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Composting of pulp and paper mill fly ash with wastewater treatment sludge

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Abstract

Wastewater treatment sludge and power boiler fly ash were combined and composted in mixed and static windrows 50 m long, 4 m high and 6 m wide. Moisture content was maintained above 50%. The final compost had a pH of 8.5, contained high concentrations of specific nutrients, and an average C:N ratio of 43:1. All metal, PCB, chlorophenol and PAH concentrations were below levels stipulated by local regulations. Over the first 8 weeks of the composting period dioxin concentration decreased by 45% to 41 pg/g TEQ. Leachate tests indicated minimal (<0.1 mg/l Cu and Pb; <50 mg/l Na, P, and SO_4^{-2}) leaching of contaminants from the composted material. Application of compost (8 cubic yards/acre) at a sod farm improved soil characteristics as measured by a number of parameters. The dioxin concentration in the final soil/compost mixture was 3 pg/g TEQ, allowing the soil/compost mixture to be classified as agricultural soil. It was concluded that composting produced an acceptable soil conditioner attractive for large volume users of inexpensive soil material (sod farms, golf courses, land reclamation sites).

Keywords: Pulp mill sludge; Fly ash; Compost; Dioxin

1. Introduction

The pulp and paper industry faces a growing solid waste disposal problem as environmental regulations become increasingly stringent and landfill space grows more scarce. These wastes include sludges from high rate biological wastewater treatment systems and ashes generated from onsite power boilers. The US and Canadian pulp and paper industries produce an estimated 12.2 and 1.6 million t/yr of combined primary and secondary sludge, respectively (Reid, 1998; Anon, 1992; Dowe, 1993; Linderoth, 1989). Dewatering followed by incineration or landfilling remain the preferred options for disposal. An estimated 3.4 million t/y of ashes are also produced. Nation-wide, greater than 80% of boiler ashes are disposed of in landfills or lagoons (Vance, 1996). In 1990, disposal by landfilling was estimated to cost US$100/t exclusive of tipping fees (McCubbin et al., 1992) and the United States Environmental Protection Agency (USEPA) has estimated that over 5000 of the 6500 landfill sites in the USA will close in the next 20 years (Pickell and Wunderlich, 1995). These environmental concerns and economic realities provide an incentive to develop new solid waste management technologies. Most attractive are those that have the potential to produce a saleable product.

Composting has the potential for generating a product from mill solid wastes that can be used as a soil amendment. Composting is the solid-phase decomposition of organic material by microorganisms under controlled conditions. The microorganisms feed on organic matter producing heat, carbon dioxide, and water vapour. Composting of mill solid wastes reduces mass and odour, degrades toxic compounds inhibitory to plant growth, decreases nitrogen immobilization, degrades chlorinated organic compounds and produces a marketable material suitable for horticultural and agricultural uses (Campbell et al., 1997; Campbell et al., 1995; Campbell et al., 1991).

Several past studies have demonstrated the feasibility and the advantages of composting pulp and paper mill sludge (Campbell et al., 1997; Campbell et al., 1995; Campbell et al., 1991; Julyan, 1995; Chase, 1991;

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Linderoth, 1989; Valente et al., 1987; Carter, 1983; Wysong, 1976). These studies have helped to establish information about the composting process, determine chemical and physical characteristics of the compost, and assess the suitability of compost for subsequent use as a plant growth medium. Other studies have investigated the use of ashes as a soil amendment (Carpenter and Beecher, 1997; Krejsl and Scanlon, 1996; Someshwar, 1996; Vance, 1996; Williams et al., 1996; Etiegni et al., 1991; Unger and Fernandez, 1989). Ashes applied to land have resulted in increased growth and yield of agricultural crops, increased pH, and increased potassium and phosphorus availability. The long term effects of land application of sludge compost and ash have not been investigated. Nor have studies focused on the combined composting of pulp and paper mill sludges with the ashes produced at a coastal mill site.

