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# Compost Quality Assessment for Use in Horticulture: Impact of the Composting Process

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Partial support for this work was provided by: New York State Energy Research and Development Authority (NYSERDA), Cornell University Agricultural Experiment Station, Cornell College of Agriculture and Life Sciences and Cornell Cooperative Extension. Without the cooperation of participating farms, this project would not have been possible. The authors also wish to thank Francoise Vermeylen with the Cornell Statistical Consulting Unit for her assistance with the statistical analysis, Murray McBride for help interpreting results of the analysis and Tom Fiesinger, NYSERDA Project Manager for supporting this project.

Key Words: compost, manure, compost use, compost quality, potting media

## Abstract

Although there are many potential opportunities for the use of agricultural composts in horticultural production systems, lack of communication between compost producers and end-users has impeded the effective recycling of manure-based composts to benefit soil health. Our survey of compost users found that compost performance in terms of plant production was a primary concern in choosing which products to use, but that there was little agreement on which parameters of compost quality would predict satisfactory performance. Twenty-five agricultural manure-based composts from NY State were analyzed in terms of 1) method of production, 2) parameters of finished material, and 3) performance as measured by seed germination and plant growth. Results showed that these composts were appropriate for a variety of horticultural uses. Manure type (poultry vs. dairy) as well as separation (separated and unseparated dairy manure) had a major impact on compost parameters. Certain aspects of the composting process affected characteristics of the finished material, with pad type (soil, gravel or concrete) impacting nitrogen, phosphorus and organic matter content and the use of $CuSO4$ foot baths for hoof health impacting both copper levels and soluble salts. A detailed information sheet for agricultural composts that provides sufficient information for horticultural end users to make informed purchasing choices is proposed.

Compost has many uses in horticultural production systems (Stofella and Kahn, 2001; Termorshuizen et al., 2004). It can be used as a field soil amendment with the primary benefit of increasing soil organic matter and stimulating soil microbial communities (Lynch et al., 2005; Raviv, 2005), and as a partial peat substitute in potting media (Moore, 2005). Compost amendments can at least partially replace some synthetic inputs by providing essential plant nutrients and increasing the disease suppressive nature of both soil and potting media. There is a large body of scientific work documenting the disease suppressive nature of some compost amendments towards a wide variety of plant diseases (Hoitink et al., 1991; Hoitink and Kuter, 1986; Weltzien, 1989), although inconsistency of disease control can impede effective use. As the science and technology of compost production and use advance, compost products will increasingly be able to meet the varied needs of end users (Fitzpatrick et al., 2005).

Another benefit of using composts in agricultural and horticultural production is the pollution prevention that can be achieved by recycling organic wastes from one agricultural sector into a valuable soil amendment in another. Excess nutrients from manure storage and over application in agriculture can cause eutrophication in bodies of fresh water (Glasgow and Burkholder, 2000) and are one component of downstream aquatic ecosystem collapse in the Gulf of Mexico (Rabalais et al., 2002). Making and selling compost is an alternative to transporting raw manure in situations where nutrients must be removed from fragile watersheds. Composts can also serve as a source of organic matter which helps restore degraded soils (NRCS, 2003) and provides nutrients for plant production.

Using composts can increase the long term sustainability of agriculture in terms of its impact on global climate change. Peat mining disrupts wetland ecosystems, causing the release of plant-based carbon that had been stored in peat bogs since the last major glaciation (Smith et al., 2001). The production of synthetic fertilizers relies heavily on the use of fossil fuels. For example, anhydrous ammonia is made from natural gas, using more natural gas to fuel the process (Schwartz, 2002). Compost can serve as a partial substitute for both peat and synthetic fertilizers, thus offsetting their associated carbon emissions. The fossil energy required for composting varies greatly depending on the management of material collection, preparation, handling and delivery. One analysis that factored in the carbon emissions associated with the composting process as well as the $CO_2$ emitted by microorganisms during biodegradation, and subtracted the offset emissions of peat and synthetic fertilizer, found that the composting process is not just ‘carbon neutral’, it can be substantially ‘carbon negative’(Smith et al., 2001). Connecting compost producers with end users in the same region could reduce carbon emissions associated with long distance transport of synthetic fertilizers and compost produced outside of the region.

A major barrier to the utilization of composts in agriculture and horticulture is the lack of communication between compost producers and end users (Raviv, 2005). Since manure management is the primary goal of many livestock producers who produce compost, they may not always be aware of their end users’ material specifications. Conversely, growers using compost may not always have access to specific information about a particular compost in order to choose a product best meeting their needs (Raviv, 2005). Composts are made from a variety of feedstocks, using many different methods, which results in a wide range of physical, chemical and biological characteristics of the finished compost (Benito et al., 2006; Termorshuizen et al., 2006; Zmora-Nahum et al., 2007). Different types of composts are thus suited for different end uses, but in many cases vital connections between producers and users of compost are not made.

The overall goal of this project is to increase the usage of composted livestock manure in horticultural production systems for the environmental benefits listed above as well as to provide a potential boost to rural economies with the sale of value-added products. Local networks of compost production and use could provide additional income for livestock farmers as well as cost-effective input replacements for end users in the horticultural and landscape sectors. In order for this concept to become a reality, compost producers must be linked with appropriate end use markets. This requires that compost users learn what information to look for to evaluate the quality and select compost products, and compost producers learn how to make products that best fit the needs of end users. In order for compost end users to make informed purchasing decisions, information on compost quality must be made available for each compost product. In our survey of 25 livestock farms producing compost in New York State, we were most interested in answering the following questions; 1) How do different composting processes affect the physical and chemical properties of the finished compost; and 2) How does the composting process affect the presence of common compost contaminants?

