Temperature and turning energy of composting feedlot manure at different moisture contents in southern Alberta

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Nelson, V.L., Crowe, T.G., Shah, M.A. and Watson, L.G. 2006. **Temperature and turning energy of composting feedlot manure at different moisture contents in southern Alberta**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **48**: 6.31 - 6.37**.** During hot dry weather conditions, composting windrows lose moisture very rapidly causing the deceleration of the composting process when the moisture contents fall below 40%. With excessive rainfall, composting windrows absorb water, and that may result in levels of moisture content higher than 60%. The large range of moisture, excessive rainfall to drought, inflicted on windrows by the environment can significantly affect the composting process. The main objective of this study was to investigate the effects of the moisture content on the composting process, specifically the compost temperature and energy required to turn the windrows. Three compost windrows were maintained at each of four moisture contents (40, 50, 60, and 70% wet basis). Windrows maintained at 60 and 70% moisture content did not reach or sustain temperature levels (55ºC) sufficient to produce safe compost as defined by the Canadian Council of Ministers of the Environment. The windrows maintained at 40 and 50% moisture content satisfied the compost process constraints with regard to temperature as defined by the Canadian Council of Ministers of the Environment. Windrows maintained at 50% moisture required the least amount of energy to turn them and achieved the best temperature profile. However, the temperature and energy data suggest a possible threshold between 50 and 60% moisture content. **Keywords**: compost, manure, moisture, temperature, energy.

Lorsque les conditions météorologiques sont chaudes et sèches, les andains de compost perdent leur humidité très rapidement, ce qui cause un ralentissement du processus de compostage dès que la teneur en eau baisse à moins de 40%. À l'opposé, durant les périodes de pluies excessives, les andains de compost absorbent l'eau et peuvent ainsi voir leur teneur en eau monter à plus de 60%. Cette importante plage de teneurs en eau entre les périodes de pluies excessives et celles de sécheresse à laquelle sont soumis les andains sous l'effet de conditions environnementales variables peut affecter de manière significative le processus de compostage. Le principal objectif de cette étude était d'investiguer les effets de la teneur en eau sur le processus de compostage, particulièrement sur la température de compostage et l'énergie nécessaire pour le retournement des andains. Trois andains de compost ont été maintenus chacun à quatre teneurs en eau (40, 50, 60 et 70% base humide). Les andains maintenus à des teneurs en eau de 60 et 70% n'ont pu atteindre ou maintenir les niveaux de température (55ºC) suffisants pour produire un compost sécuritaire tel que défini par le Conseil canadien des ministres de l'environnement. Par contre, les andains maintenus à 40 et 50% de teneur en eau ont rencontré les contraintes du processus de compostage en ce qui à trait aux températures telles que définies par ce même conseil. Les andains maintenus à une teneur en eau de 50% ont requis le moins d'énergie pour leur retournement et ont conservé le meilleur profil de température. Cependant, les données de température et d'énergie suggèrent un seuil optimal possible entre 50 et 60% de teneur en eau. **Mots clés**: compost, fumier, teneur en eau, température, énergie.

INTRODUCTION

During the past 15 years, livestock production in Alberta has expanded dramatically. The beef industry has grown 44.5% to a total of 6.6 million cattle in approximately 4500 feedlots, which is 44% of Canada's total beef cows (AAFRD 1998, Statistics Canada 1996, 2001). The area surrounding Lethbridge, in southern Alberta, has a high concentration of confined feeding operations (CFO's). Average beef cattle ready for slaughter have a mass of 567 kg and each produces 2.16 t of solid manure annually in an open lot (AAFRD 2001). In 2000, 82% of Alberta's manure was applied to land by solid spreading (Statistics Canada 2001).

