ELSEVIER

Bioresource Technology 75 (2000) 139–148

BIORESOURCE TECHNOLOGY

Physical changes during active and passive composting of beef feedlot manure in winter and summer

Francis J. Larney [a,*], Andrew F. Olson [a], Alfredo A. Carcamo [b], Chi Chang [a]

[a] *Agriculture and Agri-Food Canada, Research Centre, P.O. Box 3000, Lethbridge, Alberta, Canada T1J 4B1*
[b] *Olds College, 4500 50th St., Olds, Alberta, Canada T4H 1R6*

Received 12 July 1999; received in revised form 31 January 2000; accepted 22 February 2000

Abstract

There is increased interest in composting as a means of handling the large amounts of manure generated by southern Alberta feedlots. However few studies have been conducted on the changes in physical properties of manure as it becomes compost and the impact of these changes on haulage requirements. Additionally, there is a perceived constraint to overwinter composting in southern Alberta, due to extremely low air temperatures. This study examined active (mechanically turned) and passive (passive aeration system) windrow composting during winter and summer. Dry matter mass reductions were in the range of 21–30%. Bulk density increased 3–4 fold with both types of composting. Volume loss during the thermophilic phase was of the order: summer-active (72%) > summer-passive (55%) > winter-active (51%) > winter-passive (34%) with further smaller losses during the curing phase. Water mass loss was as high as 83% for active composting during summer. Active composting generally led to larger changes in physical properties of manure than passive composting. Winter composting was feasible despite ambient air temperatures < −30°C. The results demonstrate the ability of composting to substantially reduce the mass, volume and water content of manure that needs to be transported for land application. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Composting; Passive aeration; Windrow turning; Cattle manure; Mass; Bulk density; Volume; Water content

1. Introduction

Livestock production in Alberta has expanded dramatically in recent years. Total cattle on Alberta farms increased by 51% from 3.75 million in 1986 to 5.67 million in 1996 (Alberta Agriculture, Food and Rural Development, 1998). This increase has been accompanied by concerns about the effect of excessive manure application rates on soil (Chang et al., 1991), water (Chang and Entz, 1996) and air (Chang et al., 1998) quality.

Recently, composting has received increased attention as an alternative manure management practice for beef cattle feedlots in southern Alberta (Freeze et al., 1999; Larney et al., 1999). Through this biological process, livestock manure is decomposed and stabilized, most pathogens are destroyed and malodours during land application are eliminated (Eghball and Power, 1994; DeLuca and DeLuca, 1997; Rynk, 1992). Parr et al. (1989) recommended composting as a process technology to enhance the usefulness and acceptability of organic by-products as fertilizers and soil conditioners in arid and semiarid areas. Composted cattle manure was as effective as raw manure in restoring wheat yield (Larney and Janzen, 1996) and aggregate stability (Sun et al., 1995) to an artificially eroded soil in southern Alberta. Also, composted manure was superior to fresh manure and alfalfa hay in reclaiming decommissioned oil well sites in Alberta (Akinremi et al., 1999).

Most research on manure composting has concentrated on chemical transformations, particularly of nitrogen (N), that occur as raw manure becomes compost. Eghball et al. (1997) reported N losses of 19–42% during outdoor composting of beef feedlot manure in Nebraska, while Henry and White (1993) found N losses of 34–37% for in-vessel composting of poultry manure.

Relatively few studies have focussed on physical transformations of manure as it becomes compost, e.g. changes to mass, bulk density, volume and water content. Changes to these properties are important from a transportation or haulage viewpoint. It is a haulage limitation that gives rise to the so-called ‘bull's-eye

---

[*] Corresponding author. Tel.: +1-403-317-2216; fax: +1-403-317-2187.
E-mail address: larney@em.agr.ca (F.J. Larney).

PII: S0960-8524(00)00040-7

effect' of raw manure application rates, whereby rates are unsustainably high adjacent to source and diminish with distance from feedlots. This is related to the economics of raw manure haulage. In a southern Alberta study, Freeze and Sommerfeldt (1985) reported that the breakeven hauling distance for raw manure was 15 km. Beyond that distance, spring wheat yield benefits would not offset the cost of loading, hauling and spreading the manure.

Several beef feedlots in southern Alberta are composting some or all of their manure, and composted manure is now commercially available from farm supply centres in the area. Feedlot operators are interested in accurate values for changes to mass, bulk density, volume and water content during composting and the impact of these changes on reducing haulage requirements.

In order to be an effective management practice, composting must be a year-round option for feedlots. There is a perceived constraint to overwinter composting in southern Alberta, where ambient air temperatures may drop to −40°C for short periods. However, Lynch and Cherry (1996) demonstrated that winter composting of livestock manure was feasible in southern Idaho, USA, during ambient air temperatures of −27 to +15°C.

Most feedlots in Alberta use active windrow composting whereby air is introduced to the manure by mechanical turning and mixing. There is no information on the merits of passive aeration static windrow composting in southern Alberta. This system dispenses with the requirement for a windrow turner as air is introduced via open-ended perforated pipes placed beneath the windrow (Mathur, 1991; Rynk et al., 1992; Sartaj et al., 1997).

This study examines the effect of two composting methods (active and passive aeration) on physical changes of beef feedlot manure during winter and summer in southern Alberta.

2. Methods

2.1. Windrow establishment

The study was carried out at the Agriculture and Agri-Food Canada Research Centre, Lethbridge, Alberta (49°42′ N, 112°50′ W). Cattle manure was removed from feedlot pens (bedded with barley straw) on 22–24 October 1996 for the winter study and on 20 May 1997 for the summer study. Initial carbon/nitrogen (C/N) ratios of the manure were 15.3 for the winter study and 19.9 for the summer study. The manure was loaded into a manure spreader and passed through its mechanical beaters so that it was mixed and chopped as it fell into windrows. Three active and three passive windrows were established for each study in a completely randomized design. The windrows varied in length from 13 to 15.2 m and were about 1.6 m high and 3.6 m wide at the base.