## Materials and Methods

*Compost end user survey*. Agricultural businesses (n = 47) and home gardeners (n = 107) were surveyed through the Cornell Waste Management Institute (CWMI) website, interviews, and at turf, horticulture and vegetable-focused professional meetings. Participants were asked a range of questions on why and how they use compost and what kind of information they would like to see on compost product labels. The full details of the compost end user survey, including the survey instrument, can be found on the CWMI webpage (Harrison, 2001) and summarized elsewhere (Bonhotal, 2000; Harrison et al., 2003).

*Compost sampling*. Composite compost samples were collected from 25 livestock farms in New York State over a two year period (1997 – 1998). Descriptive data for each on-farm composting operation were collected (Table 1.) Manure types included dairy manure (separated and unseparated) and poultry manure. Dairy manure varies greatly in consistency based on how it is handled before composting. Separation of dairy manure is a mechanical process whereby solids are squeezed under centrifugal or slot-plate pressure into a liquid and a semi-solid component (usually around 30% solids) that may be composted. Bulking agents added as a carbon source were identified. Composting operations had four methods for aerating and/or turning compost piles; windrow turners (WT), bucket loaders (BL), passively aerated windrow systems (PAWS) that are turned infrequently, and forced air (FA) systems that are not turned. With PAWS, air circulates through the windrow naturally due to good pile structure, while in forced air systems air is mechanically forced through pore spaces in the pile. Composting operations were divided into turning categories; no turning, low turning frequency (< 12 times/year) and high turning frequency (> 12 times/year). A dummy variable ‘management’ was created to capture the observed combinations of bulking agent, turning method and turning frequency. Several of the management variables are only represented by one farm. This decreased possible statistical rigor, but is a reflection of the types of operations available for this applied study. The types of pad surfaces on which the compost was made included soil, gravel, and concrete. The use of copper sulfate foot baths for hoof health at some dairy farms was recorded to test its’ potential impact on compost chemical characteristics. Composite compost samples, consisting of 16 grab samples mixed together, were obtained from piles which the farmer considered ready to use. Two to six replicate composite samples were obtained during each sampling event and each sampling event at a single farm was considered a 'batch' for the statistical analysis. Composts at individual farms were sampled from one to five times over the project period.

*Laboratory analysis of compost samples.* Samples were analyzed by Woods End Laboratories (WERL, Mt. Vernon, ME) using published protocols consistent with either the United States Composting Council's Test Methods for the Evaluation of Composting and Compost (USCC TMECC) (Thompson et al., 2002), the EPA 40 CFR Part 503 rules for Biosolids testing (USEPA, 1993), or the Compost Methods Manual of the German Compost Association (Kehres and Pohle, 1998) depending on the particular parameter. Testing parameters were selected based on their routine use in characterizing composts and their level of importance reported by end users through the end user survey mentioned above.

Total Kjeldahl nitrogen (TKN) was determined using TMECC Method 4.02 (Bremmer and Mulvaney, 1982). After an aqua regia digestion, total phosphorous was determined by Inductively Coupled Plasma Emission Spectrometry (ICP) using TMECC Method 4.03-A. Total organic matter (OM) was measured through the loss on ignition (LOI) method, TMECC Method 5.07-A. Electroconductivity (EC or soluble salts) and pH were measured using a pH and EC probe (Orion Systems, Thermo Scientific, Waltham, MA), using a 1:2 v:v compost:water slurry (Wolfe, 2003). Composts were evaluated for $CO_2$ and $NH_3$ production to determine compost maturity (Woods End Research Laboratory, Mt. Vernon, ME; TMECC Method 5.08-E). Compost maturity increases with increasing levels in the index, with levels 1 and 2 defined as "raw" compost, levels 3-6 defined as "active compost" and levels 7 and 8 defined as "finished compost" (Brinton, 2002). Bulk density was measured using TMECC Method 3.01-A. Heavy metals (copper, iron, zinc, arsenic, and cadmium) and fecal coliforms were measured using methods outlined in EPA 40 CFR Part 503 rules for Biosolids testing (USEPA, 1994). For the weed seed bioassay, composts were diluted to a standard salt content (2 mmhos $cm^{-1}$, TMECC Method 5.09-B) using a professional peat-mix limed to pH 5 (Fafard, Agawam, MA). Weed seeds were reported as number of seedlings per liter compost after 14 days. For plant performance bioassays, composts were diluted to a standard salt content (2 mmhos $cm^{-1}$, TMECC Method 5.09-B) using peat with no added nutrients. Cress (*Lepidium sativum*, Johnny's Seeds, Albion, ME) growth in the peat - compost mixture was compared to a control group planted in a professional peat mix with added synthetic nutrients (B2, Fafard, Agawam, MA) for percent seed germination and plant fresh weight after 14 days (Fuchs et al., 2001; Kehres and Pohle, 1998).

*Statistical analysis*. All statistical analyses were carried out using the 'proc mixed' function in SAS 9.0.1 (SAS Institute, Cary NC). Variables were divided into four categories; 1) composting process (manure type, bulking material, addition of food scraps, turning method, turning frequency, pad type, copper footbath, and management), 2) compost parameters (nitrogen, phosphorus, pH, soluble salts, bulk density, maturity, organic matter, and C to N ratio), 3) compost performance (plant bioassays: relative growth and germination), and 4) compost contaminants (copper, fecal coliforms, and weeds). A dummy variable 'management' was created to capture all the observed combinations of bulking agent, turning method and turning frequency (Table 1.). Farm composting site and the interaction between site and batch tested were used as random effects. Mixed models were constructed to determine the following 1) the effect of composting process on compost parameters, 2) the effect of compost parameters on compost performance and 3) the effect of composting process on compost contaminants. Models were constructed using the individual variables of bulking agent, turning frequency, and turning method as well as the dummy variable 'management' that lumps these three variables into one. Poultry manure composts were distinct in many ways from dairy manure composts, skewing the analysis. Data from poultry manure composts were removed from the main dataset, but provided too small of a sample size to be analyzed separately. Alpha was set at 0.10, with all p-values less than or equal to 0.10 considered significant. Significant overall effects were followed by a multiple comparison procedure to further determine significant differences among levels of the variables.