In this paper we investigate the feasibility of composting wastewater treatment sludge with power boiler fly ash from a coastal pulp and paper mill. The suitability of the composted material for use as a soil amendment was tested by application at a local sod farm.

2. Methods

2.1. Composting process

The study was conducted on-site at the Elk Falls Pulp and Paper mill in Campbell River, BC. The mill uses a spruce/pine/fir/hemlock furnish to produce 1400 t/d newsprint, 600 t/d market pulp and 250 t/d container board. The power boiler at the mill has an inclined water cooled travelling grate and uses hog fuel with oil and natural gas as auxillary fuels. Mill effluent is subjected to primary clarification followed by biological treatment in a Unox® pure oxygen activated sludge process. Approximately 0.5 ppm of antifoamer is used in the biobasin. Primary and secondary sludges (70% primary: 30% secondary) are combined, conditioned with 7–8 kg/t polymer and dewatered to approximately 20%–25% solids.

For this study combined primary and secondary sludge and power boiler fly ash from the mill were mixed to yield a 50:50 (v/v) mixture of sludge and ash. Two windrow were constructed, each approximately 50 m long, 4 m high and 6 m wide at the base. One pile was left to compost statically, while the other was mixed with a front-end loader twice per week for the first 3 weeks and once per week for another 7 weeks. Both piles were monitored for another 24 weeks, for a total study period of 34 weeks. The compost was produced on an old landfill site with a functional leachate collection system to ensure that all leachate produced was treated at the mill's wastewater treatment plant. This site was wind exposed, requiring spraying of water on the compost piles during the summer months for dust control and to maintain optimal moisture content (50%) (Gouin et al., 1992).

The compost piles were divided into two sections for sampling. Six points were randomly selected in each subsection to provide twelve sample points per pile. Samples were taken weekly from depths ranging from 60 cm to 2 m. The twelve grab samples were mixed to form a single composite sample from each pile for analysis. Temperatures reported are averages of measurements taken three days per week at 18 different locations along each windrow at various depths.

2.2. Leachate production

The leachate collection system at the mill site collected leachate from the entire landfill, and therefore did not accurately represent leachate from the compost. Therefore, samples from the full-scale compost site were transported to the laboratory, and leachate was produced using standardized methodology (BCMOE, 1988a). The following three adaptations were made to the test method: (1) 1000 ml and 500 ml bottles and jars were used instead of the recommended 1250 ml size due to equipment size limitations (volumes and weights of sample and reagents used throughout the procedure were adjusted accordingly); (2) The separation procedure was deemed unnecessary as the sample was a dry solid (i.e. not a slurry); (3) The leachate was filtered without the need for centrifuging. Leachate samples were preserved as specified by standard methods and stored at 4°C prior to analysis (Eaton et al., 1995).

2.3. Land application trial

Soils in the vicinity of the mill are known to need both lime and other fertilizer applications. In order to assess the impact of application of the composted material on soil properties, approximately 700 yards of the final composted material was supplied to a local sod farm. A sod farm was chosen since production of sod results in a loss of soil during every harvest. In addition to the normal spreading of 15 m^3/ha of fish compost produced on the farm, 15 m^3/ha (8 yards/acre) of the composted material was applied using a manure spreader on test plots. Composite soil samples were collected from control and application sites prior to seeding and following the growing season.

2.4. Compost, leachate and soil analyses

Compost samples were analyzed for polychlorinated dibenzodioxins and dibenzofurans, polyaromatic hydrocarbons (PAH), chlorophenols, and organochlorines (PCB) by extraction/gas chromatography (AXYS Analytical Services, Sidney, BC). The toxicity equivalent quotient (TEQ) was calculated by multiplying the concentration of each dioxin or furan present by its international toxicity equivalency factor (I-TEF) and summing the products (BCMOE, 1988b). Econotech Services Ltd. (New Westminster, BC) analyzed the compost samples for total metals, salinity (EC), chloride, fluoride, total organic carbon (TOC), total nitrogen, and the carbon:nitrogen (C:N) ratio. Pacific Soil Analyses Ltd. (Vancouver, BC) performed assays for basic agronomic properties including available nutrients (P, K, Ca, Mg, Mn, B, Na, Al, N, S), C:N ratio, and organic matter on both soil and compost samples. Moisture content and pH of the compost piles were evaluated weekly in the laboratory facilities at Elk Falls Pulp and Paper. All tests were performed according to standard methods (SM) (Eaton et al., 1995).

