OXYGEN AND GROWTH

HOW COMPOST MATURITY AFFECTS CONTAINER GROWN PLANTS

Traits of composts at various stages — 21 days of active composting, and both 60 and 250 days of curing — can be indicators of negative impact on plants.

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MANY TRAITS associated with immaturity of composts have been shown to cause poor plant performance, since these composts may have elevated levels of ammonia and volatile organic acids. However, the intended use of the compost must be known since hypothesized negative traits may only make their appearance at or above critical concentration thresholds. In the case of container mixes, for example, where very high application rates of compost are used, potential problems are likely to occur. To predict these potential problems, laboratory tests may be used. In this study, we examined container plant performance in relation to qualities of compost of varying age and maturity.

In a 1998 issue of *Compost Science & Utilization*, we reported a survey of 712 compost samples showing that 26 percent had volatile organic acids (VOA) above 5,000 ppm while six percent had VOA above 20,000 ppm. VOA levels correlated with both the age and conditions of the composts. We found that most composts did not negatively affect plant growth until VOA exceeded 5,000 ppm. However, other work has shown that VOA levels as low as 500 ppm exert phytotoxic effects. Yet, when we extracted compost VOAs and applied them in liquid nutrient culture, as little as 100 ppm caused 50 percent growth depression. Clearly, the mode of delivery and the concentration of these compounds relative to other physical and biological factors will significantly determine acceptable concentration thresholds.

OXYGEN DEPLETION

Oxygen depletion resulting from immature composts is a potentially significant indirect factor that may exacerbate negative effects on plants. Oxygen is critically required for normal root development since the adequacy of air governs important respiration-driven traits such as nutrient uptake. Roots of plants growing under waterlogged or anaerobic conditions have been shown to have retarded metabolism and suppressed ion uptake rates. Researchers have shown that O_2 concentrations of five percent or less in the root zone may cause dramatic loss of potassium absorption potential. Therefore we pose the question whether it is likely that immature composts, when used in heavy concentrations in container media (or applied to soil in very high concentrations), will exert a sufficiently large effect on oxygen supply to result in suppressed root development. If so, then maturity and stability tests related to respiration of composts become even more significant.

During the summer of 2000, we prepared a set of container mixes by collecting compost from an in-vessel biosolids compost facility in Rockland, Maine. To do this, we obtained representative samples from each of three phases of the compost process: Phase I, "uncured," when compost is discharged after 21 days; Phase II, "semicured," when compost is cured for an additional 60 days under cover; and Phase III, "cured," when compost has been cured for a total of 250 days outside.

We analyzed these composts using standard methods and found the chemical and biological traits reported in Tables 1 and 2. The results indicate material undergoing a rather typical chemical-biological transition from unstable, high ammonium, medium-high C:N composts to low C:N, high nitrate composts typical of finished materials. The Dewar reheating test gave a wide range of heating, yet the scale employed to rate the results indicated that both the semicured and the cured belonged to a "finished" class.

Table 1: Physical/chemical traits of biosolids compost examined in container study

Compost	pH 1:1	OM% (dm)	TKN% (dm)	C:N	NH_3-N (ppm)	NO_3-N (ppm)	VFA (ppm)	Salt dS/ (cm)
Uncured Age 21 days	7.53	73.0	1.969	20.0	4872	1	2109	4.9
Semicured Age 81 days	7.44	73.0	2.212	17.8	3295	1	993	4.2
Cured Age 271 days	6.10	57.0	2.949	10.4	16	1734	319	4.5

Table 2: Biological traits of biosolids composts

Compost	CO_2-C% of C	CO_2-C% of TS	Solvita Test	Wheat Germ.%	Wheat Rel. % Biomass	Cress Germ. %	Cress Rel. % Biomass	Dewar C° Grade
Uncured	0.53	0.20	4	93	62	45	41	31 - II
Semicured	0.59	0.23	4	93	56	35	37	10 - V
Cured	0.14	0.04	7	93	83	98	79	3 - V

In contrast, both the laboratory CO_2 respiration tests and Solvita volumetric tests ranked the two lesser cured samples into a similar class. We have speculated that the Dewar test may be insensitive for partially mature compost, particularly if the German system of rating is employed. VOA content was high for the uncured material and diminished as the material aged.