## Results

*Compost end user survey*. The full results of the end user survey can be found on the CWMI website (Harrison, 2001) and summarized elsewhere (Bonhotal, 2000; Harrison et al., 2003). Respondents from the horticultural sector indicated using composts primarily for soil structure, but also as a growth medium, to enhance biological health, to provide plant-available nutrients, and to retain moisture. Growers were most interested in how composts perform and not as concerned about type of feedstock used in compost production when choosing compost products. The main concerns with compost use that growers indicated were inconsistency of individual compost products followed by weed seeds and chemical contaminants. In terms of compost labeling, growers were most interested in seeing information on pH and NPK content followed by organic matter and carbon to nitrogen ratio. Having maturity, feedstock and weed seeds actually listed on the label were low priority.

*Laboratory analysis of compost samples*. Results for compost parameters, compost performance (plant bioassays) and compost contaminants in dairy manure composts are summarized in Table 2 and Figs. 1-3. Site by site comparisons for all of the parameters tested can be found in the online report (Harrison, 2001). As shown by the large differences in standard deviations for parameters measured at a particular farm over the study period, the variability of results was much greater at some farms than at others where compost characteristics were quite consistent (Table 2). Viable weed seeds varied in composts from none to more than 227 $L^{-1}$ (Fig. 1). Overall, composts had consistently low weed seed levels ($\leq 5\ L^{-1}$), while composts from three specific sites had much higher levels. Cress seeds germinated well in the majority of the composts tested, with germination in the unfertilized compost – peat mixes nearly equivalent to that in the fertilized industry standard control mix. However, three of the poultry manure composts showed poor germination down to an average of 25% of the control (Fig. 2). When mixed with unfertilized peat as specified in the test method, most composts supported cress growth at rates higher than 80% of plants in the fertilized industry standard control mix, with three composts resulting in higher growth than the control, and three poultry manure composts resulting in much lower (< 34%) growth than the control (Fig. 3).

## Statistical analyses

T*he effect of composting process on compost parameters*. The following models are for dairy manure composts only. Poultry manure composts were so different from dairy manure composts that nearly all of the statistical models run with the full dataset resulted in 'manure type' as the only variable affecting each compost parameter (data not shown). Since these composts skewed the results, they were removed from the analysis.

**Nitrogen:** Total Kjendahl nitrogen levels in the composts tested were affected by pad type and manure type (Equation 1, Table 3). Composts made with separated dairy manure had significantly higher nitrogen levels (lsmean = 2.42%) than those made with unseparated dairy manure (lsmean = 1.66%). Composts made on concrete pads had the highest total nitrogen content (lsmean = 2.44%), followed by those made on gravel (lsmean = 2.05%) and those made on soil (lsmean = 1.62%).

**Phosphorus:** Phosphorus content was affected by pad type, management, and the interaction of these two variables (Equation 2, Table 3). Composts with the highest phosphorus content were made on soil pads with management variable 6 (straw as a bulking agent, passively aerated windrow system, low turning frequency) (lsmean = 0.74%) and on gravel pads with management variable 2 (straw as bulking agent, windrow turner, high turning frequency) (lsmean = 0.73%).

**Potassium:** Potassium content was affected by management type (Equation 3, Table 3). Management variable 9 had the highest potassium content (straw and wood as bulking agents, forced air and no turning) (lsmean = 3.25%). This management variable is only represented by one site which is an indoor facility.

**Organic matter:** Pad type significantly affected organic matter content (Equation 4, Table 3). Composts from sites with concrete pads had significantly higher organic matter content (lsmean = 70.27%) than those with gravel or soil pads (lsmeans = 41.38%, 36.21%).

**pH:** Manure type, management, and screening affected compost pH (Equation 5, Table 3). Separated dairy manure composts had significantly higher pH values (lsmean = 7.85) than those made with unseparated dairy manure (lsmean = 7.47). Composts made with the management variable 4 had higher pH (lsmean = 8.5) than those made with all other management types. Management variable 4 includes, unseparated dairy manure, wood as a bulking agent, windrow turner and high turning frequency. Composts that had not been screened had significantly higher pH (lsmean = 7.9) than those that had been screened (lsmean = 7.3).

**Soluble salts:** Management type and use of a footbath significantly affected the soluble salts in finished compost (Equation 6, Table 3). Management variable 9 (straw and wood as bedding, forced air, no turning) had significantly higher soluble salts than all other management types (lsmean = 7.50 mmhos $cm^{-1}$). This management variable is only represented by one site which is an indoor facility. Composts from dairies using footbaths had significantly lower soluble salts (lsmean = 2.04 mmhos $cm^{-1}$) than those from dairies not using footbaths (lsmean = 4.67 mmhos $cm^{-1}$).

**Density:** Density was only significantly affected by manure type (Equation 7, Table 3). Composts made with unseparated dairy manure had higher densities (lsmean = 50.13 lb $ft^{-3}$) than composts made with separated dairy manure (lsmean = 42.15 lb $ft^{-3}$).

