Production of High-quality Composts for Horticultural Purposes: A Mini-review

Michael Raviv

Additional Index Words: container medium, organic farming, physical characteristics, soil organic matter, suppressiveness

Summary. Compost is organic matter that has undergone partial thermo-phlic, aerobic decomposition. This environmentally safe process is called composting. The combination of raw materials and the chosen composting method yields a wide range of characteristics, such as organic matter (OM) content, nutrient content, potential for disease suppressiveness and other physical, chemical, and biological properties. The objectives of this review are describing the horticultural outlets for composts, defining compost characteristics important for the above uses, and describing composting procedures and raw materials leading to these characteristics. The two main horticultural uses of composts are as soil amendment and as an ingredient in container media. Soil-applied composts improve soil fertility mainly by increasing soil organic matter (SOM) that activates soil biota. Compost’s nutrient content, and especially that of nitrogen (N), should be high (>1.8%). Composts having these characteristics are produced of raw materials rich in both OM and N, while minimizing their loss during composting. Typical raw materials for this purpose include animal manures, offal, abattoir residues, sewage sludge, and grass clippings. Various composting methods can yield the required results, including turned windrows, aerated static piles, and in-vessel composting. Composts are also used for substrates as low-cost peat substitute, potentially suppressive against various soilborne diseases. These composts must be stable and non-phytotoxic. Physical properties of compost used as substrate are important. Hydraulic conductivity, air porosity, and available water should be high. Reconciling the physical and biological demands may be difficult. Materials such as softwood bark, wood shavings, various types of shells or hulls, and coconut coir are characterized by good physical properties after composting. However, being relatively resistant to decomposition, these materials should be subjected to long and well-controlled composting, which may be shortened using N and N-rich organic matter such as animal manures. High temperatures (>65 °C (149.0 °F)) may cause ashing, which leads to reduced porosity. In addition to ligno-cellulosic materials, composts serving as growing media may be produced from numerous organic wastes, such as manures, food industry wastes, etc. These materials are better composted in aerated static piles, which tend to minimize physical breakdown. Animal excreta are of special value for co-composting as they contain large, diverse populations of microorganisms, which accelerate the process.

Compost is a general term, describing all organic matter that has undergone a long, thermophilic, aerobic stabilization process (i.e., composting). Composts may vary with raw material(s) used, and duration and nature of the composting process. The combination of these factors results in a wide range of characteristics and qualities of the end-product. Affected characteristics include physical, chemical, and biological properties of the end-products, such as biological oxygen demand (BOD), OM content, nutrient content, and the degree of disease suppressiveness.

The various resulting compost types can find adequate outlets, according to the intended use. It is intuitively clear that highly intensive uses such as container media demand composts of high quality, while low-value outlets such as mine reclamation are less demanding.

The absence of direct communication between compost producers and consumers is, perhaps, the highest obstacle for a more widespread use of composts. On the one hand, compost producers are not well aware of the agronomic and horticultural uses of composts and, hence, do not make efforts to control their production methods so as to meet the consumers’ demands and to ensure stable and reproducible quality of the product. On the other hand, growers are not well educated as to the effect of compost quality on the horticultural performance of their growing systems. As a result, they look for cheap products and tend to ignore the unavoidable connection between quality and cost. An interesting example for a different situation can be found in Israeli kibbutzim that practice organic farming. There, the animal manure and other organic wastes are composted and later on applied onto the fields and orchards of the same kibbutz. In this case, the daily dialogue among the producers and consumers leads to near-optimal results.

The popularity of treating organic wastes by means of composting has been steadily growing in the last three decades. Unlike other treatment methods for organic waste, such as land-filling or incineration, which may cause severe pollution due to leachates reaching groundwater or air pollution, composting is considered as a much safer process (Dalemo, 1999; Harrison and Hester, 2002). It is a method that turns waste into resource and enables restoring depleted soil organic matter. Once produced properly, compost turns into a beneficial product for agriculture.

On the consumption side, the use of composts for various application types is steadily growing over the years, as well. Growers realized that compost can serve as an economical source of nutrients, that it improves soil physical properties, and that it can be used as a low-cost ingredient in soilless media. In this application type, it may also reduce the need for media disinfection or for fungicide drenches, due to suppressive effects found on many occasions, on a number of root pathogens (Hoitink and Kuter, 1986). Repeated land application of compost can render soils suppressive to soilborne diseases (Lumsden et al., 1986).

