Composting Applications in Forest & Conservation Nurseries
by Thomas D. Landis & Nabil Khadduri

What is composting?

Composting can be defined as the biological decomposition of organic matter under controlled aerobic conditions (Epstein 1997). The microorganisms that breakdown organic matter require carbon for an energy source and nitrogen for growth and reproduction, so organic materials for composting (“feedstocks”) must contain a balance of carbon and nitrogen. This balance is known at the carbon-to-nitrogen ratio (C:N), which we’ll discuss in more detail a little later. The other essential requirements for successfully making compost are water and air (Figure 1A). Because it requires either periodic mixing or active aeration, oxygen is the limiting factor in most compost piles. Simply making a pile of organic matter and waiting is not composting (Figure 1B).

“Compost”, like “organic”, is one of those words that are generally assumed to be beneficial. However, as I always do before starting an article, I did a comprehensive search of the published literature in the FNN database. Several days of perusing convinced me that, while composts are being widely used in horticulture, it is almost impossible to come to any conclusions. Each article uses a different type of compost from different source materials for different purposes. Other problems in interpreting the published research are that composting is a progressive process, and there are no widely-accepted standards for compost maturity or quality. Having said that, I still believe that composts have wide application in both bareroot and container nurseries:

1. Soil amendment in bareroot nurseries - Composts are an excellent nursery soil amendment because they encourage the formation of soil particle aggregates which improve tilth, and also stimulate the microbial component of the soil.

2. Organic component in growing media in container nurseries - Composts are being tested and used in a wide variety of artificial growing media as substitutes for peat moss.

3. Pest management - Some composts have shown “suppressive” effects on pathogens in both bareroot soil and container growing media. At a reforestation nursery in northern Mexico, pine bark is composted on-site and inoculated with benefical microorganisms. Not only does this compost grow good seedlings but it was found to suppress root rot fungi and therefore reduce the use of fungicides (Castillo 2004).

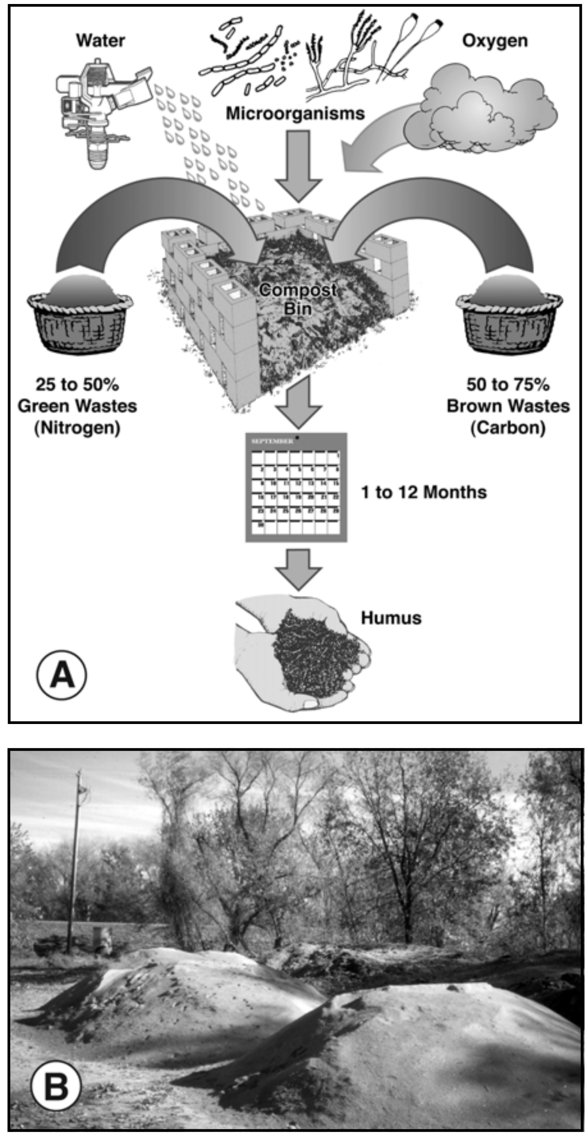

Figure 1 – Effective composting require supplying all the necessary elements so that none become limiting to the process (A). Merely piling organic wastes and waiting is not composting (B).

