

# Phytotoxicity factors and herbicide contamination in relation to compost quality management practices

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## Abstract

The practice of composting mixed green wastes from community collection programs has been on the increase as a means to reduce organic debris to landfills. Recent reports of plant injury have appeared and were attributed to residues of the herbicide clopyralid in compost. Phytotoxicity issues with compost have been reported previously to result from other factors, including heavy metal content, soluble salts, organic acids and oxygen deprivation related to incomplete decomposition. The recent reports of plant injury due to clopyralid-contaminated compost were also associated with very heavy applications of compost, yet few of these reports included observations of herbicide symptomology. Since immature compost may contain sufficient degradation intermediates, soluble salts and other contaminants to cause phytotoxicity, particularly when applied at heavy rates, an effort must be made to distinguish confounding factors. Complete composting normally allows for the degradation of phytotoxic intermediates and synthetic compounds, such as herbicides, as well as allowing for leaching of salts. Absence of compost completeness standards within the compost industry leaves such factors to the guesswork of the end-user. Recommended compost use rates have established a relationship between compost maturity, application rate and use pattern, based on compost quality metrics. Greater attention to the use of high-quality compost, properly designated as to completeness of composting and applied at appropriate use rates, would minimize the potential for phytotoxic effects, irrespective of the contributing source.

**Key words:** compost, clopyralid, herbicide, contamination, immaturity

## Introduction

Composting of mixed green-waste collection is on the increase worldwide, as societies attempt to divert biodegradable, recyclable organic wastes from landfills back into agriculture<sup>1</sup>. In 2000–2001 there were two noted incidents in the US where plant injury appeared to have resulted from the use of compost contaminated with clopyralid, an auxin (plant hormone) herbicide<sup>2</sup>. These events received very broad press attention and triggered concerns, which were later put aside, that organic growers could lose certification by using contaminated compost<sup>3</sup>. Clopyralid is thought to have entered the composting stream as residues in homeowner turf grass clippings and ornamental plant leaves, despite precautions on the product labels. High compost application rates were common to both of these locations where the apparent damage occurred<sup>2,4</sup>. In one instance a greenhouse grower transplanted tomato seedlings into

100% compost. In the other incident, an application of 3 inches (7.5 cm) of compost was made in a 'high-tunnel' system, which resembles a greenhouse, where plants are grown on raised beds in the underlying compost–soil blend. In the latter case, clopyralid symptomology was transient, in that the plants outgrew the effects. Salinity stress and oversupply of nutrients were later implicated as complicating yield-reducing factors in the high-tunnel situation<sup>4</sup>.

There have been a limited number of additional reports of residential gardens experiencing auxinic symptomology, which clopyralid and phenoxy-type herbicides would elicit, when compost was used. During their follow-up investigation to the greenhouse tomato incident, Washington State Department of Agriculture Inspectors noted that many residential vegetable gardens reported as having possible herbicide damage exhibited poor plant growth, commonly observing stunted plants, but rarely observing any auxinic response<sup>2</sup>. In these poor-performing gardens compost had

universally been used at very high rates, with plants often grown in virtually straight compost laying on the surface of the soil. The lack of auxinic symptomatology in these particular gardens eliminates clopyralid- or phenoxy-type herbicides as a causal agent, implying that other phytotoxic agents were present. The question arose as to what other factors in compost could induce poor performance, whether or not such factors could be mistaken for, or trigger, confounding effects related to herbicide damage.