**Maturity:** Compost maturity, as measured by the Solvita method, was not significantly affected by any of the compost process variables.

**C to N:** Carbon to nitrogen ratio was not significantly affected by any of the compost process variables.

*The effect of compost parameters on compost performance.* Cress (*L. sativum*) seed germination and growth were used as indicators of compost performance. Compost samples were diluted to a standard salt content resulting in different ratios of compost to peat. The characteristics of the final growth media were not analyzed and due to the variable dilution, we were unable to evaluate the impact of specific compost parameters on compost performance.

*The effect of composting process on compost contaminants.* The concentration of copper in finished composts is affected by the use of copper sulfate footbaths on dairy farms, the management variable and the interaction of these variables (Equation 8, Table 3). Composts made at dairy farms using copper sulfate footbaths had significantly higher copper levels (lsmean = 304 ppm) than those made at farms not using the footbath (lsmean = 137 ppm). Compost made with management type 10 (represented by a single farm that used straw and wood for bulking, turned infrequently with a bucket loader on a soil pad) had significantly higher copper levels (lsmeans = 729 ppm) than all other management types.

None of the composting process variables had a significant effect on the presence of fecal coliforms or weed seeds in the finished compost.

## Discussion

Composting process affects measured parameters. An initial analysis of the full data set showed that manure type affected almost every parameter tested (data not shown). In fact manure type was the only aspect of the composting process that significantly affected resulting phosphorus levels, pH, soluble salts, and bulk density of the finished compost. Poultry manure composts had significantly higher nitrogen and phosphorus levels than either type of dairy manure, as well as significantly higher soluble salts. Four of the seven poultry composting operations were conducted indoors so that precipitation could not remove these constituents through leaching. The high levels of ammonia in poultry manure composts contribute to both the higher total nitrogen content, and the soluble salts. In general, poultry manure composts were less mature than those made with dairy manures. One of the poultry farms used an alternative composting method, halting the process before it was finished by drying the material in order to sell the finished product as a fertilizer. This alternative method could account for some of the differences in maturity between dairy manure and poultry composts. Because the poultry manure composts exhibited such a strong influence on the results of the analysis, they were removed from the dataset for further modeling.

One of the most striking results is the effect of pad type on both nitrogen and organic matter content. Both models showed the same ranking of pad types; soil < gravel <concrete. It is highly likely that as equipment is used to turn compost windrows on unimproved or marginally improved pads, soil and gravel are scraped up and mixed into the windrow. This results in a dilution effect by adding extra mineral material to the compost.

TKN was consistently higher in composts made from separated dairy manure. Feedstock materials and liquid effluent (not incorporated into the compost piles) were not tested for nitrogen content so it is not clear if differences in nitrogen were a reflection of differences in the starting material or due to changes in denitrification during the composting process. No discernible trend could be seen with phosphorus content. Many dairies use phosphate as a dietary supplement in their feed, but no data were collected on phosphorus levels in feed so it is difficult to say if this herd management practice impacted compost phosphorus levels.

Manure separation affected pH levels. Fresh separated dairy solids usually have high pH, 8.5-9.0 (CWMI unpublished data), compared to manure slurries, 7.0 (Umetsu et al., 2005), and the pH values for the finished composts reflected this trend. It is not clear how management type or screening may affect pH. Manure separation also led to lower density in finished composts. Manure separators have screens through which liquid effluent passes (Gooch et al., 2005). Some of the smaller particulate matter in the raw unseparated manure is removed with the liquid effluent during the separation process, leading to a higher proportion of larger particles in the separated solids and may be the cause of the lower density.

Management type significantly influenced soluble salts in the finished compost. The management variable with the highest soluble salts is represented by one site which is the only indoor dairy manure composting facility in the study. Protecting windrows from rainfall can prevent leaching and lead to a buildup of salts, which most likely accounted for the high soluble salts at this particular site. This indoor facility also had significantly higher potassium than all other sites. Soluble salts were substantially lower in composts made at dairies that use a copper sulfate footbath. Conductivity, a measure of soluble salts, is influenced by the mineralization of organic matter, with higher mineralization leading to higher levels of organic acids, volatile fatty acids, phosphates, sulfates etc., resulting in higher soluble salts. The presence of copper can inhibit the mineralization of organic matter (Aoyama, 1998), which could explain the observations regarding soluble salts in the finished materials.

The statistical analysis found no significant model for the effect of compost process on maturity. Since our sampling protocol relied on the judgment of the compost producer to identify piles and windrows that were ready to sell, there was a large variability in compost maturity in our dataset. Because the maturity was subjectively selected by compost producers, it is not appropriate to use this variable as a compost parameter. A more controlled study using compost batches of known ages is required in order to determine how the composting process affects maturity.

### Measured parameters affect compost performance.

When this study was conducted (1997-1998) the TMECC methods had not yet been compiled by the USCC. The current TMECC method for assessing compost performance uses a standardized 50:50 compost: peat mixture and cucumber seeds (Thompson et al., 2002). The method used in this study (Kehres and Pohle, 1998) used different ratios of compost to peat depending on salt content. With this method, there is no way to attribute differences in plant response to particular compost parameters since the characteristics of the compost/peat growth media are not known.

All of the dairy manure composts and several of the poultry composts showed greater than 75% growth and 90% germination indicating that although some of those composts were diluted up to 10:1 with peat, there were still enough nutrients to allow good growth and germination. Lack of available plant nutrients was not the cause of the poor growth response observed in some composts. While one of the poultry composts demonstrated the best growth response of all of the composts tested, three indoor poultry manure composts with the highest salinities (> 17 mmhos $cm^{-1}$) showed much lower growth (<34%) and germination (<25%) than the controls, indicating the possible presence of some unidentified toxic substance since composts were diluted to a standard salt content before use in this assay.