4. Compost “teas” - Compost teas can be made by aerated and non-aerated processes, and have been used to grow plants for hundreds of years. Compost extracts and teas have been shown to prevent or control a wide range of foliar diseases, including *Botrytis cinerea*, and have been used as a seed treatment against soilborne pathogens. Other horticultural applications include increasing the rootability of cuttings (Summers 2007). The principal active agents are bacteria in the genera *Bacillus* and *Serratia* and fungi in genera *Penicillium* and *Trichoderma.* It is thought that compost teas work in 3 ways: inhibition of spore germination, antagonism and competition with pathogens, and through induced host resistance. Considerable work is required to ensure predictable disease suppression and control but operational studies on a wide variety of crops have shown promising anecdotal evidence (Litterick and others 2005).

5. Mulches for weed control - Composted organic mulches were an important method of weed control prior to the development of herbicides. Their herbicidal effectiveness is due to the physical presence of the materials on the soil surface, and the chemical action of phytotoxic compounds generated by microbes in the composting process. Physical weed control improves with the thickness of the organic mulch layer but the degree of weed control is dependent on type of mulch, weed species, and environmental conditions. Generally, a 4 to 6 inch (10 to 15 cm) mulch layer is most effective. The herbicidal effects of raw compost mulches is due to several organic acids, the most effective of which is acetic acid which has been shown to inhibit weed seed germination. Because they must be applied and maintained, compost mulches would be most effective in older bareroot seedlings, transplants, and very large container stock (Ozores-Hampton 1998). As with any new cultural practice, install trials before beginning operational use.

Types of composts that could be used in nurseries.

Any organic waste can be composed and a wide variety of feedstocks have been used (Martin and Gershuny 1992). Because of high transportation costs, it just makes sense to use local materials. Many municipalities and industries are prohibited from disposing of their wastes and so have developed an active program of composting. Composting regulations in the United States are mainly concerned with protecting public safety and limiting environmental hazards rather than producing high-quality compost (Mecklenburg 1993).

Yard waste - Up to 40% of the volume in a municipal solid waste stream is yard waste, but tests have shown considerable variation between composted yard waste (CYW) sources. Mature, biologically stable compost may require 9 months or more but one study found that typical yard waste in California has been composted for 4 months or less with no curing time. They concluded that at least 9 to 12 weeks of composting was necessary (Hartz and Gianni 1998). Compared to industrial feedstock, CYW is low in potentially toxic heavy metals and pesticides were not found to be a problem. Chemical analyses of CYW have found pesticide levels to be well below US Environmental Protection Agency (EPA) guidelines, which proves that these chemicals degrade during composting (Mecklenburg 1993). These composts are excellent soil amendments for bareroot nurseries or can be used as peat substitute in growing media. Quality will vary with the season, however, so periodic testing is recommended.

Municipal or industrial sewage sludge and biosolids - Sludge is defined as a solid, semi-solid, or liquid residue generated during the treatment of domestic or industrial sewage. Biosolids are a primarily organic solid product produced by municipal wastewater treatment processes (EPA 2008). Activated sludge is the product of vigorous areation of sewage whereas digested sludge is produced when the sewage processed without agitation. A major concern about municipal or industrial feedstock has been heavy metal levels. The EPA sets limits for heavy metals contamination in sewage-sludge compost., and all biosolids are required to be tested by the producer and these test results are available upon request (Gage 2008). Municipal or industrial sludge and biosolids are an excellent source of organic matter for bareroot nurseries, and are also being used in growing media (Bettinski 1996a).