Mismanagement of manure can have a substantial impact on our water, soil, and air resources. The environmental risks of applying manure to land include nitrate and phosphorous leaching from manure into water sources, pathogens contaminating water sources, odour nuisance from land application, and nutrient loading due to the cost of transporting nutrients to further fields or the lack of sufficient land base. Operations applying more than 500 t of manure annually must have the soil tested according to the latest edition of the Manual on Soil Sampling and Methods of Analysis, published by the Canadian Society of Soil Science (AAFRD 2004). Producers and researchers are exploring many different ways to address environmental sustainability, health concerns, and odour problems while adding value and improving transportability of manure to offset the costs of management practices.

Composting can address some of the problems and concerns related to CFOs while providing many other benefits to the producers. By composting feedlot manure, the mass and volume are commonly reduced by 30 - 50%, which reduces the hauling costs (Larney et al. 2000). Organic nitrogen, as a result of composting, is less susceptible to leaching and runoff. Composted material is in a stabilized state, which is less prone to processes that produce odours or greenhouse gases during storage and spreading. Composting uses a high carbon to nitrogen ratio (C:N), common in highly bedded manure, to its advantage by reducing the amount of ammonia loss to the atmosphere. Organic matter added to soil improves the soil tilth, water retention, nutrient conversion, and natural disease-suppression abilities of a plant. Composting temperatures are able to kill pathogens and destroy viability of weed seeds thus increasing crop yields and reducing herbicide requirements.

Composting has been applied in many American intensive livestock areas, including North Carolina and Texas, as a manure management practice (Morris 2000; Mukhtar 2005). Recently, several Lethbridge-area producers and institutions, such as the Alberta Research Council and Agriculture and Agri-Food Canada, have successfully applied composting as part of a CFO manure management strategy in Alberta (AVAC 2002; Larney et al. 2000).

Temperature increases due to microbial activity, and the increase is noticeable within a few hours of forming a windrow, as easily degradable compounds are consumed (Rynk et al. 1992). The temperature usually increases rapidly to 50 to 60°C where it is maintained for several weeks, called the active composting stage. Then the temperature gradually drops to 40°C as active composting slows down and the curing stage begins (Pace et al. 1995). Eventually, the temperature will approach the ambient air temperature. Composting essentially takes place within two temperature ranges defined as mesophilic (10 to 40°C) and thermophilic (higher than 40°C) (Trautmann and Olynciw 2003). The thermophilic temperatures are desirable because they destroy pathogens, weed seeds, and fly larvae in the composting manure (Jenkins 1999). Temperature is a very good indicator of the process within the windrow (Rynk et al. 1992).

The microorganisms responsible for the composting process require aerobic conditions to maintain their livelihood (Rynk et al. 1992). The minimum supply of oxygen is 5% for the microorganisms to survive, thus maintaining aerobic composting (Haug 1993). As the number of live microorganisms decline, the heat generated by them declines as well. Windrow temperature provides an adequate indication of the process conditions, so oxygen monitoring is not necessary (Rynk et al. 1992).

There are two different ways to introduce air into the windrows of composting manure, actively or passively. Active aeration introduces air by mechanical means, either turning and mixing the media or forcing air into ducts beneath the composting media (Haug 1993). Passive aeration requires a perforated pipe to be placed beneath a static windrow, which introduces air into the media through natural convection (Sartaj et al. 1997).

To our knowledge, all the experiments (Larney et al. 2000, Mathur 1991; Rynk et al. 1992; Sartaj et al. 1997) conducted to comparatively study active and passive aeration of windrows reported superiority of active aeration over passive aeration in terms of compost quality, volume and mass reduction, and water retention. However, Larney et al. (2000) observed higher initial costs associated with active aeration.

