Compost Maturity as Expressed by Phytotoxicity and Volatile Organic Acids

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1. ABSTRACT

We examine a database of 899 samples from our routine analyses of composts across USA which vary from active (Frischkompost) to cured (Fertigkompost) product. Of these samples, a subset of 69 exhibiting some phytotoxicity traits were examined using plant assays. About 15% of samples were moderately plant toxic and 2.5% exhibited extreme growth suppression. To determine maturity we evaluate wheat and cress seedling growth in a peat:compost blend and compare to CO_2-evolution and volatile organic acid (VOA) content. Compost samples showed a range of concentration between 72 and 88,737 mg/kg and 0.01 to 0.81%/day for VOA and CO_2-C, respectively. Both wheat and cress yield showed significant negative correlations with maturity expressed as VOA concentration or CO_2-rate, supporting the hypothesis that mature composts are more beneficial for plants. Wheat was more sensitive to VOA than was cress which exhibited greater sensitivity to conductivity. Critical levels of VOA in compost which result in observable growth depression when applied in seedling trials are approximately 5,000 mg/kg. Critical respiration rates associated with observable depression are about 0.4% CO_2-C loss/day. The relationship of a variety of factors to observed maturity is discussed.

2. INTRODUCTION

2.1. VOA in Composts

Maturity is a qualitative trait of compost that may be expressed in a number of ways and is generally held to be relevant to plant performance. Volatile organic acids (VOA) have been cited to be responsible for phytotoxicity (plant growth suppression) when immature compost is used for growing plants (Manios et al., 1989). However, the production of VOA in compost has not been well studied, nor is it known how phytotoxicity attributable to VOA may relate to other factors such as CO_2-evolution or salt content (Brinton, 1998).

The presence in compost of volatile organic acids may be recognized by an unpleasant “garbage” or spoiled-food odour. VOA may be observed in organic materials undergoing rapid decomposition with oxygen deprivation The volatile acids which normally occur in composts are short-chain fatty acids of C2 to C6 in length, with formic acid the shortest and butyric and iso-valeric acid among the largest. It is not well known how the different volatile acids affect plant growth although there is evidence the effects vary with carbon-length and volatility index(Lechner, 1994).

We previously reported a survey of 712 compost samples where 26% had appreciable VOA above 5,000mg/kg at some point during composting while 6% had VOA above 20,000mg/kg. The VOA correlated negatively with age of compost and were highest in the first 20-35 days. VOA levels appeared to be controlled by a complex, dynamic relationship of carbon biodegradability, pH and porosity. The microbial dynamics which are involved are as yet poorly understood, but it is clear that anoxia (no-oxygen) conditions may not be required to produce significant VOA.

Prior work in plant growing media reveal that VOA levels as low as 500mg/kg can exert a phyto-toxic influence on plant seedlings (Lynch, 1977). The principal deleterious effects on plants appear to be in the nature of root suppression but nutrient-ion leakage has also been implicated (Lynch, 1977; Lee, 1977). Plants exposed to high VOA do not necessarily die, but may remain static for long periods of time. Thus, rapid identification and response to problem composts is made more difficult, and the resulting economic losses can be very large. Basing plant growth evaluation on maturity standards would be a way to avoid later damage.

2.2. VOA in Compost and Resulting Phytotoxicity

The presence in composts of volatile organic acids is certainly well established but poorly under-stood (Manios, et al. 1989). VOA are metabolic by-products of anaerobic respiration and are breakdown products of grease and fats in raw wastes (Henefeld-Fourrier,1980). The composting process includes many events in which episodic oxygen depletion occurs both at macro- and micro-pore levels. Such oxygen depletion may result in temporary production of copious amounts of short-chain carbon compounds. In a previous paper we discussed odorant and microbial aspects of VOA production (Brinton, 1998).

VOA may also enter compost from source materials. VOA are found in waste water (Kawamura et al., 1985; Anselme, et al., 1985) and may be present in large concentrations in biosolids (How-grave et al., 1991; Rains et al., 1973) and raw manures (Hoshika, 1982; Zahn et al., 1997). Freshly composted sewage sludge has already been reported to contain high levels of organic acids, pri-marily acetic acid, that inhibit plant growth (Devleeschauwer et al., 1981). Food scraps from households also contain copious amounts of VOA and one study showed that storage of food waste in plastic bags instead of paper increases VOA production (Detroit, 1996).

