# Plant Performance in Relation to Oxygen Depletion, $CO_2$-Rate and Volatile Fatty Acids in Container Media Composts of Varying Maturity

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**ABSTRACT** Compost performance in container media presents a challenge to the compost industry. Seedling and container composts represent high-value horticultural products, and many competing products are available. Therefore plants grown with compost container media must exhibit excellent properties. However, there are frequent reports of poor performance of container and seedling starter mixes. Many factors, including porosity, salt content and maturity of composts prior to starting container plants, may play a large role in the observed performance. Dilution and use of bark and peat can remove salt and porosity as factors. Immaturity has frequently been associated with poor plant performance, but it is not known what precise levels of maturity affect container performance. Ammonia and volatile fatty acids (VFA), known to be phytotoxic, are frequently found in immature composts. This study uses three composts of varying maturity in container mixes and examines plant performance over 21 days. The results indicate that immature and semicured composts reduce oxygen content very significantly in container media to levels that may directly and indirectly damage roots. The study evaluates which tests may be used to predict performance. The Dewar test which rates compost on a I - V scale, did not predict damage. Initial VFA, $CO_2$ respiration and Solvita tests all predicted the poor result of immature composts in container performance.

## INTRODUCTION

Composts which are not fully stabilised are considered to be immature. Such composts may heat up in Dewar vessels, contain high levels of volatile fatty acids (VFA) and possess a high oxygen demand (Jourdan 1988; Manios et al.1989; Brinton et al. 1995, Ionaotti 1994a). A wide variety of tests have been proposed for compost maturity and toxicity (Itävaara et al. 1998; SEPA 1997).

Among many growth-suppressing traits in composts is the presence of VFA. The composting process involves unavoidable episodic oxygen depletion. This may result in temporary accumulation of short-chain volatile fatty acids (VFA).

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VFA have been previously shown to be responsible for poor plant performance in controlled studies (Devleeschauwer et al. 1981; Brinton 1998; Brinton and Tränkner 1999; Lee 1977). However, under many circumstances, we have observed poor performance where little or no VFA is present or when the Dewar test results indicated grade IV and V composts, considered to be “finished” (LAGA 1984). A more sensitive test is needed for general usage. In order to be fully meaningful to compost users, laboratory tests used for maturity must be evaluated in relation to end uses of compost. Our study examines plant performance in relation to qualities of composts used in container media.

We previously reported a survey of 712 compost samples showing that 26% had VFA above 5000 mg kg $dm^{-1}$ while 6% had VFA above 20000 mg kg $dm^{-1}$. The VFA correlated negatively with compost age and were highest in the first 20-35 days of composting (Brinton 1998). Prior work in plant growing media revealed that VFA levels as low as 500 mg kg $dm^{-1}$ exert phytotoxic effects on plant seedlings (Lynch 1977). In liquid nutrient culture, VFAs of as little as 100 mg $kg^{-1}$ cause 50% growth depression (Woods End 1997). Many factors, however, may be involved in growth depression. Some composts which have very little VFA and adequate nutrients still perform poorly in growing media. Oxygen depletion in the root zone may be one such factor. Oxygen is critical for root development, and adequacy of air governs important ion adsorption properties. Roots of plants growing under waterlogged or anaerobic conditions have extremely retarded respiration and low ion uptake rates (Salisbury and Ross 1978). It is likely, therefore, that immature composts used in containers may exert influence on oxygen supply traits. With composts being used in high-value markets such as for container media and starting of seedlings for vegetable culture, to better prediction of conditions that may cause poor performance is imperative.

## MATERIALS AND METHODS

### In-vessel compost samples

Compost samples were obtained from an in-vessel biosolids compost facility in

Rockland, Maine, in August of 2000. Representative samples were selected from three phases of the compost process; phase I, uncured compost discharged after 21 days; phase II, semi-cured compost cured for 60 days under cover and phase III discharged compost cured 250 days outside. The mixing formulae for these composts were held constant at the facility. The analytical traits of these composts are given in Table 1.