Moisture content of the composting blend is an important environmental variable as it provides a medium for transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (McCartney and Tingley 1998). The moisture in a windrow is important to the metabolic processes of the microorganisms which participate in composting, consisting mainly of actinomycetes, fungi, and bacteria (Rynk et al. 1992). Many investigators have conducted composting experiments and have identified that 50 to 60% moisture content is conducive for efficient composting (Tiquia et al. 1998; McKinley et al. 1986). Liang et al. (2003) found that when moisture levels fell below 50% the composting process slowed and reported 60% moisture contents as an optimal moisture level for biosolids composting. However, others observed that during the composting process high moisture contents can impact the process by limiting oxygen diffusion into the composting matrix due to an increase in the compaction of the composting material (Das and Keener 1997). In addition, high moisture may introduce anaerobic conditions from water logging in the pore spaces impeding composting processes (Tiquia et al. 1996).

Past attempts to investigate the effect of moisture content (50, 60, and 70% w.b.) on the composting process were not conclusive due to high variability in the moisture content of the windrows (40 to 65% moisture content) (Tiquia et al. 1998). However, in their study each treatment maintained temperatures above 50ºC, conducive for composting. In southern Alberta, maintaining 50 to 60% moisture often requires that moisture be added to the windrows, resulting in a significant time commitment during summer months and minimal time is required during the winter months. This increases demand on equipment and labour, and thus total cost of composting. The effect of changing the moisture level of the composting manure within the 40-70% range is unclear. The moisture content range for composting feedlot manure needs to be defined, especially during extreme weather conditions such as drought or excessive rainfall.

OBJECTIVE

The primary objective of this project was to investigate the effects of different moisture contents, 40, 50, 60, and 70%, on the windrow composting process of beef feedlot manure. The measured variables were the compost temperature and the energy required to turn the windrow.

MATERIALS and METHODS

Site design

The treatments for this analysis were four different moisture contents, 40, 50, 60, and 70% by mass on a wet basis. The Agriculture and Agri-Food Canada compost pad at the Lethbridge Research Centre was selected as the test location. The compost site was prepared with 12 windrows of 15 t each. The mass of the manure used to create the windrows was determined using a truck equipped with four load cells (1210AF, Interface, Inc., Scottsdale, AZ). The manure used to form the windrows came from pens of cattle that were similar in number of animals, bedding amount and type, and feed rationing. The manure contained spring wheat straw as bedding. Raw manure and final product created was analyzed for moisture content, pH, total nitrogen, total phosphorous, ammonia, electrical conductivity, organic matter, and total carbon.

Twelve windrows were arranged in a randomized complete block design with three replicates and four treatments to minimize the effect of variances in the manure and bedding. The

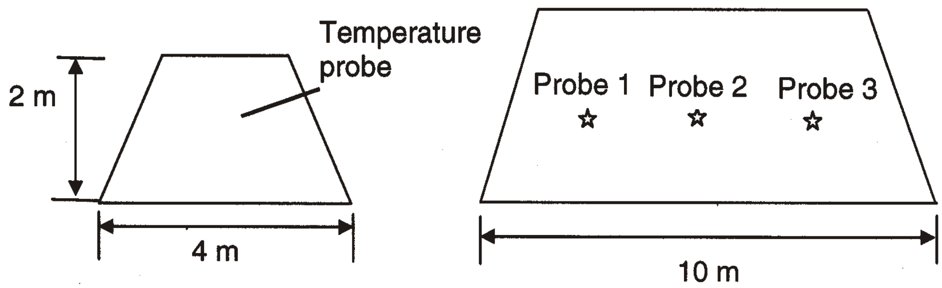

Fig. 1. Cross-sectional and side profiles of windrows indicating temperature probe locations.

pens were cleaned and the windrows were created on September 17, 2002. Each windrow was approximately 2 m high, 4 m wide, and 10 m long, and created with a truck (Fig. 1). A windrow profile meter was used to provide a cross-sectional view of the compost windrows without disturbing them. A laser distance meter, in conjunction with a horizontal traverse system and potentiometer created a grid of heights that provided a cross-sectional graph to determine windrow dimensions. The laser (NR-40, Nova Ranger, San Diego, CA) recorded 362 readings over 4.4 m at three locations for each windrow. The system used a 4 to 20 mA current loop option, with adjustable upper and lower limit switches. The onboard data acquisition system fed the information into a laptop computer in the tractor. The windrow profile meter was run at three locations in each windrow at 3, 5, and 7 m from one end.

