Compost Science & Utilization, (2008), Vol. 16, No. 2, 114-118

Extractability, Plant Yield and Toxicity Thresholds for Boron in Compost

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Boron (B) is a trace element essential to crop growth in small soil concentrations (0.2-1.5ppm), yet may produce plant toxicity symptoms readily as the amount in the soil solution increases over 2ppm. Boron is present in significant amounts in recycled materials such as municipal solid waste (MSW) and coal fly ash, and therefore composts containing these ingredients may potentially exceed agronomic B levels, especially when used at heavy rates. Boron requirements and expression of toxicity vary widely among varying plant types. Furthermore, boron behavior in organic soils (high organic matter) is more dependent on pH than in mineral soils, thus boron effects from compost-based media may be very variable and difficult to predict. Our study examined commercial compost made with coal fly-ash used to prepare growing media for cultivars of varying sensitivity (corn, beans, cucumber, peas). We examined total vs. extractable boron content and relate final visual symptoms of B-toxicity to yields and tissue concentrations. Visual toxicity effects included tip burn (corn), leaf mottling and necrosis (beans and peas) and leaf mottling and cupping (cucumbers). Fly ash added to compost increased hot-water soluble (HWS) B in proportion to rate and in dependence on pH, with 30% and 10% of total-B expressed as HWS-B at a media pH of 6 and 7.5, respectively. Biomass for bean and cucumber was significantly reduced by 45 to 55%, respectively, by addition of 33% fly-ash compost to growing media (28ppm total-B) while plant tissue-B increased by 6- to 4-fold, respectively. Economic yield depressions in compost media are evident for all crops and appeared at levels of HWS-B in compost media exceeding 5 ppm. The study underscores the need for careful management of exogenous factors that may be present in composts and suggests detailed understanding of media-pH and cultivar preferences may be required in preparation of growing media in order to reduce potential negative growth effects.

Introduction

The increasing use of a variety of postindustrial wastes believed to be benign in the compost process raises the concern of presence and toxicity of xenobiotics, defined as compounds that have been introduced into the environment by artificial means at any point in their useful cycle, and which may or may not later exert harmful influences if present in composts. Boron (B) is a trace element that is infrequently found at very high levels in composts(Purves and Mackenzie 1974) . Boron may be introduced into composts as a type of point-source and in others as nonpoint origin. Examples of the former are in the use of treated gypsum board and coal fly ash, both of which contain high levels of boron, the first by deliberate addition of borated fire retardant chemicals and the latter as an unavoidable residue of environmental contamination (UREC) from coal mining. Apparently, as much as 62% of coal fly ash from power utilities goes unutilized (Stevens & Dunn 2004; USEPA 1988) and has been useful in agriculture under controlled conditions. Examples of the analogous nonpoint source pollution in the case of boron would be MSW composting, where numerous household products and industrial chemicals and textiles are comingled in the final compost, each having boron from prior use in products such as PVC (for softening) and textiles and synthetic mattresses (for fire-resistance treatment).

Boron is an interesting element since it is essential to crop growth in small soil concentrations (0.2-1.5 ppm) yet may produce plant toxicity in plants as the soil concentration increases over 2.5 ppm (Reisenauer *et al.* 1973). The margin between boron sufficiency and toxicity is therefore very narrow for a very wide variety of crops. Concentrations of boron in plant tissue only slightly above the required level have been shown to cause serious injury to the plant (Smith *et al.* 1997). Therefore, composts containing the listed ingredients may potentially exceed agronomic B levels, especially when used at heavy rates, and therefore be of great concern to end-users.

A complicating factor in addressing boron from composts is that the bioavailability of boron is dependent on several variables, and therefore is difficult to predict. This results from its behavior being influenced by the nature of the media, the media pH and presence of other factors. In rare cases, elevated boron may remediate plant damage under adverse soil conditions that cause excessive aluminum (Wojcik 2003). Others have shown that increasing rates of compost decreases the uptake of boron where compost was not also the source of boron (Yermiyahu *et al.* 2001).