## Compost Quality and Management

Compost is the product resulting from the controlled biological decomposition of organic material, and is presumed to have been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth<sup>5,6</sup>. With reports of heavy compost application associated with poor-performing gardens, a review of compost use guidelines is appropriate in the context of reported herbicide contamination. Furthermore, whereas standards for completeness of composting exist in most European countries, few similar standards have been established in the US<sup>7,8</sup>. This fact is pertinent, as it has a bearing on the quality of plant growth from compost in two respects: xenobiotic (exogenous compounds) effects resulting from incomplete biodegradation related to short-term composting, and biological effects related to immaturity<sup>9</sup>. In the absence of compost completion standards, it is not unreasonable to assume that xenobiotics or other phytotoxic agents may potentially present a problem at one point in time or another. The common belief that a contaminant is strictly the problem of the compost ingredient source rather than the composting process is challenged here. Previously, deliberate composting of pesticide residues has been well received, the only difference being that the contamination was known at the outset, and a maturity-based outcome was specified for safe use of the end-product<sup>10</sup>. Thus there appears to be a basis for several confounding circumstances related to plants expressing injury symptoms, depending on compost quality, compost age or maturity, application rate and the presence of phytotoxic xenobiotics.

Many growers report that they do not use compost, owing to uncertainty about its properties<sup>11</sup>. This is supported by concern that many commercial composts are of low to mediocre quality<sup>12</sup>. A very recent survey of 409 organic growers indicated that compost use rate is low due to concerns about poor quality<sup>13</sup>. An examination of the professional growing media industry in the UK indicated that compost usage or substitution of compost for peat is low and is declining due to inconsistency of compost products<sup>14</sup>. A compost use survey conducted recently in Switzerland, covering a 10-year period prior to 2002, concluded that compost sales into horticultural and gardening markets have steadily declined, while use of bulk compost in field farming has increased, partly due to quality problems with regard to higher-value markets<sup>15</sup>.

The importance of educating the consumer on health, safety and environmental concerns with respect to compost use has been noted for nearly a decade<sup>16</sup>. The 503 regulations of the US Environmental Protection Agency (USEPA), and some state-specific regulations, have addressed basic safety and environmental issues<sup>17</sup>, but may inadequately address horticultural issues. The EPA's 503 rule limits application rates of biosolids (sludge), and composts made from biosolids, based primarily on heavy metal content. The rule incorporates the concept of risk-pathways to limit heavy metal application on an annual, as well as a cumulative, basis. However, the EPA 503 rule also requires that biosolids-derived products be applied at no greater than reasonable fertilizer rates for the anticipated crop, based on nitrogen needs. This rule has been widely applied in the US as a regulatory structure at the state level for most types of composting<sup>18</sup>, and the pathogen reduction portion was carried forth into the USDA NOP (National Organic Program) compost guidelines<sup>19</sup>. Furthermore, some states are exercising their right to enforce application rate control at no greater than a phosphorus-fertilizer rate<sup>16</sup> (confirmed by Rufus Chaney, USDA-ARS, Beltsville, MD, personal communication, April 2003) and there has been a general shift towards phosphorus rate control over nitrogen. With certain composts, it has been shown to be impossible to provide sufficient nitrogen for wheat culture without also oversupplying phosphorus, potassium, salts and possibly other hazardous elements<sup>20</sup>. The ratio between nitrogen and phosphorus in compost widens due to N-losses that occur during composting. The overall loss of mass means the phosphorus concentration increases, and thus the nutrient balance, in terms of crop requirements, may be worse in compost, requiring more careful rate control than with raw waste<sup>21</sup>. These findings, overall, demonstrate that it is a well-established fact in environmental management of wastes, and composts in particular, that more than one variable may act to significantly modify application rates where limiting or regulated factors are concerned.

Other compost-related parameters that impact the environment and plant growth have been studied widely, with many countries adopting regulations based on a more refined definition of compost quality<sup>7</sup>. These regulations tie compost quality parameters (as determined by laboratory analysis), such as self-heating, CO<sub>2</sub>-respiration and cress (plant growth) tests<sup>22</sup>, to certain applications and use rates. In Switzerland, compost cannot be sold for use in horticulture and gardening unless it passes a plant performance test<sup>23</sup>. Under the same rule, compost is only exempted from the requirement to meet a plant toxicity test where the anticipated use is in field farming, since the application rate is assumed to be much lower. In the US, compost other than biosolids is either not regulated at all or is generally not regulated to the same extent as in Europe; although, as has been pointed out, the EPA 503 rule has been widely applied as a general standard for all composts in terms of heavy metal concentration, fecal coliform and salmonella presence. Application of biosolids is also