Moisture

Three samples were taken from separate locations in each windrow twice each week using a cross-sectional windrow sampler which removed a 75-mm slice from half the cross-section of the windrow after the crust had been removed. The samples were each mixed, quartered, and frozen immediately. A sample from each cross-section was placed in a small pie plate, weighed, and oven dried at 70°C for 24 hours. The moisture content was calculated and used to determine the amount of water required to bring each windrow up to the desired moisture content. When the sample moisture content indicated the windrow needed 0.5 m^3 of water to reach the target moisture content, water was added to bring it up to the appropriate level the day after sampling. The watering system was a truck-mounted sprayer system capable of spraying 454 L/min. The spray boom added water to the top and upper sides of the windrow. To prevent leaching, water was not added to the bottom sides of the windrow. The truck moved slowly along the side of the windrow to evenly distribute the water. The amount of water added to each windrow was recorded using a digital flowmeter (Flow Max 110, Raven Industries, Sioux Falls, SD). The date, time, and amount of water were recorded.

Fig. 2. Earthsaver CT-12 windrow turner used to turn the windrows.

Temperature

A digital temperature sensing network (OneSix Version 1.0, Point Six Inc., Lexington, KY) was used to monitor compost temperatures on an hourly basis. The network was comprised of a data acquisition dynamic data exchange (DDE) server that acquired data from a data logger that received data from temperature sensors attached to a 1-Wire™ network and logged the data as 9-bit digital values. The temperature sensors were digital thermometers (1-Wire™ digital thermometer 18S20 IC, Dallas Semiconductor Corp., Dallas, TX).

The temperature sensors were located at the tips of one-metre long probes which allowed the sensors to be inserted into the core of the windrows (Fig. 1). Each windrow contained three temperature probes positioned along the length of the windrows, for a total of 36 probes (Fig. 1). The sensors were removed before turning and inserted in the same location after turning.

The temperatures of the windrows were recorded hourly and reviewed four times each week. To maintain the most efficient composting process, windrows were turned for one of three reasons: the temperature was below the 54ºC level, the temperature was above the 60ºC level, or the temperature was within the 54 to 60ºC range but falling. Composting is most efficient when the temperature is between 54 and 60ºC (Miyatake and Iwabuchi 2006; MacGregor et al. 1981). If the temperature remained stable or increasing between the 54 and 60ºC range, no mechanical turning occurred. Thus, turning the windrows provided additional aeration that could cool the windrows and/or replenished oxygen levels.

A sustained drop in temperature indicated the end of the active composting stage. In windrow composting, the failure of a cooled compost windrow to reheat after turning indicates that decomposition has slowed enough for the compost to be cured (Rynk et al. 1992).

Energy

A rotating drum style windrow turner (Earthsaver CT-12, Fuel Harvesters Equipment Inc., Midland, TX) was used to turn the windrows (Fig. 2). The turner was steerable and the operator could easily position the turner in the direction transverse to the

Table 1. Properties of the raw manure and the product created.

Property	Initial level	S.D.	Final level	S.D.
Ammonia (ppm)	425.73	175.88	140.18	105.17
Total nitrogen (%)	0.62	0.05	0.42	0.08
Total phosphorus (%)	0.21	0.02	0.19	0.04
pH	8.71	0.14	8.67	0.23
Electrical conductivity (s/m)	1.412	0.092	0.597	0.158
Organic matter (%)	39.42	3.22	26.53	3.00
Total carbon (%)	19.49	2.23	12.06	1.55

travel direction while it was in use. The two 0.46-m gathering arms ensured that all material in its path entered the turner. The turner had 112 blades on the 3.60-m long drum. The drum was 0.28 m in diameter, had 0.46-m vertical height adjustment, and the blades had an outside swing of 0.58 m. The drum operated at approximately 600 revolutions per minute.