Leachate from the compost was assayed for copper, lead, sodium, nitrate, sulphate, phosphate, phenanthrene, naphthalene, and pyrene. These analytes were selected based on previous work (Julyan, 1995). Dissolved copper, zinc and sodium were analyzed using flame atomic absorption spectrometry using SM 3111 (Eaton et al., 1995). A Video 2e atomic absorption spectrophotometer with an air-acetylene flame length of 10 cm and bandpath of 1 nm was used. Measurements were made at wavelengths of 324.7, 213.9 and 589.0 nm for Cu, Zn and Na, respectively. Lead was analyzed by atomic absorption spectrophotometry at 217.0 nm using a Perkin Elmer Zeeman atomic absorption spectrophotometer model 4100ZL. The leachate was characterized for nutritional value (eutrophication potential) by analyzing for nitrate (NO_3^{-1}), total phosphorus, and sulphate (SO_4^{-2}). These anions were measured using flow injection analysis (FIA) following the QuikChem Method No. 10-115-01-1Z, 10-107-04-1-E and 10-116-10-1C for NO_3^{-1}, total-P and SO_4^{-2}, respectively (QuikChem, 1990). Naphthalene, pyrene and phenanthrene were analyzed by gas chromatography/mass spectrometry (GC/MS) according to SM 6210 (Eaton et al., 1995). Analyses were performed using a HP 8690 GC with a mass selective HP 5973 detector. The extraction of these PAHs from the leachate was completed using C18 solid phase extraction cartridges (Tekmar-Dohrmann, 1996). Soluble salts content of the leachate was also measured to assess the potential for salt accumulation in soils due to compost addition. The soluble salt content was measured using the electrical conductivity (EC) technique according to SM 2520 (Eaton et al., 1995).

3. Results and discussion

3.1. Physical characteristics of the raw materials

Both sludge and fly ash have properties which, when combined with each other, serve to promote active composting (Table 1). The combined wastewater treatment sludge has three properties essential to a soil amendment, including: neutral pH, high concentration of total nitrogen and an acceptable C:N ratio of 16 (target = 25) (Hoitink et al., 1991). Moisture content of the sludge (77%) was well above the optimal level.

The addition of the fly ash to a compost mixture has several benefits. The addition of fly ash helps to achieve a targeted solids content (50%) in the compost mixture (Hoitink et al., 1991; Golueke and Diaz, 1990). Ash prevents clumping, which improves porosity and airflow through the compost pile. The fly ash also adds many macro and micronutrients to the compost mixture. Negative aspects of fly ash addition include high EC, dioxin and C:N ratio, all of which necessitate monitoring throughout the composting process, and in subsequent applications.

3.2. Physical changes during composting

During the first 3 days of the composting process, the temperature increased to 65°C (Fig. 1). Composting above 55°C for 15 days is necessary to ensure weed and pathogen destruction (BCMOE, 1993). Temperatures between 45 and 60°C promote the growth of a wide range of organisms necessary for biological degradation (Julyan, 1995). In the present study, pile temperatures remained in this ideal range between weeks 1–10 and

Table 1
Chemical characteristics of sludge and fly ash

		Raw materials		Raw compost
		Sludge	Ash	1:1 S:A
MC	%	77.1	41.0	53.4
pH		6.7	9.0	8.9
Soluble salts (EC)	dS/m	39.2	25.5	16.0
Ash	%	6.5	68.0	68.9
C:N		16.1	167.0	70.1
Carbon	%	47.8	35.1	35.1
Nitrogen	%	2.9	0.2	0.5