restricted by nitrogen content, to that expected to be used by the crop grown on that site. High application rates of green-waste or animal manure-based compost can supply on the order of  $5600 \text{ kg ha}^{-1}$  ( $5000 \text{ lb acre}^{-1}$ ) of total nitrogen. Although it is considered that only 7–10% of the total nitrogen is readily available<sup>24,25</sup>, annual applications of high rates of compost are likely to eventually supply nitrogen considerably in excess of crop demands. This will result in a significant potential nitrate leaching hazard, among other potentially harmful effects such as those due to salts or other hazardous ingredients<sup>20</sup>. Furthermore, the extent to which agencies and composters may be truly perplexed about the relationship of compost quality to use pattern is seen in the recent AASHTO MP-9 specification<sup>26</sup>. This document sets forth compost test grades to enable products to be applied for erosion and sediment control. A separate evaluation of these standards indicated that virtually all composts, save only feedlot manure compost, would pass the specification to be used on slopes and in berms for runoff control<sup>27</sup>. This is a very surprising development, since leaching of salts, and especially nitrates and phosphates, is likely to result from the heavy rates of some high-analysis products.

Producer-based, government and university publications have been produced for compost users that describe compost quality benchmarks and appropriate uses<sup>6,28–30</sup>. Key factors for objective measurement and reporting include pH, salinity, nutrient content, organic matter content, carbon to nitrogen ratio, heavy metal analysis, maturity, stability and plant growth screening. All of these factors can have a direct influence on the beneficial effects of compost on plants.

Compost is generally recommended as a soil amendment, intended for blending with soil or other matrices. High blending rates (80–100%) of compost have been noted for some potting mixes, but explicit disclaimers or cautions, regarding testing before use, are included<sup>6,16,25,31</sup>. Even with blending for potting mixes, direct seeding into the mixes is not recommended. Rather, blends of 20–30% compost are only recommended for transplanting seedlings<sup>6,25,31–33</sup> (confirmed by Rufus Chaney, USDA-ARS, Beltsville, MD, personal communication, April 2003) that are at least 1 week beyond the cotyledon stage<sup>32</sup>.

Salinity and maturity, in particular, are two significant factors in compost quality that can elicit phytotoxicity symptoms. High salinity affects the water relations of the plant, eliciting a range in symptomology from yield reduction<sup>34</sup> to leaf burning<sup>35</sup>, leaf deformation<sup>31</sup> and epinasty<sup>35</sup>. These effects can be attributed falsely to herbicide toxicity, especially by untrained individuals. Immature or unstable compost may contain sufficient volatile organic acids, fatty acids, phenolic acids, ammonia or ethylene oxide to elicit stunting and other phytotoxicity symptoms<sup>25,31</sup>. In container-mix studies, it has been demonstrated that immature compost deprives the soil of oxygen content for a significant period of time, resulting in stunting of roots<sup>36</sup>.

As a result of the potential for a myriad of innate factors in compost which can cause negative growth effects, research and industry groups have published generalized application rates for compost, which are summarized in Table 1. Clearly, there is a relation between application rates and utilization pattern. Vegetable crops, which likely comprise the most sensitive cropping system, have the lowest recommended use rates, less than 2.5 cm or approximately  $147 \text{ tonnes ha}^{-1}$  (~15% by volume). The exception to this is use in potting mixes, but use in potting mixes is normally accompanied by explicit precautions on quality assessment, especially in regards to salt content, stability and maturity, as noted above. Some publications are quite emphatic that applications for gardens and field crops should not exceed a 2.5 cm layer or  $112 \text{ dry tonnes ha}^{-1}$ <sup>37</sup>, a rate which, nevertheless, is extremely high from a nutrient management point of view.

