On-Farm Manure Management Through Composting

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Foreword

This manual is intended to provide Nova Scotia producers with an improved understanding of on-farm composting of livestock manure. It will serve as a practical guide for establishing and managing on-farm composting systems, and will be of importance to producers interested in starting compost initiatives. It emphasizes fundamental aspects of on-farm composting, including basic principles, site assessments, monitoring, management, compost quality and regulations, and standards relevant to the production and use of compost. The specific focus of the manual is the composting of manure-based feedstocks using the windrow method; other on-farm composting systems (i.e., bin systems and biopiles for managing livestock mortalities), will be described in subsequent publications.

Manure Management Through Composting

Agricultural operations generate quantities of manure and other wastes or by-products, and producers are often faced with the challenge of finding economical and environmentally acceptable ways of managing these materials. The potential impacts of soil, water and air pollution from improper handling and storage of manure are a widespread concern. Several provinces in Canada have recently implemented legislation with respect to nutrient management, siting and construction of confined feeding operations, and environmental standards for farms (Brethour *et al.* 2002). While Nova Scotia has favoured sustainable farm-level industry stewardship approaches over legislation, new nutrient management programs, and revisions to the existing manure management guidelines, are consistent with the trend towards more stringent environmental standards for agriculture seen in other jurisdictions.

On-farm composting is increasingly being viewed as one component of an integrated waste management system that is feasible, beneficial and cost effective. Composting is a controlled decomposition process that transforms raw organic waste materials into a biologically stable humic substance which can be used to improve the fertility and quality of soils.

The advantages of on-farm composting fall into three main categories: (1) improved quality and handling properties of manure; (2) reduced environmental risk in manure management; and (3) economic advantages over several other manure management options. More specifically:

- composting of manure results in reduced moisture, weight and volume compared to stored manure; these improved physical properties translate into lower hauling and spreading costs
- composting can produce a biologically stable end-product which poses a low environmental risk, which can be stored or spread with little or no odour or vector attraction potential

For most producers, one of the best reasons for composting is the soil amendment and fertilizer value of the compost when used on-farm. Compost provides a loose, friable, moisture retentive growing medium for plants. Manure-based composts have the added benefit of frequently demonstrating plant disease suppressive properties. When applied to soils, compost can improve soil physical properties, as well as provide organic matter, essential plant nutrients and beneficial microorganisms.

The disadvantages of composting are the time and expense involved, the land required for composting, the potential loss of nitrogen (N) in manure during composting and the slower release of nutrients in compost compared with manure. The benefits and drawbacks of on-farm composting are summarized in Table 1.

Table 1: *Benefits and drawbacks of on-farm composting (modified from Rynk 1992).*

Benefits of composting	**Drawbacks of composting**
Excellent soil conditioner	Time and money involved
Improved manure handling and application	Land required for composting
Lower risk of pollution and nuisance complaints	Slow release of nutrients in compost
Pathogen destruction	Potential loss of nitrogen in manure
May reduce soil borne plant diseases	Possibility of odours during composting
Improved handling of "problem" wastes (e.g., old bedding, diseased crop residues)	Diversion of manure and crop residues from cropland
Saleable product	Weather interferes with composting

The Composting Process

Composting is the aerobic decomposition of organic materials by microorganisms under controlled conditions to produce a humic-like substance. During composting, microorganisms such as bacteria, fungi, actinomycetes and protozoa consume oxygen (O_2) while using biodegradable organic materials (manure, straw, leaves, food waste, etc.) as their food source (Fig. 1). The raw or ingredient materials used for composting are commonly referred to as 'feedstocks'.

In addition to heat, the composting process releases water vapour and carbon dioxide (CO_2). At least 50% of the carbon in the organic material is lost (as a result of microbial respiration) and nitrogenous compounds are converted into more stable organic forms. Consequently, there is a substantial reduction in the volume of material, and the resulting compost is both physically and biochemically different from the original materials.

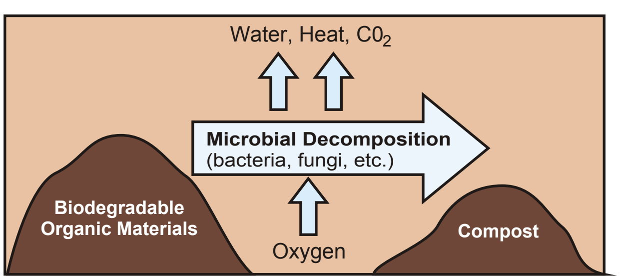

Figure 1: *Simplified diagram of the composting process.*

Composting is best achieved when conditions that encourage the growth of microorganisms are established and maintained. It is important to ensure that:

- organic materials are blended together to provide the energy and nutrients needed for microbial activity and growth, and providing a balanced supply of carbon and nitrogen (C:N);
- oxygen is available to promote aerobic decomposition and minimize odours;
- enough moisture is available to permit biological activity without hindering aeration;
- temperatures are within a range that promote vigorous activity of thermophilic organisms (thrive at temperatures > 40°C); and
- a pH near neutral (i.e. 7.0), to promote the growth of the most active microflora and minimize loss of N.

As soon as compost materials are mixed into a pile and the conditions suitable for microbial activity are established, the composting process begins. Controlled composting involves two main phases: (1) an *active phase;* and (2) *a curing phase* (Fig. 2). The active phase generally lasts three to nine weeks, depending on the nature of the materials and the frequency of turning of the compost pile. Following active composting, the compost requires a final curing period of at least four weeks to allow the compost to develop the desired characteristics for its intended use.