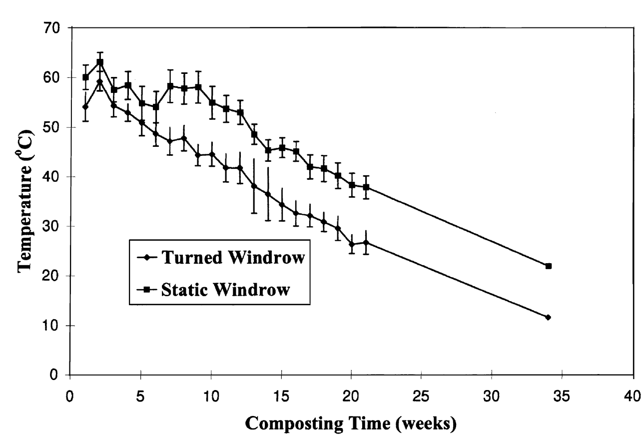

Fig. 1. Temperature of the compost piles over the period of the study.

1–15 for the turned and static windrows, respectively. The temperature profile in the two piles was similar; however, the static windrow maintained a temperature 11 ± 1.2°C above the turned windrow during the process.

Moisture content should be maintained above 50% to ensure optimal microbial activity (Julyan, 1995). Moisture content in both piles was maintained at 51 ± 2.4% for the first 10 weeks of the composting process for both piles (Fig. 2). Heavy rainfall during the latter half of the composting period increased the moisture content to 63 ± 1.5% in the final product. The increase in moisture content was a concern because it would significantly increase the cost of transport of the material. For full-scale processes, perforated plastic sheeting could be used to prevent excessive moisture uptake.

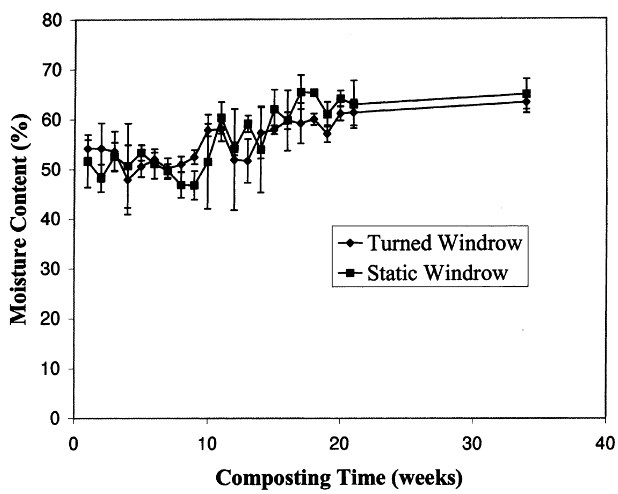

Fig. 2. Moisture content of the compost piles over the period of study.

The pH of the compost mixture was approximately 8.9 ± 0.2 and decreased slowly throughout the composting process (Fig. 3). The final compost pH was approximately 8.5 ± 0.1 for both piles, slightly higher than the recommended value of 5–8 for municipal compost products (BCMOE, 1993). This concern is mitigated by the fact that the compost could be used as a liming agent on acidic soils commonly found in the region surrounding the mill (Julyan, 1995).

The initial C:N ratio of 70:1 decreased over the composting period to 46:1 and 40:1 in the turned and static windrows, respectively (Fig. 4). That the initial C:N ratio was higher than the ideal value of 25:1 (Golueke and Diaz, 1990) likely extended the time required to stabilize the sludge/ash mixture. The addition of a nitrogen containing waste such as manure would likely reduce the composting time required and make the final product a more effective soil amendment.

3.3. Chemical characteristics of the compost products

Digestion of organic matter during the composting process caused an increase in the concentration of the metals in the final compost products (Table 2). However, total metal concentrations in all compost samples were below agricultural land limits (BCMOE, 1996). It should be noted that local regulations specify the criteria for a range of parameters in final soil mixtures once compost and other amendments have been applied rather than the concentrations in the compost itself (BCMOE, 1996).