Wood waste - Sawdust and wood chips have traditionally been waste products from mills but are now being burned for fuel or sold as mulches for landscaping and agriculture. Wood wastes have a high carbon-to-nitrogen (C:N) ratio and compost best when mixed with a high nitrogen material like manure. When used in composts, wood wastes are valuable not only for a carbon source but as a bulking agent that increases air movement in the pile. Wood chips can be superior to sawdust because they contain bark (Martin and Gershuny 1992). When conifer seedlings were grown in sewage sludge or mixes of sludge and woodwaste, they were inferior to those grown in peat-vermiculite media but the authors thought that adjusting fertilization regimes could resolve the differences (Simpson 1985). The C:N of tree bark is considerably lower than sawdust and so has become a preferred material for horticultural composts. Composted pine bark (CPB) has become the standard growing media components for horticultural nurseries, especially in the southern states where the cost of *Sphagnum* peat moss is prohibitive (Pokorny 1979).

Pulp and paper sludge - Sludges from pulp and paper mills are mainly cellulose fiber generated at the end of the pulping process prior to entering the paper machines. They are composed essentially of fibrous fines and some inorganics such as kaolin clay, calcium carbonate, titanium dioxide and other chemicals used in the specific manufacturing process. Over 70% of the recyclable organic solid wastes produced by the US pulp and paper industry are presently landfilled. A single mill in Georgia produces about 100,000 dry tons of solid waste a year. Pulp and paper sludge has a high C:N and must be composted with a high nitrogen feedstock; in one study, mixing with chicken litter produced a superior compost (Das and others 2008). Before using pulp and paper sludge, however, all feedstocks should be tested because some materials like bleached sludge can contain high salt levels.

Spent mushroom compost - This is the residual organic compost waste generated by mushroom farms. The exact composition of mushroom compost varies from location to location depending on available organic material. Analysis of one facility in Pennsylvania revealed 40% straw bedded horse manure, 25% hay and small amounts of cottonseed hulls, gypsum, and chicken manure. Mushroom compost has good potential as an organic soil amendment or a component of growing medium, especially when mixed with peat moss and wood or bark chips. A chemical analysis found that both soluble salts and nitrate-nitrogen far exceeded the recommended ranges but both can easily be corrected by leaching with water. The pH levels were mildly alkaline but this could be easily adjusted by mixing with more acid components such as peat moss. The compost showed good levels of other mineral nutrients. Porosity measurements were favorable and a mixture of 1 part mushroom compost: 2 parts peat drained comparably to other growing media (Dallon 1989).

Vermicompost - This is earthworm-processed organic wastes and contains finely-divided peat-like particles with high porosity, aeration, drainage. There are 2 main methods of large-scale vermiculture. The first uses a windrow containing bedding materials for the earthworms to live in and acts as a large bin. The second is the raised bed or flow-through system in which the worms are fed across the top of the bed while castings are harvested from below (Wikipedia 2008). Although it is undoubtedly the highest quality compost, the relatively small volumes produced make land application impractical but vermicompost is an excellent growing media component.

Nursery wastes - Cull seedlings and weeds can generate a substantial volume of waste in nurseries. One recent trial in Finland compared the growth of Norway spruce (*Picea abies)* in the traditional media of 100% *Sphagnum* peat moss versus mixes of peat with composted nursery waste. The nursery waste compost consisted of cull container and bareroot seedlings and weeds, which had been composted for 4 years and then filtered through a 4 mm screen. Survival after outplanting was comparable but seedlings from the compost-amended media were still significantly shorter after 4 years. The authors concluded that changes in irrigation and fertilization could correct for these growth differences (Veijalainen and others 2007).

Evaluating composts.