The challenge in compost evaluation for potentially toxic boron concerns whether we use total or extractable boron for interpretation. Even if the total B level is known in the compost, the availability to plants for positive and negative effects is not known. Similarly, if plant available or hot-water soluble boron in compost is known, this may not necessarily predict soil effects, even though this is the preferred method of soil test B interpretation. This is because of the direct and indirect control exerted by pH and other factors. Given that the pH of the compost has been determined accurately, then the end-pH in the soil after application is still unknown. If compost is used at low rates, the final pH normally is that of the background soil pH. However, if compost is used at increasing and high rates, such as in garden beds or in container mixes, where it may achieve levels as much as 33% of the media, then the pH of the end solution may be compost dominated. There is no way to predict this, and even if so, unfortunately for many compost producers, the actual end use by customers is likely to be unknown.

A system of cautionary labeling for boron content has been used for fertilizer products, as recommended by the Association of American Plant Food Control Officials (AAPFCo). Under these measures, a boron-warning threshold based on concentration has been identified and forms the basis for the requirement of a warning label in many states on boron-amended products. Except as a state commissioner otherwise designates, the recommendation for commercial fertilizers, soil conditioners, plant amendments and agricultural liming materials are those adopted by AAPFCO. The warning system appears to hold only for inorganic fertilizers. In Washington State, for example, a cautionary statement is required on the label for any product that contains 0.03% or more of boron in a water-soluble form. While it is unlikely that compost would ever attain this level unless total boron reaches 1,000-ppm total-B or more, compost may be used at rates substantially higher than inorganic fertilizers and therefore attain a delivery rate of boron that could be harmful at levels far lower than the AAPFCO boron warning threshold. Unfortunately, this common warning system may be inadequate when used in the case of compost used at heavy application rates or in container media in order to protect the user from severe harm. Composters may be hesitant to accept a soil-amendment cautionary system where boron is not amended but rather is an inadvertent presence from source materials.

There is an additional dimension that may warrant examination, based on application rates factored into restrictions. In Washington State, fertilizer regulations prohibit more than 12 pounds/acre (13 kg/ha) cumulative boron application in 4 years (WSDA 2001). An application of 10 t/a of compost solids will deliver 4 pounds boron at 200 ppm, or 16 lbs if continued over 4 years. It is unlikely these application boron standards have ever been tested in the case of composts, and it is not clear if soluble or total boron was implied. Assuming these levels are strictly water soluble, and assuming 30% hot-water-soluble (HWS) B, then only 30 t/a compost solids or approximately 60 t/a fresh compost would reach or exceed the allowed limit.

Boron is a very mobile element that does not accumulate to a great extent in well-drained or sandy soils. This is somewhat analogous to a xenobiotic that may be plant harmful but is biodegradable. Under these circumstances where leaching or biodegradation are a factor, heavier rates of composts may not automatically present a problem. This would also explain absence of observed effects under conditions where application rate appears high. In one case, several years of application of very high rates of high-B gypsum-amended compost were required on light soils before toxicity symptoms in beans emerged (Woods End Laboratory *file report* 1992). It can actually be difficult to maintain boron in sandy soils at sufficiently high levels for certain crops. In other soils, boron may be adsorbed and unavailable for crop use. Boron toxicity may be limited to situations where boron-containing soil amendments are used on highly sensitive crops such as beans, corn, grass and small grains (Vitosh, *et al.* 1994). These considerations make it all the more complicated to estimate the potential for boron toxicity from composts. Finally, boron toxicity may be readily confused with other more common forms of plant damage since the symptoms are broad in nature — including leaf curl, leaf-cupping, chlorosis and tip burning (Eaton 1944; Nable *et al.* 1997). In view of new, recent concerns that focus on xenobiotic contamination of composts, symptoms such as leaf-cupping and curling appear very problematic.

The objective of our study included:

• To determine the quantity of total and water-soluble boron in compost and other sources and their relationship to plant performance and toxicity symptoms.

• To establish toxicity thresholds and/or prediction equations useful to guide use of B-wastes in compost and application of end-composts.

Materials & Methods

In order to perform the study to achieve the stated objective the following materials and procedures were adopted. Commercial Fly-Ash Compost (*CFA-Compost*) was obtained from a compost facility in Washington State. This product tested at 230*ppm* total B. A preliminary dose-response study was developed. This was to establish toxicity thresholds and symptomology at varying levels by use of a soil:compost:perlite based mixes for fly-ash and standard borax additions. For fly-ash compost, the maximum container media mix rate was 33% compost, at which point conductivity of the media was 2 dS/cm. Sensitivity range of plants chosen as follows; Phase I (preliminary growth test): wheat, onions, broccoli, beat, clover, carrot, tomato, beans, corn, cucumber, and peas. Tolerance threshold of grow-out plants (Phase II); beans, corn, cucumbers and peas.

