How Compost Maturity Affects Plant and Root Performance in Container Grown Media.

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INTRODUCTION

Composts which are not fully completed are considered to be immature. Just what constitutes a mature compost, and how far one should allow the composting process to go, is a question many growers ask. From the practical grower point of view, an immature compost is still hot, or smells poorly, or both, and may be risky to use directly on plants. On the analytical side, a wide variety of tests have been proposed to quantify compost maturity; most of them are employed only in Europe (Itävaara et al., 1998; SEPA 1999). In America, both in the organic movement and in the compost world in general, there has been a lack of focus concerning quality of composts. One explanation is that compost is generally considered to be good. Another is that for many farmers, any compost looks “mature” by comparison to raw manures they are accustomed to using. A certain amount of uncertainty exists if a grower is purchasing composts. According to recent reports, this is somewhat of a “buyer beware” situation (Long, 1999).

Plant growth problems are commonly experienced as a result of incorrect usage or immaturity of compost products. Some examples may be provided. At a recent landscaping project in the city of Boston, a contractor spread a compost/topsoil mix. However, the contractor had later to remove at great expense all the compost due to complaints of the odor of the product resulting from obvious immaturity. In another case, a corporation purchased bulk compost for a major landscaping renovation project. Yet, trees planted into the soil/compost mixes died rapidly, within 6 weeks, due to ammonia and immaturity factors. In one further instance, a plant nursery in Rhode Island used a compost blend for container plants, and the result was that the transplanted perennials became virtually dormant, eventually dying (see photo), also a result of incompletely matured product. Aside from the issue of maturity, what is regretful about these events is the economic losses to the growers and landscapers that ensued. It has also been demonstrated that, where such events are noticed by the media, a loss of public appreciation for composts results. This in turn affects perception of other compost products.

Events the lead to immature product

The composting process is characterized by episodic oxygen depletion, meaning as the material heats up, decomposition becomes more intense and consequently oxygen may be consumed by microbes faster than it is re-supplied by natural air diffusion. Some composters turn composts mechanically to hasten aeration, yet, this has been found to have little more than a very short term effect on the oxygen levels (Brinton, 1997). In actuality, the oxygen/carbon-dioxide cycle of composting is far more dynamic, and indicates the entire relationship of the state of decay of the materials in question. Just providing air to a pile does not significantly change the microbial activity rate, nor cause faster absorption of oxygen across water films which coat all the organic particles. Moving a pile may help reduce clumping, which is partly responsible for poor aeration in some composts. In actuality, compost requires a certain pre-determined time to go through its natural decay and reordering process. It is unfortunately the case that many composters attempt to shorten the cycle, anxious as they are to get product out of the way.

One of the chief results of the intense decomposition accompanied by low oxygen levels and high CO_2-levels in compost is the temporary accumulation of what are called short-chain volatile organic-acids (VOA). These are familiar compounds to most growers and food processors: they are formed in silage making, and are also counted on in fermentation of plant products. In these examples, the organic acids such as lactic, propionic and acetic, lead to a slow-down or cessation of further decomposition and a state of preservation. If air is later introduced, then rapid aerobic activity starts with consumption of the organic acids, and spoilage results. Surprisingly, the process is very similar in composting, only the organic acids are ideally consumed early in the process, and a stable, growth promoting humus results later. The example of VOA is not the only factor in young composts that we can cite that might have a poor effect on plant performance. Hydrogen sulfide, ammonia and even ethylene are also produced in small amounts in early stages of composting, and are all deleterious to plant growth.

Volatile organic acids have been shown to be notoriously responsible for poor plant performance from composts in controlled studies (Devleeschauwer et al., 1981; Brinton, 1998; Brinton & Tränkner, 1999; Lee, 1977). However, under many circumstances we have observed poor performance where little or no VOA was involved. In these cases other explanations are sought for poor performance. Surprisingly, even when performing the official German test for compost stability, the Dewar test, some poor performing composts indicated grade IV and V composts, considered to be “finished” (LAGA, 1984). Our suspicion that the German test is too insensitive for factors that may be important for plant quality has been partly responsible for this investigation

The significance of oxygen to root development

An entire array of factors can be listed as causative of plant growth depression from immature composts, and because of this, plant studies in relation to compost analysis are needed to show how immature composts affect growth. In particular, we view oxygen depletion in the root zone as one such significant, but over-looked, factor. Oxygen is critical for healthy root development. Roots of plants growing under waterlogged or anaerobic conditions have been shown to have extremely retarded respiration rates and low nutrient uptake (Salisbury & Ross, 1978). A key trait of immature compost is that it consumes oxygen. It may then be very likely that immature composts used in containers - or in soil at high rates- will exert a negative influence on oxygen supply to the roots. The actual extent of the effect may depend on the pot size, porosity of the mix, and the level of immaturity of the compost.