A data acquisition system was used to measure and record the power take-off (PTO) speed and torque of the windrow turner and the time to turn the windrow. The data acquisition system was mounted in the cab of the tractor and was powered by the tractor's 12 V electrical system. The PTO speed was measured using a magnetic pick-up on a 60-tooth gear, and the PTO torque was sensed by a full bridge transducer (1248H-20K, Lebow Associates Inc., Tory, MI). The turning time was recorded by the system via an internal clock, and data were recorded at a rate of 2 Hz. The total power required was calculated using the PTO speed and torque (draft was not included). The energy used to turn each windrow per turning was calculated by integrating the total power over the time to turn the windrow.

Composting process

The active composting stage began when the windrows were piled on September 17 (JD 261), 2002. The windrows were sampled on September 17, 19, 23, 26, and 30 and October 3, 7, 10, 15, 17, and 22. Turning of the windrows occurred on September. 25 and 30 and October 2, 8, 10, 17, and 22.

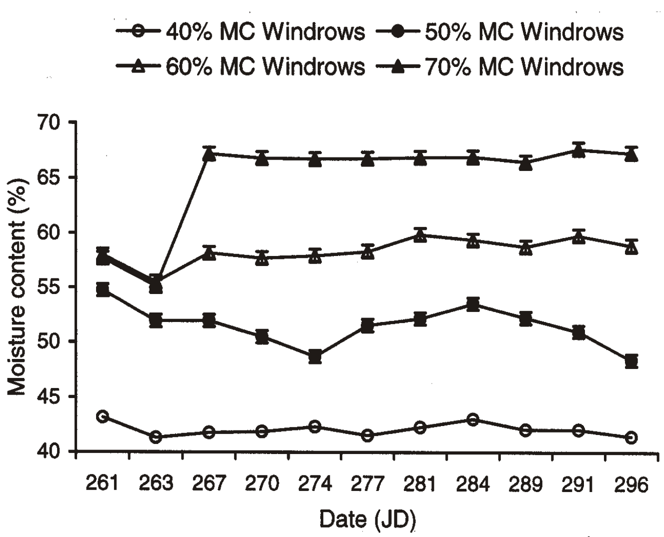

Fig. 3. Least squares mean windrow moisture the day before water addition occurred throughout the active composting phase. Error bars on 40% MC omitted as they fell within the ○ symbol.

Statistical analysis

All data were analyzed using the mixed model procedure of SAS (Statistical Analysis Software, Cary, NC). Data for different time points were used as a repeated measure in the model for analyzing temperature and energy. Statistical differences between treatments and times were evaluated.

RESULTS and DISCUSSION

Manure and final product properties

The cattle manure removed from the pens and the final product created were sampled and analyzed (Table 1). The final product analysis is not displayed by treatment.

Moisture measurement

Samples were taken 11 times for moisture evaluation, and water was added to the appropriate windrows ten times. The moisture content of the composting materials on each sampling day, including when the windrows were created is shown in Fig. 3. An appropriate amount of water was added to each windrow on the day following the day the samples were collected to maintain the desired moisture contents. After the first moisture sample was collected, the watering equipment malfunctioned and watering had to be abandoned until the second moisture sampling; this was apparent on September 19 (JD 263) (Fig. 3).

The amount of water added each time to each windrow is shown in Fig. 4. The fall of 2002 in southern Alberta permitted windrows whose target moisture content was 40% moisture to remain constant with no water addition while windrows maintained at 50% required water addition on four occasions (Fig. 4). Windrows maintained at higher moisture contents, 60 and 70%, required regular addition of water throughout the trial. The data, in Fig. 3, show that windrows at 60% moisture content required minimal water as compared to windrows at 70% moisture content as the active composting process slowed. The windrows at 60% moisture required 24.8% of the water required to maintain windrows at 70% moisture.