*Composting process affects contaminants.* Not surprisingly, copper levels were highest in composts made at dairies that reported using a copper sulfate foot bath for hoof health. Five farms using separated dairy manure and copper sulfate foot baths had average copper levels ranging from 197.5 to 769.8 ppm. Three other farms that reported using copper sulfate foot baths had copper values below 100 ppm. None of the other metals tested were present at levels high enough to cause concern (data not shown).

No recorded aspects of the composting process significantly affected the presence of fecal coliforms. Under federal and state regulations pertaining to sewage sludge composts, one of the requirements for achieving Class A status for public distribution is all compost samples must either have less than 1000 MPN/g fecal coliform or have Salmonella levels less than 3 MPN/4 gm of compost. We did not test for Salmonella, but fecal coliform testing showed that a majority of the composts in this study would have passed this rigorous level of biological safety testing applicable to sewage sludge composts (only 13/155 samples had > 1000 MPN fecal coliforms). There are currently no standards for potentially pathogenic microorganisms in livestock manure-based composts, although composts used in National Organic Program-certified organic agricultural systems must meet the time – temperature requirements developed for the EPA part 503 sewage sludge rule (NOP, 2002).

There was no clear effect of composting process on the presence of viable weed seeds. Factors such as site maintenance and distances from weed sources could potentially explain the differences in weed seed content between sites. There are no guidelines for weeds in compost in the U.S., while guidelines for individual countries in Europe call for anywhere from none (Belgium) to < 5 seeds $L^{-1}$ (UK) (Hogg et al., 2002). In this study, 17 of the 25 farms tested had average weed seed counts of below 5 $L^{-1}$.

*Types of end uses based on performance*. Composts may be applied directly to soil for various uses and they can also serve as potting media amendments. Suitability for a particular end use depends on a number of physical and chemical attributes such as salinity, bulk density and water holding capacity (Gouin, 1994; MSC, 2004). In some cases, growers are avoiding compost use due to uncertainties about properties and appropriate application rate (Roe, 2003). In western nations, testing composts for safety (microbiological and metals) is much more common than testing for and reporting traits important for determining the appropriate end use of the material (Hogg et al., 2002). Compost producers submitting samples to laboratories may not specify test parameters that are relevant to determining appropriate end uses and laboratories generally do not know the intended use. Thus appropriate tests may not be performed and users may not have sufficient information to make choices resulting in successful performance.

Organic Gardening Magazine performed a test survey of bagged composts and reported an extremely wide range in appearance and test traits, and suggested end-users would be unable to properly distinguish the suitability of the composts for the desired use based on the information available on the packaging (Long, 1999).

Several organizations have developed programs to assist users in determining the suitability of composts for particular uses. The U.S. Composting Council provides guidelines for density, organic matter content, pH, soluble salts, maturity and several metals for a number of compost uses (USCC, 1996; USCC, 1997; USCC, 2001) The Swiss Compost Association ranks composts into several use groups based on salinity, maturity and other parameters (Fuchs et al., 2001). Wood End Research Laboratory in conjunction with the Rodale Institute has developed a method to evaluate the suitability of composts for particular end uses. Samples submitted to the lab are analyzed for a number of parameters and the method employs data arrays to sort compost test results into six potential best-use groups (Brinton and Meyer, 2002). A program of the Mulch and Soil Council certifies soils, not composts, for several uses based on growth tests (MSC, 2004). All of the rating systems rely on the availability information on a variety of chemical, physical and biological traits.

*Policy and barriers to labeling*. Compost producers may want to provide compost quality information to the end user, but surprisingly in most cases they are legally prevented from doing so. The ability of compost producers to provide information regarding their compost is hampered by fertilizer rules in most states of the U.S. that predate the common use of composts. Those rules, based on a model regulation developed by the American Association of Plant Food Control Officials, stipulate that any product stating nutrient content must label the guaranteed minimum NPK content based on weight (AAPFCO, 2000). They also prohibit labeling of other attributes and parameters. Developed for formulated fertilizers, these rules are not appropriate for composts since compost moisture content will change, nutrient content will vary and other parameters, such as organic matter and pH, are important attributes to include in any labelling. In response to stakeholder input coordinated by CWMI, the New York State Department of Agriculture and Markets, which regulates fertilizers, recently modified rules to address these concerns (NYSDAM, 2006), thus enabling agricultural compost products sold in New York State to provide relevant production information for consumers.

Testing is generally not required for agricultural composts. Thus there are few data on the quality of manure-based composts, which further hampers their marketing. Under the NYS revised rules, periodic testing is required for participating compost producers and labels reflect the average of test results. Since compost characteristics may change over time and with the feedstocks used, compost consumers end-users should look at results of tests taken close to the time of sale and examine both the average values and the range of test results in order to consider the variability of the product since the test results may not reflect the specific batch they purchase. Table 2 indicates the variability among the composts we tested. Over the study period, consistency varied greatly between composts. Some composts exhibited a large range in measured parameters, while others were relatively consistent over time. To address the need for providing information on compost quality to compost users, we propose the use of a standard information sheet for agricultural composts, similar to the nutrition label on foods in the U.S., to help increase communication between compost producers and end users (Fig. 4).