With composts being used increasingly in gardening and especially for formulation of seedling or plant starter mixes, all these factors are very important issues. It is furthermore very important to find out if a means exists to easily predict conditions in the compost that may cause poor performance in plant production.

The Compost Maturity Study

Compost Samples of Various Ages

It was our goal to conduct a plant container study using preblended compost from the same source, but of varying maturity. In this study we would examine plant growth and conduct tests during the growth to see what changes occur in the pots. To conduct this study, we obtained compost samples from a local Maine compost facility in August of 2000. Representative samples were selected from three phases of the compost process; Phase I, “Uncured” when compost is discharged after the 21-day intensively turned phase; Phase II, “Semi-Cured” compost which has been cured for another 60-days in windrows under cover, and Phase III- “Cured” at the end of outdoor curing in open piles for 250 days. These composts all came from the same “recipe” at the facility. The lab tests of these composts are as follows (see Table 1):

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

Compost	pH 1:1	OM% dm	Total-N% dm	C:N	NH3-N ppm	NO3-N ppm	VOA ppm	Salt dS/cm
Un-Cured Age 21 days	7.53	73.0	1.969	20.0	4872	1	2109	4.9
Semi-Cured Age 76 Days	7.44	73.0	2.212	17.8	3295	1	993	4.2
Cured Age 250 d	6.10	57.0	2.949	10.4	16	1734	319	4.5

Table 2: Biological Traits of Composts

Lab:No	CO2-C% of C	CO2-C% of TS	Solvita Test	Wheat-Germination%	Wheat Rel. % Biomass	Cress Germination %	Cress - Rel.% Biomass	Dewar C˚ - Grade
Un-Cured	0.53	0.20	4	93	62	45	41	31 - II
Semi-Cured	0.59	0.23	4	93	56	35	37	10 - V
Cured	0.14	0.04	7	93	83	98	79	3 - V

The test traits clearly show a transition is underway from high a ammonium, medium-high CN ratio compost to a low CN, high nitrate compost. The loss of ammonia and gain of nitrate is a mark of maturing and mineralization in composting (Bockemühl, 1981). The results of the German Dewar test are very curious. These tests show a wide range of heating, yet, with the rating scale employed for the Dewar interpretation, both the two immature composts rated as “finished”. The Solvita tests correlated closely with the CO_2 respiration tests. VOA content was very high for the uncured material and diminished as the material aged. The three groups of samples alone display very excellent analytical differentiation between the “maturing” stages. The numbers alone, however, do not guide us in knowing the effects on plants.

Container Mix Formulation

We made up container mixes by dilution of the composts with limed peat moss in order to reach a suitably low conductivity of approximately 2 dS m^{-1} . We found that diluted compost mixtures varied in air porosity, depending on the depth and packing. So, to level out air porosity differences, and to achieve the right dilution based on salt content as noted above, we made a blend of compost +peat + washed sand (2 :1 : 1). This resulted in very uniform air porosity after packing at all depths in the pots. For the containers, 3-quarts and 3 -gallon pots were selected. These were seeded to sorghum-sudan grass at an equivalent rate of 350 lb/a or approximately 1 seed / 3cm^2. Final harvest measurements were made at about three-weeks after planting.

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Figure 1. Tubes inserted into pots at varying depths, used to measure oxygen levels before and during growth of plants.

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Test Methods

To measure oxygen concentration in the actual containers during plant growth, we inserted narrow vinyl air tubes to specified depths at the top, middle and bottom or 1.5, 4 and 7 inches from the top, respectively (see photo). To measure oxygen, the tubes are clipped to a O_2 sensitive electrode via a mini-air sampler using a small suction syringe to pull sufficient air for the test. Other laboratroy tests were conducted according to standard procedures. To estimate presence of hydrogen sulfide in the compost, we placed Merckoquant lead acetate indicator strips over samples of acidified compost (Merck, 1996). Solvita maturity was determined with Solvita test kits (TMECC, 2000).

