V., A.K. Lau and P.H. Liao. 1993. Composting of separated solid swine manures. *Journal of Agricultural Engineering Research* 54:307-317.

Mathur,S.P., N.K. Patni and M.P. Lévesque. 1990. Static pile, passive aeration composting of manure slurries using peat as a bulking agent. *Biological Wastes* 34:323-333.

Martin A.M., J. Evans, D. Porter and T.R. Patel. 1993. Comparative effects of peat and sawdust employed as bulking agents in composting. *Bioresource Technology* 44:65-69.

Midwest Plan Service. 1985. Composting Organic Waste. Ames, IA: Iowa University Press.

Mustin, M. 1987. *Le compostage:gestion de la matière organique*. Paris, France: Les Editions François Dubusc.

Parent, B.C. 1983. Composting technical and economical aspects. In *Disinfection of Sewage Sludge: Technical, Economical and Microbial Aspects*,139-149. Brussels, Belgium: Elsevier Scientific Publishers.

Parent, L.E. and J. Caron. 1993. Physical properties of organic soils. In *Soil Sampling and Methods of Analysis*, ed. M.R. Carter, 441-459. Boca Raton, FL: Lewis Publishers Inc.

Rodrigues, A.M., L.J. Ferreira, A.L. Fernando, P. Urbano and J.S. Oliveira. 1995. Co-composting of sweet sorghum biomass with different nitrogen sources. *Bioresource Technology* 54:21-27.

Russell, W.E. 1973. *Soil Conditions and Plant growth.* London, England: Longmans, Green and Co. Ltd.

Weeden, J.K. and J.G. Norrish. 1981. Stationary blending/grinding - A field evaluation. CSAE Paper No. 81-101. Saskatoon, SK: CSAE.

Zhan, W., L. Fernandes and N. Patni.1992. Composting of poultry manure slurries. CSAE Paper No. 92-515. Saskatoon, SK: CSAE.