Soluble salts in the compost were also monitored using EC due to the concern of high salinity found in ash from coastal mills. The EC of the initial mixture was

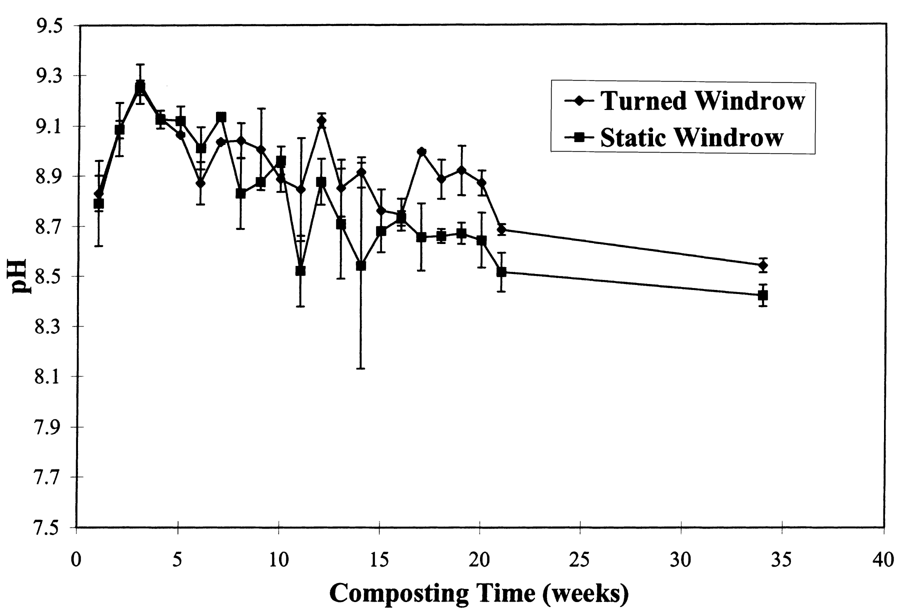

Fig. 3. pH of the compost piles over the period of study.

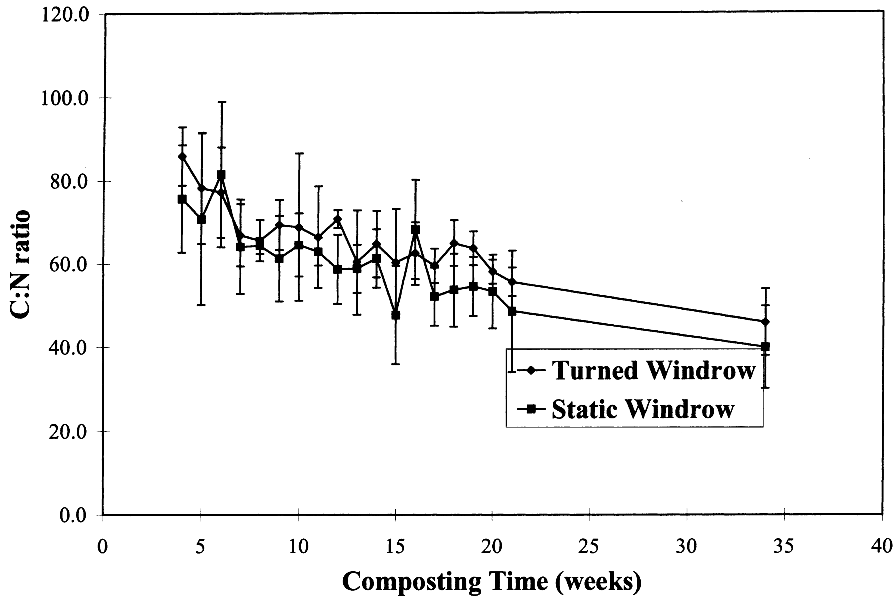

Fig. 4. C:N of the compost piles over the period of study.