It was extremely difficult to maintain windrows at 70% moisture. Maintenance of the structural integrity of the windrows maintained at 70% moisture was compromised by the high moisture content resulting in windrows that were unable to maintain the height and shape required for composting. A pyramidal shape is the best for allowing natural convection to occur, where air flows in from the bottom and up through the material exiting out the top of the windrow. Windrows maintained at 70% moisture slumped, causing the width at the base to increase.

Temperature

The temperatures between the treatments were all significantly different (Table 2). As the moisture content increased linearly,

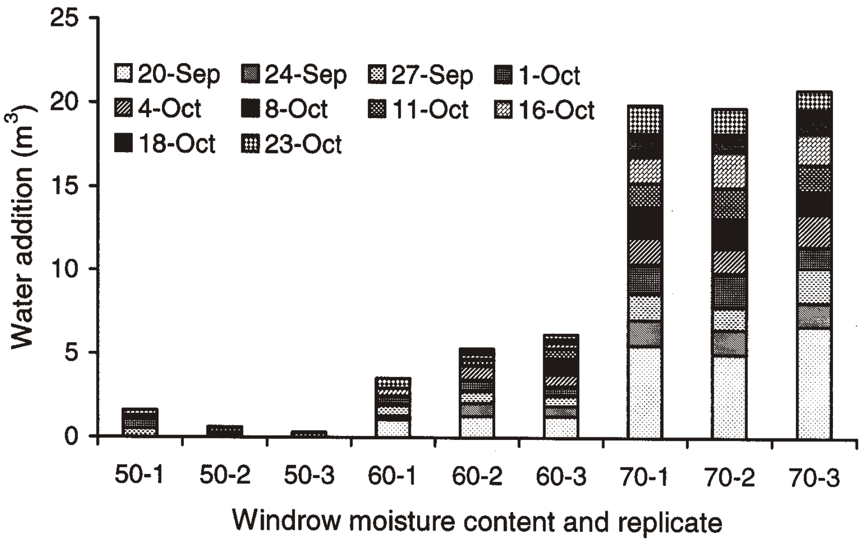

Fig. 4. Amount of water added to windrows after each sampling day.

Table 2. Temperature and energy least squares mean for each moisture content (MC).

	40% MC	50% MC	60% MC	70% MC	SE	P-value
Temperature (°C)	45.4 b*	48.5 a	29.4 c	23.7 d	0.07	<0.0001
Energy (MJ)	30.8 b	28.9 ab	31.3 b	27.4 a	1.1	<0.0001

*Values followed by the same letter in a row are not significantly different.

in a linear fashion except for windrows at 50% moisture. The windrows with 50% moisture maintained the highest temperatures throughout the composting process (Fig. 5). Liang et al. (2003) found moisture contents above 60% to be optimal for biosolids composting; however, the composting material oxygen concentration was maintained above 10%. Tiquia et al. (1996) reported low temperatures and microbial activity in composting piles maintained at 70%. In addition, they found minimal differences in temperature and microbial activity between piles maintained at 50 and 60% moisture content, however, in their study throughout the composting process the windrow moisture contents dropped many times below the target. Possibly, a threshold moisture content of between 50 and 60% exists for composting feedlot manure in windrows.

Although the moisture contents of the four treatments increased by a 10% step linearly from 40 to 70%, the change in temperature was not consistent (Table 2). The average least square mean temperature differences were 3.3, 24.5, and 10.7% between 40 and 50%, 50 and 60%, and 60 and 70% moisture contents, respectively. On day 272 the difference between the temperatures was 5.3% between 40 and 50% moisture; 37.3% between 50 and 60% moisture; and 26.8% between windrows maintained at 60 and 70% moisture (Fig. 5). This may suggest there is a threshold between 50 and 60% moisture, similar to results concluded by Tiquia et al (1998).

