In-storage composting of solid dairy manures

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Barrington, S.F., Cap, R. and Le Phat, Q. 1994. In-storage composting of solid dairy manures. Can. Agric. Eng. 36:225-230. Pneumatic manure evacuators aerate manure while transferring it from the barn to the storage facility. To determine if pneumatic evacuators enhance the composting process of stored dairy manures, the temperature of a pneumatically evacuated solid dairy manure pile was monitored during two winters. The monitored manure pile maintained a temperature of 25 to 30°C from mid-October to mid-November. This temperature exceeded the average outside temperature by 10°C to 20°C. As the average outside temperature dropped below 0°C by mid-November, the pile temperature also dropped to 20°C, 10°C, and 5°C for the remainder of November, December, and January, respectively. The low temperatures indicated poor microbial activity despite the aeration effect of the pneumatic evacuator. This lack of aerobic activity was attributed to the high moisture content of the manure and its lack of porosity as well as the poor air distribution from the evacuator. The moisture level remained at 80% over the storage period, but nitrogen losses of 50 to 60% were observed.

Les systèmes d’évacuation pneumatique aèrent tout en déplacant les fumiers de l’étable à l’entrepôt. Pour vérifier si les evacuateurs pneumatiques peuvent composter les fumiers en entreposage, la température d’un amas évacué par système pneumatique, fut observée pendant deux hivers consécutifs, d’octobre à février, inclusivement. L’amas de fumier atteignait une température de 20 à 30°C de la mi-octobre à la mi-novembre, soit une température excédant celle de l’extérieur, de 10 à 20°C. Quand la température ambiante moyenne est tombée sous 0°C, après la mi-novembre, la température de l’amas est descendue à 20, 10 et 5°C respectivement pour le reste du mois de novembre et pour les mois de décembre et janvier ainsi que février. Ces faibles températures, firent preuve du peu d’activité microbiologique dans l’amas en dépit de l’effet d’aération de l’évacuateur pneumatique. Ce manque d’activité microbiologique fut relié au haut taux d’humidité des fumiers, à leur faible porosité une fois évacué et au manque ainsi qu’à la mauvaise distribution d’air fourni par l’évacuateur. La qualité des fumiers fut suivie à l’état frais dans l’étable et dans l’amas en entreposage, pendant la période expérimentale, le taux d’humidité est demeuré à 80% pendant la période d’entreposage alors que les fumiers perdait de 40 à 50% de leur contenu en azote.

INTRODUCTION

In Quebec, dairy farms produce 50% of all animal manures. This industry relies upon 550,000 cows and the equivalent number of replacement stock (Lebeau et al. 1991; Agriculture Canada 1991). These domestic animals produce some 17 million tonnes of manure annually, which represents an equivalent fertilizer value in N, P, and K of 50 million dollars (Beauchamp and Bertrand 1988). This manure also offers an important source of organic matter which can compensate for the annual cultivation losses (Gosselin 1986). Composting improves the quality of manure by transforming its organic matter into a more stable form of higher cation exchange capacity (Mustin 1987). Because Quebec dairy farms handle their manures mostly as solids (Lebeau et al. 1991), they are particularly well-suited for composting.

Nevertheless, dairy farmers seldom compost their manures because of the labour and investment involved. Since 40% of all dairy farms now use a pneumatic evacuator to convey manure from the barn to their storage facility, this handling system could perhaps compost manures in the storage with no additional labour and equipment. The temperature of stored manure that was conveyed pneumatically from the barn was monitored over two consecutive winters to evaluate its degree of microbial activity and to gather data for recommendations on improving the composting process.

LITERATURE REVIEW

Farm manures constitute an important source of organic matter which is often overlooked as a requirement for all cropped soils. Dairy cattle manures are made up of 80 to 90% organic matter on a dry weight basis, when handled as a solid with 2% to 3% bedding. Approximately half of this mass is transformed into humus once incorporated into the ground (Mustin 1987). Cultivated soils lose from 300 to 500 kg•ha⁻¹•yr⁻¹ of organic matter when crop residues are incorporated, otherwise, the losses are more of the order of 700 to 1000 kg•ha⁻¹•yr⁻¹ (Gosselin 1986). The average application of 10 t•ha⁻¹•yr⁻¹ of manure, on a wet basis, is more than sufficient to compensate for this loss.