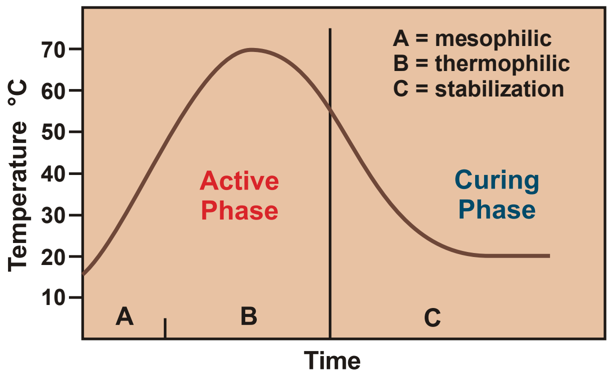

***Figure 2:** Temperature development over time during the composting process (adapted from Cooperband 2002).*

During the active phase, microbial activity causes the temperature of the composting material to rise. This phase is therefore further subdivided according to the pattern of microbial activity and corresponding temperature development (Fig. 2). There is an initial *mesophilic phase* (typically 1-3 days), during which microorganisms decompose the readily degraded compounds and the temperature increases rapidly to approximately 40°C. This is followed by a longer, high rate *thermophilic phase* in, which more complex materials are degraded and the temperature rises above 60°C. Finally, as more resistant materials are targeted, the reaction rate decreases and the temperature begins to decline. This cooling down stage is referred to as the *stabilization phase*. Both the thermophilic and stabilization phases may last anywhere from 10 to 100 days, depending on the materials being composted and the methods or technologies employed (Keener *et al.* 2000).

During the thermophilic phase, oxygen is consumed at a high rate. To prevent odours (associated with anaerobic conditions) and maintain an efficient decomposition process, oxygen must be replenished through passive or forced aeration, or by turning the compost pile.

The curing phase, which follows the active composting phase, occurs at ambient temperatures and lasts for one to several months. In the curing phase, complex chemical reactions in the residual organic matter produce a stable (or mature) compost product. Compost is judged to be 'finished' when factors such as C:N ratio, oxygen demand, temperature and odour (Rynk 1992) are at levels desired according to its intended use.

The key factors affecting the composting process and their target ranges for active (thermophilic) composting are listed in Table 2. Nutrient balance, moisture, particle size, porosity and pH are most important in the formulation of compost mixes, whereas oxygen concentration, temperature and moisture content are most important during management of the process.

***Table 2:** Recommended conditions for active composting (modified from Dougherty 1999).*

Factor	Target Range
C:N ratio*	20:1 – 40:1
Moisture content (%)**	40 – 65
Particle size (diameter in cm)	1.25 – 5.0
Pile porosity (%)	> 40
Bulk density (kg/m^3)	475 – 712
pH	6.0 – 9.0
Temperature (°C)	43 – 65

* (C:N ratios above 30 will minimize the potential for odours)

** (Optimum depends on the specific materials, pile size and/or weather conditions)

Composting Methods

There are at least four methods or approaches used in composting which differ primarily in the way that aeration is delivered. The four approaches are:

1. **Passive (open-pile):** materials are stacked in piles, with little agitation or management; aeration is accomplished by natural convection.

2. **Windrow:** materials are placed in long, narrow piles or windrows, which are agitated or turned on a regular basis; aeration is achieved through natural convection and a front-end loader or specialized turning equipment is used to vent excess heat and moisture while increasing porosity of the pile to improve airflow (Fig. 3).

Figure 3: *Windrow composting.*

3. **Aerated static pile:** materials are placed in windrows; blowers are used to move air through perforated pipes (forced aeration) (Fig. 4).

Figure 4: *Aerated static pile at Terrance Boyle's farm, Antigonish Co., NS. (photo by T. Boyle). Note cap of finished compost on windrow in background (biofilter for odour control, maintains windrow temperatures).*

4. **Contained (in-vessel):** composting materials are confined within a building (Fig. 5), container or vessel; forced aeration and mechanical turning.

Figure 5: *Contained composting.*

All of these methods have been successfully used on farms. The majority of on-farm composting operations, however, are low-intermediate technology systems, employing actively managed (turned) windrows or passive (unturned) windrows or piles.

Windrow composting employs long, elongated piles (windrows) of material, 1 to 3 m high, 3 to 6 m wide, and up to 100 m long (Fig. 5&6). The size, shape and spacing of the windrows are determined by the equipment used for turning.

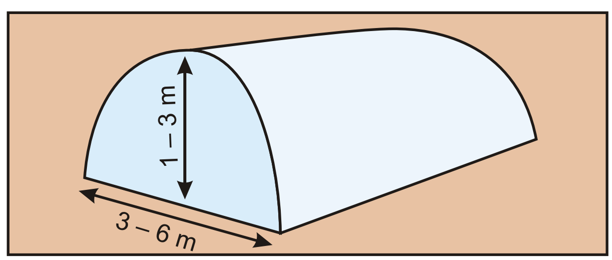

Figure 6: *Typical shape and dimensions of a composting windrow.*

Windrows are aerated by natural convection; as hot air from the centre rises through the top of the pile, it draws cooler air from the sides, thereby circulating air throughout the pile. The oxygen benefit from turning is relatively short-lived (i.e., 2 hours) and therefore, the important effect of turning is not so much aeration but rebuilding porosity of the pile to improve airflow.

Specific tasks associated with the windrow method include mixing and windrow formation, periodic turning, moving stabilized compost to a designated curing area and management of curing piles. The greatest cost associated with producing compost by this method is the labour and equipment costs involved in forming piles and turning the compost. Windrows are usually turned weekly during the active composting phase and then one to two times a month during curing. More frequent turnings during active composting will accelerate the process. There is a trade off, however, between process time efficiency, product quality, and cost, because frequent turning tends to accelerate N-losses while increasing the cost per tonne of producing compost. Eliminating unnecessary turnings, using existing farm equipment and/or renting machinery which is used only for a few weeks per year, are all ways of improving the cost-effectiveness of the windrow method.