So, we can see that composts can be used many ways in the culture of both bareroot and container nursery stock. Before making or purchasing any compost, however, nursery managers should ask the following questions:

1. What materials were used in this particular compost?

There is no such thing as standard or typical compost; instead, they are complex mixtures of humus-like constituents such as partially decomposed organic wastes, the decomposing organisms themselves, and their byproducts. A wide variety of feedstocks have gone into compost which contributes to the variability of the final product. Municipal and industrial composts have proven to be the most variable (Table 1). Some composts could even contain toxic contaminants that could harm seedlings. Other composts contain a high proportion of inert materials such as stones, glass, or plastic that may lower their horticultural value.

Chemical and physical analysis of 4 common composts used in growing media illustrate this variation (Table 1). Chemical properties were the most variable. Soluble salt levels, as measured by electrical conductivity (EC), were excessive for both total salts and sodium, which can cause serious problems with germinating seeds and young plants. Leaching these composts with fresh water before use can effectively lower soluble salts below damaging levels (Carrion and others 2006).

The physical properties of the composts in Table 1 were generally good as all measures of porosity met or exceeded the ideal ranges, but varied considerably with the feedstock. When composted green waste was mixed with peat moss in ratios from 10 to 50%, total porosity and water-holding capacity was reduced (Maher and Prasad 2005). Some municipal wastes containing tree leaves and lawn clippings have particles so small that they can seriously reduce aeration porosity (McCloud 1994). Composts should be screened to remove excessive fine particles before use; the percentage of fines passing through a 100 mesh screen should not exceed 15% of the total volume (Miller 2004).

2. What is the carbon-to-nitrogen ratio (C:N)?

The C:N is one of the most important characteristics to

Table 1 - Chemical and physical analysis of raw materials commonly used in composts (modified from Chong 2003 & Chong and Pervis 2006)

Characteristic tested	Ideal range	Mushroom waste	Turkey litter	Municipal waste	Paper mill sludge
pH	5.5 to 6.5	8.2	8.7	8.4	7.2
Electrical conductivity* (ds/m)	< 1.0	4.0	4.1	3.0	1.2
Ammonium nitrogen (ppm)	< 10	15	103	4	37
Nitrate nitrogen (ppm)	100 to 200	89	232	0.02	0.02
Phosphorus (ppm)	6 to 9	6	27	2	8
Sodium (ppm)	0 to 50	511	501	139	387
Total porosity (%)	> 50	71	73	66	72
Aeration porosity (%)	15 to 30	40	45	32	40
Water-holding porosity (%)	25 to 35	31	28	34	31

* EC measured as dilution of 1 part substrate to 2 parts water

measure in both raw materials and finished compost. One of the traditional concerns with composts and other organic matter sources in nurseries is whether the material will tie-up nitrogen after use (Rose and others 1995). Many composts that are made from wood wastes have a very high C:N ratio (Table 2) and the decomposing microorganisms will outcompete your seedlings for nitrogen and induce chlorosis and stunting. Bareroot nurseries that have added too much uncomposted sawdust to their seedbeds have learned this lesson all too well.

The higher the C:N, the higher the risk of nitrogen drawdown. The carbon in easily decomposed compounds such as sugars and cellulose are quickly used as an energy source for soil microorganisms which need also nitrogen for growth and reproduction. Because this nitrogen is stored in their cells, it is unavailable for plant uptake. As carbon sources become depleted, the high populations of soil microorganisms gradually die and nitrogen is released for plant growth. When C:N is greater than 15 to 20:1, available nitrogen is immobilized but, as ratios drop lower, nitrogen becomes available for plant uptake. A major problem of compost use in nurseries has been the variation in nitrogen drawdown between different products (Handreck 2005).

Wood wastes such as sawdust have been used in nurseries for decades. Because of their very high C:N ratios, these materials are often composted with manure or supplemented with fertilizer to supply the needed nitrogen. The C:N of tree bark can be considerably lower than wood (Table 2). As previously mentioned, composted pine bark has become the standard growing media components for horticultural nurseries. Bark of other tree species may also prove useful for composting, but tests should be conducted before beginning operational use.