Organic matter is an important soil constituent because it helps to maintain the soil macro-structure, to retain plant nutrients as well as water, and to adsorb fertilizers (Unwin and Lewis 1986; Ndayegamique and Cote 1989; Weill et al. 1988). As compared to soils with 2% organic matter, MacKenzie (1991) demonstrated that soils with 4% organic matter are twice as efficient in adsorbing chemical fertilizers for the crop.

Composting manures before using them as amendments can improve the quality of the soil’s organic matter. The microbial composting processes have the effect of increasing the humic acid content of the mass and, as a result, of doubling its cation exchange capacity (Mustin 1987). Composting also stabilizes the organic matter of the manures thus providing less readily available organic carbon to stimulate soil denitrification. Composted manures contain lower levels of volatile fatty acids that have been associated with lower levels of soil denitrification (Reddy et al. 1980; Paul and Beauchamp 1988). Nevertheless, composting is not a treatment which can help conserve the nitrogen content of fresh masses of organic matter (Mustin 1987). Finally, com-
tionable odours, contain fewer viable weed seeds and posted wastes are less attractive to flies, release less objectionable parasites, offer a more stable source of fertilizer, and alleviate the effect of heavy metals (Mustin 1987; Lopez-Real and Foster 1985).

Although the concept of composting farm manures is an interesting management scheme, the techniques developed so far require the investment of labour and capital over and above the almost prohibitive handling and storage costs. To produce a true compost, the organic matter must be managed in such a way as to reach a temperature ranging from 55°C to 65°C within two to five days of processing. Furthermore, composting is an aerobic process requiring the control of microbial activity in such a way as to produce humic acids as the end product. Such limitation on the microbial activity is achieved when oxygen is fed continuously but in small amounts throughout the mass. This condition is reached when the mass itself has a porosity of 25 to 35%. Subsequent aeration of the mass will replace the pores’ carbon dioxide with oxygen (Mustin 1987).

From an engineering point of view, composting therefore implies the following requirements:

1) the use of organic matter with sufficient bulk to give the mass a porosity of 25% to 35%;
2) the use of a mass with a moisture content adapted to its structural strength; when using manure and straw, no more than 60% moisture content is allowed or else the pores will be filled with water and the mass will tend to collapse due to its weight; when using manure with peat moss or wood shavings, the material can resist heavier loads and can be wetted to 70% moisture;
3) the reworking and turning of the mass which recreates its porosity;
4) the aeration of the mass to replace the carbon dioxide in the pores with oxygen; this can be achieved simultaneously while turning.

Several mechanized systems have been developed for the proper composting of farm manures. Pos (1982) designed a technology using several bunk silos built side by side. The first bunk is filled with fresh manure. This manure is transferred to the second third, fourth, and fifth bunk while turning and mixing. In the meantime, new manure refills the first bunk and is subsequently moved along the other bunks. When the manure reaches the last bunk, it has been sufficiently mixed and aerated to be composted. A similar greenhouse system has been introduced to reduce the number of bunks to one. The greenhouse covering protects the manure from wetting by rainfall and from drying by sun exposure. The material is deposited daily at one end of the bunk and moved along this structure by turning and mixing. By the time it reaches the other end of the bunk, it is composted. A simpler way of composting manures has been introduced by Mathur et al. (1990) where peat moss is used to give permanent bulk to the mass and the pile is statically aerated. Although all these systems produce a good quality compost, they are still labour intensive and they require high capital investment of the order of $5 to $15 m³ of waste composted.

Because of their ability to lift and aerate at their outlet, pneumatic conveyors could be used to compost as well as transfer manures into storage, thus requiring no additional labour or equipment. In Québec, 40% of all dairy farms use a pneumatic conveyor to transfer their herd’s manure from the barn to the exterior storage (Lebeau et al. 1991). These conveyors consist of a 7 m³ holding tank in which the manure is dropped. The tank is then closed tightly at the top and a 5.25 kW compressor pumps 6 to 7 m³ of air at 50 kPa into the tank. This air pushes the manure out of the tank by a bottom valve, through a 600 mm diameter underground PVC pipe and onto the storage platform. The pipe outlet extends 600 mm above the platform floor, pointing away from the barn. The conveyed manure is thus projected out of the pipe along with the compressed air where it is observed to lift all the surrounding material in storage. This manure lifting process, along with the release of air, can possibly initiate some composting activity. Furthermore, the fresh manure may be aerated in proportion to its age in the storage if it is pushed further away from the outlet with time.