Throughout the composting process, the windrows maintained at 60 and 70% moisture content followed similar trends. However, toward the end of the process, the difference between these two trends began to decrease (Fig. 5). The fluctuations in temperature as a result of turning remained similar, for example days 273 and 274. Windrows maintained at 40 and 50% moisture responded differently when the windrows were turned. On day 274 the temperature of windrows maintained at 40% moisture content remained constant and the windrows maintained at 50% decreased, reducing the temperature difference between the treatments (Fig. 5).

In the windrows maintained at 40 and 50% moisture, the temperatures indicated the composting process was progressing in a manner conducive to creating good quality compost. After day 282, the temperatures began a downward trend despite turning the windrows to try and stimulate microbial activity signaling the transition between the active composting phase and the curing phase (Fig. 5). On day 291 the windrow's temperature declined and reached a plateau as it neared that of ambient air. The 50% moisture content allowed the windrows to reach higher temperatures than the 40% moisture content. This suggested that the microbial activity in windrows at 40% moisture

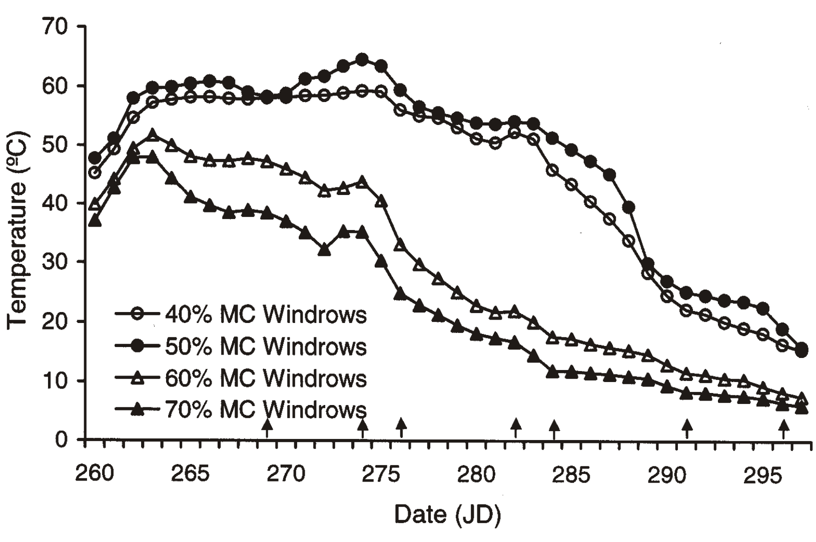

Fig. 5. Least square mean temperature profile throughout the active composting phase. Arrows on the x-axis indicate when the material was turned.

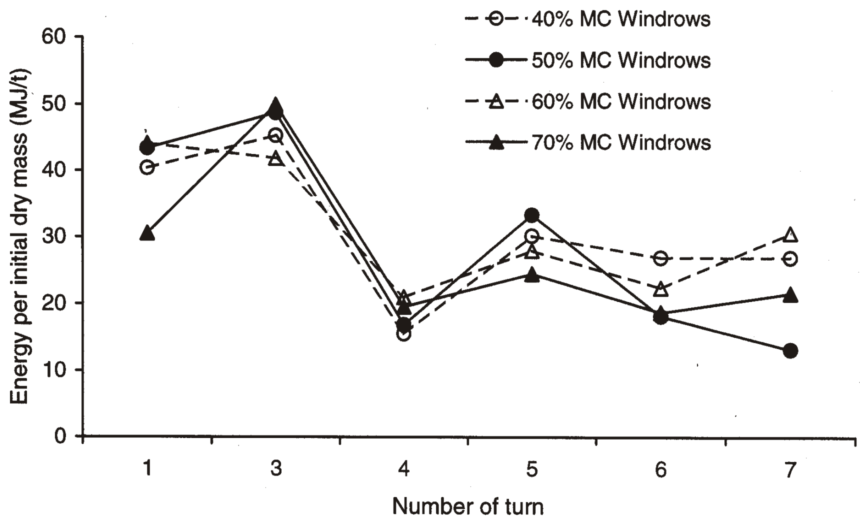

Fig. 6. Least square mean energy used to turn the windrows, on a dry matter basis.

content was lower due to lack of moisture for survival of the microbes and for the movement of microbes through the windrow.