3. What are the mineral nutrient levels and pH?

Although some sources recommend composts as a type of fertilizer, that's not a good idea: if you want to add fertilizer to your crop, buy fertilizer. You can get some added nutritional benefit from composts but nutritional value, as reflected by the nitrogen and phosphorus levels, showed extreme variation (Table 1). Animal wastes used for composting are often very high in nitrogen and phosphorus — note that the turkey litter is way above recommended rates. Composts with high ammonium levels can induce ammonium toxicity in growing media.

The EC test can be used as a good indication of nutrient content as composts that have a high EC are often high in mineral nutrients. The C:N also provides information on potential nutrient levels. Compost with C:N below 10:1 can provide a ready source of available mineral nutrients, are therefore considered fertilizers. Still, the overall nutrient composition of most composts is low compared to traditional fertilizers. Milorganite©, the composted municipal waste that has been used in bareroot forest nurseries for decades, has a fertilizer analysis of only 6-2-0. Vermicomposts have greater CEC, lower soluble salts, and they contain nutrients that are readily available for plant uptake (Atiyeh and others 2000). Nutrients in mature composts are slow-release and so compost application rates should be based both on nutri-

Table 2 - Carbon-to-Nitrogen Ratios of Common Organic Materials (Modified from Rose and others (1995)

Organic Waste Materials	Carbon-to-Nitrogen Ratio
Wood (Ponderosa pine & Douglas-fir)	1200:1 to 1300:1
Bark (Ponderosa pine & Douglas-fir)	400:1 to 500:1
Wood (Red alder)	377:1
Paper	170:1
Pine needles	110:1
Wheat straw	80:1
Bark (Red alder)	71:1
Dry leaves	40:1 to 80:1
Dry hay	40:1
Yard clippings	25:1 to 30:1
Oat straw	24:1
Aged manure	20:1
Alfalfa hay	13:1

ent content and release rate.

Composts can also affect fertility indirectly through their effect on pH. Many composts have a neutral pH but others can as high as 8.7 (Table 1), which could cause serious nutrient availability problems.

4. What about the potential of toxic elements in municipal and industrial waste composts?

Some composts can contain high levels of heavy metals and other elements that can be toxic to plants and animals. These elements are naturally found in soils (Table 3) but become accumulated through human activities from fertilizer additions to industrial processes. In recent years, the Clean Air Act and other environmental legislation have limited industrial discharge into municipal wastewater facilities and so the level of toxic elements in biosolids has also decreased. High soluble salts, and sodium in particular, are another common problem, especially with composts containing a high proportion of manure or municipal sludge

Conifer seedlings were grown in bareroot beds supplemented with various amounts of 3:1 sawdust:composted municipal sludge from Seattle. Initial growth stimulation was followed by reduced growth, probably due to a high C:N. Of more concern, however, is that tests showed increased levels of toxic heavy metals such as cadium and zinc in seedlings (Coleman and others 1987). Municipal wastes containing glue and industrial wastes can contain high levels of boron. While small amounts of boron are needed by plants, toxicity is more of a concern so composts with more than 25 ppm of boron should be monitored closely (Rosen 2000).

So, although you should always request a complete chemical analysis of feedstocks or finished composts, professionally produced composts are safe because toxic element levels are constantly monitored. For example, chemical analyses of biosolids show that all toxic elements are well below legal standards and are often less than levels found in natural soils (Table 3).

5. How sensitive is my crop?

Forest and conservation plants can tolerate most composts if they are applied at the proper rate, in the proper manner, and at the proper time. Because of their restricted root volume, container stock will be more sensitive than bareroot plants and newly-sown seedlings will be much more sensitive than transplants.

Testing Feedstocks or Compost Products

Whether you are considering making your own compost or buy the finished product, it's a good idea to consider testing. Before we discuss the various options, let's define two terms that often cause confusion when evaluating composts—maturity and quality (Bettineski 1996b).