Phytotoxicity has been previously associated with immaturity of compost (Ianotti et al., 1994) and depletion of organic acids is correlated with improved plant performance (Herrmann et al., 1993). Many MSW composts have been associated with high levels of phytotoxicity associated with organic acids (de Bertoldi, 1992, 1993). Phytotoxicity of immature composts has been positively correlated with organic acid content (Logsdon, 1989; Manios et al., 1989; Evans and Brinton, 1997).

3. MATERIALS AND METHODS

3.1. Sample Collection

Compost samples have been obtained from selected compost facilities, including several reporting horticultural problems from their customers. About 7 facilities had compost samples reported by authorities for plant damage to horticultural centers and resultant economic damage with associated legal actions. Samples obtained from a distance were collected is non-sterile, plastic 4-liter containers and were shipped via 2-day service to the laboratory in chilled coolers. Samples involved in the investigations contained source ingredients including biosolids, yard trimmings, manures and food scraps. The age of composts ranged from 3 days to 925 days.

3.2. VOA and CO2-Evolution Analysis

VOA were determined by total distillation and individual compounds by chromatography. For distillation, samples were water extracted and distilled in H_2SO_4 at pH1.8 and the resulting distillate titrated to a standard endpoint (SWMM, 1994). For testing individual volatile organic acids in the C2-C9 range, we extracted composts with weak alkaline solution, filtered and diluted prior to injection into a liquid-ion chromatograph with a PRP-X300 base-anion exchange column equipped with macroporous co-poly(styrene-divinylbenzene) and single-gradient eluent (Lee, 1984; Bevilacqua and Califano, 1989). CO_2 evolution rate was determined on 40 g samples after 1-day of equilibration after sampling with an incubation temperature of 32C. CO_2 is trapped in a NaOH-barium chloride solution and titrated to endpoint against HCl.

3.3. Phytotoxicity Analysis

Plant phytotoxicity was determined on one of two ways. To examine the effects of VOA on rootlets we utilized Hoagland nutrient solution in 1/2 liter containers to which were added extracts of compost and standardized VOA concentrations of acetic, butyric and propionic acids. In a growth stud, we employ a 1:3 (v/v) blend of test compost in limed sphagnum peat (pH= 6.2) and grow garden cress and wheat to 7 days at which point they are counted and cut and weighed. Plant growth is reported as percent germination and as fresh weight percent of Pro-Mix BX control (Premier Peat, LTD. Québec).

3.4. Preliminary Investigations: Bacteriology of VOA Production

The phenomenon of VOA production is recognized in farming since crop residues may result in oxygen deprivation when plowed in. The resultant VOA may trigger temporary phytotoxicity (Lynch, 1977). In composting, similar oxygen deprivation factors are involved and VOA is produced at high rates (Liao et al., 1994, Van Durme et al., 1992; Lechner 1993).

It should be recognized that volatile organic acids are regularly and temporarily produced in normal composts. Fermentative respiration occurs when oxygen is low but not necessarily absent. Under semi-aerobic conditions, a wide variety of microbes utilize compounds other than oxygen as terminal electron acceptors for respiration (Brock and Madigan, 1991). The levels of O_2 which favor production are not precisely known; nevertheless they are clearly less than the oxygen content frequently cited as ideal for composting. Facultative anaerobes will grow aerobically during regular composting yet will produce VOA soon after a period of oxygen stress sets in. Furthermore, several aerotolerant anaerobes such as lactobacillus grow in the presence of oxygen and will produce VOA.

In compost, oxygen supply is clearly episodic. This reflects the diversity of the microbial background (Brinton & Droffner, 1994). Thusly, there exists a shunting of metabolic by-products between aerobes and facultative anaerobes in composts. This results in a dynamic self-regulatory mechanism (see Figure 1, after Brinton 1998).

We have previously observed a moderate correlation (r = 0.61) between substrate CO2-respiration rate and the production of VOA in diverse composts. This suggests that the issue of phytotoxicity may be closely tied to maturity in general. Thus, the way is open to attempt a broader definition based on laboratory attributes.