We made up container mixes by determining the needed dilution with peat moss to reach a suitably low conductivity of about 2 dS m^{-1}. The final media was a blend of compost, peat and washed sand (2:1:1 volume) that resulted in uniform air porosity from top to bottom of the containers after filling and packing. We duplicated the tests and ran two each of container volumes of three quarts and three gallons.

A critical aspect of the study was to measure oxygen concentration in the container media during growth. To do this, we inserted narrow vinyl air tubes to specified depths at the top, middle and bottom or 1.5-inch, five-inch and eight-inch depths from the top, respectively. These tubes could be attached to a O_2 sensitive electrode via a mini-air sampler apparatus that requires only 5cc of air to get in a reading. The pots were seeded to fast-growing sorghum-sudan grass and harvests were made at about 20 days after planting.

The oxygen content in the pots diminished with depth from the surface and correlated closely with the apparent maturity of the composts.

Figure 1. Interstitial Oxygen in 3-gallon containers in relation to depth and compost maturity

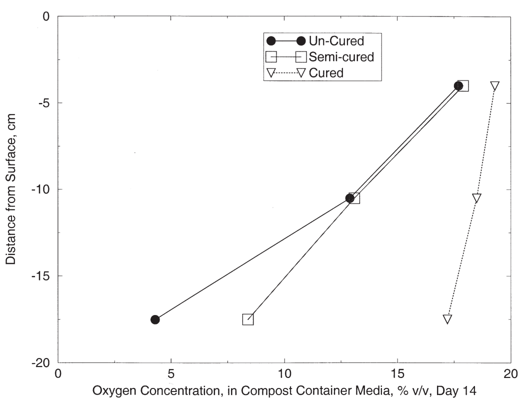
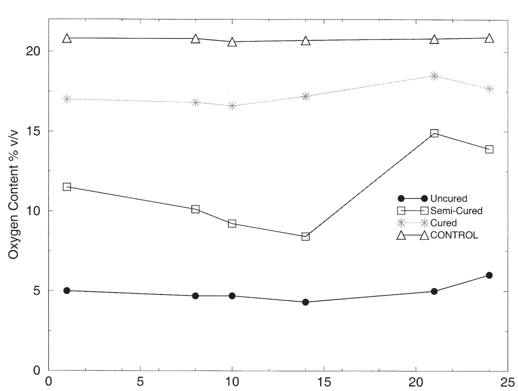


Figure 2. Container mix oxygen content during growth period in relation to type of compost media



HOW PLANTS PERFORMED

We observed that the oxygen content in the pots diminished with depth from the surface and correlated closely with the apparent maturity of the composts (Figure 1). Cured compost was only slightly affected by the depth of the media.

We recorded oxygen levels in the containers during the course of the study. The concentrations of oxygen and the relative differences between treatments persisted somewhat throughout the growth term, while semicured composts improved after the second week. The uncured composts remained relatively low in oxygen throughout the study. These apparent levels of oxygen correspond closely to the relative growth differences observed for tops and roots of the plants (Figure 2).

To evaluate quality, many growers routinely remove plants from pots to observe the root ball. At day 21, we pulled the plant/root mass for examination. Root development and plant yield reflect the increasing maturity of the compost media. In fact, the differences between the uncured and semicured composts were more pronounced than between the cured and the control.

There is very little root growth visually apparent in the immature compost, and actually, when breaking open the media, we see that the rootlets were mostly confined to the top and edges of the container, the only places where oxygen is found. In the cured treatment, the roots extend to the bottom of the pot.