## Herbicide Contamination

The utilization pattern and rate of application are directly related to the issue of pesticide residues in compost. Recent work has shown that compost containing residues of clopyralid can elicit phytotoxicity symptoms on sensitive species<sup>38</sup>. Results of this work indicated that even sensitive plants were likely to escape damage at relatively high compost application rates (Table 2). Research at Washington State University-Puyallup demonstrated that sensitive plants produced greater biomass even at higher compost application rates where clopyralid was present, by responding to the greater nutrient levels and possibly also organic content provided by the compost<sup>39</sup>. Under these circumstances, it is arguable that any negative effects have occurred at all.

Researchers in California composted cotton gin waste that had residues of insecticides, herbicides (paraquat) and defoliant<sup>40</sup>. Field experiments indicated that germination was inhibited at application rates greater than  $11 \text{ tonnes ha}^{-1}$  for composted waste and  $45 \text{ tonnes ha}^{-1}$  for non-composted waste. Rates higher than  $17 \text{ tonnes ha}^{-1}$  inhibited yields, largely as a result of inhibition of seedling emergence. Composting doubled the salt concentration of the compost and likely contributed to the inhibition of both germination and growth. After 51 days of composting, some pesticides had substantially degraded, and others, while degrading, actually increased in concentration. Similar results, showing an apparent increase in clopyralid concentration, have been observed after a 49-day thermophilic composting period, during which organic matter loss exceeded the rate of clopyralid degradation<sup>41</sup>. However, maintaining favorable curing conditions beyond the 49-day thermophilic period resulted in rapid degradation of clopyralid residues. Work in Canada showed similar results—concentration of pesticide residues in the early stages of composting was followed by a decline—evidence that the organic matter was degraded faster than the pesticide<sup>42</sup>. In the Canadian study, after 10 weeks of

**Table 1.** Compost blending rates for various utilization patterns.

Compost utilization	Blending rate <sup>1</sup> (% by volume)	Approximate application rate		References
		(m <sup>3</sup> /ha <sup>-1</sup> )	(cm-layer)	
Potting media				
General potting media	33	750	5	6, 25, 31, 32
Containerized bedding plants	20	330	2.5	6, 31, 32
Vegetable transplants (not direct seeding)	20	330	2.5	6, 25, 31, 32
Horticulture				
Ground cover bed/mulching	20–33	220–750	2.5–5	6, 25, 31, 32
Nursery crops (tree and shrubs)	33	750	5	6, 31, 32
Agriculture/horticulture				
Row crops and vegetable crops	5	82	0.61	6, 16, 25, 31
Pasture and hay/legume crops	2	24	0.25	16
Strawberries, blueberries, grapes	15	245	1.88	16
Pumpkins, winter squash	15	245	1.88	16
Turf grass establishment	33	750	5	6, 25
Top soil blend	33	750	5	6, 25
Hydroseeding	Air-blown	120	1.25	2

<sup>1</sup> Maximum blending or inclusion rates. When using compost in a specific application for the first time, or when using a specific type or source of compost for the first time, the compost should be tested on a small scale. A soil test is also strongly suggested. All compost products, climatic conditions, crop requirements and field situations are different, and require specific recommendations from experts familiar with those specific field situations. Consultation should be supplied by compost producers and their technical staff, and may also be obtained from agricultural institutions and the Cooperative Extension Service of the USDA. States may have specific regulations regarding compost utilization. State regulations should be consulted concerning maximum allowable application rates for specific situations or crops. Compost suppliers should be able to provide relevant data on these issues. (Above precaution from: the US Compost Council's Field Guide to Compost Use<sup>6</sup>.)

<sup>2</sup> Mark Mauer, Washington State Department of Transportation, personal communication, April 2002.

composting, phytotoxicity was still observed from compost made from grass clippings that had been treated with 2,4-D, mecoprop and dicamba. A comprehensive literature review of pesticide degradation in compost showed that most, but

not all, pesticides completely degrade during composting, while some increased in concentration<sup>43</sup>. Unfortunately, the review did not contain data on quality indices, such as completeness of composting; it would be valuable to determine the correlation between maturity or other quality indices and the presence of pesticide or xenobiotic residues. Recently the State of New York<sup>5</sup> developed a definition of compost maturity to mean 'the characteristics of a soil conditioning material that render it harmless to the plant grown when used as a topsoil or soil supplement'. Adoption of a maturity-based standard for compost use, as suggested by the New York guidelines, or as implemented in the Swiss standards, should uniformly address phytotoxicity and herbicide residue issues from immature compost. However, industry may be hesitant to accept such maturity standards if the required time frame of composting is thereby increased.