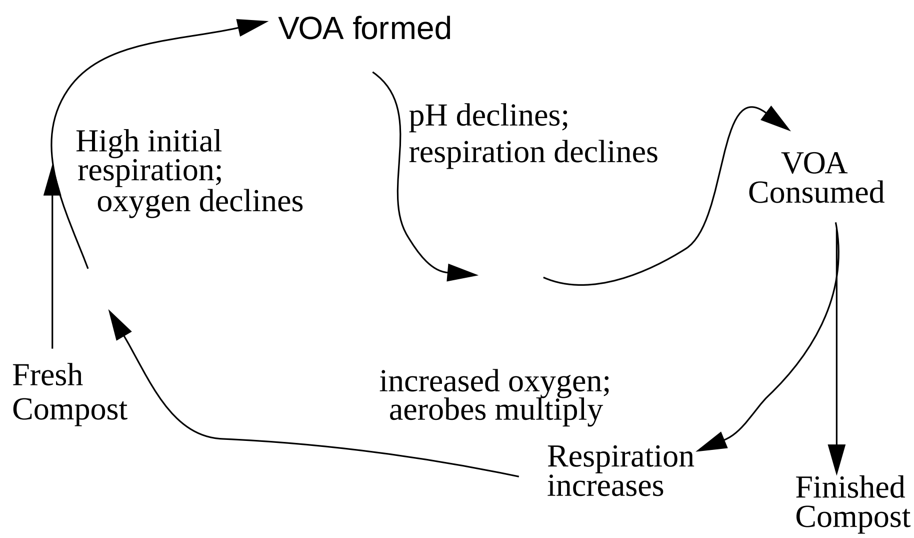


Figure 1. Hypothesized Cycle of Respiration-VOA in Active Compost (after Brinton, 1998)

4. RESULTS

4.1. Selection of Samples from Surveyed Compost Facilities

In a previous study we examined volatile organic acid content of 712 composts from 340 compost facilities (Brinton, 1998) . This data indicated a potential for plant phytotoxicity in many composts as 149 samples exhibited VOA greater than 5,000 mg/kg, with a mean concentration of 4,385 mg/kg (Brinton, 1998). In order to further develop the study process, we identified problem facilities from within this group. These are defined as compost producers receiving complaints about poor growth performance. In this case, 69 out the total of 340 were selected for further study. Compost from these facilities was subjected to wheat and cress seedling assays in addition to standard laboratory characterization.

4.2. Laboratory Data Set

For the selected compost samples that we examine more closely for growth properties, we developed a analysis database. This and a correlation matrix are seen as follows (See Table 1, Table 2).

Table 1: Measured Properties of Compost Samples Examined for Phytotoxicity

#Lab	Wheat Germ. %	Wheat Yield % Control	Cress Germ. %	Cress Yield % of Control	pH 1:1 H2O	Salt mmhos/ cm	CO2-Rate % / day	VOA Conc. mg/ kg
MIN	30.0	25.00	0	0	4.95	0.200	0.010	72
MAX	116.0	129.00	117.00	128.00	8.55	25.300	0.808	88737
MEAN	93.8	70.23	91.91	63.15	6.95	6.194	0.278	5862
SD	14.3	18.13	17.05	25.03	0.98	4.762	0.228	14949

Based on this data, the range was slightly greater but the mean similar to the previous survey of 712 composts where our average was 4,385 mg/kg with a SD of 7,298.

4.3. VOA in Compost vs. Age and Treatment

In this project no attempt was made to distinguish age of material although all composts surveyed were considered by the producer to be finished.. Previously, we found that age and material do affect observed VOA content and VOA declines on average 1,000 mg/kg per week (Brinton, 1998). We have previously observed that VOA may be highly significantly correlated with respiration activity of composts as determined by CO_2 evolution rate. High respiration is felt to be an indicator for immaturity, as elsewhere we have demonstrated a close correlation with the Dewar self-heating test (Brinton et al., 1995). VOA levels therefore appear to dependent partly on compost conditions and age of the process. Thus, each compost possess a unique capability to become phytotoxic.

4.4. Correlation Regress of Observed Traits

In the following table (Table 2) we compute correlations between variables. Of the most significant are negative correlations between VOA and yield of wheat seedlings and salt and yield of cress. All traits of VOA and CO_2 respiration are negatively correlated with observed plant yield properties, however, wheat indicates VOA levels more predictably than does cress. Cress yield is correlated with VOA (r=0.252, p=0.05) but wheat is highly significant (r = 0.45, p=0.001).