Table 1
Turning dates for active windrows and curing phase of active and passive windrows during winter and summer composting, 1996–1997

Operation	Winter, 1996–1997	Summer, 1997
Windrow setup	22–24 October	20 May
Turning #1	6 November	3 June
Turning #2	18 November	10 June
Turning #3	27 November	18 June
Turning #4	16 December	9 July
Turning #5	8 January	29 July
Turning #6	30 January	12 August
Turning #7	4 March	27 August
Curing	4 March–19 August	27 August–24 November

The terms winter and summer composting refer to the seasons when the thermophilic ($>45°C$) composting phase occurred. The active compost windrows were turned during the thermophilic phase with a tractor-pull *EarthSaver*™ windrow turner (Fuel Harvesters Equipment, Midland, TX) [1]. Turning frequency varied from 7 d to 23 d (Table 1) and was dictated by temperature of the composting windrows. The thermophilic lasted 132 d for the winter study (23 October 1996–4 March 1997) and 98 d for the summer study (20 May–26 August 1997).

The passive aeration system has been described by Mathur (1991) and Fernandes and Sartaj (1997). Open-ended perforated 10 cm diameter steel pipes were placed 45 cm apart on a 15 cm deep bed of finished compost. There were two rows of perforations (12.5 mm diameter) on each pipe (each at 45° from the top) with individual perforations spaced 30 cm apart. The raw manure was dropped onto the pipes from the manure spreader ensuring that the pipe-ends were not blocked. Air entered passively through the pipe-ends and passed through the perforations into the windrow. The passive windrows were covered with a 15 cm thick layer of finished compost which acted as a biofilter to reduce ammonia losses (Rynk, 1992).

The mesophilic (<40°C) or curing phase (Table 1), was actually during the spring/summer (4 March–19 August 1997, 168 d) for the winter study and during the fall (26 August–24 November, 90 d) for the summer study. During the curing phase, both active and passive windrows were left unturned.

Average (active and passive) C/N ratios after the thermophilic phase were 12.1 for the winter study and 12.3 for the summer study. Temperatures during the

---

[1] Trade names are provided for the benefit of the reader and do not imply endorsement or preferential treatment of the product by Agriculture and Agri-Food Canada.

winter study reached 65°C for both the active and passive windrows (Carcamo et al., 1997). During the summer study, temperatures peaked at 71°C for the active windrows and 70°C for the passive windrows (Larney et al., 1999).

2.2. Total, water and dry matter mass

Each load of raw manure was weighed to estimate the total mass required to build each windrow. Average total mass was 28.3 Mg for the winter-active, 32.1 Mg for the winter-passive, 22.2 Mg for the summer-active and 32.9 Mg for the summer-passive windrows. The mass of the passive treatments was higher due to the addition of the compost base bed and covering layer. Water content samples (10 per windrow) were taken at windrow establishment to estimate water mass and hence dry matter (DM) mass (total mass less water mass). For the passive windrows, the total, water and DM mass of the finished compost material used for the pipe beds and windrow covers was also determined and added to those values for the raw manure required to build the windrows.

Total, water and DM masses were also determined for each windrow at the end of the thermophilic stage for the winter (4 March 1997) and summer (26 August 1997) studies, and at the end of the mesophilic or curing phase for the winter (19 August 1997) and summer studies (24 November 1997). On these dates, all six windrows (three active and three passive) from each study were loaded into a truck and weighed for total mass determination. Samples for water content (10 per windrow) were also taken to calculate water and DM mass.

2.3. Bulk density

Dry bulk density of the manure/compost was estimated as the mass of dry matter required to fill an aluminum pail with a volume of 0.064 m^3. The pail was filled with material composited from five locations along the windrow. For the active windrows, the material was collected from the face of the windrow, after it was cut open with a small front-end loader (Bobcat™). For the passive windrows, the material was collected by removing the mature compost blanket, and then digging into the windrow about 30–40 cm with a shovel to obtain a representative sample.

For the winter study, bulk density was measured on both the active and passive treatments at windrow establishment on 23 October 1996, on the 8 and 30 January, 25 February and 4 March 1997 turning dates, and after curing on 19 August 1997. For the summer study, bulk density was determined on both active and passive treatments at windrow setup, on the dates of the seven turning events, and after curing (Table 1).

2.4. Volume

Windrow volume was determined by two methods. Since mass and density data were available for each windrow at establishment, after the thermophilic phase and after curing for each study, volume was determined as

$$\text{mass}/\text{density}.$$

The second method for estimating volume was used on all dates (Table 1) except after curing for the winter (19 August 1997) and summer (24 November 1997) studies and was based on windrow length and circumference. It was assumed that each windrow was semi-circular in shape. Circumference (C) was estimated by straddling each windrow at three locations with a measuring tape (e.g. from ground level to ground level on opposite sides of the windrow). The radius (R) of this semi-circle was calculated as

$$R = C/\pi.$$

The area (K) of the semi-circle was calculated as

$$K = \pi R^2/2,$$

and the volume (V) of the windrow was determined as

$$V = LK,$$

where L was the windrow length. Fernandes et al. (1994) described windrow shape as trapezoidal in cross-section. However, we found that volumes calculated using a semi-circular shape best-approximated those calculated from mass and density measurements.

2.5. Water content

For both winter and summer studies, water content of the active and passive treatments was measured at windrow establishment, on each turning date and after curing (Table 1). Generally, sub-samples (~0.8 kg) of material collected for measurement of bulk density were used for water content determination. Sub-samples from five locations along the windrow were halved to give ten measurements per windrow. Samples were oven-dried at 60°C to a constant weight and water content was expressed on a wet weight basis (weight of water/wet weight of manure).