Table 1: Physical / Chemical Traits of Biosolids Compost Examined in Container Study

| Compost | pH 1:1 | OM % (dm) | Total-N% (dm) | C:N | NH4-N ppm (dm) | NO3-N ppm (dm) | VFA ppm (dm) | Salt S $m^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Uncured age 21 days | 7.53 | 73.0 | 1.969 | 20.0 | 4872 | 1 | 2109 | 0.49 |
| Semicured age 76 days | 7.44 | 73.0 | 2.212 | 17.8 | 3295 | 1 | 993 | 0.42 |
| Cured age 250 days | 6.10 | 57.0 | 2.949 | 10.4 | 16 | 1734 | 319 | 0.45 |

Table 2: Biological Traits of Biosolids Composts

| Compost | $CO_2$-C% of C | $CO_2$- C% (dm) | Solvita test unit | Wheat-Germination Rel% | Wheat Biomass Rel% | Cress Germination Rel % | Cress Biomass Rel% | Dewar C° (Grade) |
|---|---|---|---|---|---|---|---|---|
| Uncured age 21 days | 0.53 | 0.20 | 4 | 93 | 62 | 45 | 41 | 31 (II) |
| Semicured age 76 days | 0.59 | 0.23 | 4 | 93 | 56 | 35 | 37 | 10 (V) |
| Cured age 250 days | 0.14 | 0.04 | 7 | 93 | 83 | 98 | 79 | 3 (V) |

The test traits indicate a transition from high-ammonium, medium-high CN ratio composts to low CN, high nitrate composts. Although the Dewar test temperature indicates a wide range of heating, the rating scale employed in the Dewar places both the semicured and the cured in the same finished class. Moisture was added to the compost to reach optimal level prior to conducting Dewar and $CO_2$ respiration tests. Solvita tests correlated closely with $CO_2$ respiration whether reported as percent of carbon or percent of dry matter. VFA content was high for the uncured material and diminished as the material aged.

## Simulated Container-Mix Formulation

In order to construct container mixes, we determined the needed dilution with peat moss to reach a suitably low conductivity of approximately 0.2 S $m^{-1}$ . In addition, we determined that diluted compost mixtures would vary in air porosity, depending on the depth in pots. Air porosity of compost alone diluted with peat was higher (45 - 49%) than normally encountered with container mixes. Thus, we prepared a blend of compost / peat / washed sand (2:1:1) that resulted in a uniform air porosity, ranging from 16 - 18% throughout the container after packing. Two container volumes were selected: 3 and 12 l. No additional nutrients were provided.

To measure oxygen concentration in the container media, we inserted narrow 1.5-mm vinyl air tubes to specified depths at the top, middle and bottom or 4, 10.5 and 17.5 cm depths from the top, respectively. At the time of measurement, these tubes were attached to an $O_2$-sensitive electrode via a mini-air sampler that requires only 5 $cm^{-3}$ of air to obtain a reading. A small suction syringe was used to extract sufficient air daily during the growth of the plants. The pots were seeded to sorghum-sudan grass at an equivalent rate of 400 kg $ha^{-1}$ (approximately 1 seed / 3 $cm^{-2}$ ). Final harvests were made at 16 days after planting. Plants were held under Gro-Lux lights for 12-hr light/dark cycles at 22 °C.