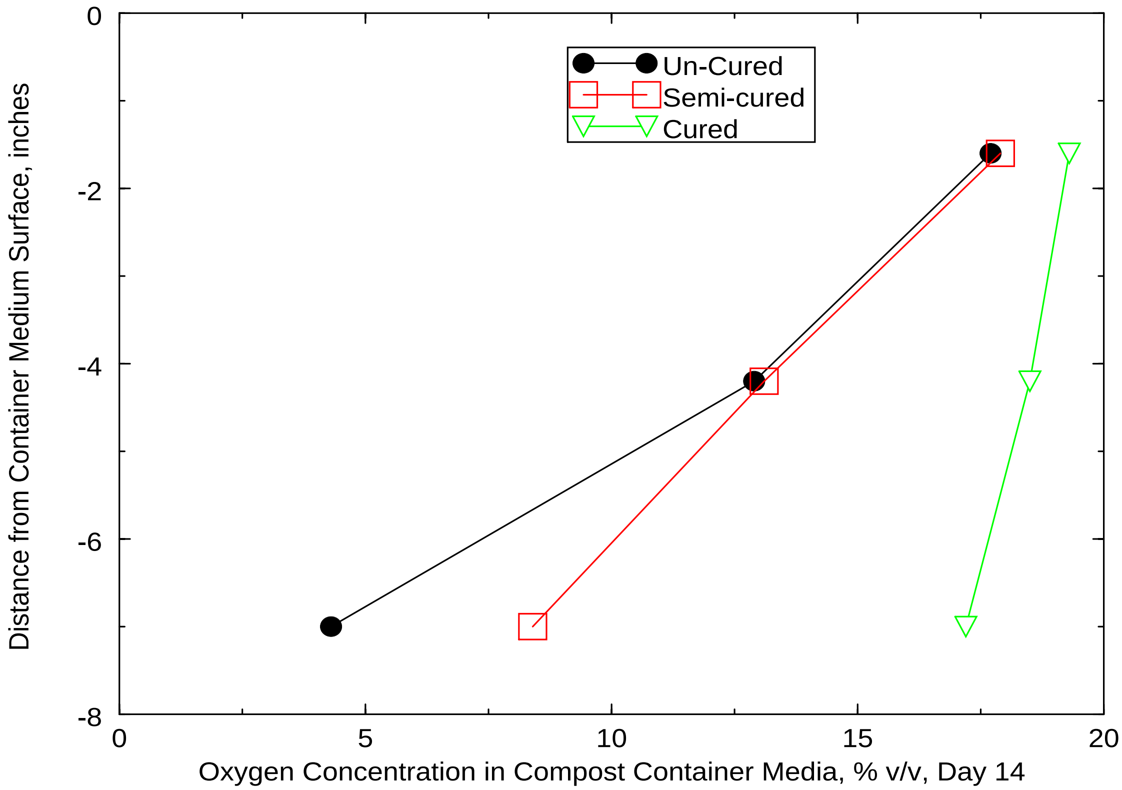
Separately, we conducted phytotoxicity tests on each of the three initial composts and on a control, in a manner similar to the German LAGA-10 procedure (LAGA10). For this we used a 1:1 dilution of compost in limed, spaghnum peat (pH = 6.2) calculated to reach a proper salt level. Then we placed 10 seeds each of garden cress (*Lepidium sativa*) and wheat (*Triticum aestivum* var. Rose) into each of six 50cc cells, the small garden seedling-tray variety. Germination and growth of these plants was measured after 7 days by weighing fresh material and comparing against a control of professional media (Fafard 3-B Mix, Fafard, New Brunswick). Finally, for root measurements of large container trials, plants were removed by cutting media cross-sectionally and washing with a gentle stream of water.