The advantages of the windrow method are process flexibility and low capital investment. The primary drawback is the large land base required relative to other composting methods. Aerated static pile and in-vessel channel systems, by virtue of their efficient composting rates and design, require less land to operate and may be the best methods where there are space constraints. The high capital cost of these methods, however, often discourages their use in on-farm composting.

Bin systems, which are a 'hybrid' of passive, open-pile and in-vessel composting, are increasingly being used in Nova Scotia. Bins can be used for managing livestock mortality biopiles and are also suitable for composting small volumes (e.g., 12 m^3 or 8 tonnes) of manure (Fig. 7). Mortality biopiles are specialized systems with specific design and management requirements, that use composting principles as guidelines to ensure that biodegradation is efficient, environmentally sound and biosecure.

Figure 7: *Composting in bins.*

In most small to medium-sized farm composting systems (i.e., processing less than 380 m^3 or 266 metric tonnes assuming bulk density for solid manure of 0.7 tonnes/m^3 and 40% solids), existing farm equipment is used to perform the basic composting operations. The bucket loader is the primary mixing device (Fig. 8). Manure spreaders, especially side-delivery, flail-type spreaders, can also be used to mix materials and form windrows. Windrow turning may be accomplished using existing farm equipment (tractor and bucket loader, or manure spreader-loader combination) or specialized windrow turning equipment. Specialized windrow turners can process much larger volumes of material and therefore substantially reduce the amount of time spent turning piles. In most cases, the purchase of such equipment is only justified for larger composting operations.

Figure 8*: Mixing and forming compost piles (photo by M. Hope-Simpson).*

Site and Environmental Requirements

There are a number of requirements in selecting and preparing the composting site to provide the area and conditions for year-round composting, while limiting environmental risk.

Area requirements for windrow composting are greater than for more technological methods such as the aerated static pile or in-vessel systems. Generally, 1 m^3 of raw composting material will require about 0.8 m^2 of ground area for a windrow setup. Additional space for curing, storage, runoff and leachate control, and separation distances should be considered. Determining the area requirements for composting, curing and storage areas will require performing some calculations based on such variables as waste production rates, the required amounts of amendments, composting and curing times, and storage requirements. A sample calculation for sizing a windrow system is available at http://www.agf.gov.bc.ca/resmgmt/publist/300series/382500-6.pdf, courtesy of the British Columbia Ministry of Agriculture and Food (BCMAF) Factsheet, "Site Selection for Composting"

Separation distances between farm composting operations and nearby streams, water sources and residences, are intended to lessen water quality concerns as well as nuisance factors, such as odour. The minimum recommended separation distances for siting animal production and manure storage units, which may also apply to on-farm composting operations, are listed in Table 3.

Table 3: *Minimum recommended separation distances (NSDAM 1991).*

Sensitive Area	Minimum Separation Distances (m)
Area zoned residential	600
Property line or dwelling	50
Water course/well	100
Provincial highway	50

The composting pad is the surface occupied by windrows and piles during the active composting period. A firm surface is necessary and concrete pads are the recommended surface. Concrete pads, have the advantage of reducing seasonal problems (related to mud, access and equipment operation) as well as pad maintenance (Fig. 9).

Figure 9: *Delivering feedstocks to compost site on concrete pad (photo by M. Hope-Simpson).*

Failure to control runoff and pile leachate at the composting site can lead to management and environmental problems, including ponding of water, saturated composting materials, muddy site conditions and excessive runoff and leachate from the site. Leachate may be minimized by controlling moisture during the composting process. Runoff and leachate are also controlled by providing the following site modifications:

- construct site on top of a hill;
- grade the site to a 2 – 4% slope (2 – 4 m vertical drop over horizontal distance of 100 m) and run windrows or piles parallel to the slope. This prevents runoff from ponding on the uphill side of windrows/piles and allows liquid leachate to be transferred to a vegetated filter area;
- use ditches or berms to divert clean, up-slope surface water around and off the site to minimize the total volume of site runoff that must be controlled; a berm around the site will also prevent runoff from entering a watercourse; and
- remove topsoil and construct paved pads with 15 cm of gravel between subsoil and the pad.

Material Testing

The first step in testing materials is obtaining a representative sample. The recommended procedure for sampling a compost pile or feedstock for laboratory analysis is shown below.

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1. Use a clean 20 L (approximately 5 gallon) bucket and shovel.
2. Take 5 – 7 samples from all parts of the pile. Avoid taking samples from the centre, edges and outer surfaces of the pile and dig at least 40 cm into the pile for each sample.
3. Combine the samples in the bucket and mix thoroughly.
4. Place approximately 1 L of the mixed sample in a sealable plastic bag or sample container provided by the testing laboratory.

Samples should be analyzed as soon after collection as possible, to minimize moisture loss and other changes in the material. If a significant delay in processing is anticipated (i.e., > 24 hours), samples should be stored at 4°C in an airtight container until they can be submitted to the lab.

Material testing includes analysis of the physical and chemical properties of compost and feedstock materials, as well as growth screening tests on samples of finished compost. Testing of compost or feedstock materials is used to:

- formulate or verify a composting recipe;
- evaluate progress in an active pile;
- determine when compost is mature; and
- evaluate the quality of the finished compost.

Two main types of analyses which may be required, laboratory analysis and on-site measurements, are described as followed.

Laboratory Analysis

Laboratory analysis is used to determine the C and N content, or C:N ratio, in the materials at the beginning and end of composting (see Appendix C for laboratory services). At the beginning of composting, the C:N ratio is used to assess the degradability of compost mixtures (Table 2). At the end of composting, the C:N ratio provides an indication of compost maturity (see Compost Quality, page 13). Laboratory analysis is often required for moisture analysis however, it is also possible to obtain a reasonably accurate measure of moisture content on-site (see Moisture Content, page 8).