Table 2: Regression Equation of Observed Compost Traits, n= 69 [a]

Wheat Germ.	1.000							
Wheat Yield	0.281	1.000						
Cress Germ	0.542 [a]	0.291	1.000					
Cress Yield	0.385	0.697 [a]	0.540	1.000				
pH	0.174	0.088	0.103	-0.045	1.000			
Salt	-0.316	-0.380	-0.596 [a]	-0.455 [a]	-0.051	1.000		
CO_2-Rate	-0.017	-0.252	0.152	-0.106	0.078	0.181	1.000	
VOA	-0.408 [a]	-0.459 [a]	-0.210	-0.254	-0.282	0.221	0.352	1.000
FACTOR	Wheat Germ	Wheat Yield	Cress Germ	Cress Yield	pH 1:1 H2O	Salt mmhos	CO_2-Rate	VOA Conc.

a. Values of correlation coefficient, r , that are significant at p = 0.001

4.5. Volatile Organic Acids and CO_2-Evolution Rate

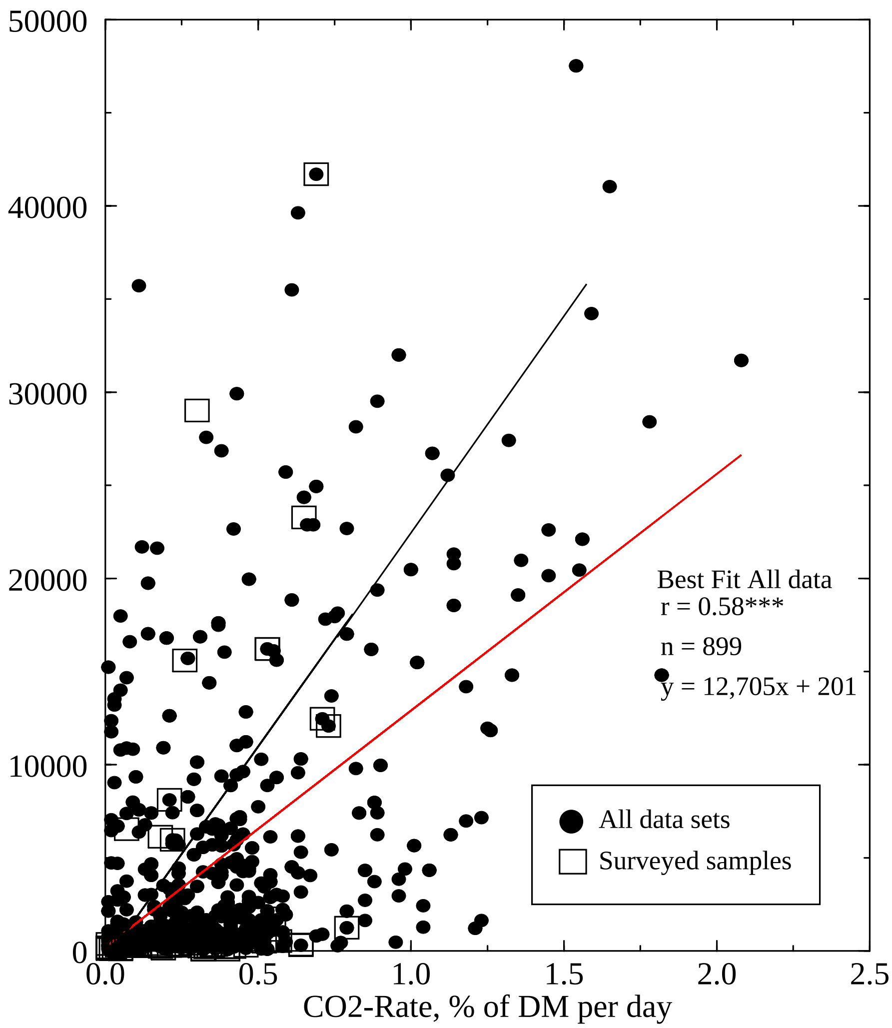
Since volatile organic acids play an important role in affecting the quality of plant growth, it was considered important to evaluate VOA levels based on CO_2 evolution rate, a determinant of compost maturity. Using previous data, and combining with current results, we produce the following graph (Figure 2). Of the observed variability in VOA for all 899 samples, 34% is explained directly by the CO_2-rate (r=0.58, $p \leq 0.001$). Our subset of 69 samples, identified separately in the graph (see Figure 2, boxes) exhibit a steeper slope in correlations with observed CO_2-rate (r = 0.352; p = 0.003). In other words, the 69 samples we examine produced more VOA per unit of respiration than the average of the whole set.

VOA and CO_2-rate are dynamic properties and will depend on relative factors such as porosity and moisture content. Therefore, high CO_2 rate alone may not explain VOA levels, and this explains the variability in the data. Indeed, since high VOA often leads to a depression of pH, and CO_2 is pH dependent, a “negative feedback” dynamic is certainly probable. Because of the many related factors, it is only possible to postulate a cycle in which a variety of factors influence each other simultaneously during composting (Brinton, 1998).