16 dS/m but decreased over time to approximately 1.4 ± 0.08 dS/m in both the turned and static windrows (Fig. 5). The decrease in electrical conductivity was likely a result of leaching of salts due to the excessive rainfall, especially during the latter stages of the composting process. Typical soils in the northwest contain an EC of 1 dS/m (Brady, 1990). Levels as high as 6.0 dS/m in the compost would be acceptable because the compost is only an amendment (Brady, 1990); however, the EC of the receiving soil should be measured to ensure salt accumulation does not occur.

In both composting processes, the concentration of dioxin decreased from 74.9 ± 4.9 pg/g TEQ to 41.3 ± 3.5 pg/g TEQ during the first 8 weeks of the process (Fig. 6). Further decreases in the dioxin concentration were not noted for the rest of the composting period or during the curing stages. Under USEPA regulations, waste material containing dioxin concentrations less than 50 pg/g TEQ can be applied to land, however a monitoring program is necessary if the material is applied to agricultural land. To meet the BC criteria for agricultural land, the addition of dioxin-

Table 2
Total elemental metal concentrations in raw mixture and final composted product

		Regulation[a]	Raw compost	Final compost	
			1:1 S:A	Turned windrow	Static windrow
Antimony	mg/kg	20	<2	<2	<2
Arsenic	mg/kg	13	<2	<2	3.5
Barium	mg/kg	750	144	190	197
Beryllium	mg/kg	4	<0.2	0.2	0.2
Cadmium	mg/kg	2.6	0.5	0.4	0.06
Chromium	mg/kg	210	16.3	32.5	28.6
Cobalt	mg/kg	26	4.7	6.3	5.6
Copper	mg/kg	100	31.5	35.8	34.8
Fluoride	mg/kg	200	130	NM	NM
Lead	mg/kg	150	3.0	2.0	5.5
Mercury	mg/kg	0.8	0.23	0.09	0.07
Molybdenum	mg/kg	5	3	2	2
Nickel	mg/kg	50	14.9	18.1	17.7
Selenium	mg/kg	2	<2	<2	<2
Silver	mg/kg	20	<0.5	<0.5	<0.5
Tin	mg/kg	5	<1	<2	<2
Vanadium	mg/kg	200	30	44	41
Zinc	mg/kg	315	61.4	56.7	64.5

[a] Strictest regulations – BC Reg 375/96, BC Reg 334/93.
NM – Not measured.

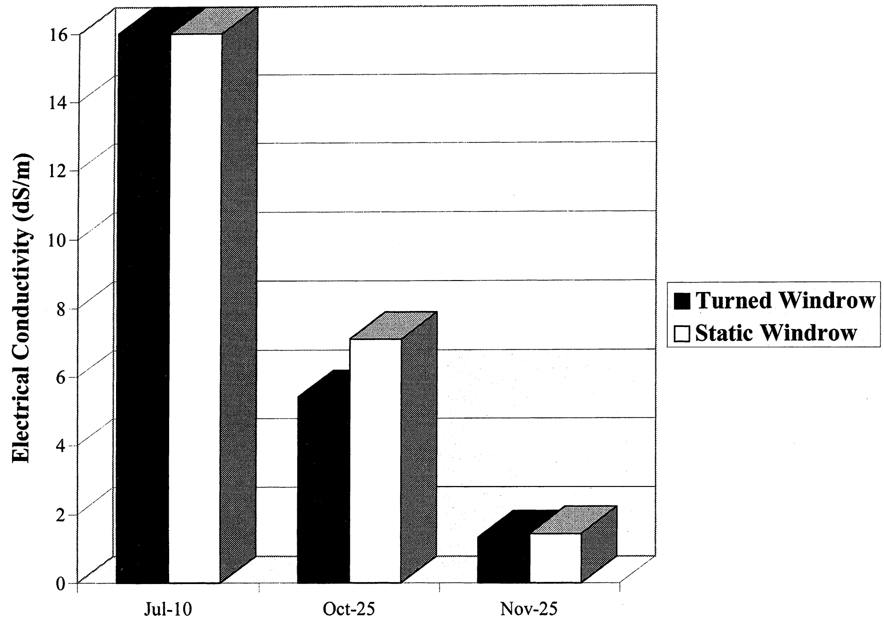

Fig. 5. Electrical conductivity of the compost at three different times during the composting period.