*Conclusions.* In the end user survey, growers were most interested in seeing pH, NPK, organic matter and C:N ratio listed on a compost product label. Weeds, metals and pathogens were all listed as grower concerns associated with compost use. While almost all metals were present in low concentrations in the manure-based composts, copper was elevated in compost from dairies using copper sulfate hoof baths. We were not able to predict the presence of fecal coliforms or weed seeds using the variables we measured. These contaminants are likely to be factors of individual site management, including equipment hygiene and proximity to weed seed sources. We found that the type of pad on which the compost is managed affected organic matter, nitrogen, and phosphorus content. The use of copper sulfate for hoof health was related to copper levels in the composts. It may be beneficial to perform a portion of the composting process outside to allow precipitation to leach out some of the salts and then to cure the compost in the final months under cover in order to control moisture and exposure to weed seeds.

Growers could have more consistent results if they had access to information on compost quality, allowing them to choose individual compost products based on their specific needs. These needs vary with the goal of the horticultural producer. For example, compost maturity may be relatively unimportant for composts used as soil amendments in the field while it will be of significance for use in a potting mix. Compost testing and labeling would help consumers make appropriate choices. It is unlikely, however, that test results would be available for the specific batch of compost at the time that of purchase. Because composts are a dynamic product relying on biological activity, a single batch is likely to change over time. Growers listed the inconsistency of compost parameters over time as their top concern and our results show that some composts vary while others are more consistent. Growers should examine compost test results from compost producers and should evaluate the consistency of test results over time. Because management measures are important in consistent compost quality, growers should develop long term business relationships with specific compost producers who intensively manage their operations and produce compost with consistent characteristics from batch to batch. Understanding how different aspects of the composting process affect important parameters of the finished compost will allow compost producers to manage their process in a way that will increase their potential pool of end users. Greater communication between compost producers and growers will increase the effective recycling of organic wastes in agricultural systems, while enhancing the long term sustainability of food production.

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Table 1. Description of on-farm composting operations.

| Manure | Bulking agent and other feedstocks | Turning method | Turning freq | M | Pad type | Cu | S | E | Farm ID | I/O |
|---|---|---|---|---|---|---|---|---|---|---|
| DS | Straw | WT | High | 2 | Gravel | + | 8 | 5 | 12 | O |
| DS | Straw | WT | High | 2 | Soil | - | 5 | 2 | 15 | O |
| DS | Straw, wood | BL | High | 3 | Soil | + | 3 | 1 | 16 | O |
| DS | Straw, wood | WT | High | 5 | Soil | + | 6 | 3 | 14 | O |
| DS | Straw | PAWS | Low | 6 | Concrete | - | 8 | 3 | 17 | O |
| DS | Straw, wood | FA | No | 9 | Concrete | + | 8 | 5 | 13 | I |
| DS | Straw, wood | BL | Low | 10 | Soil | + | 12 | 5 | 18 | O |
| DU | Straw | BL | High | 1 | Soil | + | 6 | 2 | 1 | O |
| DU | Straw, food scraps | WT | High | 2 | Soil | - | 5 | 3 | 2 | O |
| DU | Straw, wood | BL | High | 3 | Soil | + | 12 | 3 | 3 | O |
| DU | Straw, wood, food scraps | BL | High | 3 | Gravel | - | 6 | 2 | 7 | O |
| DU | Straw, wood | BL | High | 3 | Soil | - | 5 | 2 | 8 | O |
| DU | Straw, wood, food scraps | BL | High | 3 | Gravel | - | 6 | 3 | 10 | O |
| DU | Wood, food scraps | WT | High | 4 | Soil | - | 10 | 2 | 4 | O |
| DU | Straw, wood | WT | High | 5 | Soil | - | 6 | 2 | 5 | O |
| DU | Straw | PAWS | Low | 6 | Soil | - | 6 | 2 | 6 | O |
| DU | Straw | BL | Low | 7 | Soil | - | 5 | 2 | 9 | O |
| DU | Straw, wood, food scraps | WT | Low | 8 | Soil | - | 6 | 2 | 11 | O |
| P | Straw | WT | High | 2 | Concrete | NA | 6 | 2 | 23 | I |
| P | Wood | WT | High | 4 | Concrete | NA | 6 | 3 | 19 | I |
| P | Wood | WT | High | 4 | Soil | NA | 3 | 1 | 20 | I |
| P | Wood | WT | High | 4 | Soil | NA | 3 | 1 | 21 | O |
| P | Wood | WT | High | 4 | Concrete | NA | 5 | 2 | 24 | I |
| P | Wood | WT | High | 4 | Soil | NA | 3 | 1 | 25 | O/I |
| P | Straw | PAWS | Low | 6 | Soil | NA | 5 | 2 | 22 | O |

Manure types: DU = dairy manure (unseparated), DS = dairy manure (separated), P = poultry manure. Turning method: BL = bucket loader, WT = windrow turner, PAWS = passively aerated windrow system, FA = forced air. ‘Management’ (M) is a dummy variable used in the statistical analysis encompassing all variations of bulking agent, turning method and turning frequency. Cu + indicates farms that use a copper sulfate foot bath for hoof health. A sampling event (E) is a single visit to a specific farm where composite samples (S) were taken from the same or different compost piles as the previous visit. Composting was carried out indoors (I), outdoors (O), or a combination of the two (O/I).