For laboratory analysis hot-water soluble (HWS) boron was defined as boron from boiling water extracts, in accordance with ASA procedures (ASA-SSSA 1999). Total boron was from nitric-acid digestate run on ICP. In addition, a cold water extractable boron fraction was obtained by shaking 30 min with deionized water.

Green house plant-chamber studies (Phase I) employed gro-packs (6 cells each 50cc) and for Phase II, 4″ (100mm) pots with a volume of 1.25 L. Grow lights for the green house trials were HydroFarm® Gro-Lux Metal Halide on 14hr daylight. All plants were grown for 30 days.

Results

In a preliminary study, we examined extractability of boron. The relationship of HWS B to total extractable B is shown in Figure 1 for coal ash and borax, as added to prepared growth media containing compost + peat + perlite. Boron from coal ash showed lower solubility in compost than borax did, with about 12% of total-B recovered as HWS B as compared to 18% for borax, when present at 80 ppm total B.

We examined next how compost pH affected extractability or availability of boron. We adjusted the pH of compost:perlite: peat blends by varying the ratio of peat, which has a low pH. The pH of the resulting peat:compost mixture was verified after equilibration, at the time the samples were extracted. Commercial FA compost employed in this study had a high initial pH (8.7). The results for HWS B in relation to media pH are shown in Figure 2.

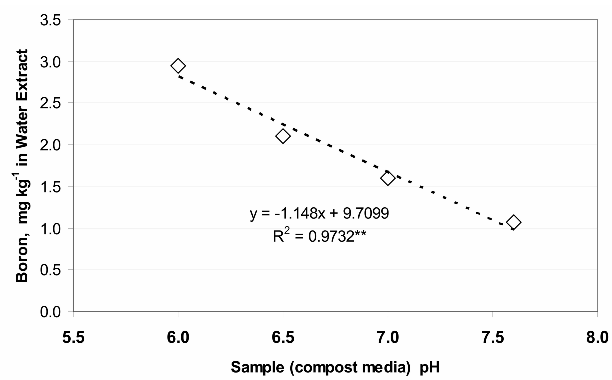

FIGURE 2. Effect of sample pH on boron in water extract of compost-peat belends. Sample was extracted by sharing water for 60 minutes.

Altering the pH of the compost from 7.6 down to 6.0 increases the availability of boron by up to a factor of 3. We compared the availability of boron as dependent on pH both in compost and in the original coal fly ash (Figure 3). The percentage of the total boron present as soluble boron ranged from 12% at pH 7.5 to 32% at pH 6.0 for compost, but varied much less for

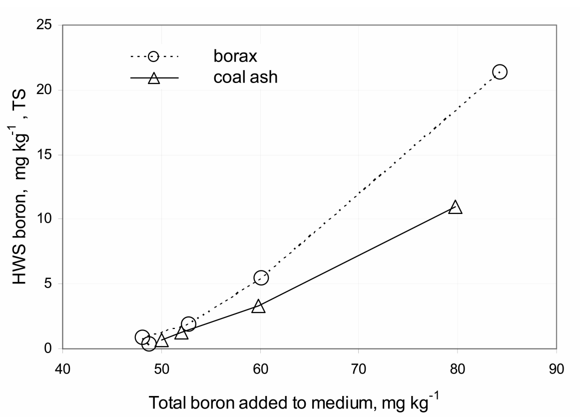

FIGURE 1. Effect of addition of borax or coal fly-ash on extractable HWS boron in prepared container media.