The 5.25 kW compressor of the pneumatic evacuator generally pumps air for approximately 5 minutes with each daily evacuation. Thus, 6 to 7 m³ of compressed air is released for each 3 to 4 m³ of manure evacuated (Bloch et al. 1982).

Pneumatic evacuators could, therefore, be used to compost manures in storage without the purchase of additional equipment and without further handling of the waste. Because these conveyors are used by a large number of dairy farmers, composting could be automatically carried out as a manure management practice. To investigate the possibility of developing an in-storage composting system, the aeration effect of pneumatic evacuators was investigated.

MATERIALS AND METHODS

The project was designed to monitor the temperatures of a solid manure pile evacuated pneumatically and stored over winter on a drained platform. The structure was covered with a black geotextile 12 mm in thickness to provide protection from rain and snow fall. This cover was also assumed to protect the manure pile, to a limited extent, from convective heat losses and to absorb some radiation heat during sunny days. Monitoring of temperatures under the manure pile was carried out during the winter months. Because manures cannot be spread on frozen grounds, winter is the most important storage period.

Experimental site

The experiment was conducted on a dairy farm near Acton Vale, Québec. This farm is located 100 km east of Montréal and operates a herd of 48 cows (38 milking and 10 dry) and 60 replacement head. The milking herd is fed a mixed ration of hay, corn silage, mixed grain, and a protein supplement (Table I). The manure produced by this herd is transferred from the barn to a solid platform by means of a pneumatic evacuator.

A 31 m x 31 m concrete platform receives the manure (Fig. 1). This platform was sloped providing drainage into two liquid tanks located in opposite corners of the structure. The evacuator outlet discharged the manure 0.60 m above the floor of the storage facility. The concrete platform was designed to hold 1600 m³ of manure.
Fig. 1. The experimental evacuator and platform.

Table 1. Experimental herd management

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of cows</td>
<td>48 (2.6)*</td>
</tr>
<tr>
<td>Average number of milking cows</td>
<td>38 (11.3)</td>
</tr>
<tr>
<td>Milk production, (L•d⁻¹ per cow)</td>
<td>28.0 (3.00)</td>
</tr>
<tr>
<td>Average age of cows (yr)</td>
<td>4.0 (0.5)</td>
</tr>
<tr>
<td>Average mass of cows (kg)</td>
<td>628.0 (17.7)</td>
</tr>
<tr>
<td>Feed:</td>
<td></td>
</tr>
<tr>
<td>• totally mixed ration, (kg•d⁻¹ per cow)</td>
<td>34.2 (1.88)</td>
</tr>
<tr>
<td>• dry matter of ration (%)</td>
<td>59.1 (7.39)</td>
</tr>
<tr>
<td>• protein level (%)</td>
<td>10.2 (0.56)</td>
</tr>
<tr>
<td>Bedding used, (kg•d⁻¹ per cow)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*The value in parenthesis is the standard deviation.

The monitoring system

The degree of composting occurring in the manure pile over the winter storage period was evaluated by monitoring the generation of heat within the mass. This was detected by a rise in temperature. The pneumatic evacuator transferring the manure from the barn to the storage platform was responsible for the aeration of the organic mass. The manures were sampled in the barn and in the pile for chemical and physical analysis.

The procedure consisted of installing the thermocouples on the newly constructed platform, in November 1990. That aged on a daily basis. The data collected by those thermocouples observed not to be covered by the manure pile were not analyzed. This was particularly true for thermocouples 9 to 14 installed during the first year of experimentation. The exposed portion of the thermocouple was protected by steel caps during the second year to prevent corrosion. For both years, the thermocouple wiring was contained within PVC tubing and connected within PVC tubing to a data logger stored in a dry and clean room adjoining the barn. The thermocouples were installed on the floor of the structure to fix their position. To relate their experimental readings to the actual temperature of the manure, a 1 m long stem thermometer was inserted manually into the centre of the pile above thermocouples 4, 7, and 11 as well as 1 and 3, in January and February of both years, respectively. The readings of the thermocouples were found to require no correction as they corresponded within 2°C of that measured by the long stem thermometer.