Table 2. Summarized results for physical and chemical parameters of dairy manure composts. Site averages and standard deviations are reported for sites with the lowest and highest standard deviation for each parameter. Values are followed by the site numbers in parentheses.

| Parameter | Mean | Median | Range of standard deviations at specific farms | |
|---|---|---|---|---|
| | | | low | high |
| Nitrogen (%) | 1.7 ± 0.8 | 1.6 | 0.9 ± 0.03 (11) | 3.1 ± 0.76 (22) |
| Phosphorus (%) | 0.4 ± 0.2 | 0.3 | 0.3 ± 0.01 (11) | 0.7 ± 0.32 (6) |
| Potassium (%) | 0.7 ± 0.5 | 0.6 | 0.2 ± 0.01 (11) | 0.08 ± 0.5 (6) |
| C:N ratio | 13.9 ± 3.5 | 13.2 | 12.0 ± 0.7 (6) | 9.5 ± 9.8 (3) |
| Organic matter (%) | 42.8 ± 18.2 | 38.4 | 23.9 ± 1.2 (11) | 50.3 ± 18.7 (6) |
| pH | 7.7 ± 0.5 | 7.8 | 8.1 ± 0.03 (16) | 7.6 ± 0.4 (6) |
| Salts (mmhos $cm^{-1}$) | 4.1 ± 2.6 | 3.6 | 3.0 ± 0.2 (11) | 5.8 ± 6.9 (10) |
| Solvita maturity rating scale | 6.0 ± 1.0 | 6.0 | 7.0 ± 0.0 (2, 3, 10, 11)<br>5.0 ± 0.0 (16) | 6.6 ± 1.06 (12) |
| Bulk density (lb $ft^{-3}$) | 47.3 ± 8.4 | 47.0 | 47 ± 0.00 (2) | 38.1 ± 11.08 (18) |
| Copper (ppm) | 200 ± 257 | 70 | 26 ± 1 (2) | 405 ± 213 (14) |
| Fecal coliform (log MPN $g^{-1}$) | 1.3 ± 1.2 | 0.8 | 1.3 ± 0.3 (15) | 2.1 ± 1.9 (17) |

Table 3. Model equations for a) the effect of composting process on compost parameters, and b) the effect of composting process on compost contaminants. These models use only data from dairy farms, poultry farms have been excluded.

| Equations | p values |
|---|---|
| a) Effect of composting process on compost parameters | |
| 1. nitrogen = pad + manure | 0.0917, 0.0092 |
| 2. phosphorus = pad + management + pad*management | 0.0194, 0.0378, 0.0489 |
| 3. potassium = management | <0.0001 |
| 4. organic matter = pad | 0.0121 |
| 5. pH = manure + management + screen | 0.0671, 0.0533, 0.0422 |
| 6. salts = management + footbath | 0.0462, 0.0068 |
| 7. density = manure | 0.0022 |
| b) Effect of composting process on compost contaminants | |
| 8. copper = management + footbath + management*footbath | <0.0001, <0.0001, <0.0001 |

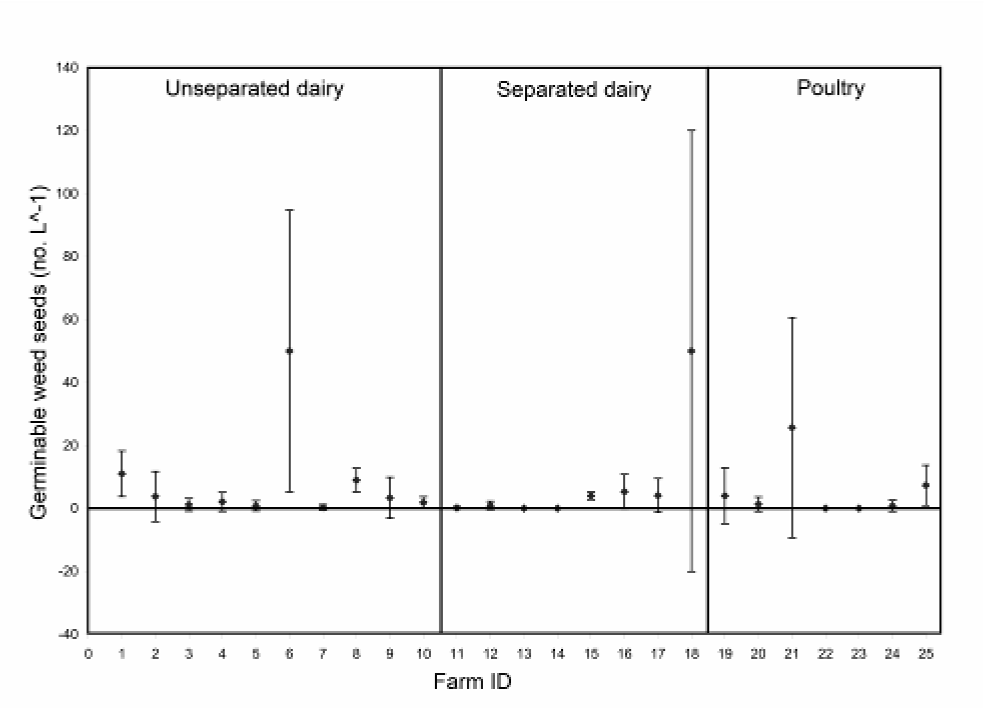

Fig. 1. Presence of viable weed seeds (# L-1) in manure-based composts. Error bars represent standard deviations for averages of all samples taken from a single farm.