2.6. Statistical analyses

Statistical analyses on physical parameter data was conducted using the General Linear Models procedure (SAS Institute, 1989). Least significant differences (LSD, $P < 0.1$) were used to separate treatment means for the mass data. For the other data, LSD ($P < 0.05$) were used.

3. Results and discussion

3.1. Weather conditions

For the thermophilic phase of the winter study, precipitation was 33% above normal for December 1996, near normal for January 1997 and 53% of normal for February 1997 (Table 2). Temperatures during November–December 1996 were 5.0–6.4°C below normal (Table 2). During the curing phase of the winter study, precipitation was below normal for April and July 1997 and above normal for May–June 1997. Temperatures during the curing phase were close to normal (Table 2).

For the summer study, precipitation was wetter than normal for May–June 1997 but drier than normal for the July–November 1997 (Table 2). Conditions during the curing period (September–November) were especially dry, e.g. September precipitation was only 19% of the long-term normal.

Mean monthly temperatures were close to normal for May–July 1997 (Table 2). However, August and September were warmer-than-normal. During the later curing stages (October and November 1997) temperatures were close to the long-term normal (Table 2).

3.2. Total, water and dry matter mass

During the thermophilic phase of the winter study the active treatment showed significantly higher losses than the passive treatment for both total (32.1% vs. 19.3%) and DM (23.8% vs. 10.2%) mass while there was no difference in water mass loss between the two treatments (Table 3). During the curing phase, overall mass losses were much lower than during the thermophilic phase and the effect of composting treatment was non-significant (Table 3). During the entire composting period, total mass losses were significantly higher with active (39.5%) than with passive (28.3%) composting, while water mass losses were also higher with active (43.6%) than with passive (31.2%) composting (Table 3). Treatment effects on DM mass loss over the entire composting period were non-significant (Table 3).

Table 2
Summary of weather data for study period, 1996–1997

	Precipitation, mm (% of long-term normal)	Temperature, mean monthly (°C) (long-term normal, °C)
October, 1996	6.3 (28)	6.3 (7.0)
November, 1996	26.5 (142)	−7.1 (−0.7)
December, 1996	24.4 (133)	−10.8 (−5.8)
January 1997	16.7 (90)	−10.5 (−8.6)
February, 1997	9.2 (53)	0.0 (−6.2)
March, 1997	33.1 (142)	−0.7 (−1.6)
April, 1997	14.2 (46)	3.9 (5.5)
May, 1997	95.7 (176)	11.3 (10.8)
June, 1997	100.6 (137)	16.0 (14.9)
July, 1997	31.8 (75)	18.2 (18.0)
August, 1997	32.8 (78)	18.8 (17.1)
September, 1997	7.6 (19)	12.5 (12.1)
October, 1997	10.0 (45)	7.0 (7.0)
November, 1997	4.6 (25)	−0.9 (−0.7)

Table 3
Effect of composting method on total mass, water mass and dry matter mass losses of feedlot manure during the winter study 23 October 1996–19 August 1997[a]

Composting method	Total mass loss (%)	Water mass loss (%)	DM mass loss (%)
During thermophilic phase			
Active	32.1*a*	35.8*a*	23.8*a*
Passive	19.3*b*	23.4*a*	10.2*b*
During curing phase			
Active	11.0*a*	12.2*a*	8.7*a*
Passive	11.2*a*	9.6*a*	11.0*a*
During entire composting period			
Active	39.5*a*	43.6*a*	30.5*a*
Passive	28.3*b*	31.2*b*	20.6*a*

[a] *a* and *b*: means ($n = 3$) followed by the same letter are not significantly different from each other at the 10% level.

For the summer study, total mass losses were significantly higher with active (56.2%) than with passive (17.7%) composting during the thermophilic phase (Table 4). Similarly, water mass losses were significantly higher with active (75.3%) than with passive composting (20.1%). However, DM mass losses were not affected by treatment during the thermophilic phase (Table 4). In the curing phase, losses were again much lower than in the thermophilic phase, and there was no treatment effect on total or water mass losses (Table 4). For the entire composting period, total mass losses were significantly higher for the active treatment than the passive treatment (64.3% vs. 36.6%) while water mass losses (Table 4) behaved similarly (83.0% vs. 54.8%). Due to errors in estimating water contents at

Table 4
Effect of composting method on total mass, water mass and dry matter mass losses of feedlot manure during the summer study, 20 May–24 November 1997[a]

Composting method	Total mass loss (%)	Water mass loss (%)	DM mass loss (%)
During thermophilic phase			
Active	56.2*a*	75.3*a*	11.9*a*
Passive	17.7*b*	20.1*b*	13.4*a*
During curing phase			
Active	18.5*a*	31.0*a*	10.8
Passive	23.0*a*	41.7*a*	–
During entire composting period			
Active	64.3*a*	83.0*a*	21.5
Passive	36.6*b*	54.8*b*	–

[a] *a* and *b*: means ($n = 3$) followed by the same letter are not significantly different from each other at the 10% level.

the end of the thermophilic and curing phases, DM mass losses could not be calculated for the curing period or for the entire composting period for the passive treatment.

A comparison of active composting during the winter and summer studies is shown in Table 5. Total mass losses during the entire composting period were much higher in summer (64.3%) than in winter (39.5%). Water mass losses were also higher in summer (83%) than in winter (43.6%). However, DM mass losses were similar for both studies (21.5% in summer vs. 30.5% in winter). The summer DM mass loss compared favourably with the 15–20% losses reported from Nebraska by Eghball et al. (1997). Henry and White (1993) reported DM losses of 23–25% for composted broiler litter.