**Figure 1 Oxygen measuring lines inserted container-media into pots at varying depths.**

## Analytical Methods

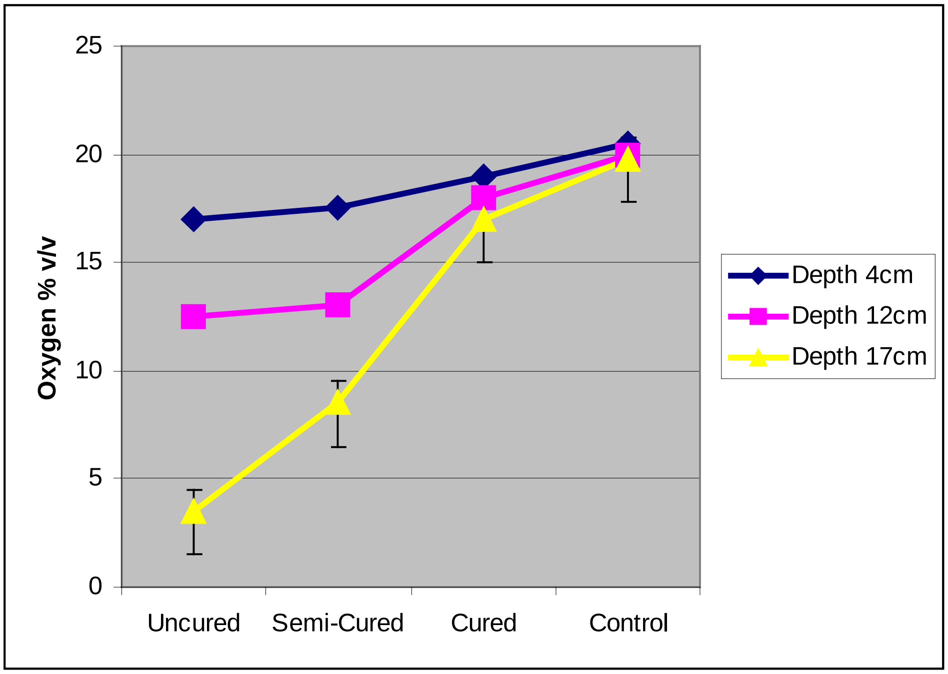
Volatile fatty acids (VFA) were determined after water extraction and distillation in $H_2SO_4$ at pH 1.8; the resulting distillate was titrated to a standard endpoint (SMM 1994). The $CO_2$ evolution rate was determined on 40-g samples after 1 day of equilibration after sampling and incubation temperature of 34 °C. $CO_2$ was trapped in a NaOH-barium, the Kjeldahl procedure for solid waste (EPA1996) and nitrate by water extraction followed by liquid ion chromatography (SMM 1994). Ammonia was determined by LiAC extraction followed by ion-electrode determination (Orion 1982). The presence of hydrogen sulfide was estimated by placing Merckoquant lead acetate indicator strips over samples of acidified compost (Merck 1996). Solvita maturity was determined with Solvita test kits (TMECC 2000). Phytotoxicity tests were conducted on each of the three composts and one control by 1:1 (v/v) dilution of limed, spaghnum peat (pH = 6.2) to obtain a conductivity of approximately 0.2 S $m^{-1}$. Subsequently, ten seeds each of garden cress (*Lepidium sativa*) and wheat (*Triticum aestivum* var. Rose) were sown into each of six 50-cc cells. Germination and growth was measured after 7 days by counting plants and cutting and weighing fresh material. Results are reported against a control of professional peat/nutrient media (Fafard 3-B Mix, Fafard, New Brunswick). To measure roots in large pots, plants were removed by cutting media cross-sectionally and then roots were washed with a gentle stream of water.

## RESULTS

### Oxygen Content in Growing Media

Oxygen content of interstitial pores diminished with depth in media and was significantly affected by the apparent maturity of the composts (see Fig. 2). Surprisingly, the $O_2$ content did not vary appreciably over time but persisted near the levels shown in Fig. 2 throughout the growing period.

**Fig. 1.** Interstitial oxygen concentration in compost container media




**Performance of Plants as Seen in Tops and Root Development**

At 21days, the entire plant/root mass was carefully removed from the media for visual examination (Fig. 3). These examinations correspond to the data collected for distribution of oxygen in the containers (Fig. 2). Root development and plant yield responded to increasing maturity of compost (Fig. 3). The differences between the uncured and semicured were more pronounced ($p < 0.04$) than between the cured and the control ($p < 0.10$).

**Fig. 2.** Container media series, from left to right: uncured, semicured, cured, control

It is evident that there is little root growth in the immature composts where rootlets were confined to the top and edges of the container. In the cured treatment, the roots extend to the bottom of the pot.

**Effects of Compost Maturity on Root Development: Root Washings**

Immediately after the root-ball of plants was removed from the pots, we also harvested the rootlets from the containers by washing them gently out of the compost-peat-sand mix. In Fig. 4 we provide evidence of the rootlet damage incurred as a result of the immaturity of uncured and semicured composts. Table 3 gives results from plant effects observed in Fig. 4.