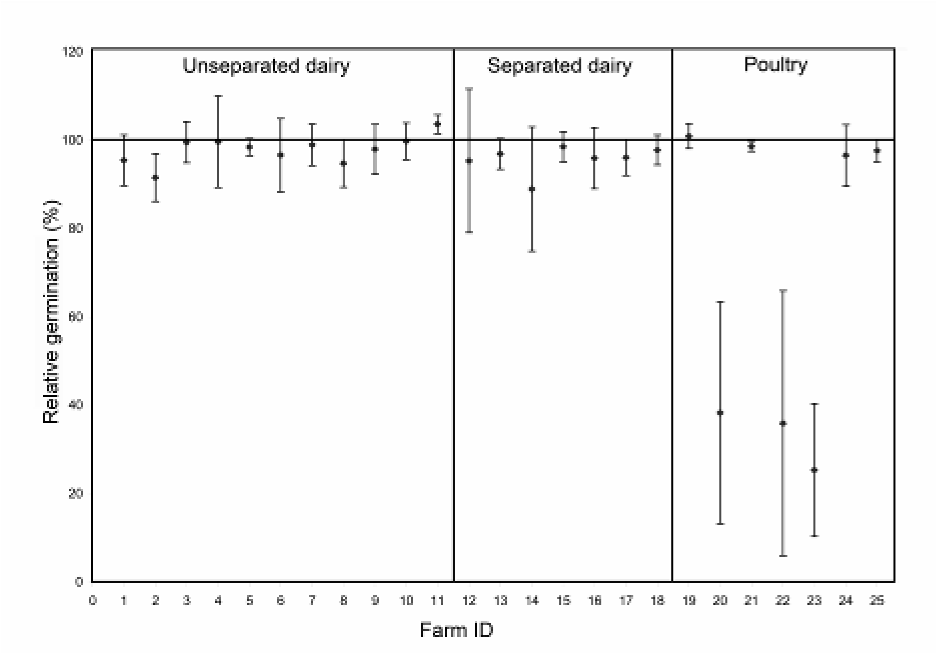

Fig. 2. Relative germination of cress (*Lepidium sativum*) seeds in manure-based composts. Error bars represent standard deviations for averages of all samples taken from a single farm.

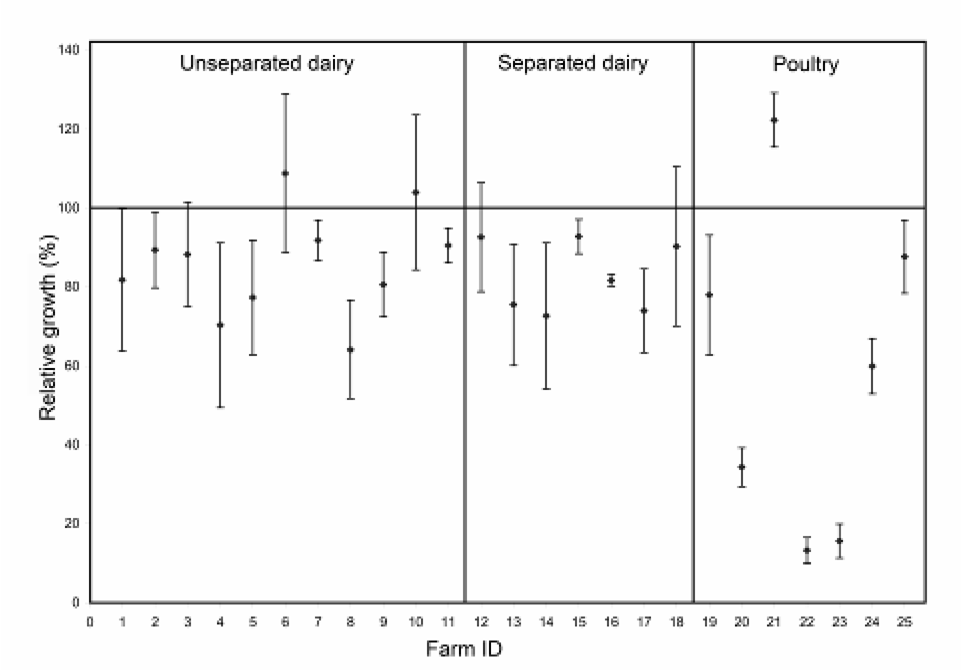

Fig. 3. Relative growth of cress (*Lepidium sativum*) in manure-based composts. Error bars represent standard deviations for averages of all samples taken from a single farm.

## Compost characteristics measured with TMECC methods

Feedstock: Dairy cow manure (unseparated), straw, wood
Pad Type: Soil
Turning Frequency: High

| Analysis | | | | | |
|---|---|---|---|---|---|
| Date | April 06 | August 06 | April 07 | Average | SD |
| General characteristics | | | | | |
| Maturity (Solvita ranking) | 7 | 7 | 7 | 7 | 0.0 |
| Organic Matter (%) | 26.9 | 24.6 | 17.1 | 23.5 | 5.6 |
| Weed Seeds (#L$^{-1}$) | 1 | 2 | 0 | 1 | 2.1 |
| Density (lb ft$^{-1}$) | 51 | 57 | 57 | 56 | 2.9 |
| pH | 7.8 | 7.7 | 8.2 | 7.8 | 0.4 |
| Conductivity (mmhos cm$^{-1}$) | 2.4 | 3.7 | 3.1 | 3.3 | 1.4 |
| Nutrients | | | | | |
| Total nitrogen (%) | 0.7 | 0.7 | 0.8 | 0.7 | 0.1 |
| Total phosphorus (%) | 0.3 | 0.3 | 0.3 | 0.3 | 0.0 |
| Total potassium (%) | 0.4 | 0.4 | 0.5 | 0.4 | 0.1 |
| Metals | | | | | |
| Copper (ppm) | 36.4 | 27.9 | 136.7 | 51.4 | 47.5 |
| Plant response | | | | | |
| *Lepidium sativum* relative germination (%) | 102.5 | 100.5 | 102.0 | 101.2 | 2.9 |
| *Lepidium sativum* relative growth (%) | 105.0 | 82.7 | 85.5 | 87.7 | 14.5 |

Fig. 4. Proposed information sheet for agricultural composts

Note: Composts made with non-agricultural feedstocks that may contain other contaminants should be tested for those additional parameters. Regulations requiring tests for other parameters may apply to composts with feedstocks such as sewage sludge.