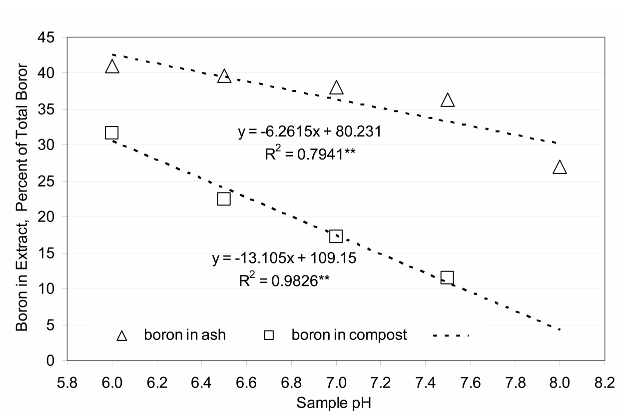

FIGURE 3. Extractable boron as percent of total boron, effect of sample pH on boron extraction in deionized water at 25°C.

the coal fly ash over the same range. pH clearly affects availability, but if the final pH of the soil:compost solution after application is unknown this can be empirically determined by dose-response pH studies with any compost in question.

These data suggest that not only is pH a major controlling factor in release of boron from compost for potential plant harm, but individual cultivars vary tremendously in accumulation and toxicity expression. The final pH can not be found, however, by testing compost alone, but must be empirically determined by admixtures of the compost:soil or compost:peat, etc., media, as determined by the final end use of the product.

Plant trial data suggested a wide range of effects in early seedling growth as evidenced by none to severe symptoms of boron toxicity, consistent with published reports. For the grow-out trials in 1.25-liter pots, the toxicity was expressed visually with beans > peas > cucumbers > corn > wheat (i.e. the beans showed the greatest symptoms). The beans exhibited moderate leaf curl and cupping together with chlorosis and tip necrosis. Corn and wheat in contrast showed tip and edge burn only. These symptoms may be confused with other reported symptoms of nutrient disorders and plant toxication. A very thorough review of the varying physical-chemical bases of boron toxicity symptoms has been presented by Loomis and Durst (1992).

All plants showed some negative yield effect from boron in compost trials. We regressed the dry yield of plants against total plant tissue boron (Figure 4).

The r^2 of 37% is weak but nevertheless statistically significant at $P \leq 0.01$. The explanation of the scattered fit lies in the dispersed least-observed effect thresholds for the varying cultivars. According to Eaton's classic work (Eaton 1944), boron tissue concentrations in Iowa yellow dent corn increased steadily from 32 and 72 ppm at no yield depression to 123 and 179 ppm at 24 to 28% yield depression, respectively. Peas in contrast showed a higher tolerance with a drastic yield drop of 67% only after tissue boron concentration reached 360 ppm.

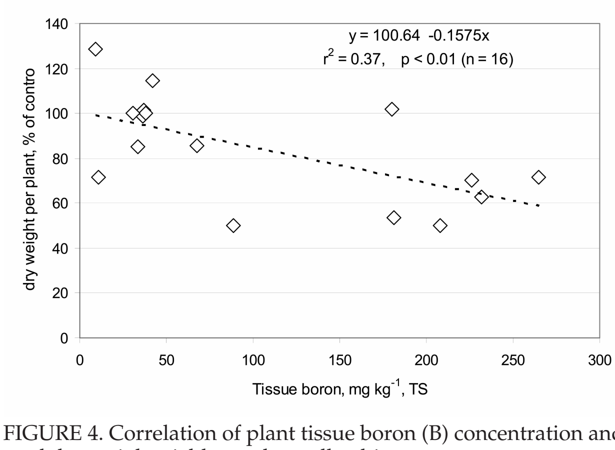

FIGURE 4. Correlation of plant tissue boron (B) concentration and total dry weight yield per plant, all cultivars.

When we regressed yield data for individual cultivars, as indicated by tissue boron and yield reductions, the following result was attained (Figure 5). In these data, the range of plant tissue boron for control treatments (compost+peat) was 10, 28, 30, 45 ppm for corn, cucumbers, beans and peas, respectively, up to 85 200, 250 and 210 ppm, respectively for the same cultivars grown with 33% fly-ash treated compost. The yield depressions from these treatments are evident in the graph. Cucumber and pea yield depression are highly statistically correlated with tissue boron concentration. Boron concentrations we observed in corn tissue with FA-compost are similar to the range Schumann and Sumner reported to cause increased phytotoxicity scores using biosolids:fly-ash: manure mixtures (Schumann & Sumner 1999).