**Fig. 3.** Development of plant roots as affected my compost maturity: from left to right uncured, semicured, cured, control

We tabulated the root length and weight of tops. Table 3 gives the results for plant fresh weight and root length.

Table 3: Yield and root weight in relation to compost treatment. Means followed by the same letter in the row do not differ significantly at the $p < 0.05$ level

| Variable | Uncured | Semicured | Cured | Control |
|---|---|---|---|---|
| Plant fresh weight (mg) | 73 a | 116 b | 183 c | 196 c |
| Root length (cm) | 7.5 a | 9.0 b | 12 c | 19 d |

The plant effects observed from immature composts are more evident on closer inspection. A pronounced stiffening of the rootlets is evident, with tissue thickening above the hypocotyl, where the stems joins the root. There was also evident discoloration of the rootlets from immature composts. We detected hydrogen sulfide in uncured and semicured compost media at the 17 cm depth.

## Relationships Between Measured Parameters

We tabulated statistical correlations from averaged treatment effects. In Table 5 the significant correlations ($p < 0.05$) are listed.

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**Table 4: Correlations Observed Between Test Traits and Plant Growth**

| Relationship Examined | r factor |
|---|---|
| Solvita test : cress weight | 0.996* |
| Solvita test : $CO_2$ rate | -0.992 |
| $CO_2$ rate : cress weight ($CO_2$ rate as % of TS) | -0.998* |
| $CO_2$ rate : cress weight ($CO_2$ rate as % of Carbon ) | -0.999** |
| $CO_2$-Rate : Wheat Weight ($CO_2$ as % of TS) | -0.998* |
| Root length : VFA content | -0.999** |
| Plant yield : ammonium | -0.997* |
| Plant yield : $O_2$ content ($O_2$ measured at 17cm depth) | -0.997* |

The data suggest that a number of important, interrelated factors played a role in determining plant effects arising from immature composts. The causal mechanism was most likely elevated $CO_2$ evolution and VFA production, elevated ammonia levels, along with oxygen deprivation and hydrogen sulfide production in containers during growth. Early workers have showed that $O_2$ levels of 5% or less in the root zone may cause dramatic loss of potassium absorption potential (Vlamis 1944). We did not measure ethylene gas, but it is likely to have been produced under anaerobic conditions in the lower layers of the containers. Hydrogen sulfide was produced and is known to have damaging effects on root development.

**Implications for Further Work: CO2 Evolution Rate Versus Plant Growth**

In view of the relationship of immaturity to plant growth we observed here, we decided to examine additional data on plant yield (cress test) in relation to compost $CO_2$-evolution rate. In Fig. 5 we present 155 compost analyses by regressing cress fresh weight at 7days against $CO_2$ rate. The linear correlation gave a very significant relation of $r = 0.37$ ($p < 0.001$) and the logarithmic scale $CO_2$ rate gave a very highly significant relationship at $r = 0.53$, $p < 0.0001$.

Germination results from the same study indicated that $CO_2$ evolution rate had little or no significant effect on seed germination for either cress or wheat. Germination is thus a poor predictor for compost maturity. The observed $CO_2$ rate relationship to growth may be direct, indirect, or both. $CO_2$ rate very likely affects other important parameters that in turn influence plant growth, such as levels of VFA, ammonia and C:N ratio. These observations suggest that maturity is indeed a complex phenomena.

Data in Fig. 5 show that about 1/3 of all composts examined achieved a growth performance comparable to a professional peat-based mix, while another 1/3 inhibited it slightly to significantly, and 1/3 very significantly. Additionally, several of the composts reduced yields even more than the unfertilized controls (50% growth), which suggests severe phytotoxicity traits. This may result indirectly from oxygen deprivation plus any one of the previously mentioned traits. More work should be focused on appreciating the significance of compost-induced growth suppression, but only in context of the intended use, since clearly maturity is relative to all factors encountered in the use of composts. Tests that act as predictors must show relevant relationships to the results of compost usage.

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