Analyses such as pH, soluble salts, levels of nutrients (P, K, Ca, Mg, etc.), metals or other contaminants are useful in evaluating the quality of compost. They may also be required when evaluating feedstock materials or testing the effect of a given material on the composting process or product quality.

On-Site Measurements

On-site measurements are approximate measurements which may be obtained on the farm. Four simple and useful measurements are determining the bulk density, porosity, moisture content and moisture status of materials.

Bulk Density and Porosity

Bulk density is the weight or mass of a material per unit of bulk volume, including the air space. Porosity is a measure of the pore space of a material or pile of materials. At the start of composting, bulk density measurements are used to optimize the aeration and porosity of the mixture. When bulk density is within an optimum range, it is often not necessary to measure porosity. For example, mixtures which have a bulk density less than 640 kg/m^3 generally demonstrate porosities greater than 40%, which is considered adequate (Table 2).

How to measure bulk density and air-filled porosity (modified from Keener *et al.* 2000)

Bulk density and porosity measurements are best performed where feedstock or compost materials are located, as you will need to obtain and weigh several large samples (i.e., 20 L) and then average the results. To determine density and porosity, you will need a container, scale, water and a pile of the compost material. The procedure is as follows:

1. Weigh empty container. W_o, kg
2. Fill with water and weigh. W_{ow}, kg
3. Fill container with only material and weigh. W_{oc}, kg
4. Add water to material in container and weigh. W_{ocw}, kg

Use the following equations to calculate bulk density ($\tilde{n}_c$) and porosity (E_c):

$$\tilde{n}_{c,\,wet}\ (\mathrm{kg/m^3}) = 1000\,(W_{oc} - W_o) / (W_{ow} - W_o)$$
$$E_{c,\,wet}\ (\%) = (W_{ocw} - W_{oc}) / (W_{ow} - W_o) \times 100$$

__Example:__ Bulk Density and Porosity Calculations

Given a feedstock material with:

$W_o = 1.0$ kg; $W_{ow} = 20.5$ kg;

$W_{oc} = 9.8$ kg; $W_{ocw} = 18.2$ kg;

$\tilde{n}_{c,\,wet} = 451.3\ \mathrm{kg/m^3}$

$E_{c,\,wet} = 43\ \%$

__Moisture Content__

To obtain a **semi-quantitative** measurement of moisture content on-site, you will need access to a reasonably accurate scale (0.01 g) as well as a conventional oven or microwave oven for drying the samples. Ideally, these appliances should be dedicated to material testing (i.e., not for household use) and located in a well ventilated area. Determine the moisture content of materials by following the steps listed below:

1. Weigh empty container (approximate size of 0.5 L). W_o, g
2. Fill with material (100 - 200 g) and weigh. W_{oc}, g
3. Dry sample in oven at 100°C for 3 days.
4. Weigh dried sample and container. W_{ocd}, g

Use the following equation to determine the moisture content (W_c) of the sample:

$$W_{c,}\ (\%\ \mathrm{w/w\ wet\ basis}) = 100 - \left[\frac{(W_{ocd} - W_o)}{(W_{oc} - W_o)} \times 100\right]$$

__Example:__ Moisture Calculation

Given a manure sample with:

$W_o = 10$ g; $W_{oc} = 178$ g; $W_{ocd} = 46$ g;

$W_c = 78.6$ % w/w wet basis

__Moisture Status ("Squeeze test")__

Semi-quantitative measurements of moisture content (as above) are useful when evaluating the suitability of feedstocks and when formulating compost recipes. Field measurements, such as the squeeze moisture test, however, are usually adequate for process control. The squeeze moisture test is used at the start of composting to evaluate and adjust the moisture content of the mixture and is used on an on-going basis throughout composting to monitor pile moisture status. To conduct this test:

1. Squeeze a handful of material tightly in your fist.
2. Moisture content is within the correct range for composting (40 - 65 %) when the material feels like a wrung-out sponge, releasing at most only a few drops of moisture (Fig. 10).

Figure 10: *Performing the squeeze moisture test (photo by M. Hope-Simpson).*

Blending Materials for Composting

Feedstock Characteristics

The feedstock characteristics to be considered are C:N ratio, moisture content, bulk density and porosity (Table 2). Carbon containing feedstocks that supply energy to the microorganisms (sawdust, straw, shredded corn stalks, leaves) must be mixed with N containing materials (animal manures, plant residues, food processing wastes) in ratios dictated by microbial metabolic requirements. Raw materials blended to provide a C:N ratio of 25:1 or 30:1 are considered ideal, however, initial C:N ratios of 20:1 to 40:1 consistently give good composting results.

Physical properties of the raw materials (moisture content, particle size and shape, porosity and structure) largely affect the composting process through their effect on aeration. The composting material must be relatively porous (to permit aeration) and contain sufficient, but not excessive, levels of moisture. Ingredients added to adjust C:N or moisture are referred to as amendments, whereas materials added to provide structure and porosity are known as bulking agents. The characteristics (C:N ratio, moisture content and bulk density) of some common composting feedstock materials are outlined in Table 4.

The moisture content of manure is important, as wetter manures require large amounts of dry carbon amendments. The volume of amendments required is often two to three times the volume of manure. Composting wet manures can therefore quickly become uneconomical due to the cost of purchasing additional bedding materials, as well as the large amount of labour involved in handling and mixing manure with amendments .

Developing Compost Mixes

The raw materials need to be blended together in a manner and proportions that optimize the composting process factors and balance the mixture. There are several approaches to accomplishing this; the best approach depends on your composting objectives, experience, and the type of materials being used.

A **quantitative** approach involves performing calculations to determine mixing proportions, based on a laboratory analysis of the ingredient materials (see Appendix A). This allows the calculation of the actual weights or volumes of materials required to achieve a given C:N ratio or moisture goal, thereby eliminating much of the 'guesswork' in combining materials. Feedstock material testing and calculations are useful for determining how much wet manure to mix with dry C amendments.