3.3. Bulk density

For the winter study, average dry bulk density values (Fig. 1(a)) of the active and passive treatments at windrow establishment were identical (0.14 Mg m^{-3}). There was no significant treatment effect on bulk density at any of the sampling times (Fig. 1(a)). By the end of the curing phase, bulk density had increased to 0.27 Mg m^{-3} for the active treatment and 0.24 Mg m^{-3} for the passive treatment (Fig. 1(a)).

For the summer study, initial dry bulk densities (Fig. 1(b)) were somewhat lower (0.1 Mg m^{-3}) than for the winter study, perhaps indicating the presence of larger amounts of straw bedding. At the end of the thermophilic phase, bulk density of the active treatment was significantly higher (0.36 Mg m^{-3}) than that of the passive treatment (0.18 Mg m^{-3}). At the end of the curing phase, the active treatment had a bulk density of 0.45 Mg m^{-3} while the passive treatment was 0.35 Mg m^{-3}. The higher bulk density of the active treatment was attributed to the chopping and mixing action of the windrow turner which may have accelerated the breakdown of straw fragments, hence reducing air space and increasing bulk density. Our bulk density values fall within the range reported by He et al. (1995) for municipal solid waste (MSW) composts collected from facilities throughout the USA. Their dry bulk densities ranged from 0.22 to 0.74 Mg m^{-3} with a mean of 0.46 Mg m^{-3} ($n = 10$). Schaub-Szabo and Leonard (1999) reported an average dry bulk density of 0.25 Mg m^{-3} for MSW composts in Alberta which is almost identical to that of the cured compost from our winter study (average 0.26 Mg m^{-3}).

Table 5
Effect of season on total mass, water mass and dry matter mass losses of actively composted feedlot manure, 1996–1997[a]

Season	Total mass loss (%)	Water mass loss (%)	DM mass loss (%)
During thermophilic phase			
Winter	32.1*b*	35.8*b*	23.8*a*
Summer	56.2*a*	75.3*a*	11.9*b*
During curing phase			
Winter	11.0*b*	12.2*b*	8.7*a*
Summer	18.5*a*	31.0*a*	10.8*a*
During entire composting period			
Winter	39.5*b*	43.6*b*	30.5*a*
Summer	64.3*a*	83.0*a*	21.5*a*

[a] *a* and *b*: means ($n = 3$) followed by the same letter are not significantly different from each other at the 10% level.

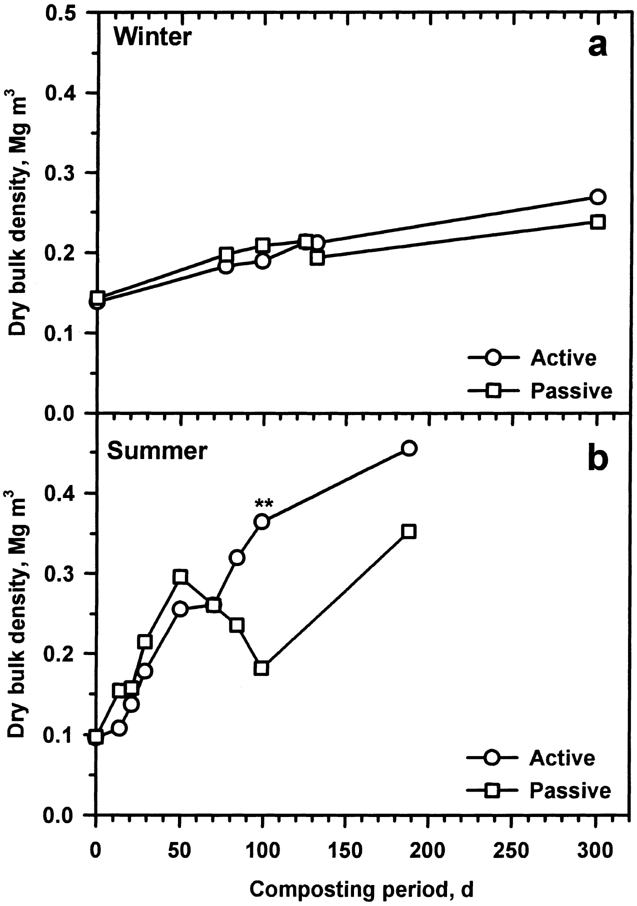

Fig. 1. Effect of composting period and treatment on average bulk density of compost for (a) winter and (b) summer studies. **, Treatment means significantly different at 1% level.

There were significant linear relationships between the duration of composting and bulk density for the active treatment of both the winter and summer studies (Fig. 2). The slope of the relationship was much steeper for the summer study, showing an increase in bulk density of 20×10^{-4} Mg m^{-3} d^{-1} compared with an increase of 4×10^{-4} Mg m^{-3} d^{-1} for the winter study. The increase in bulk density with time demonstrates an increase in homogeneity of the straw and manure particles as they compost, brought about by the mixing and churning action of the windrow turner.

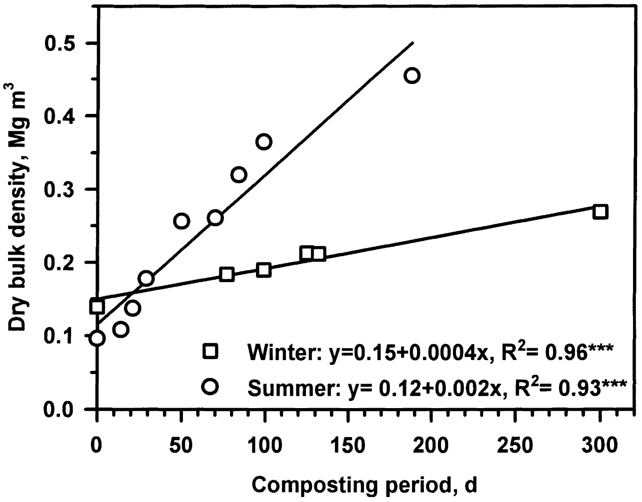

Fig. 2. Relationship between composting period and bulk density for the active treatment of the winter and summer studies. ***, Significant at 0.1% level.