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The monitoring system

The degree of composting occurring in the manure pile over the winter months to evaluate the degree of microbial activity. Temperature is the most obvious physical parameter which can be used to identify the degree of microbial activity within an organic mass. Ideal composting conditions will exist if the temperature of the pile reaches 55°C to 65°C.

During the first and second winter of monitoring, respectively, fourteen and eight thermocouples were fixed to the floor of the platform in a grid pattern (Fig. 2). For each thermocouple, hourly measurements were recorded and aver-
year, manure storage on the platform started in December and
the monitoring followed shortly after. Hourly readings were
taken throughout the winter, from December to March, inclu-
sively. The manure pile was removed in July and September
1991. The second series of thermocouples was installed in
early October 1991 to monitor the storage pile up to March 1992.

Because of financial limitations, temperature readings
were not taken during the summer of 1991 as the thermocou-
ple set-up was destroyed every spring when the platform was
emptied. Nevertheless, winter was considered to be the main
storage period and the most critical for monitoring microbial
activity. Thus, only fall and winter temperatures were moni-
tored.

The physical and chemical properties of the manure were
determined in the barn and in storage, throughout the exper-
iment. Fresh manure was sampled monthly from the barn
gutter from February 1991 to January 1992. In storage, the
manure was sampled in February 1991 and 1992, as well as
in July 1991. The manure in storage was sampled in three
locations in February 1991 and 1992. The sampling sites
were located over thermocouples 8, 11, and 13 as well as 3,
5, and 6, respectively. In July 1991, 10 samples of manure
were collected throughout the pile as the storage facility was
emptied. All samples were examined for colour, odour, and
texture to visually evaluate their degree of composting. They
were also analyzed chemically for total solids (T.S.), nitrogen
(TKN, NH4-N, NO3-N), total P, total K, and organic matter
(APHA 1985). Porosity and specific gravity of the particles
were determined (NRC 1979).

Standard analytical procedures were followed for the
chemical and physical analysis. The T.S. was determined by
drying all samples at 80°C for 23h and at 103°C for 1h. TKN
and total K were quantified with an ammonia and potassium
sensitive electrode, respectively, after a digestion with sul-
phuric acid. NH4-N and NO3-N were measured using
selective electrodes on undigested samples soaked in dis-
tilled water. Total P was determined colorimetrically after
digestion with sulfuric acid. Organic matter was quantified
by burning in an oven at 450°C for 5 hours. Carbon content
was determined by dividing the organic matter value by 1.8.
Specific density and porosity of the manure mass were deter-
mined by submergence in kerosene.

RESULTS AND DISCUSSION
The observed floor as well as pile temperature (Figs. 3 to 6)
demonstrated that some microbial activity occurred during
the fall until mid-November but that very little activity actu-
ally occurred afterwards as exterior temperatures remained
below 10°C. It should be noted that all the manures were
evacuated from a barn maintained at 5 to 10°C. In 1990-91,
manure storage started in December when exterior tempera-
tures already averaged below 10°C. An increase in
temperature, up to 25°C, was observed only with thermocou-
ple 12. This resulted from the displacement of manure by the
farm operator. All other thermocouples indicated manure
temperatures of the order of 10°C in December and 0 to 5°C
in January and February 1991. In October to November 1991,
as the fall storage started again, some microbial activity was
detected by thermocouples 1, 2, 3, 5, 6, and 7 measuring
temperatures of 25 to 30°C. Manure temperatures fell to a
range of 0 to 5°C from mid-November to the end of Decem-
ber again as the average ambient temperature dropped below
10°C. Ambient temperature affected the observed pile tem-
perature. Microbial activity leading to composting