Table 4: *Characteristics of some common composting feedstock materials (adapted from Rynk 1992).*

Material	C:N Ratio	Moisture Content %	Bulk Density (kg/m^3)
High in Carbon			
Hay	15 – 30	8 – 10	–
Corn silage	40	65 – 68	–
Straw	40 – 150	4 – 27	58 – 237
Sawdust	200 – 700	20 – 65	200 – 270
Leaves	30 – 80	38	
High in Nitrogen			
Poultry manure – broiler litter	13 – 30	22 – 46	449 – 609
Cattle manure – dairy tie stall	18	79	785 – 993
Swine manure	5 – 19	65 – 91	–
Horse manure	22 – 50	59 – 79	720 – 961
Mink manure	7	55 – 75	–
Cull potatoes	18	70 – 80	890
Vegetable wastes	11 – 13	60 – 80	–

Semi-quantitative approaches involve the use of blended mixtures of C- and N- containing feedstocks, and adjusting various process factors on the basis of testing conducted on the mixture. For example, well-bedded cattle manure or poultry litter often demonstrates a moisture content and C:N ratio which is close to ideal for composting. Other ingredients are added, if necessary. Useful tests for this purpose include the total N and C content of the mixture, as well as initial bulk density, porosity and moisture status (see Material Testing, pages 7 and 8).

Qualitative, or more intuitive approaches, may be described as a best estimate of the correct ratio of ingredients, based on composting experience and the 'look and feel' of the mix. Qualitative approaches are common in on-farm composting and they may also be highly successful. They work best, however, for individuals with composting experience, and familiarity with the required ingredients and conditions for composting.

Regardless of what method or approach is used to formulate the mix, keep in mind that composting is a relatively robust process that occurs over a wide range of conditions. In other words, mix materials with an eye to acceptable moisture content and C:N ratio, and manage the process properly; this way you are more than likely to produce an acceptable compost product for on-farm use.

Managing the Composting Process

Composting involves maintaining optimum conditions for biological activity until decomposition slows and compost is considered to be reasonably stabilized. Other important requirements include achieving an acceptable reduction in pathogens and weed seeds, and minimizing N losses.

Temperature, aeration and moisture are the three main factors which need to be managed to promote an active and efficient composting process.

Temperature

Since temperature is directly related to microbial metabolic activity, it is the primary gauge of the composting process. The temperature of your compost should be monitored daily for the first week of composting and at least every two to three days thereafter for the duration of the active composting period (three to nine weeks).

How to measure compost temperature

Using a 60 or 90 cm stem dial thermometer (see Appendix C, for a supplier of compost thermometers), take the temperature of the pile at approximately 30 and 90 cm depths in at least two locations of the pile. Leave the thermometer in place long enough for the reading to stabilize. Record these temperatures, as well as the average of the pile (Fig. 11).

Your daily temperature monitoring log will be an invaluable tool for understanding and managing the composting process. During active composting, pile temperatures should be maintained between 40 and 55°C. Excessive heating (temperature over 65°C), abnormally low temperatures (below 40°C), or steep temperature gradients (difference between the 30 and 90 cm temperature readings is greater than 7°C) all indicate that the pile needs to be turned. A sustained or irreversible drop in temperature (i.e., temperature does not recover after turning or adjusting moisture) after several weeks of thermophilic conditions, usually signals the end of the active composting stage.

***Figure 11**: Measuring compost temperature.*

Control of temperatures during composting is important for the following reasons:

- maintaining pile temperatures between 40 – 55°C for several weeks is necessary to decompose the more resistant materials (e.g., straw, wood shavings) and achieve adequate stabilization;
- temperatures should be maintained over 55°C for at least 15 days to destroy pathogens, weed seeds and fly larvae. Windrows should be turned several times during this period to ensure that all of the composting material is exposed to pathogen kill temperatures; and
- temperatures over 65°C should be avoided to prevent immobilization of beneficial microorganisms and minimize the loss of N during composting.

Moisture and Aeration

Moisture content and aeration are two critical inter-dependant factors in composting. The lower limit moisture content in composting is normally about 45–50% while the upper limit is typically 65%. However, in practice, this limit is largely determined by the nature of the composting materials. For a relatively porous mixture, such as stacked dairy manure, the upper limit may be as high as 70%. For a mixture which cannot maintain well defined pores within its mass, such as poultry layer manure mixed with shredded paper, the upper limit of moisture should not exceed 60% (BCMAF 1998). Oxygen concentration is not normally measured in on-farm composting, however, aeration status is inferred by the presence or absence of odours, and from the measurement of moisture content and porosity. Procedures for measuring moisture content and porosity are provided on pages 7 and 8 (see Material Testing).

It is important to control moisture during composting for the following reasons:

- if compost materials become too dry, biological activity will slow down and eventually cease;
- if compost materials are too wet, excess water fills the pore spaces, impeding the diffusion of oxygen within the pile, leading to anaerobic conditions. Anaerobic conditions are undesirable, as they quickly result in slow decomposition and the production of foul odours (organic sulfides); and
- in humid regions such as Atlantic Canada, uncontrolled precipitation (or > 600 mm annual precipitation) can result in excessive leaching of nutrients, resulting in a low nutrient compost product.

Moisture control strategies during composting include adding water to a dry pile, composting in a covered building (Fig. 12), use of fabric windrow covers, and maintaining a steep pitch on the windrow to reduce infiltration and promote the runoff of precipitation. Increasing the turning frequency is a practical and easy way to dry an excessively moist windrow or pile. If the moisture content is greater than 60%, however, it is usually recommended to add dry amendments and re-mix.

Figure 12: *Composting in a covered building at Herman Mentink's farm, Kings Co., NS (photo by Derek Lynch).*

Odour

There are three primary sources of odour at a composting site: (1) odours associated with anaerobic conditions within windrows and piles; (2) ammonia lost from high-N materials; and (3) odours associated with raw materials. As indicated in Table 5, each of these issues require different management strategies.