3.4. Volume

Volume determinations by the two methods (mass–density and length–circumference) are compared in Fig. 3. The data points represent windrows at the initial and pre-curing sampling dates of the winter and summer studies. The significant R^2 value (0.94, $P < 0.001$) shows that volume estimates by the easy length–circumference method and the more labour-intensive mass–density method were quite close.

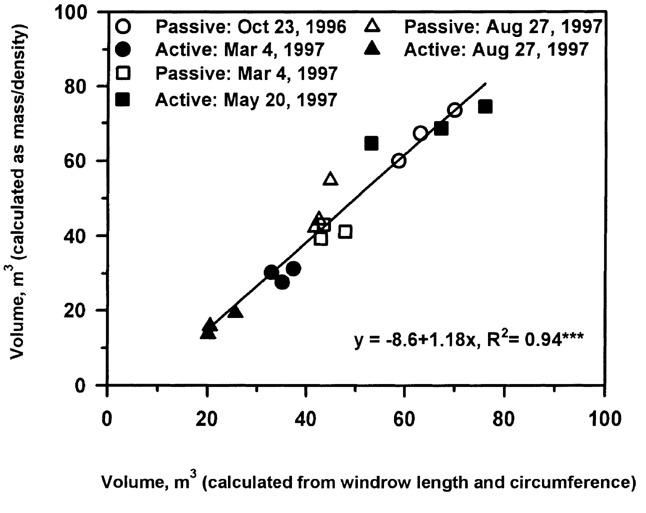

Fig. 3. Comparison of windrow volume determination by two methods. Data points represent three active windrows and three passive windrows at the initial and pre-curing sampling dates of the winter and summer studies. ***, Significant at 0.1% level.

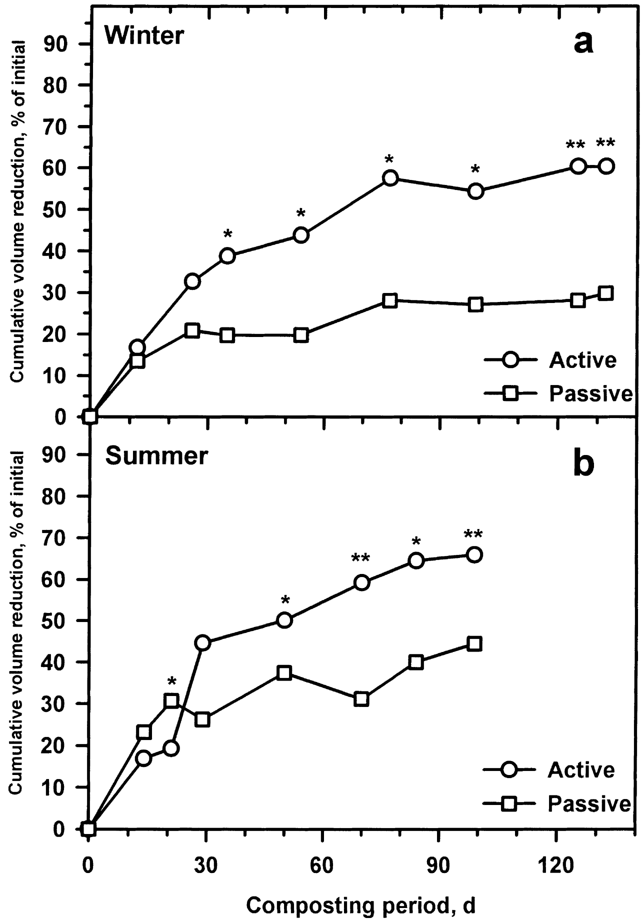

Fig. 4. Effect of composting period and treatment on volume reduction of compost during thermophilic phase for (a) winter and (b) summer studies. *, **, Treatment means significantly different at 5% and 1% levels, respectively.

In both studies, higher volume reduction (calculated by the length–circumference method) in the active compared to the passive treatments became apparent in the first 30 d of thermophilic composting (Fig. 4). After 30 d, although cumulative volume reduction was significantly higher for the active treatment, the rate of volume reduction for each treatment was not that different. For the winter study, volume reduction at the end of the thermophilic phase on day 132 was 60% for the active treatment and 30% for the passive treatment (Fig. 4(a)). These losses were slightly different than those calculated by the mass–density method which were 50% for the active treatment and 38% for the passive treatment. By the end of the thermophilic phase of the summer study, volume reduction was 66% on the active treatment and 44% on the passive treatment (Fig. 4(b)). These losses were somewhat lower than the losses calculated by the mass–density method which were 77% for the active treatment and 57% for the passive treatment.

There was a highly significant quadratic relationship ($R^2 = 0.97$, $P < 0.001$) between the number of turnings during the thermophilic phase and volume reduction (calculated by the length–circumference method) of the active windrows when data from both studies were pooled (Fig. 5). This relationship showed that windrow turning early in the thermophilic phase had a greater impact on volume reduction than later turnings,

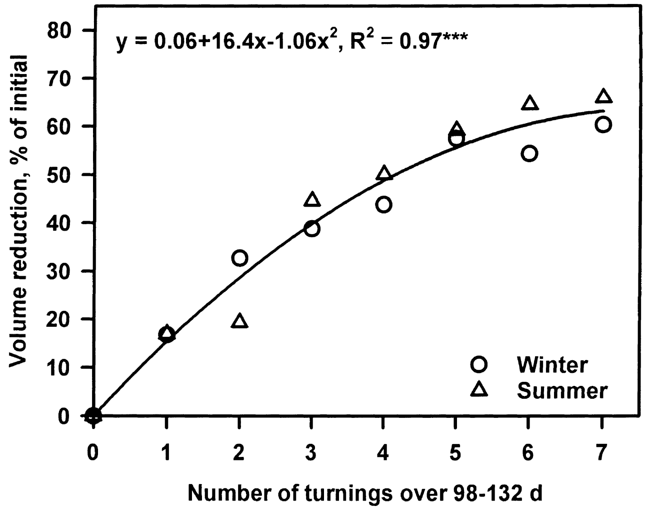

Fig. 5. Relationship between the number of turnings and volume reduction during the thermophilic phase of the active treatment in the winter and summer studies. ***, Significant at 0.1% level.