Table 3 - Toxic elements limits and ranges from common composts			
Element	Range in natural soils (ppm) *	Legal lLimits for biosolids ** (ppm)	Concentrations in biosolids from US and Canada *
Arsenic	5 to 13	41	1.0 to 12.8
Cadmium	0.01 to 7.00	39	3.6 to 16.0
Copper	1 to 300	1,500	180 to 890
Lead	3 to 25	300	14 to 340
Mercury	------	17	0.01 to 3.50
Nickel	3 to 300	420	18 to 42
Selenium	0.00001 to 3.4	100	0.10 to 0.55
Zinc	10 to 2000	2,800	534 to 990
* (Epstein 1997) ** US EPA (2008)			

1. **Compost maturity** tests evaluate whether the composting process has been completed, and that the C:N ratio has stabilized. The traditional way to evaluate compost maturity is to monitor temperature within the compost pile or in the finished product (Martin and Gershuny 1992). The activity of the decomposing microorganisms generates heat which follows a standard curve (Figure 2A). Long-stemmed compost thermometers can be inserted into the pile at regular intervals, and the temperatures used to monitor compost maturity (Figure 2B). While this monitoring system is simple and inexpensive, it does not provide a true picture of compost quality. The composting process might have stalled at some point because one of the essential factors became limiting—this often happens due to poor aeration.

2. **Compost quality** tests are more comprehensive; they reflect maturity but also reveal chemical properties, mineral nutrient content, and intended use. The traditional test of compost quality has been a bioassay using the germination ability of a quick growing plant. The original compost maturity test used cress (*Lepidium sativum*) germination as the bioassay (Zucconi and others 1981) but subsequent testing found this procedure has been difficult to replicate. A more recent study (Emino and Warman 2004) tested cress and a variety of other commonly-used indicator plants and found that none did a good job of predicting compost quality. Their tests showed that Joseph's coat, a cultivar of *Amaranthus tricolor*, did a good job in distinguishing between immature and mature compost. It appears that there is considerable variation between plant response but, if enough time were available, nurseries could do germination testing with their own specific crops. A high quality mature compost should be able to support earthworms and other soil fauna (Figure 2C).

Most states don't require compost producers to label their products with an analysis of quality (Mecklenburg 1993). So, growers either have to test it themselves or have a supplier do the testing (Bettineski 1996b).

In-House Testing - In addition to measuring compost temperature, a series of hands-on tests are available from Woods End Research® and numerous compost supply firms on-line (Table4):

* The Solvita Compost Maturity Test is a colorimetric test that takes only 4 hours, and costs about $14 per sample. The relative color is keyed to a numerical index from 1 to 8, which then describes the compost condition.

* The Dewar Self-heating Test Kit evaluates the stability of the compost by measuring residual heating ability by monitoring the temperature in a special reusable flask.

* The Compost Oxygen Probe is a kit containing a hand vacuum pump with a long probe for taking gas samples from within the compost pile. Some models also feature a thermometer.

Laboratory Testing - Several laboratories offer specialized compost analysis, and many different tests and services are available (Table 5). These tests are more expensive ($75 to $300), but give a more detailed picture of compost maturity and quality. Washington State University Extension provides excellent guidelines on how to sample composts and what to ask from a testing laboratory (Bary and others 2002):

<u>Sampling</u>. Without a good representative sampling procedure, compost analysis is a waste of time and money. To collect a representative sample of your compost, take