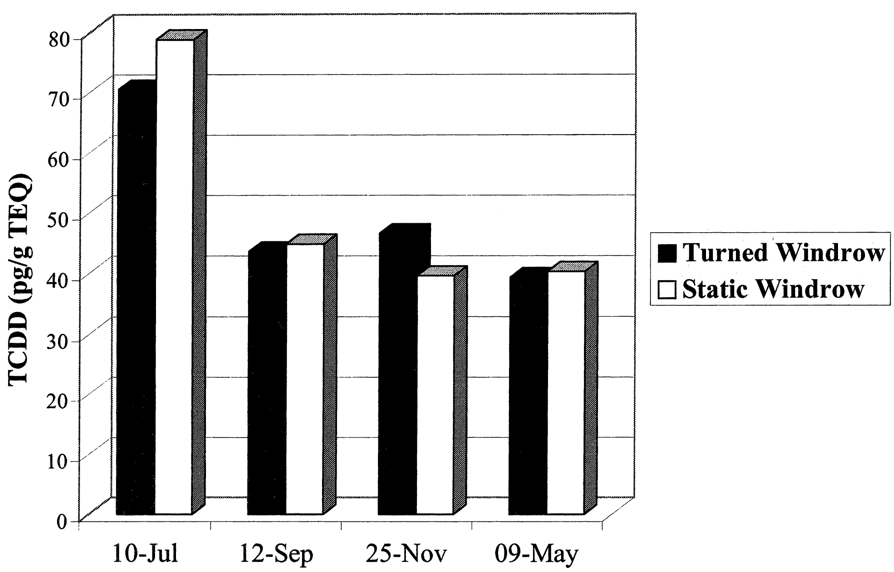

Fig. 6. Dioxin concentration of compost at three different times during the composting period.

containing material must be carefully monitored so that the dioxin concentration in the final soil/compost mixture is kept below 10 pg/g TEQ (BCMOE, 1996).

The raw materials and initial compost mixture were evaluated for other regulated parameters (chlorophenols, PCB, PAH) (BCMOE, 1993; BCMOE, 1996). Only 2 PAHs (naphthalene and phenanthrene) exceeded the criteria for an agricultural soil (BCMOE, 1996). As the compost is only used as an amendment, the concentrations of these compounds in a soil/compost mixture are expected to be undetectable. Based on these results, the compost is not expected to pose a significant environmental risk.

Most nutrients in the composted material were above the target values for a healthy soil supporting plant growth (Table 3). Like all fertilizers, the compost could serve to amend the levels of certain nutrients in nutrient deficient soils. It would be necessary to evaluate soils prior to compost application to determine proper application rates and whether other amendments were necessary.

3.4. Characteristics of leachate from the compost

The results of the leachate analysis are summarized in Table 4. Local regulations do not stipulate allowable

Table 3
Available nutrients in composted product

		Soil targets	Final compost	
			Turned windrow	Static windrow
Phosphorus	ppm	150	119	100
Potassium	ppm	250	970	870
Calcium	ppm	2000	3000	3500
Magnesium	ppm	250	550	540
Copper	ppm	10	0.6	0.6
Zinc	ppm	25	16.2	10.6
Iron	ppm	150	3	3
Manganese	ppm	50	315	205
Boron	ppm	1	4.2	4.4
Sulfate–sulfur	ppm	25	12.6	10.7
Sodium	ppm	50	1300	810
Aluminum	ppm	10	150	70
Total nitrogen	%	0.55	0.63	0.55
Organic matter	%	10	57.8	63.1
Total sulfur	%	0.05	0.32	0.14