RESULTS

Oxygen Content in Growing Pots

Oxygen content in the plant containers diminished with depth in media in proportion to the immaturity of the composts (see Fig. 2). Surprisingly, the O_2 content did not change very much over time, but persisted near the levels shown in Figure 2throughout the growing period. These are very surprising results and show how strongly immature

Figure 2. Interstitial Oxygen in 12-L Container Media in Relation to Depth and Compost Maturity



composts pull down the oxygen level in the container media. Just what critical levels relate to optimum growth is uncertain; however, early workers have shown that O_2 levels of 5% or less in the root zone may cause dramatic loss of potassium absorption potential (Vlamis, 1944). Because we observe poor growth in both Un-cured and Semi-Cured pots, we may assume that oxygen levels below 15% are probably detrimental.

Performance of Plants as seen in Tops and Root Development

At day 21, the entire root-ball was carefully removed from the containers. In Figure 3, the treatments are shown corresponding to the data for distribution of oxygen in the containers. Root development and plant yield clearly responded to increasing maturity of the compost media. The differences between the Uncured and Semi-Cured were more pronounced than between the Cured and the Control.

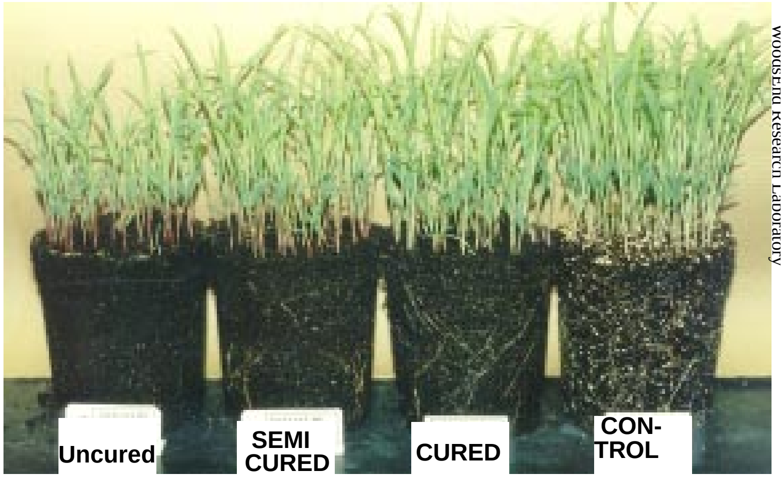


Figure 3. Sorghum-Sudangrass in Containers of Compost of Varying Maturity. Treatments from left to right are: Uncured (21-day) Semi-Cured (60-day) Cured (250-day), Control

The following figure provides a detail on the Uncured versus the Cured compost treatments (see Figure 4). 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.

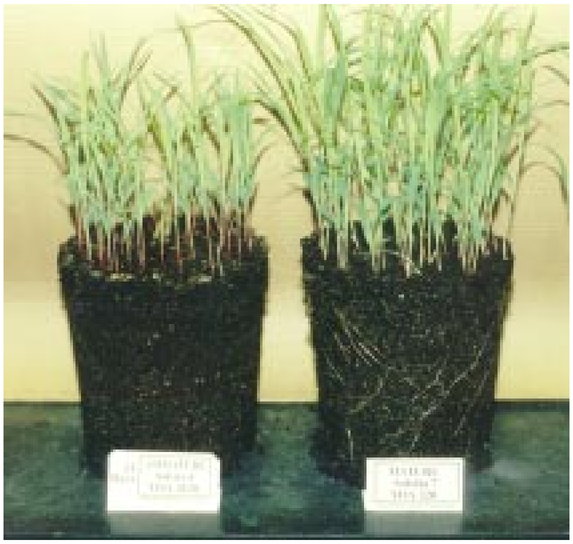


Figure 4. Detail of Uncured (21-day) compost mix (Left) compared to the 250-day Cured compost (right).

Effects of Compost Maturity on Root Development: Root Washings

We harvested rootlets from the containers by washing them gently out of the compost mix. In Figure 5 there is clear evidence of the extent of the rootlet damage resulting from of the immaturity of Uncured and Semi-cured composts. Figure 6 gives closer detail of the Uncured in contrast to the Cured compost treatment. Table 3 gives results from plant effects observed in Fig 5.

Figure 5. Top and Root Stress of plants as affected by container compost maturity.
From left: Uncured, Semi-cured, Cured, Control.

We tabulated the average root length and separated the tops which were weighed. The following table gives the respective results for plant fresh weight and root length (Table 3).