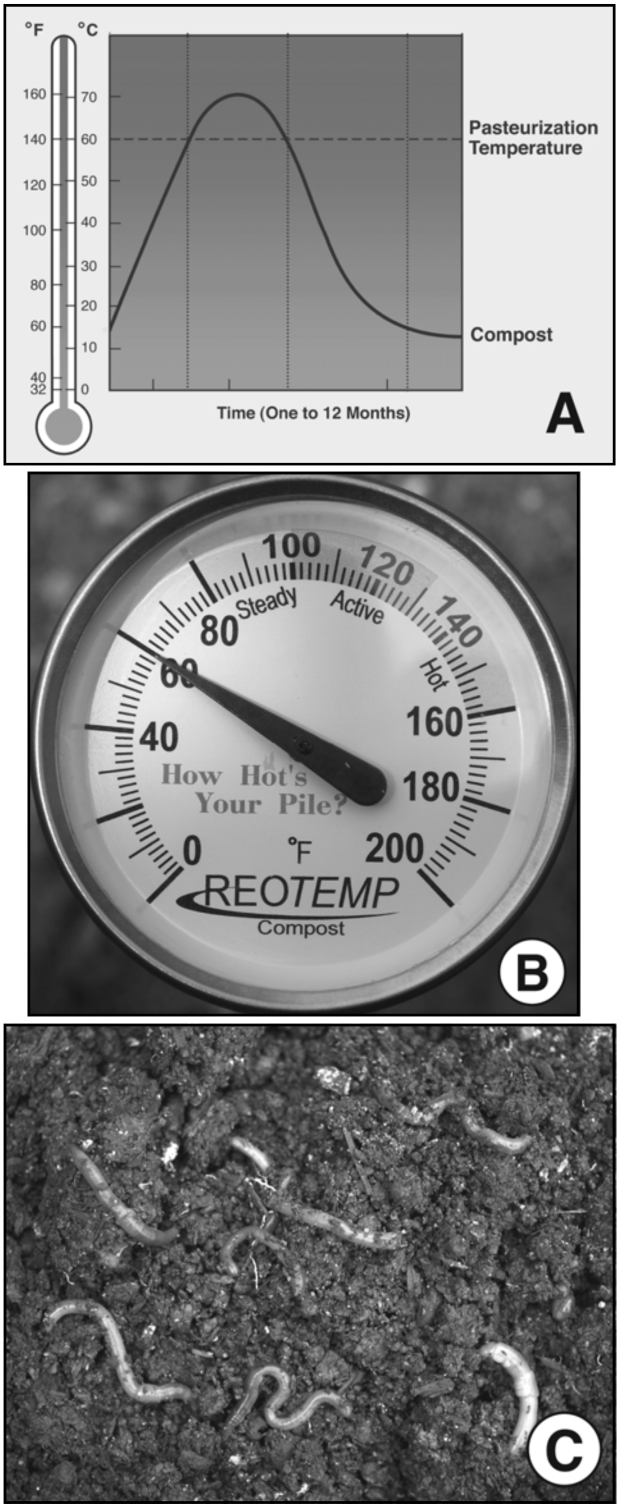

Figure 2 – The traditional way of monitoring the composting process has been to measure the temperature in the pile (A) with a long-stemmed thermometer (B). The ultimate measure of compost maturity and quality is a bioassay using a germination test or checking for earthworms and other microfauna (C).

15 to 20 samples from different parts of the pile and combine them together. Don't sample the surface of the pile; rather, break the pile open in several places and sample the exposed surfaces. Mix the sample thoroughly and take a 1 quart subsample to send to the lab. Cool or freeze the sample for shipment or pack with "blue ice". Contact the lab for specific handling and shipping instructions.

Laboratories. Use a laboratory that analyzes for compost on a regular basis. Ask for a copy of their report form to see if the results are presented in a manner that you can understand and in units that are useful. Ask what specific tests they do, and what are the costs of each? Inquire about handling and shipping requirements and when the results will be ready.