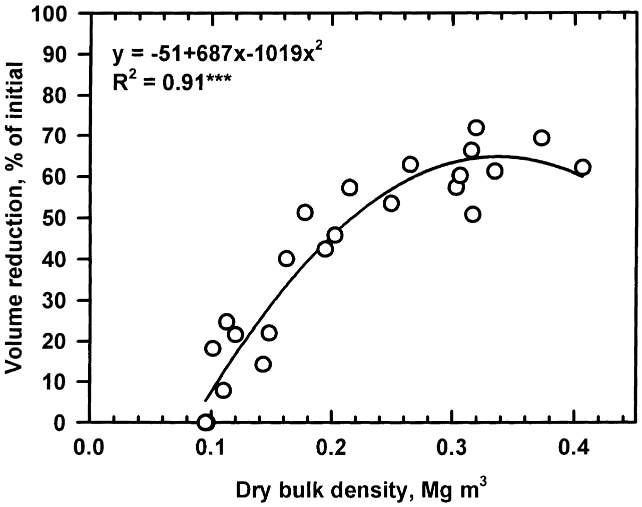

Fig. 6. Relationship between bulk density and volume reduction during the thermophilic phase of the active treatment in the summer study. ***, Significant at 0.1% level.

e.g. volume reduction between the first and second turning was 13.2% of the initial volume while volume reduction between the sixth and seventh turning was only 2.6% of the initial volume.

Volume losses during the curing phase were calculated by the mass–density method only, and added to those calculated by the mass–density method during the thermophilic phase (reported above). For the winter study, total volume losses were 64% (50% during thermophilic + 14% during curing phase) for the active windrows and 53% (38% during thermophilic + 15% during curing phase) for the passive windrows. For the summer study, total volume loss was 83% (77% during thermophilc + 6% during curing phase) for the active windrows and 73% (57% during thermophilic + 16% during curing). As with mass losses, volume losses during the curing phase were much lower than those during the thermophilic phase.

Volume loss (estimated from windrow length and circumference) and bulk density measurements were compared for the thermophilic phase of the active treatment in summer study (Fig. 6). There were 24 data points (eight sampling dates × 3 replicates for each windrow treatment). The significant quadratic relationship ($R^2 = 0.91$, $P < 0.001$) showed that as bulk density increased, volume reduction increased initially but then levelled off. This equation could be useful in predicting volume losses of actively composted windrows from bulk density measurements during summer composting of straw-based feedlot manure in southern Alberta.

3.5. Water content

For the winter study, the initial water contents of the raw manure were 71% for the active treatment and 70% for the passive treatment (Fig. 7(a)). Optimal water contents for composting lie between 40% and 65% (Rynk, 1992). There was no treatment effect on water content of the compost at any point during the winter composting study. Water contents remained very stable throughout the thermophilic phase between 23 October 1996 and 4 March 1997. At the end of this phase, the water content of the active treatment was 68% while the passive treatment was 69%. Water content changed little during the curing phase, with finished compost at 66% water content for both treatments. This may be partly due to the wetter-than-normal conditions during May–June, 1997 when 196 mm of rainfall was received compared to the normal 128 mm (Table 2).

For the summer study, average water contents of raw manure for both treatments were very similar (70% for active, 71% for passive) on 20 May 1997 (Fig. 7(b)). Water content decreased steadily on the active treatment throughout the composting process to a value of 40% on day 98 (end of active composting) and 34% on day 188 (end of curing). While water content of active windrows remained relatively stable for the winter study, there was a highly significant linear relationship ($R^2 = 0.96$, $P < 0.001$) between the number of turnings and water content of the active windrows during the thermophilic phase of the summer study (Fig. 8). The relationship showed that water content dropped 4.4% points per turning.

Water content trends on the summer passive treatment were less predictable, declining initially but then increasing from 55% on day 50 to 67% on day 98 (end of thermophilic phase) when it was significantly wetter than the active treatment (Fig. 7(b)). Unlike the active windrows which lost water by evaporation (425 mm evaporation between day 50 and day 98) on turning

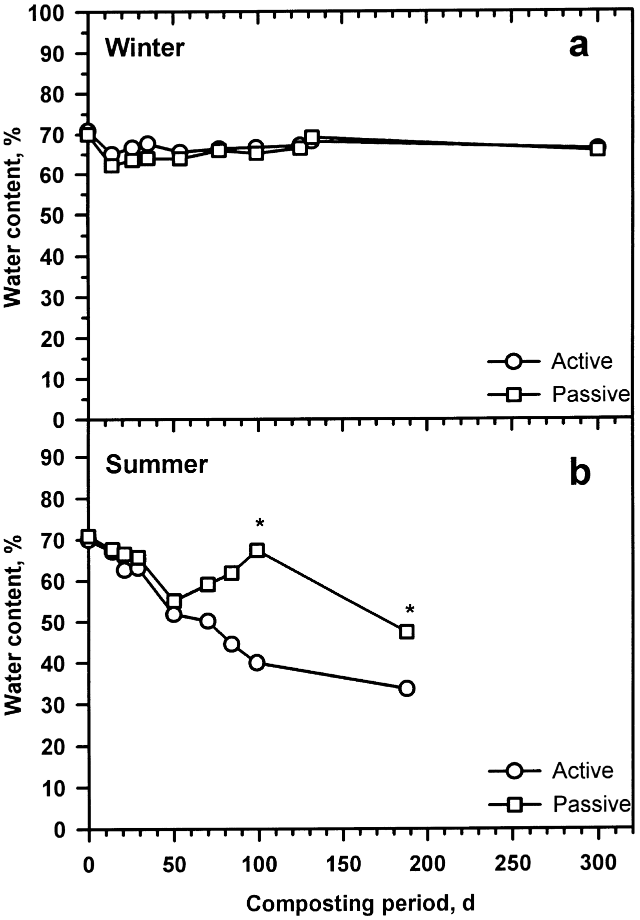

Fig. 7. Effect of composting period and treatment on water content of compost for (a) winter and (b) summer studies. *, Treatment means significantly different at 5% level.