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	Semi-Cured	Cured	CONTROL
Plant Fresh Weight, mg.	73 a	116 b	183 c	196 c
Root Length, cm	7.5	9.0	12	19

The strong effects of immature composts on rootlets are made more evident by closer inspection. In Figure 6 we show the pronounced stiffening of the rootlets and tissue thickening at the hypocotyl. There was a strong discoloration of the rootlets from the un-cured composts. This may be partly explained by hydrogen sulfide whichwe detected in both the Uncured and Semicured compost media at the 7” cm depth.

Figure 6. Detail view of root effects resulting from different maturity composts. RIGHT view: Uncured, fresh compost after 21-days in vessel; LEFT; cured 250-days. The deformation of the rootlets is marked in the un-cured composts.

Container Plant Performance in Relation to Container Size

An hypothesis in this study has been that if plant damage from immature compost has to do with oyxgen it may also be related to container size. The reason would be that with increasing volume ther is a diminishing surface-to-volume ratio, which might increase the potential negative effects of lack of oxygen. We compared data for plant growth in three sizes of containers, as follows:

Table 4: Plant Performance in Dependence on Container Volume

Container Size	Vol: Area Ratio cc:cm	Un-Cured	Semi-Cured	Cured
		Relative Yield %		
3-gallon	19	45	62	100
3-Quart	14	34	71	100
6-pk small cell	4	51	67	100

These results provide little evidence for a pronounced difference in effect of container size when comparing the large containers (3-quart versus 3-gallon). But there is some evidence that the negative effect of the uncured compost is somewhat less pronounced in the small speedling cells, although the negative effects are still apparent. These small containers obviously have a significantly lower ratio of volume to surface area than the large containers. However, it is nontheless surprising that the differences are not greater . This suggests that the damaging effects of immature compost on container plants are strong and very persistent.

Relationships Between Measured Parameters

What relationships between the test traits and the performance are important? We tabulated statistical correlations from the averaged treatment effects and in Table 5 we show the important correlations.

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Table 5: Correlations Observed Between Test Traits and Plant Growth. r-values close to 1 (or -1) signify very close correlations; * or ** indicate significant or very significant results

Relationship Examined	r factor
Solvita Test : Cress Weight Solvita Test : CO2-Rate	0.996* -0.992
CO_2-Rate : Cress Weight (CO2 as % of TS) CO_2-Rate : Cress Weight (CO_2 as % of Carbon)	-0.998* -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 7" depth)	-0.997*

These results indicate clearly that a number of interrelated factors determine plant effects from immature composts. There is no direct causal mechanism. Perhaps the series of events are triggered by elevated CO_2-evolution in the compost and this leads to high organic acid production (before being put into pots), elevated ammonia levels (prior to use in pots), and finallt to oxygen deprivation and hydrogen sulfide production in the containers during growth. The tests that have promise to predict the potential plant performance from compost included: VOA, CO_2-respiration and the Solvita test. The Solvita test is the only field test and also the only simple procedure that can be performed by the end-user just before using compost product. The tests for hydrogen sulfide are quick correlated generally with root results; however, this particular procedure does require some lab materials and the use of strong acid to obtain a result.

Overview of Compost Activity versus Plant Growth

In view of the relationship of immaturity to plant growth we show here, we asked whether other more plentiful data regarding plant yield (cress test) and compost activity (CO_2evolution rate) would suggest a similar result. For this we examined 155 composts previously tested during 1999-2000 in the laboratory by comparing cress fresh weight at 7 days to the compost CO_2-rate. Cress growth and CO_2-rate were found to be very significantly correlated ($r = 0.53$, $p <$

0.0001) (Brinton & Evans, 2000). In general, it appears that the rate of break-down of compost is a factor that competes with the quality and quantity of plant growth.

Some workers use seed germination tests as a measure of compost quality. However, in our study neither germination of cress or wheat showed any relationship to the CO_2-rate. Germination thus appears to be a poor predictor for compost maturity. In any event. the observed relationship of CO_2 rate to plant growth does not tell if it is a direct or indirect effect—it may be both. As already explained, CO_2-rate most likely affects various other traits that may in turn influence plant growth, such as increased levels of VOA, more ammonia and most importantly, a reduction in oxygen supply to the roots. These observations suggest that it is important to look at the whole unit of compost media relative to the container, to understand effects on plant performance.

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References

(Available by inquiry of the author)

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