__Table 5:__ Sources of odour in on-farm composting and corresponding odour management strategies.

Odour source/situation	Management
Odours associated with anaerobic conditions	• maintain pile porosity at 40% or greater • keep pile height low enough to avoid compaction (≤3.6 m) • ensure good pile drainage • keep pile moisture content between 45 - 65%
Excessive ammonia release	• maintain optimum C:N ratio (>30) • avoid excessively high pH (not ≥8.0)
Site-related odours, or odours associated with raw materials	• keep compost site clean • keep piles of unused feedstocks dry • prevent accumulation of on-site standing water and dust • immediately mix N-rich raw materials with a balanced, degradable carbon source

Compost Curing

Following active composting, compost requires a curing period of at least one month to finish the process and to allow the compost to develop the desired characteristics for its intended use. Actively composting piles may be ready for curing in as little as three weeks, however, three months is more typical and longer times are possible (Dougherty 1999). The two best indicators that compost is ready for curing are:

- there is a sustainable drop in pile or windrow temperature; and
- the pile or windrow no longer re-heats after turning.

Compost which has not undergone a significant curing period may still be used as a soil amendment, however, it should not be sold or used in most horticultural applications.

Since the material in the curing piles undergoes slow decomposition, aerobic conditions must still be maintained. Anaerobic or 'sour' curing piles develop odours and compounds which are toxic to plants (i.e. Phytotoxins). Although turning and forced aeration are unnecessary, curing piles should be small enough to permit adequate natural air exchange. Site requirements and management activities for curing and storage piles are as followed (Rynk1992):

- provide a well-drained area, with surface runoff channeled away from the piles;
- maintain a small pile size to allow efficient natural aeration. A maximum pile height of 2.4 m is often suggested, with smaller piles (maximum height of 1.8 m) recommended if the intended use requires a highly stable compost;
- monitor temperature and odour to ensure that high temperature and anaerobic conditions do not develop in the curing piles;
- to correct wet or anaerobic conditions, re-mix the pile contents and spread compost in an open area for 1 – 2 days; if pile re-heats after re-stacking, allow the material to actively compost for a short period to allow volatile or anaerobic compounds to degrade or dissipate;
- a safe practice for curing or storing piles is to restack compost from large storage piles into smaller piles a few weeks prior to use or sale; and
- in Nova Scotia, the Nova Scotia Department of Environment and Labour states that finished compost must not be stored outdoors.

Table 5: *Sources of odour in on-farm composting and corresponding odour management strategies.*

Odour source/situation	Management
Odours associated with anaerobic conditions	• maintain pile porosity at 40% or greater • keep pile height low enough to avoid compaction (≤3.6 m) • ensure good pile drainage • keep pile moisture content between 45 - 65%
Excessive ammonia release	• maintain optimum C:N ratio (>30) • avoid excessively high pH (not ≥8.0)
Site-related odours, or odours associated with raw materials	• keep compost site clean • keep piles of unused feedstocks dry • prevent accumulation of on-site standing water and dust • immediately mix N-rich raw materials with a balanced, degradable carbon source

Compost Curing

Following active composting, compost requires a curing period of at least one month to finish the process and to allow the compost to develop the desired characteristics for its intended use. Actively composting piles may be ready for curing in as little as three weeks, however, three months is more typical and longer times are possible (Dougherty 1999). The two best indicators that compost is ready for curing are:

- there is a sustainable drop in pile or windrow temperature; and
- the pile or windrow no longer re-heats after turning.

Compost which has not undergone a significant curing period may still be used as a soil amendment, however, it should not be sold or used in most horticultural applications.

Since the material in the curing piles undergoes slow decomposition, aerobic conditions must still be maintained. Anaerobic or 'sour' curing piles develop odours and compounds which are toxic to plants (i.e. Phytotoxins). Although turning and forced aeration are unnecessary, curing piles should be small enough to permit adequate natural air exchange. Site requirements and management activities for curing and storage piles are as followed (Rynk1992):

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- a safe practice for curing or storing piles is to restack compost from large storage piles into smaller piles a few weeks prior to use or sale; and
- in Nova Scotia, the Nova Scotia Department of Environment and Labour states that finished compost must not be stored outdoors.

Compost Quality

What is Compost Quality?

Compost quality refers to various characteristics of compost that determine its agronomic value, as well as its commercial value or marketability as a soil amendment. Compost that is *the mature product of a well managed composting process* can exert a variety of favorable effects on soils, horticultural media and plant growth. These include the improvement of soil physical properties, an increased ability of soils or other media to hold and supply water and nutrients, and enhanced soil biological activity. Beneficial effects of compost on plants include root stimulation and plant disease suppression. On the other hand, improper composting procedures may produce composts which are unstable, phytotoxic, disease-conducive, low in plant nutrients or generally detrimental to plant growth. Immature composts are particularly detrimental when added to soils or growing media, because they tie up available N and may contain phytotoxic volatile organic acids.

Compost quality characteristics are determined by:

- quality of the feedstock materials (e.g., volatile solids content, nutrient content, level of contaminants); and
- management of the composting process (steps taken to minimize nutrient loss, destroy pathogens and weed seeds, and achieve stabilization).

The compost quality characteristics which may be important at a given time are defined by the intended market or use, as well as the starting feedstock materials. For example, organic matter content and C:N ratio may be important parameters for on-farm use of compost as a field soil amendment, whereas maturity, soluble salts and particle size are often of greater interest when compost is used as a potting mix ingredient. High value markets, such as the nursery, landscaping and turf industries, generally require a screened product that meets high standards for product quality and consistency. Because of its important and far-ranging effects on plant performance, compost maturity is one of the main parameters for classifying compost in Canadian compost quality standards.