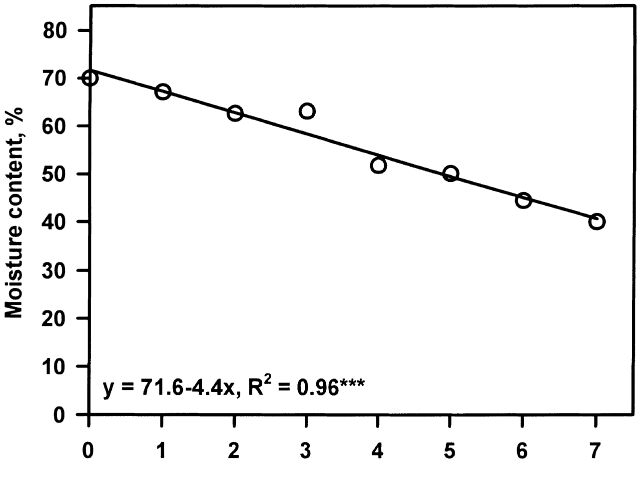

Fig. 8. Relationship between the number of turnings and water content during the thermophilic phase of the active treatment in the summer study. ***, Significant at 0.1% level.

during the hot July–August period, the passive windrows had no opportunity for water loss by this mechanism as they remained undisturbed and hence retained more of the 65 mm of precipitation that occurred during this period. Water loss during active windrow composting has been reported previously (Rynk, 1992).

During the curing phase however, water content of the passive windrows dropped from 67% to 47% (Fig. 7(b)). This was a much larger change than the active windrows which were already quite dry (40% water content) at the onset of curing. This decrease in water content of the passive windrows may be partly attributed to below-normal precipitation during the curing period (Table 2). The September–November 1997 period received only 22 mm of precipitation compared to the normal 81 mm.

3.6. Active vs. passive composting

Generally, active composting performed better than passive composting for mass, volume and water content reduction. When the passive windrows of the winter and summer studies were cut open after the thermophilic phase, a large proportion of the centre of the windrow had the appearance of raw manure and was only partially composted. Even though the passive composting system dispenses with the costs of owning and operating a windrow turner and lowers energy inputs, it may not be feasible for large volumes of manure. Building windrows on the perforated pipes is also more labour-intensive than with the active system where the manure is simply formed into windrows.

3.7. Summer vs. winter composting

There was some concern that ambient air temperatures may be too low during southern Alberta's cold winter to maintain thermophilic activity in compost windrows. However, this was not the case, even though November 1996 was over 6°C colder than normal and December 1996 was 5°C colder than normal (Table 2). Carcamo et al. (1997) reported peak temperatures of 65°C for both active and passive treatments on day 6 of the winter study. Temperatures dropped to ambient immediately after each turning event on the active treatment but returned to thermophilic conditions within 2 d of turning.

The minimum air temperature recorded during the winter study was −38.9°C on 11 January 1997. Overall, during the 132 d thermophilic phase there were 12 d when the minimum air temperature was < -30°C and 33 d when it was < -20°C. This was much colder than the winter temperatures (−27 to +15°C) reported by Lynch and Cherry (1996) for a successful overwinter composting study in Idaho, USA.

Cumulative evaporation during the thermophilic phase was only 39 mm for the 132 d of the winter study compared with 803 mm for the 98 d of the summer study. Mean air temperature during the thermophilic phase of the winter study was −6.8°C compared with 16.8°C for the summer study. These large differences in evaporation and temperature influenced the magnitude of physical changes in each study.

Average volume reduction (mean of losses calculated by two methods) during the thermophilic phase was of the order: summer-active (72%) > summer-passive (55%) > winter-active (51%) > winter-passive (34%). Higher evaporation rates during summer composting may have accounted for greater volume reductions compared with winter composting.

Even though the raw manure for both winter and summer studies started out with similar water contents, the final compost was much drier after summer composting (34% water content) than winter composting (66% water content) due to higher ambient air temperatures and evaporation rates. While reduced water content is advantageous from a transportation viewpoint, there is the danger that active windrows may become too dry in southern Alberta summer conditions, which could inhibit or even stop the composting process. With the significant decrease in water content due to increased turnings in summer (Fig. 8), care must be taken to balance the number of turnings and avoid overdrying of the windrows.

3.8. Implications for haulage requirements

The reductions in mass, volume and water content and increased bulk density of compost compared to raw manure have implications for haulage requirements. A volume of 13.5 m^3 is typical of manure trucks in the southern Alberta region. Haulage requirements based on this truck volume for raw manure and compost for both studies are shown in Table 6. Reductions in haulage requirements mirrored volume reductions. Haulage reductions were greatest for active summer composting and least for passive winter composting. If the raw manure (average windrow volume) from the summer study had been hauled directly to the field, 5.1 truckloads or trips would be required. However, when the manure was actively composted, only 0.9 truckloads were required, which represents a haulage requirement reduction of 83%. Freeze et al. (1999) reported that the breakeven hauling distance for compost was approximately twice as far as that of raw manure in southern Alberta.