The United States Composting Council operates an approval system for composting facilities. The Seal of Testing Assurance (STA) is a program that requires compost manufacturers to regularly test their composts using an approved third-party testing facility. The procedures for sampling and testing are outlined in the Test Methods for the Examination of Composting and Compost protocols. The STA program takes the worry out of purchasing compost because you know that you can be assured that the company is reputable. Through this program, compost manufacturers are required to report test results to customers that request them as well as provide guidance on application rates and methods (Gale 2008). A current list of STA laboratories can be found at URL:<www.compostingcouncil.org>.

Woods End Research Labs performs more complicated tests that require specialized facilities. Compost conditions, such as decomposition rate, volatile organic acids, and phytotoxic compounds can be done on a fee basis. For more information, contact:

Woods End® Research Laboratories
PO Box 297
Mt. Vernon, ME 04352
TEL: 207.293.2457
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Website: www.woodsend.org/

Summary and conclusions.

Both bareroot and container nurseries can use high-quality organic matter, and composts are a way to both meet that demand and also provide an eco-friendly source for organic wastes. Although the published literature is rife with articles on compost use in nurseries, the highly variable nature of the feedstocks and differ-

Table 4 - Measuring compost maturity with in-house testing kits and equipment				
Stage in Composting Process	**Solvita Maturity Test**	**Dewar Self-Heating Test**	**Oxygen Probe (mg/ gVS/hr)**	**Carbon Dioxide Evolution (%C/day)**
Fresh, raw compost - Extremely high rate of decomposition. High in volatile organic acids so very odiferous	1 Yellow	I	1.60	2.75
Moderately fresh compost - Very high respiration rate, requiring frequent turning & aeration	2 Orange-Yellow	II	1.40	2.25
Acitve compost - high respiration rate, requiring frequent turning & aeration	3 Light-Orange	III	1.00	2.00
Moderately Active Compost - still decomposing	4 Orange	III	0.50	0.75
Moderately Active Compost - beginning to cure	5 Reddish-orange	IV	0.75	1.25
Modertely Mature Compost - Curing phase	6 Maroon	IV	0.50	0.75
Well-matured and aged compost - **Ready for growing media & soil amendments**	7 Reddish-Purple	V	0.25	0.50
Highy-matured & aged compost - **Best for all uses**	8 Purple	V	0.00 to 0.10	0.00 to 0.25

ences in composting technique make interpretation difficult. Using composts as mulch is the most conservative use but incorporating a light 1 to 2 inch (2.5 to 5.1 cm) layer of compost into bareroot beds can also be recommended. As an added safety measure, do the incorporation at the beginning of the fallow year. Using composts as an organic substitute in growing media is a more critical application especially in the small volume containers used in forest and conservation nurseries. Always make sure that the compost has been tested and only use 20 to 30% until you are sure of the results.

As with all changes in cultural practices, always start with a small trial before using composts on an operational scale. Be aware that compost maturity and quality can vary from batch to batch and supplier to supplier, so always ask for test results or do them yourself.

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Table 5 - What to request in a compost analysis & how to interpret results *

Analysis	Units	Target Range	Importance & Application
Carbon to Nitrogen Ratio (C:N)	None	12:1 to15:1	This is the range of stable compost & will not cause nitrogen availability problems
Electrical conductivity (EC)	dS/cm or mmhos/cm	0.0 to 4.0	This measures soluble salts which can burn sensitive plants
pH	Log Units	5.5 to 6.5	This measures acidity or alkalinity, and composts outside this range can lead to nutritional problems
Ammonium nitrogen	ppm	Less than 500	This fertilizer ion can damage plants at high levels
Nitrate nitrogen	ppm	200 to 500	Low levels of this fertilizer ion can reduce plant growth. High levels can cause water pollution.
Moisture content (MC)	% "as is" weight	40 to 60	Composts with high MC are hard to handle & spread; those with low MC are dusty
Organic matter (OM)	% dry weight	40 to 60	Low values (<30%) indicate composts mixed with sand or soil. High values (>60%) indicate fresh, uncomposted material.

* modifed from Bary and others (2002)

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