We also harvested the rootlets from the containers by gently washing from the compost-peat-sand mix. When comparing growth in the uncured container mix to mix of 250 days compost, there is clear evidence of the rootlet damage sustained as a result

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	9.0	12	19

Table 4: Plant performance in dependence on container volume

Container Size	Vol. Area Ratio cc:cm	Uncured	Semi-cured	Cured
		Relative Yield %		
3-gallon	19	45	62	100
3-quart	14	34	71	100
4 oz	4	51	67	100

of immaturity in both uncured and semicured composts (Figure 3). We tabulated the average root length and separated the tops, which were weighed. Table 3 gives the respective results for plant fresh weight and root length. The plant effects observed in the immature composts are more obvious on closer inspection. Both a pronounced stiffening and thickening of the rootlets above the hypocotyl are observed. There was also evident discoloration of the rootlets from immature composts. We detected hydrogen sulfide in uncured and semicured compost media at the eight-inch depth.

If oxygen concentration in the media affects plants, we asked if plant damage also would be dependent on container size. This could be due to diminishing surface:volume ratio with larger containers, causing the potential negative effects of oxygen depletion to become more pronounced. Data for plant growth in three sizes of containers is reported in Table 4. These results provide little evidence for a difference when comparing the medium and large containers (three-quart versus three-gallon). The negative effect of the uncured compost was only slightly less pronounced in the very small seedling cells. While it is surprising that the differences are not greater between the containers, we do not know whether the effects would be more pronounced with even larger pots. The damaging effects observed for the immature compost appear to be very substantial. Surprisingly, there was no evident VOA remaining in the container mixes (< 500 ppm) at the end of the growth period. Thus, the damaging effects seem to be very persistent and once an immature high-oxygen depleting compost is put into a container, it is not likely to improve adequately in the relevant time frame to cause a reduction in the negative effects.

PREDICTING EFFECTS ON PLANTS

How may we interpret various test traits as predictors of the plant effects? We tabulated a variety of statistical correlations from the averaged treatment effects. In Table 5, the significant correlations ($p < 0.05$) are listed. Clearly, these results suggest that several tests are useful for predicting potential problems. The most significant relationship was VOA content and root length. Plant yield also negatively correlated with observed oxygen levels in the containers. Furthermore, laboratory CO_2-rate measurements, and volumetric CO_2-tests (Solvita), appear to closely predict seedling test results employing cress and wheat.

These findings overall suggest that a number of important, interrelated factors play a role in determining plant effects arising from immature composts. Any attempt to separate stability and maturity factors into different groups may therefore be irrelevant. The causal interconnected pathways most likely begin with elevated CO_2 evolution translating into elevated VOA. While effects from VOA and ammonia may be stronger early in growth at root emergence, the oxygen deprivation and hydrogen sulfide effects may be longer lasting or occur later during growth.

Some workers have used germination percentage to predict maturity, yet in our study there was no correlation between germination of several test parameters including CO_2 evolution and VOA. This was also confirmed in the earlier study that correlated test traits for many composts. Germination is thus a poor predictor for compost maturity. The observed oxygen and CO_2 rate relationship to growth may be direct, indirect, or both. While these observations suggest that maturity is a complex phenomenom in terms of causal mechanisms, several test traits we employed accurately predicted the resulting problem conditions that were observed in container growth. ■

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Table 5: Significant relationships of test parameters

Relationship Examined	r factor*
Solvita Test : Cress Weight	0.996
Solvita Test : CO_2 Rate	-0.992
CO_2 Rate : Cress Weight (CO_2 as % of TS)	-0.998
CO_2 Rate : Cress Weight (CO_2 as % of Carbon)	-0.999
CO_2 Rate : Wheat Weight (CO_2 as % of TS)	-0.998
Root Length : VOA Content	-0.999
Plant Yield : Ammonium	-0.997
Plant Yield : O_2 Content (O_2 measured at 17cm depth)	-0.997

** The closer the r value is to +1 or -1, the greater the relationship is. Therefore, an r value of 0.80 is much more significant than one of only 0.20. The correlations observed are between test traits and plant growth.*

***In a previous study, the authors examined 70 composts for growth traits and found no significant correlation between cress germination and respiration rate or any other maturity parameters. In this study, cress appeared to closely correspond.*

Figure 3. Container grown sorghum-sudangrass as affected by compost maturity

From left: uncured, semicured, cured, control