Table 4
Characteristics of leachate from compost

Analyte	Leachate (mg/l)	BC Reg 375/96 aquatic (mg/l)	Drinking (mg/l)
Metals (mg/l)			
Cu	0.07 ± 0.02	0.002	1
Pb	0.004 ± 0.0015	0.004	0.01
Na	48 ± 3	NR	200
Anions (mg/l)			
NO_3^{-1}	3.0 ± 1.5	400	10
SO_4^{-2}	20.0 ± 2.5	1000	500
Total P	4.0 ± 1.0	NR	NR
PAH's (mg/l)			
phenanthrene	ND	0.003	NR
naphthalene	ND	0.01	NR
pyrene	ND	0.002	NR
EC[a] (dS/m)	5.0 ± 0.25	NR	NR

[a]EC less than 4 dS/m is the level found in most soils. EC range 2–5 dS/m for irrigation waters.
NR: None Recommended.
ND: Non Detectable.

levels of contaminants in leachate but rather specify allowable levels of contaminants in a receiving body of water once all discharges (including leachate) have been received (BCMOE, 1996). Based on the assayed values, the undiluted leachate should pose no environmental concern and restrictions on the spreading of compost should not be limited by concerns surrounding leachate production or entry into receiving bodies of water.

3.5. Characteristics of soil from land application trials

The soil prior to application of the compost was deficient in several minerals, and required lime application to bring it into the optimal pH range for sod growth (Table 5). After the application of the compost at 15 m^3/ha, the soils were improved; however, the target values for a number of soil components were still not met. Although careful integration of the compost with fertilizer and lime applications would be required, the compost was a useful soil amendment. It was easily spread, contained essential nutrients, and would provide an inexpensive source of soil material.

Table 5
Elemental analysis of sod farm soil samples

		Soil targets	Soil only (0 yard/acre)	Soil/Compost (8 yard/acre)
Phosphorus	ppm	150	25	36
Potassium	ppm	250	75	175
Calcium	ppm	2000	2500	2750
Magnesium	ppm	250	230	195
Copper	ppm	10	1.5	1.7
Zinc	ppm	25	2.9	5.3
Iron	ppm	150	24	23
Manganese	ppm	50	59	66
pH		7	5.8	6.6
C:N		25	14	17
EC	dS/m	1	0.37	0.48
Total nitrogen	%	0.5	0.63	0.55
Organic matter	%	10	6.9	7.9

Dioxin concentration in the final soil/compost mixture was 3.0 pg/g TEQ and the concentration stayed constant over the 6 months following the application of the compost. Since the limit for dioxin in the soil/compost mixture is 10 pg/g TEQ, these soils would qualify as agricultural soil (BCMOE, 1996). However, repeated applications of the compost would have to be carefully monitored to ensure that dioxin did not accumulate beyond permitted levels in the soil.

4. Conclusions

Both turned and static windrow compost piles produced an acceptable product; however, the compost which was mixed resulted in a more homogeneous product. The C:N ratio, pH, and EC of the final product were 40–46:1, 8.5 and 1.4 dS/m, respectively. The dioxin concentration decreased from an initial value of 74.9 ± 4.9 to 41.4 ± 3.5 pg/g TEQ during the composting study.

A compost product from a 1:1 volume ratio of sludge and fly was easily spread, contained many essential nutrients for plant growth as well as liming ability. Compost applications at a rate of 15 m^3/ha resulted in a soil/compost mixture with an improved nutrient profile and a dioxin concentration of 3.0 pg/g TEQ, enabling it to qualify as agricultural soil.

Production costs were estimated to be US$20/yard for both products. It is expected that using a static process and an established monitoring program could reduce this cost to below US$10/yard. This cost would make the product attractive for customers who require a large volume of inexpensive soil material (sod farms, golf courses, and land reclamation sites).

In many parts of North America, pulp mill sludges are being used as beneficial soil amendments. During the two year period ending December 1998, the BC Ministry of Environment has sponsored a multistakeholders committee aimed at defining guidelines or regulations governing the use of sludges from BC pulp mills as soil amendments. The outcome of this process remains uncertain, as does how solids handling requirements will relate to the zero AOX regulation due to be implemented in British Columbia in 2002.

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