The objectives of this review are to describe the main horticultural outlets for composts and their requirements; define specific characteristics of composts important for the above horticultural uses; and describe composting procedures and raw materials that lead to the required characteristics.

Horticultural usages of composts

The two main horticultural uses of composts are as soil amendment for vegetable and fruit crops, and as an ingredient in container media.

Agricultural Research Organization, Neve Yair Research Center, P.O.B. 1021 Ramat Yishay 30095, Israel. E-mail: mraviv@volcani.agri.gov.il

Workshop - January–March 2005 15(1)
Compost for Soil Application. Compost intended to serve as soil amendment is applied in order to improve soil fertility. In many cases prolonged intensive agronomical or horticultural cultivation causes gradual depletion of SOM (Acosta-Martínez et al., 2003; Romkens et al., 1999).

Reduced SOM is frequently associated with lower soil biological activity (Garcia and Hernandez, 1997) and with deteriorating soil’s physical properties (Jordahl and Karlen, 1993). The result is an overall reduced soil fertility (Bauer and Black, 1994). Repeated application of various types of organic matter, and especially of compost can reverse this negative process (Grandy et al., 2002; Jordahl and Karlen, 1993). Quantitative parameters that are affected by organic amendments include soil biomass (Lee et al., 2004), soil respiration (Sikora and Rawls, 2000), various enzymatic activities (Antonious, 2003), nitrification rate (Bernal et al., 1998), large aggregate stability (Grandy et al., 2002), water infiltration rate and hydraulic conductivity (Zeytin and Baran, 2003), and water holding capacity (Punshon et al., 2002). If done properly and for relatively long period (5–10 years, depending upon climatic conditions, soil management and soil type), original soil fertility can be restored.

Required Compost Characteristics. The main effects of soil-applied composts are on soil biology, plant nutrition (either directly and/or through its effect on nutrient cycling), and on soil physical characteristics. Composts having high OM (typically >40%) positively affect soil fertility, due both to its effect on soil biota and on soil physical characteristics. Composts can also be applied as a direct source of nutrients. This situation is typical of organic farming systems, where composts serve as the sole or one of the main sources of plant nutrition because application of synthetic fertilizers is not allowed while organic fertilizers are usually expensive. To satisfy nutritional requirements of many crops, typically high (>1.8%) N content is required as a plant nutrient. An example for such stable and nutrient-rich compost is shown in Table 1 (M. Raviv, unpublished).

Young composts are usually rich in polysaccharide content (Sela et al., 1998). Polysaccharides enhance flocculation of partly dispersed soil and increase its large aggregate stability, thus restoring its original physical properties. Applying young compost, however, dictates a long stabilization period before planting. An example for the characteristics of young composts is shown in Table 1.

The required characteristics of stable and young composts are substantially different (Table 1). Differing parameters are, for example, BOD and nitrate content. The first one reflects the continued decomposition of biodegradable compounds with composting time, such as hemicellulose (Raviv et al., 1987). The second parameter results from enhanced activity of nitrifying bacteria when the compost temperature drops below ~40 °C (104.0 °F).

Composting for high-quality composts. In order to produce composts having the above-mentioned characteristics, raw material rich in both OM and N should be used, and the composting procedure should minimize OM and N loss. Typical raw materials adequate for this purpose include animal manures, animal offal and abattoir residues, sewage sludge, and grass clippings. The subject of N loss during composting and ways to minimize its rate are discussed by Raviv et al. (2004). N loss during composting is usually quite high, and typical values are around 50% (Eghball et al., 1997; Martins and Dewes, 1992; Vuorinen and Saharinen, 1998). Most N is lost to the atmosphere as ammonia (Eghball et al., 1997; Tiquia and Tam, 2000). Three main factors contribute to ammonia volatilization during composting of organic wastes: initial low carbon : nitrogen (C:N) ratio (Larsen and McCartney, 2000), high pH (Korner and Stegmann, 1998), and high oxidation rate (Michel and Reddy, 1998). Nitrogen loss during composting may be reduced by using high C:N mixtures that enhance N immobilization, or by lowering the pH of the compost solution, which shifts the balance between ammonium ions and dissolved ammonia toward the former, thus reducing ammonia volatilization during the thermophilic stage of composting (Ekinci et al., 2000). Moderating the airflow rate through the compost pile is another way of lowering ammonium volatilization (Vuorinen and Saharinen, 1998). High temperatures (>70 °C (158.0 °F)) during the thermophilic stage of composting lead to rapid loss of organic matter, resulting in a significant loss of N (Sanchez-Monedero et al., 1996). Hence, maintaining moderate temperatures (<65 °C) is another means of lowering N loss (Raviv et al., 1999).