Table 6
Haulage requirement of raw manure and compost from the winter and summer studies assuming a truck volume of 13.5 m^3

Study	Treatment	Average windrow volume (m^3)	Number of truckloads required
Raw manure			
Winter	Active	59.2	4.4
	Passive	66.9	5.0
Summer	Active	69.3	5.1
	Passive	109.2	8.1
Compost			
Winter	Active	21.4	1.6
	Passive	31.8	2.4
Summer	Active	11.9	0.9
	Passive	29.9	2.2

4. Conclusions

The results demonstrate that year-round composting is an option for beef cattle feedlots interested in reducing the volume of raw manure and producing a product that has lower haulage requirements. This should be conducive to increasing haulage distances and moving livestock manure from nutrient-loaded areas close to feedlots to nutrient-deficient areas further afield.

Acknowledgements

We acknowledge the Alberta Agricultural Research Institute (Farming For the Future Matching Grants Program, Project No. 97M-179) and the Program for Energy Research & Development (PERD) of Natural Resources Canada for financial support. We thank Mary-Lynn Muhly and Brett Michelson for excellent technical help and Rodney Volk for windrow turning and maintenance. This paper is LRC Contribution No. 3879945.

References

Akinremi, O.O., Larney, F.J., Lemke, R.L., Klaassen, V., 1999. Effect of topsoil depth and organic amendments on productivity of oil well sites. In: Proceedings of the 36th Ann. Alberta Soil Sci. Workshop, 16–18 February 1999, Calgary, AB, pp. 229–233.

Alberta Agriculture Food and Rural Development, 1998. Agriculture Statistics Yearbook, 1996. Statistics Unit, Production Economics & Statistics Branch, Alberta Agriculture Food and Rural Development, Edmonton, AB.

Carcamo, A.A., Larney, F.J., Olson, A.F., Chang, C., Muhly, M.L., 1997. Nutrient, moisture and mass changes associated with composting of cattle manure. In: Proceedings of the 34th Ann. Alberta Soil Sci. Workshop, 18–20 February 1997, Calgary, AB, pp. 207–211.

Chang, C., Cho, C.M., Janzen, H.H., 1998. Nitrous oxide emission from long-term manured soils. J. Environ. Qual. 62, 677–682.

Chang, C., Entz, T., 1996. Nitrate leaching losses under repeated cattle feedlot manure application in southern Alberta. J. Environ. Qual. 25, 145–153.

Chang, C., Sommerfeldt, T.G., Entz, T., 1991. Soil chemistry after eleven annual applications of cattle feedlot manure. J. Environ. Qual. 20, 475–480.

DeLuca, T.H., DeLuca, D.K., 1997. Composting for feedlot manure management and soil quality. J. Prod. Agric. 10, 235–241.

Eghball, B., Power, J.F., 1994. Beef cattle feedlot manure management. J. Soil Water Conserv. 49, 113–122.

Eghball, B., Power, J.F., Gilley, J.E., Doran, J.W., 1997. Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. J. Environ. Qual. 26, 189–193.

Fernandes, L., Sartaj, M., 1997. Comparative study of static pile composting using natural, forced and passive aeration methods. Compost Sci. Utilization 5 (4), 65–77.

Fernandes, L., Zhan, W., Patni, N.K., Jui, P.Y., 1994. Temperature distribution and variation in passively aerated static compost piles. Biores. Technol. 48, 257–263.

Freeze, B.S., Heigh, J.T., Larney, F.J., Olson, A.F., 1999. Economics of windrow composting and land application of manure. In: Proceedings of the Manure Management '99 Conference, 22–25 June 1999, Saskatoon, SK. pp. 311–320.

Freeze, B.S., Sommerfeldt, T.G., 1985. Breakeven hauling distances for beef feedlot manure in southern Alberta. Can. J. Soil Sci. 65, 687–693.

He, X.T., Logan, T.J., Traina, S.J., 1995. Physical and chemical characteristics of selected US municipal solid waste composts. J. Environ. Qual. 24, 543–552.

Henry, S.T., White, R.K., 1993. Composting broiler litter from two management systems. Trans. ASAE 36, 873–877.

Larney, F.J., Chang, C., Blackshaw, R.E., 1999. Composting as a manure management alternative. Final Technical Report, Project No. 97M-179, Alberta Agricultural Research Institute, Alberta Agriculture, Food and Rural Development, Edmonton, AB.

Larney, F.J., Janzen, H.H., 1996. Restoration of productivity to a desurfaced soil with livestock manure, crop residue and fertilizer amendments. Agron. J. 88, 921–927.

Lynch, N.J., Cherry, R.S., 1996. Winter composting using the passively aerated windrow system. Compost Sci. Utilization. 4 (3), 44–52.

Mathur, S.P., 1991. Composting processes. In: Martin, A.M. (Ed.), Bioconversion of Waste Materials to Industrial Products. Elsevier, London, UK. pp. 147–183.

Parr, J.F., Papendick, R.I., Hornick, S.B., Colacicco, D., 1989. Use of organic amendments for increasing the productivity of arid lands. Arid Soil Res. Rehab. 3, 149–170.

Rynk, R., 1992. On-farm composting handbook. Publ. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Sartaj, M., Fernandes, L., Patni, N.K., 1997. Performance of forced, passive, and natural aeration methods for composting manure slurries. Trans. ASAE 40, 457–463.

SAS Institute, 1989. SAS/STAT user's guide. Version 6, 4th ed. vol. 2. SAS Institute, Cary, NC.

Schaub-Szabo, S.M., Leonard, J.J., 1999. Characterizing the bulk density of compost. Compost. Sci. Utilization 7 (4), 15–24.

Sun, H., Larney, F.J., Bullock, M.S., 1995. Soil amendments and water-stable aggregation of a desurfaced Dark Brown Chernozem. Can. J. Soil Sci. 75, 319–325.