Freedom from pathogens (i.e., *Salmonella* and *E. coli*) and weed seeds may be specific requirements for composts prepared from manure-based feedstocks, whereas levels of other contaminants, such as heavy metals, plastics and glass, are common quality concerns when municipal feedstocks (municipal solid waste or leaf and yard waste) are included.

Compost Regulations and Standards

Agricultural composting which is conducted as part of normal farming practice is generally exempt from the provincial regulations and approval process which apply to commercial and municipal composting facilities. Separation distances and other site requirements for on-farm composting are outlined on page 6 of this manual (see Site and Environmental Requirements).

Wastes brought in from outside the farm (e.g., municipal organics, food processing wastes, leaf and yard wastes) may require special approval. Commercial production of compost and composting off-farm wastes requires approval from the Nova Scotia Department of Environment and Labour (NSDEL). Agricultural producers planning to compost off-farm wastes or produce compost for sale should always consult with provincial and federal authorities.

Standards for compost include both standards established by regulatory and standard-setting bodies, and performance-based standards established by the composting industry. For example, the Canadian Food Inspection Agency regulates compost that is sold in Canada under the authority of the Fertilizers Act and Regulations. There are also national and provincial compost standards that determine the suitability of compost for use on a regulated or unregulated basis. Compost quality standards established by the Canadian Council of Ministers of the Environment (CCME) and Bureau de Normalisation du Québec (BNQ) are currently under revision. These standards, however, are likely to have little application to on-farm produced composts unless these are sold or distributed off the farm. The composting industry in Canada is currently developing a quality seal program for compost which meets or exceeds performance requirements for a specific, stated, end use (e.g., growing media component, garden compost, topsoil blend, etc.). Producers who wish to obtain information on the status of current revisions to the Canadian compost standards and the new compost quality seal program, should contact the Composting Council of Canada at **http://compost.org**.

Conclusions

Composting is a managed decomposition process that transforms raw organic waste materials into a biologically stable material (compost) which can be used to improve the fertility and quality of soils. When conducted properly, composting can improve the quality and handling properties of manure, reduce environmental risk in manure management and provide economic advantages over other manure management options. Consequently, on-farm composting is being viewed as one component of an integrated waste management program that is feasible, beneficial and cost-effective.

On-farm composting systems can be designed to accommodate a wide range of feedstock materials, composting methods and compost management objectives. Certain conditions need to be met, however, in order to achieve the desired outcomes in terms of process efficiency, environmental stewardship and end product quality. These conditions range from providing the necessary area and site requirements, combining appropriate materials in the correct proportions, and managing factors such as temperature, moisture and aeration, until the compost is sufficiently stabilized for its intended use.

The purpose of this manual is to provide Nova Scotia producers with an improved understanding of on-farm composting of livestock manure. It will also serve as a practical guide for how to establish and manage on-farm composting systems with the least amount of odour, loss of N or other problems. The manual also identifies the characteristics of compost that determine its agronomic value and marketability as a soil amendment, as well as standards and regulations which apply to on-farm composting in Nova Scotia.

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References

Brethour, C., MacGowan, P., Mussell, A. and Mayer, H. 2002. Proposed New Environmental Legislation Affecting Canadian Agriculture. George Morris Centre, Guelph, ON. Available at: http://www.georgemorris.org/NMOnandABSpecialReport0102FINALCCB.pdf

British Columbia Ministry of Agriculture and Food (BCMAF). 1998. Agricultural Composting Handbook. Resource Management Branch, British Columbia Ministry of Agriculture, Food and Fisheries, BC. Available at: http://www.agf.gov.bc.ca/resmgmt/publist/Waste_Mgmt.htm

Canadian Council of Ministers of the Environment (CCME). 1996. Guidelines for Compost Quality. Canadian Council of Ministers of the Environment, Composting Sub-Committee. Winnipeg, MB. Publication No. CCME-106E.

Cooperband, L. 2002. The Art and Science of Composting - A Resource for Farmers and Compost Producers. University of Wisconsin-Madison, Centre for Integrated Agricultural Systems, Madison, WI. Available at: http://www.wisc.edu/cias/pubs/artofcompost.pdf

Dougherty, M. 1999. Field Guide to On-Farm Composting. Natural Resource, Agriculture and Engineering Service, Ithaca, NY. Publication No. NRAES-114.

Keener H.M., Ekinci, K., Elwell, D.L. and Michel, F.C. 2000. Mathematics of Composting Facility Design and Process Control. *In* Warman, P.R. and B.R. Taylor (Eds.). Proceedings of the International Composting Symposium (ICS), September 19-23, 1999, Halifax, NS. pp 164-197.

Rynk, R. (Ed.). 1992. On-Farm Composting Handbook. Natural Resource, Agriculture and Engineering Service, Ithaca, NY. Publication No. NRAES-54.

APPENDIX A: Balancing C:N and Moisture Content in Compost Mixtures (adapted from BCMAF 1998)

The formula used to optimize moisture content in compost mixtures (i.e., determine the required amount of ingredient **a** per kg of **b**) is:

$$a = \frac{Mb - M}{M - Ma}$$

The formula used to optimize C:N ratio is:

$$a = \frac{\%Nb}{\%Na} \times \frac{(R - Rb)}{(Ra - R)} \times \frac{(1 - Mb)}{(1 - Ma)}$$

Where:

a, b = weight of ingredients a, b

Na, Nb = N content (%) of ingredients a, b (dry weight basis)

Ma, Mb = moisture content (%) of ingredients a, b

Ra, Rb = C:N ratio of ingredients a, b

M = desired moisture content of mixture

R = desired C:N ratio of mixture

Example: C:N Ratio and Moisture Calculations
Assume a broiler breeder farm has manure to compost and that sawdust will be used as a bulking agent. How much sawdust and water needs to be added to the manure to have a good compost mix?