4.6. CO_2 Evolution Rate versus Cress Growth Properties

By blending compost at a standard dilution into limed-peat we produce growing conditions that are potentially optimal in regard to porosity, salt and nutrients. Considering the relationship we describe of VOA concentration to CO_2 rate, and the relative ease with which CO_2 evolution can be measured in the lab, it becomes interesting to examine more closely data for cress yield and com-

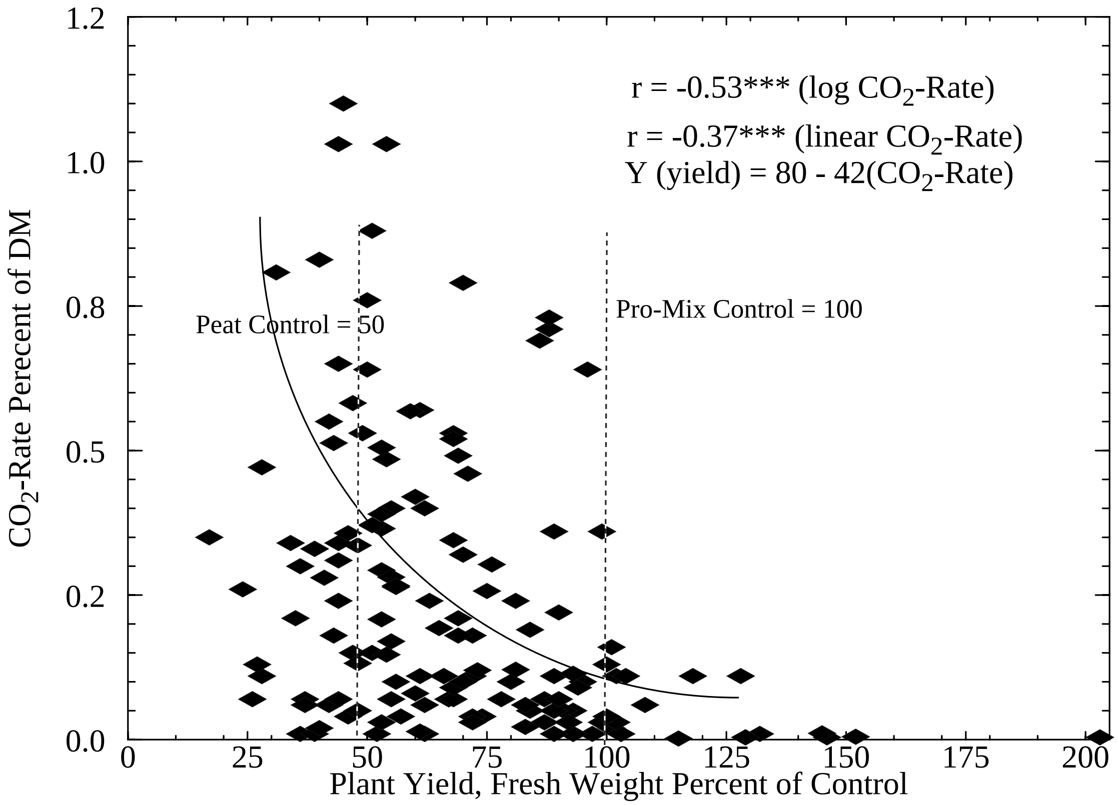
Figure 2. Volatile Organic Acid Concentration of Compost in Relation to Laboratory CO_2 Evolution Rate.



post CO_2-rate. We enlarged the sample set from 69 to 155 composts for which we had data on cress and CO_2 levels. The correlation of this group increased from r = 0.254 (Table 2) to become r = 0.37 (p=0.001). By logarithmically transforming CO_2-rate, we produce a highly significant simple correlation coefficient of r= 0.53, p < 0.0001.

In these trials, CO_2 evolution rate had no significant effect on seed germination for either cress or wheat. The CO_2- rate induced depression of plant growth may be explained as deprivation of oxygen in the root zone of seedlings. The curvi-linear nature of the relationship may be partly explained in that the depression of growth approaches the baseline of 50% which is that of the untreated controls.