After decomposition of nitrogenous compounds, ammonium ions can be removed from the compost solution and adsorbed onto surfaces of materials having high cation exchange capacity (CEC), such as zeolite. Adding such materials (25%, by weight) can reduce ammonia volatilization (Witter and Kirchmann, 1989).

Various composting procedures can yield the required results, including turned windrows, aerated static piles, and in-vessel composting. Normally, the economics of turned windrows is

---

Table 1. Characteristics of raw mixture (0 d), young (74 d), and stable (111 d) compost, made of the coarse fraction of 2 cattle manure: 1 wheat straw (by volume) (M. Raviv, unpublished).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Raw</th>
<th>Young</th>
<th>Stable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost age (d)</td>
<td>0</td>
<td>74</td>
<td>111</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>74.8</td>
<td>55.7</td>
<td>53.3</td>
</tr>
<tr>
<td>Nitrogen (%)</td>
<td>1.67</td>
<td>2.17</td>
<td>2.39</td>
</tr>
<tr>
<td>Phosphorous (%)</td>
<td>0.52</td>
<td>0.79</td>
<td>0.74</td>
</tr>
<tr>
<td>Potassium (%)</td>
<td>1.31</td>
<td>1.79</td>
<td>2.11</td>
</tr>
<tr>
<td>pH</td>
<td>7.6</td>
<td>7.5</td>
<td>6.8</td>
</tr>
<tr>
<td>Electrical conductivity (dS·m⁻¹)</td>
<td>4.02</td>
<td>5.76</td>
<td>7.74</td>
</tr>
<tr>
<td>Nitrate nitrogen (mmol·L⁻¹)</td>
<td>0.01</td>
<td>0.3</td>
<td>164.4</td>
</tr>
<tr>
<td>Ammonium nitrogen (mmol·L⁻¹)</td>
<td>0.9</td>
<td>14.9</td>
<td>19.5</td>
</tr>
<tr>
<td>Soluble organic nitrogen [mg·L⁻¹ (ppm)]</td>
<td>142.9</td>
<td>98.7</td>
<td>81.5</td>
</tr>
<tr>
<td>Carbon : nitrogen ratio</td>
<td>26</td>
<td>15.1</td>
<td>13.1</td>
</tr>
<tr>
<td>Biological oxygen demand (g·kg⁻¹·d⁻¹)</td>
<td>16.1</td>
<td>9.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

*Composting was done in an aerated static pile, turned at days 28 and 78.

†In a 10:1 aqueous extract; 1 mmol·L⁻¹ = 1 meq·L⁻¹.
more favorable, while the other two methods provide better control.

Compost as an ingredient in container media

In addition to the age-old use of compost as soil amendment, the importance of its use as a constituent in container media is steadily growing. There are three main reasons for this trend: 1) In many cases, nonedible crops, such as ornamentals, forest and garden trees and shrubs, etc., can serve as a safe outlet for composts that may be considered as nondesirable for food crop production. 2) Various composts act as well as peat moss does in container media, while their cost is considerably lower. 3) Mature composts may suppress many soilborne diseases. Reviews describing the production and use of composts as growing media were written by Miller and Metting (1992), Inbar et al. (1993), Epstein (1997), Raviv (1998a), and Raviv et al. (2002). The use of bark and wood composts as growing media was reviewed by Gartner and Williams (1978), Worrall (1978), Pokorny (1979), Aaron (1982), Riviere and Milhau (1984), Pudelski (1985), Bunt (1988), Miller and Jones (1995), and Benoit and Ceustermans (1995).