Given:

Ingredients	% N (dry weight)	C:N Ratio	% Moisture
Broiler breeder manure	3.6	10	46
Sawdust	0.1	500	20

1. Determine the weight of sawdust (**a**) needed for a desired C:N ratio of **R = 30**.

$$a = \frac{\%Nb}{\%Na} \times \frac{(R - Rb)}{(Ra - R)} \times \frac{(1 - Mb)}{(1 - Ma)}$$

$$a = \frac{3.6}{0.1} \times \frac{(30-10)}{(500-30)} \times \frac{(1 - 0.46)}{(1 - 0.20)} = \frac{3.6}{0.1} \times \frac{20}{470} \times \frac{0.54}{0.80} = 36 \times 0.043 \times 0.68 = 1.0$$

Answer: For each kg of manure, add 1.0 kg of sawdust to obtain a C:N ratio of 30.

2. The mixture moisture content (**Mb**) is 33%. Determine the quantity of water (**a**) required to adjust moisture content to **M = 55%** (Note: **Ma** is the quantity of water, and has a moisture content of 100% or 1.0).

$$a = \frac{Mb - M}{M - Ma} \qquad a = \frac{0.33 - 0.55}{0.55 - 1.0} = \frac{-0.22}{-0.45} = 0.49$$

Answer: Add 0.49 kg of water for every 1.0 kg of manure/sawdust mix.

Appendix B: Useful Conversions

Units	Approximate Conversion Factor (multiply by)	Results in
AREA		
hectares	2.47	acres
square kilometers	0.39	square miles
square meters	1.12	square yards
acres	0.4	hectares
square feet	0.09	square meters
square inches	6.5	square centimeters
square miles	2.59	square kilometers
square yards	0.84	square meters
MASS (weight)		
grams	0.002	pounds
ounce	28	grams
metric tons	0.98	tons (long 2240lb)
metric tons	1.102	tons (short 2000lb)
pounds	0.453	kilograms
tons (long 2240lb)	1.01	metric tons
tons (short 2000lb)	907.18	kilograms
tons (short 2000lb)	0.90	metric tons
VOLUME		
liters	0.26	gallons
liters	0.9	quarts
cubic feet	0.028	cubic meters
cubic yards	0.76	cubic meters
gallons	0.0038	cubic meters
gallons	3.78	liters
DENSITY (mass per unit volume)		
pounds / cubic foot	16.019	kilograms / cubic meter
pounds / cubic inch	27 679.90	kilograms / cubic meter
pounds / cubic yard	0.5933	kilograms / cubic meter

Units	Approximate Conversion Factor (multiply by)	Results in
LENGTH		
centimeters	0.39	inches
cubic meters	35.31	cubic feet
meters	3.28	feet
meters	39.37	inches
feet	0.3	meters
inches	2.54	centimeters
yards	0.91	meters
AGRICULTURE		
gallons / acre	11.230	litres / hectare
quarts / acre	2.8	litres / hectare
pints / acre	1.4	litres / hectare
tons / acre	2.24	tonnes / hectare
pounds / acre	1.12	kilograms / hectare
ounces / acre	70	grams / hectare

TEMPERATURE

°F = degrees Fahrenheit

°C = degrees Celsius

$$°F = (°C \times \frac{9}{5}) + 32$$

$$°C = \frac{5}{9} \times (°F - 32)$$

APPENDIX C: Composting Resources

Web-Based Resources

Agricultural Composting Handbook. 1998. British Columbia Ministry of Agriculture and Food (BCMAF), Resource Management Branch. Eighteen individual Composting Factsheets available at:
http://www.agf.gov.bc.ca/resmgmt/publist/Waste_Mgmt.htm.

Moisture and C/N Ratio Calculation Spreadsheet. Spreadsheets available for download at the Cornell Composting website:
http://compost.css.cornell.Edu/download.html.
This may be used to determine how much carbon-containing amendment needs to be mixed with manure or other N-containing materials.

Compost Testing. The Ohio State University Extension on-line Factsheet. Available at: http://ohioline.osu.edu/anr-fact/pdf/0015.pdf.

On-line Composting Course. "Basic Composting Skills" is a 13-week "hands-on" web-based course, offered on both a credit and not-for-credit basis by the Centre for Continuing and Distance Education at the Nova Scotia Agricultural College. In this course, students share (on-line) their experiences in making compost from manure-based feedstocks while acquiring the knowledge and skills for efficient composting and the successful use of compost in organic production systems. A more detailed description of this course, including information on how to register, are available at the website of the Organic Agriculture Centre of Canada at: http://www.organicagcentre.ca/Courses/wc_compost.html.

Video

Farm-Based Composting: Manure and More – This 38 minute video, available from the Cornell Waste Management Institute, covers methods and equipment used in composting, with an emphasis on use of existing agricultural equipment. In addition to aerobic thermophilic composting, the film describes other methods such as vermicomposting, manure aeration and anaerobic digestion.
($19 (US) plus S&H)

Natural Resource, Agriculture and
Engineering Service
P.O. Box 4557, Ithaca, NY
14852-4557.

Tel: (607) 255-7654
Email: NRAES@cornell.edu

Compost Thermometers

The supplier listed below provides a dial stem (61 cm) composting thermometer, with both Celsius and Fahrenheit scales, for approximately $30.00. Request Cat. No. 45953-00

Boreal Laboratories Ltd.
399 Vansickle Rd., St. Catherines, ON
L2S 3T4

Tel: (905) 984-3000 (800) 387-9393
Fax: (905) 984-3311 (800) 668-9106
Email: boreal@niagra.com

Laboratory Services

Nova Scotia Department of Agriculture
and Fisheries
Quality Evaluation Division,
Laboratory Services
P.O. Box 550, Truro, NS
B2N 5E3

Tel: (902) 893-7444
Fax: (902) 893-4193
http:www.gov.ns.ca/nsaf/