Fig. 3. Temperature variations for December 1990 and

Fig. 4. Temperature variations for October 1991.
Table II. Manure characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pile Feb 91</th>
<th>Barn Feb-July 91</th>
<th>Pile July 91</th>
<th>Barn Oct 91-Jan 92</th>
<th>Pile Feb 92</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (%)</td>
<td>16.7(0.67)**</td>
<td>20.4(2.07)</td>
<td>20.0(0.60)</td>
<td>19.8(0.65)</td>
<td>22.6(0.53)</td>
</tr>
<tr>
<td>Organic matter (% d.b.)*</td>
<td>87.0(0.41)</td>
<td>81.4(6.45)</td>
<td>85.0(5.12)</td>
<td>83.8(4.17)</td>
<td>87.6(0.31)</td>
</tr>
<tr>
<td>TKN (% d.b.)</td>
<td>3.67(0.67)</td>
<td>2.89(0.53)</td>
<td>1.40(0.041)</td>
<td>2.59(0.021)</td>
<td>3.4(0.013)</td>
</tr>
<tr>
<td>NH₄-N (% d.b.)</td>
<td>0.61(0.001)</td>
<td>0.63(0.017)</td>
<td>0.23(0.005)</td>
<td>0.51(0.016)</td>
<td>0.9(0.027)</td>
</tr>
<tr>
<td>NO₃-N (% d.b.)</td>
<td>0.05(0.006)</td>
<td>0.05(0.007)</td>
<td>0.01(0.005)</td>
<td>0.08(0.007)</td>
<td>0.16(0.013)</td>
</tr>
<tr>
<td>P ( % d.b.)</td>
<td>-</td>
<td>0.7(0.10)</td>
<td>-</td>
<td>0.71(0.023)</td>
<td>0.54(0.031)</td>
</tr>
<tr>
<td>K ( % d.b.)</td>
<td>0.64(0.03)</td>
<td>0.92(0.045)</td>
<td>1.5(0.06)</td>
<td>0.99(0.09)</td>
<td>0.83(0.08)</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>10(1.0)</td>
<td>43(3.2)</td>
<td>10(1.0)</td>
<td>43(3.2)</td>
<td>-</td>
</tr>
<tr>
<td>Specific density</td>
<td>0.68(0.01)</td>
<td>0.63(0.04)</td>
<td>0.65(0.02)</td>
<td>0.63(0.04)</td>
<td>0.68(0.02)</td>
</tr>
<tr>
<td>C/N</td>
<td>12</td>
<td>14</td>
<td>30</td>
<td>16</td>
<td>13</td>
</tr>
</tbody>
</table>

* d.b. - dry base
** The value in parenthesis is the standard deviation.

The chemical composition of the manure sampled in the barn as well as in the storage pile is summarized in Table II. The total solids and organic matter content remained in the order of 20% and 85%, respectively. The C/N ratio of 12 to 16 increased to 30 after storage, indicating a loss of nitrogen in the range of 50%. When comparing the N content with that of potassium, between the barn samples (February to July 1991) and that of the storage (July 1991), nitrogen losses can be estimated at 40%. The increase in K content was not accompanied by a similar loss of organic matter simply because the K fraction of manure is very small to begin with.

When sampled from storage in July 1991 and February 1992, the manure had a smell, colour, and texture indicating that little composting had taken place. To identify some of the problems associated with this lack of microbial activity, the physical properties of the manure were characterized while fresh and once evacuated onto the platform. In the barn gutter, the manure offered a porosity of 43% where it contained 2% to 3% straw. Once evacuated onto the platform, the manure porosity dropped to 10%. Examination of the manure in the pile indicated that it forms large clumps which discourage mass aeration. Along with the level of porosity, the high moisture content of the material once evacuated was another factor inhibiting aerobic microbial activity.

The pneumatic evacuator could enhance the composting process if a chopper could be installed at its outlet. This machine could be used to add additional bedding to the manure and to form the pile ahead of the outlet rather than behind it. Pneumatic evacuators will handle the material as long as the bedding content does not exceed 3% to 4%, as opposed to that of 6 to 8% required to properly correct the moisture level of the manure, in parallel with the C:N ratio.

SUMMARY AND CONCLUSION

While transferring solid dairy manure from the barn to the storage facility, pneumatic conveyors have the capacity of enhancing the composting process. A temperature monitoring experiment was therefore carried out to determine the actual degree of microbial activity brought about by the aeration effect from the pneumatic evacuators. Because the observed temperature remained low, the physical characteristics of the manure were investigated.

The composting process failed due to the poor porosity of the material after evacuation and the high moisture content of the manure.

ACKNOWLEDGEMENT

The authors acknowledge the financial contribution of Le Ministère de l’Agriculture, des Pêcheries et de l’Alimentation du Québec as well as that of Agriculture Canada. Special thanks are extended to Pierre and Joseph Vincent, agricultural producers, who collaborated by offering their farm facilities.
Fig. 5. Temperature variations for November 1991.

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