Peat moss is widely used as a stand-alone medium or as an ingredient in growing media. It attained this important position due to its excellent physical properties. The main relevant properties are its high air-filled porosity (AFP) and easily available water (EAW) under conditions of container capacity, i.e., after the end of free drainage (Bunt, 1988). Simultaneously, peat’s hydraulic conductivity under these conditions is high (da Silva et al., 1993; Heiskanen, 1995, 1999). Another positive characteristic of peat is its high oxygen diffusion rate (ODR) (Bunt, 1991). Yet growers and researchers throughout the world have been looking for peat substitutes for almost three decades now. The initial drive for replacing peat in growing media was its high cost. In addition, researchers found that peat is a conducive substrate for numerous soilborne diseases (Hoitink et al., 1977). The sterilization of peat does not alleviate the problem, as it leaves a biological vacuum that can easily be filled by pathogenic fungi. Once it was established that mature compost can counteract this phenomenon (Hoitink, 1980), its use together with or as a substitute for peat became commonplace. In addition, ecological considerations, such as the role of peat bogs in atmospheric carbon dioxide (CO₂) assimilation and their role in ensuring groundwater quality, call for peat replacement with other, renewable organic substrates.

Required compost characteristics. The use of young composts that can be tolerated for land application is not possible when compost constitutes a major part (≥10% by volume) of the rhizosphere, as is the case in container media. Young composts frequently contain phytotoxic organic molecules (Wu et al., 2000). As young composts still contain readily biodegradable compounds, they can undergo secondary biodegradation, leading to oxygen and N deficiencies in the rhizosphere. Therefore, composts used as substrates must be stable. Although compost stability is not identical to compost maturity, mature composts are necessarily stable. Therefore, compost maturity, being a prerequisite for its suppressiveness of many soilborne diseases (Nelson and Hoitink, 1983), also ensures the required stability.

The physical properties of compost used as a container medium are of major importance; hydraulic conductivity (both under saturated and unsaturated conditions) should be high, as should its AFP and EAW (Raviv and Medina, 1997). When used in soilless media, both immediate and slow-release contribution of nutrients must be taken into consideration. Otherwise, excessive vegetative growth and/or salinity effects may occur. Salinity and excessive concentrations of phytotoxic ions can be easily taken care of by leaching. The question of nutrients is more complex. Long and complicated incubation experiments may be necessary in order to predict availability of gradually released nutrients and to take that into account in the nutritional program of the crop (Hadas and Portnoy, 1994, 1997).

It must be reiterated that unless all these requirements are met simultaneously, the compost may fail to serve successfully as a container medium. This may be the reason why Cull (1981) stated “Of the nine major organic materials reviewed, not one stands out as the alternative to peat in the U.K.” Since then, a wide variety of materials has been composted and served successfully as components of container media, and clear criteria of the suitability of such composts have been described (Inbar et al., 1993; Raviv et al., 1986).

Physical characteristics. Physical characteristics of composts vary greatly. At the two extremes of the scale are sewage sludge–bark compost [bulk density (BD) 0.4 g·cm⁻³ (0.23 oz/inch³), total porosity (TP) 73%, AFP 17%, and EAW 10% (Nappi and Barberis, 1993)] and compost made of rice hulls with 20% cow manure [BD 0.11 g·cm⁻³ (0.06 oz/inch³), TP 94%, AFP 46%, and EAW 25% (M. Raviv and Y. Mor, unpublished)]. Compost made of the coarse fraction of separated cattle manure is closer to the middle of the scale, with BD 0.18 g·cm⁻³ (0.10 oz/inch³), TP 92%, AFP 21%, and EAW 23%, (Raviv et al., 1998b). It can be concluded that composts can be tailor-made for a wide variety of requirements related to physical properties. Many types of compost with high and low TP (e.g., most sewage sludge and MSW composts) can serve only as minor ingredients in potting mixes. Their proportion can be higher, however, when high yield or fast growth rate are less important. On the other hand, composts with high TP and AFP, such as compost made of the coarse fraction of cow manure and grape marc, can replace peat moss successfully and even serve on their own (Inbar et al., 1986; Raviv et al., 1998b, 1998c).