The temperature profiles of the windrows maintained at 60 and 70% moisture contents were not conducive to creating good quality aerobic compost. The temperature sensors displayed a gradual rise in temperature, but below desirable pathogen-killing temperatures (55°C) followed by a consistent gradual decline in temperature. The irreversible fall in temperature after turning on day 274 confirmed that the environment within the windrow was not suitable for the microorganisms necessary for composting. Possibly the oxygen necessary for their survival was limited after two mechanical turnings as much of the straw present in the initial material had broken down.

The temperatures of all the windrows during the curing phase (November 15, 2002 to February 3, 2003) gradually decreased to levels between 0 and 10°C.

Energy

The effects of the treatment ($P<0.05$), turning ($P<0.0001$), and the interaction between treatment and turning ($P=0.0009$) were significant (Table 2). Overall, less energy was required to turn the windrows at 70% moisture than the windrows at 40% ($P=0.03$) and 60% ($P=0.01$), yet there was no significant difference between the energy used to turn windrows at 50 and 70% ($P=0.34$) moisture. Although there was no significant difference between windrows at 40 and 50% moisture ($P=0.24$), the windrows maintained at 60% moisture tended ($P=0.13$) to require more energy than the windrows at 50% moisture, 31.3 ± 1.1 MJ and 28.9 ± 1.1 MJ, respectively (Fig. 6).

During the third turning, the energy consumed for all treatments was significantly higher, 46.4 ± 1.1 MJ, than the other turnings ($P<0.05$) and the fourth turning required the least energy, 18.2 ± 1.1 MJ (Fig. 6). During the second turning, the computer malfunctioned and recorded no energy data. The fourth turning occurred on day 282, near the end of the active composting cycle in windrows maintained at 40 and 50% moisture (Fig. 5). Windrows at 60 and 70% moisture did not reach temperatures conducive for active composting; however, the mesophillic temperatures maintained suggest mesophillic microbes were present and decomposition occurred. The least square means for turnings four to seven was 22.9 ± 1.1 MJ compared to 43 ± 1.1 MJ for turning one and three.

The temperature and energy data (Figs. 5 and 6) suggest all treatments required more energy during their highest rates of decomposition, turning one through three. Energy used for turnings four through seven remained consistently low. During the fifth turning the windrows at 50% moisture required more energy as compared to the other treatments, although not significantly. This is consistent with the temperature data (Fig. 5) where 50% moisture content windrows temperature lagged the windrows at 40% moisture. By the sixth turning these temperatures were similar and the energy required was lower.

CONCLUSION and RECOMMENDATIONS

The temperature of windrows maintained at 60 and 70% moisture contents did not reach and maintain 55°C, necessary for effective composting. The temperature of windrows maintained at 40 and 50% moisture contents did reach and maintain 55°C.

The windrows maintained at 50% moisture content required the least amount of energy to turn the material, however there was no significant difference between the 50 and 60% moisture content windrows. The temperature data suggests a possible threshold between windrows maintained at 50 and 60% moisture content. However, further research is required to investigate a possible threshold between 50 and 60% moisture content in windrows in field conditions with respect to energy required and temperatures achieved to create good quality compost.

These results indicate that beef feedlot producers can effectively compost their manure between 50 and 60% moisture. In addition, the overall time and energy to compost could be shortened while maintaining the benefits of high temperature composting. Further studies could investigate the quality of compost created through various turning schedules and time to compost.

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