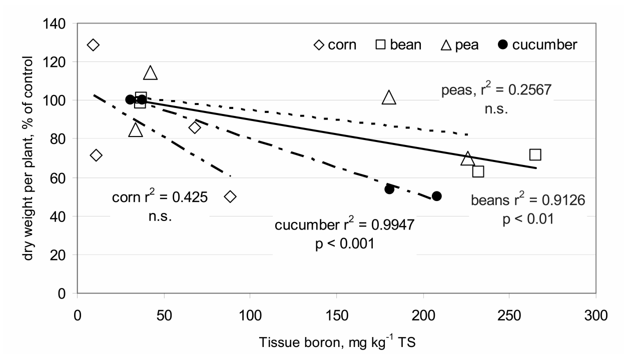

FIGURE 5. Plant tissue boron (B) vs. yield of plants grown in compost-soil media, and fly-ash amended compost (CFA).

The foregoing lab trials examining extractability suggest that not only is pH a major controlling factor in release of boron from compost for potential plant harm, but individual cultivars vary tremendously in accumulation and toxicity expression. The final pH can not be found, however, by testing compost alone, but must be empirically determined by admixtures of the compost:soil or compost:peat, etc., media, as determined by the final end use of the product. The amount of potentially available boron that may arise out of compost can be estimated from our equation as follows:

$$B_{avail} = B_{tot} * [109.2 - 13.1(pH_{media})] \div 100$$

where B_{tot} is the total boron by nitric-acid digestion, and where pH_{media} is the final pH of soil/compost mixture.

Conclusions

Replicated plant trials examining plant growth performance in compost mixtures indicate a clear potential for growth disruptions and visual toxicity symptomology occurring over a wide range of plant tissue concentrations of boron, induced by moderate to high levels of boron in the compost (Figures 6 and 7). The level of boron that causes reduced growth and plant toxicities is determined by plant sensitivity and total boron concentration and pH of the end media. This is in contrast to soil tests where total-B is considered unreliable for estimating boron availability (Nable *et al.* 1997). However, in composts, total boron concentration forms a basis for predicting soil-plant effects.

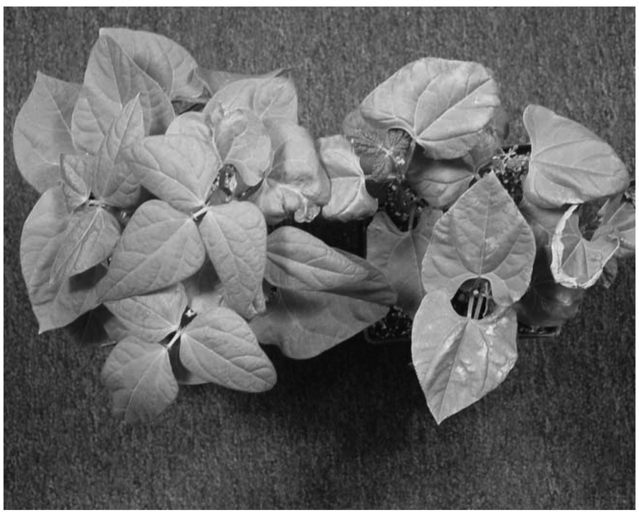

FIGURE 6. Bean symptoms in boron trial: left control; right: leaf-curl, cupping and chlorosis with fly-ash amended compost at 33% container media.

FIGURE 7. Corn symptomology for boron trials: leaf tip burn in FA-compost trials.

These foregoing studies show that high levels of total *and* avail-B are present in a fly ash (FA) amended compost. At container-mix rates of 25-33% FA-compost exhibits plant yield depressions with visually negative symptomology that varies with cultivar. The pH of end compost/soil mix will likely dictate the severity of effects as opposed to pH of compost alone. A rule of thumb to estimate potential effects is that 10-30% of total B in compost will be available for plant effects. The acceptable dilution rate per acre must be calculated from this range to produce a plant available boron not to exceed 3.0 ppm in soil, using an assumption of soil depth. Toxicity varies by species with beans > peas > cukes > corn > wheat. Hot water soluble B toxicity symptoms appear at approximately 3 ppm, similar to soil data. Symptoms vary tremendously with the species and include tip-burn, clorosis and leaf cupping. In view of the increasing popularity of addition of some fly ashes to compost, more effort to characterize compost addition rates limits to avoid toxicity symptoms is recommended.

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