Chemical characteristics. A beneficial effect of including compost in a growth medium is its nutritional contribution. Nonmature compost can immobilize a significant amount of N, but once stabilized, compost acts, to a large extent, as a slow-release fertilizer (Jespersen and Willumsen, 1993; Williams and Nelson, 1992). Most composts have pH values slightly above the desirable range (Nappi and Barberis, 1993). This can be corrected during plant growth by applying nitric or phosphoric acids as sources of N and phosphorus, respectively.

Biological characteristics. Many mature composts suppress a large range of phytopathogenic fungi after undergoing a curing stage (Hadar and Gorodecki, 1991; Hoitink and Kuter, 1986; Mandelbaum and Hadar, 1990). Sterilization largely inhibits this phenomenon (Mandelbaum et al., 1988; Raviv et al., 1998d; Reuveni et al., 2002), suggesting that most of its results
from microbial activity, although some residual activity is probably related to fungistatic compounds existing in the composts (Hoitink and Fahy, 1986).

Composting for High-quality Composts. The main expectations from composts used for container media are of physical (high AFP, high EAW) and of biological (low BOD, suppressiveness) natures. Reconciling these demands is not always straightforward. Materials such as softwood bark, wood shavings, rice hulls, and coconut coir are usually characterized by good physical properties after composting. However, as these materials are relatively resistant to decomposition, compost operators tend to assume that they are ready before full maturation is actually achieved. In such a case, they may undergo secondary breakdown while in the container, which may be accompanied by high N consumption by microorganisms. It interferes with standard, predictable plant nutrition and results with less-than-satisfactory plant performance (Handreck, 1992a, 1992b). It is therefore clear that these types of raw materials should be subjected to long and well-controlled composting, normally conducted in well-controlled turned windrows. The composting of these raw materials may be shortened using N and N-rich organic matter such as animal manures. High temperatures may cause ashing of these materials, which lead to reduced porosity and increased bulk density. Temperatures must be controlled carefully and values above 65 °C are not desirable.

Compost disease suppressiveness is clearly linked with the compost degree of maturity, although excessively stabilized composts tend to lose suppressiveness capacity (Hoitink and Grebus, 1997).

In addition to the more ligneous materials, composts serving as growing media may be produced from numerous organic wastes: sewage sludge, municipal solid waste, animal excreta, and wastes of food industry, such as sewage sludge, chicken manure, and slaughterhouse wastes. In such cases, they will serve as bulking agents and N traps (Genevini et al., 1997).

Animal excreta are of special value for both composting and co-composting because they contain large, diverse populations of microorganisms, which accelerate the process.

Wastes of the food and processing industry are especially convenient for composting since they are uniform, rich in organic matter, and concentrated in place. In some cases, the physical and chemical characteristics of these composts make them suitable to serve as components in container media, thus greatly increasing their economic value. A few examples for such raw materials are apple pomace (van de Kamp, 1986), sugar-cane fiber (bagasse) (Trocchoulias et al., 1990), vegetable residues (Vallini et al., 1992), olive marc (Pages et al., 1985), grape marc (Inbar et al., 1986), grape stalks and corn cobs (Accati et al., 1996), fish and crab wastes (Mathur et al., 1990), and cotton gin waste (Wang, 1991). Various types of shells or hulls are particularly useful due to their inherent stability and good physical properties. Examples are rice hulls (Accati et al., 1996; Einert and Baker, 1973) and peanut hulls (Bilderback, 1982). As a general rule, both turned windrow composting and in-vessel composting tend to exert a negative effect on the physical properties of the end-products of many of these raw materials. It is therefore recommended to stabilize them using static piles that are turned only rarely, in order to ensure proper homogenization.

Conclusions

It can be concluded that the large variety of types of raw materials, composting procedures, and possible composting durations allows an almost endless flexibility in terms of the resulting compost types. In many cases the relevant know-how exists, and obtaining the required product is a matter of communication between the compost producer and consumers. Even if precise recipes do not exist, understanding the expectations of the consumer can lead to a gradual process of optimization. Open minds and open channels are the most valuable tools in the quest for ideal composts.

Literature cited


Witter, E. and H. Kirchmann. 1989. Peat, zeolite and basalt as adsorbents of ammoniacal nitrogen during manure decomposi-