Fig. 3. Compost CO_2-Evolution and 7-Day Cress SeedlingYield

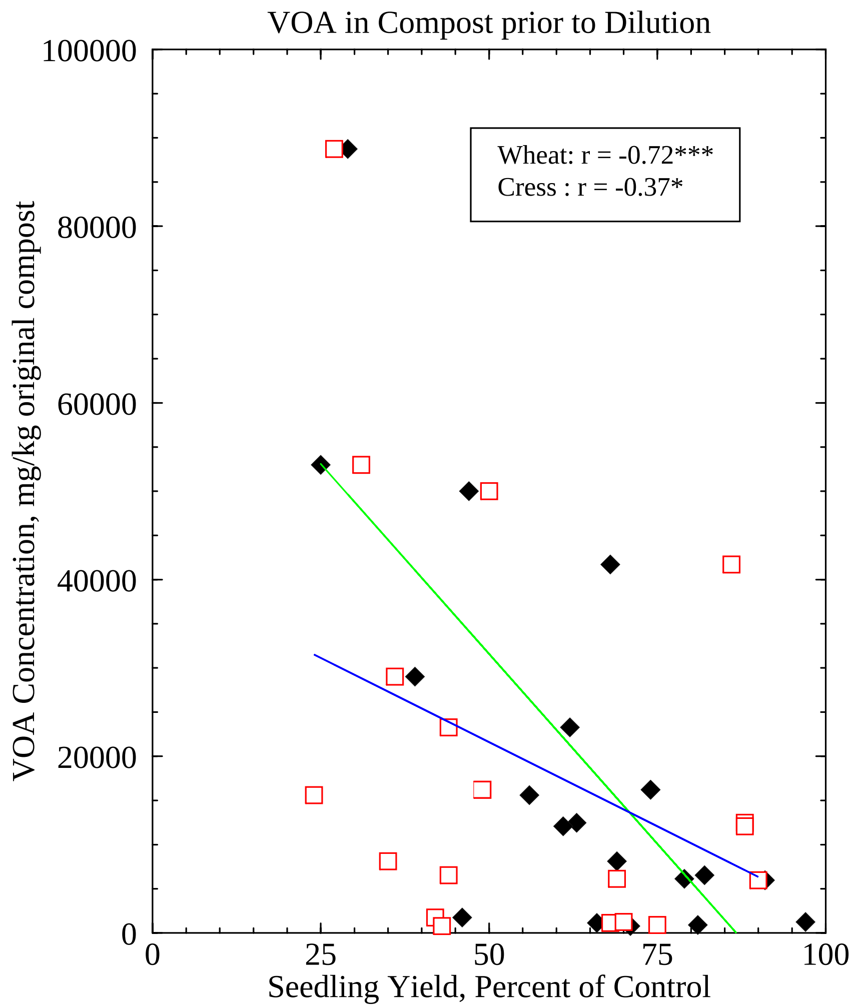


According to these findings, few of our composts achieve growth performance comparable to fertilized peat (Pro-Mix). Many of the composts depressed seedling growth significantly to as low as the yield of unfertilized controls which give 50% growth response. Additionally, several of the composts reduced yields even lower than the unfertilized controls, possibly indicating severe to extreme phytotoxicity conditions. As has been explained, this can be a result of oxygen deprivation of root zone, with or without VOA and other factors being present, which most likely compound the loss. Our study employs small-celled (50cc) seedling containers. It can not therefore be ruled out that larger containers would increase the growth depression associated with high CO_2-rate and resultant loss of oxygen in interstitial pores. Thus, any correlations between CO_2 rate and plant growth must take container size into account.

4.7. VOA Concentration and Plant Seedling Growth

As a final evaluation we measure growth of both wheat and cress in relationship to VOA content of original compost (prior to 1:3 mixing). The data for 7-day seedling yield is shown in the following figure (Figure 4). Seedling yield correlates significantly with VOA for wheat and less significantly for cress. The best fit lines cross at 71 percent yield associated wi the data for wheat, a VOA concentration of 5,000 mg/kg in the original compost (or about 1,250 mg/kg in a growing media) is likely to produce an observable growth depression (80% yield).

Fig. 4 Seedling Yield as Affected by VOA Concentration



While clearly there are many factors that affect plant growth, the results of these seedling assays using diluted compost suggest VOA’s and CO_2-evolution taken alone or together play both direct and indirect roles in plant growth properties. It is important to recognize how these results may depend on circumstances of the plant trials. Small celled seedling assays may reduce the impact of VOA and respiration rate by providing ample oxygenation during the trial. In addition, our use of high-porosity peat as a basis for the seedling trial instead of soil is likely to further reduce the impact. With more effort to focus on the analysis and significance of maturity-related growth suppression it is likely that the industry will demand more compost quality standards.

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