These results indicate that pesticides can be detected and may be phyto-active throughout the composting process. Previous work has shown that a NOEL (no observable effect level) for herbicide residues can be identified that does not pose a threat to plant growth<sup>38,39,44</sup>. Differences in degradation can be related to inherent differences in the biological metabolism of the compound, but may also be related to the composting process<sup>45,46</sup>. Short-term composting (<60 days) largely consists of the thermophilic phase. Without proper curing (mesophilic phase), the degradation of xenobiotics, including pesticides, may not be sufficiently

**Table 2.** Predicted crop damage due to clopyralid in compost applied to soil.

Clopyralid in compost (µg kg <sup>-1</sup> , dry wt)	10 µg kg <sup>-1</sup>			50 µg kg <sup>-1</sup>			200 µg kg <sup>-1</sup>		
	112	448	22	112	448	22	112	448	
Compost application rate (tonnes ha <sup>-1</sup> )									
Compost application rate (tons acre <sup>-1</sup> )	50	200	10	50	200	10	50	200	
Winter wheat	N	N	N	N	N	N	N	N	
Garden beet	N	N	N	N	N	N	N	N	
Sweet basil	N	N	N	N	N	N	N	N	
Japan buckwheat	N	N	N	N	N	N	N	N	
Radish	N	N	N	N	N	N	N	N	
Cucumber	N	N	N	N	N	N	N	S	
Lettuce	N	N	N	N	N	N	N	S	
Tomato	N	N	N	N	S	N	S	E	
Peas	N	N	N	N	M	N	M	E	
Dwarf sunflower	N	N	N	N	M	N	E	E	
Red clover	N	S	N	S	M	S	M	E	

Ratings: N = none, S = slight, M = moderate, E = extreme. None and slight judged acceptable by independent growers. (Modified after Brinton and Evans<sup>36</sup>.)

complete for all possible utilization patterns, or for compost used at high application rates. Additionally, the importance of the curing phase to the biological maturity of compost cannot be ignored. Critical biological recovery and activity continues during the curing phase, resulting in the reduction of naturally produced phytotoxic agents, and an increase of desirable properties for plant growth, such as neutralized pH and increased available nitrogen. More than token attention (as in merely stockpiling) for this critical curing phase is needed in the overall compost process engineering design.

## Conclusion

The observations in Washington State of poor-performing gardens following compost application may be due to the overapplication of immature compost, compost that immobilizes nitrogen, or both. In some instances, sufficient residues of clopyralid or other herbicides may have been present in the compost to elicit auxinic symptomology. Immature compost thus provides at least four avenues for potential phytotoxicity: the natural production of phytotoxic degradation intermediates (e.g., organic acids and phenolic acids); high salt concentration; ammonia build-up; and insufficient time or conditions to allow for adequate decomposition of phytotoxic xenobiotics, such as herbicides. The presence of phytotoxic xenobiotic residues must be viewed in the context of overall phytotoxicity potential that includes those of biotic etiology. The presence of these residues should not be alarming if compost use for any particular application is not consistent with its overall properties.

The prevalence of immature composts is of concern, as it presents problems for gardeners whether herbicide contamination is present or not. Greater attention to pesticide labeling, understanding pesticide degradation in compost as well as soil, and the use of properly matured compost at appropriate use rates would minimize the potential for phytotoxic effects, regardless of their source. Misapplication of compost needs to be more effectively addressed by designing and testing finished compost to meet certain performance criteria for a particular utilization market or range of markets. Additionally, more effective education to the end-user on compost performance test results, as they relate to appropriate application rates for a given utilization pattern, needs to be communicated, either by product labeling or product information leaflet at the point of purchase.

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