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Release Rates of Soluble and Controlled-release Boron Fertilizers

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SUMMARY. The relative release rates of boron (B) from nine soluble and controlled-release B fertilizer sources were determined in sand leaching columns at 21 °C. Solubor was almost completely leached from the sand within 5 weeks. Boric oxide released the majority of its B within 7 weeks, whereas Dehybor provided B for up to 13 weeks. Granubor release rates were linear through ≈12 weeks. The five products containing calcium or sodium calcium borates released B much more slowly, with probertite and ulexite being the most rapid followed by B32 G, colemanite, and B38 G. B38 G released only ≈40% of its B content during the 104-week leaching study. The rapid release and high B concentrations associated with Solubor suggest a greater potential for phytotoxicity with this source than other slower-release sources.

Boron (B) deficiency is an important problem in the production of many crops around the world (Reisenauer et al., 1973; Sharrocks, 1997). Although B deficiency is known to be accentuated by soil drying and high soil pH (Biggar and Fireman, 1960; Keren and Gast, 1981), it is also common in wet climates (Moraghan and Mascagni, 1991). Because B is available to plants only in water-soluble forms such as boric acid or borate anions, it is highly leachable, particularly on coarse-textured soils (Sharrocks, 1997). Boron is slowly released from organic matter or soil minerals (Peryea et al., 1985), but under conditions of high rainfall or irrigation, temporary deficiencies of B in the soil can occur and may result in visible deficiency symptoms in the new growth of plants (Sharrocks, 1997).

For many fruit and vegetable crops, well-timed foliar applications of water-soluble B fertilizers are a common practice to prevent deficiencies (Martens and Westermann, 1991). For perennial crops, prevention of B deficiencies may be achieved through the use of controlled-release B fertilizers that are not greatly affected by leaching (Page and Cooper, 1955). In slow-growing plants such as palms (Palmae family), chronic and recurring acute B deficiencies are a widespread and serious problem (Broschat, 2007; Corrado et al., 1992; Manciot et al., 1980). In these situations, the use of controlled-release B fertilizers should be more effective than treatment of these deficiencies after the fact. Although controlled-release B fertilizers have been available for many years, little is known about the relative release rates of the various products under similar leaching conditions. Knowledge about the relative longevities of controlled-release B fertilizers under leaching conditions would be useful for determining reapplication intervals and thereby avoiding potential toxicity situations or lapses in B availability. The purpose of this study was to determine the relative release rates of nine soluble and controlled-release B fertilizers.

Materials and methods

Polyvinyl chloride columns (12 inches long × 2 inches i.d.) were mounted vertically into Buchner funnels (70 mm in diameter) that were supported by special funnel support racks. Columns were filled to a depth of 28 cm with medium-grade (14% less than 0.5 mm, 18% greater than 1.0 mm) acid-washed silica sand. This sand was prepared by rinsing thoroughly with tap water, soaking for 48 h in 1 *N* ammonium hydroxide, rinsing thoroughly with tap water, soaking for 48 h in 1 *N* hydrochloric acid, and finally leaching with a minimum of 12 L of deionized water per 4-L batch of sand (Hewitt, 1952).

Five grams of each of the nine B-containing fertilizers (Table 1) were applied to the sand surface of three replicate columns per product. The columns were maintained at 21 ± 1 °C. They were irrigated three times per week with 50 mL of deionized

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Units

To convert U.S. to SI, multiply by	U.S unit	SI unit	To convert SI to U.S., multiply by
10	%	$mg{\cdot}g^{-1}$	0.1
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1	ppm	$mg{\cdot}L^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Table 1. Boron (B) fertilizer materials evaluated for their release rates in sand columns.

Product	Composition	B (%)	Particle size (mm)[z]	Source
B32 G	Sodium calcium borates	10.0	4 + 1	Frit Industries, Walnut Ridge, AR
B38 G	Sodium calcium borates	12.0	–4 + 1	Frit Industries
Colemanite	Calcium borate	16.6	–0.074	American Borate Co., Amargos Valley, NV
Probertite-7 mesh	Sodium calcium borate	5.9	–2.83 + 0.42	American Borate Co.
Ulexite	Sodium calcium borate	12.1	–0.074	Industrial Minerals, Kings Creek, SC
Granubor	Sodium tetraborate pentahydrate + disodium octaborate tetrahydrate	15.0	–4 + 1.4	U.S. Borax, Inc., Valencia, CA
Dehybor-12 mesh	Anhydrous sodium tetraborate	22.5	–1.68	U.S. Borax
Boric oxide-4 mesh	Anhydrous boric acid	32.3	–4.76	U.S. Borax
Solubor	Disodium octaborate tetrahydrate	20.5	–0.074	U.S. Borax

[z]A minus (–) sign indicates that 90% of the particles will pass through this size sieve opening. A plus (+) sign indicates that 90% will be retained by this sized sieve opening (1 mm = 0.0394 inch).

water, and all leachates were collected in polyethylene beakers. Once per week the leachate volumes were measured (leaching fraction averaged 0.73) and the samples were analyzed for B concentrations using inductively coupled plasma emission spectroscopy (Keren, 1996). Three replicate columns containing no fertilizer were also included as controls, although no measurable amounts of B were ever recovered from these columns. The amount of B in each sample was divided by the percentage of B in each fertilizer to correct for differences in percentages of B among products. Weekly sampling continued for a particular product until leachate B concentrations dropped below 1 $mg \cdot L^{-1}$ or 104 weeks, whichever came first. Results were expressed as milligrams of B released per week per gram of B applied and as the cumulative percentage of applied B released over time. Cumulative release curve equations were developed using TableCurve 2D (v2.03; Systat Software, San Jose, CA).

Results

Weekly release of B varied greatly among the nine products tested (Fig. 1A–B). As expected, Solubor released most rapidly with virtually no B detected in the leachate after 5 weeks (Fig. 1A). The highest B concentrations from Solubor were obtained during weeks 1 to 3 when more than 70% of its B was released (Fig. 2A). However, only ≈83% of the total B content of Solubor was ever recovered in the leachate. The reasons for this low recovery rate are not known.

Boric oxide had the second fastest release rate with the majority of its B released in the first 7 weeks (Figs. 1A and 2A). Approximately 90% of the B in this product was ultimately recovered in the leachates (Fig. 2A).

The majority of Dehybor's B was released within the first 9 weeks with

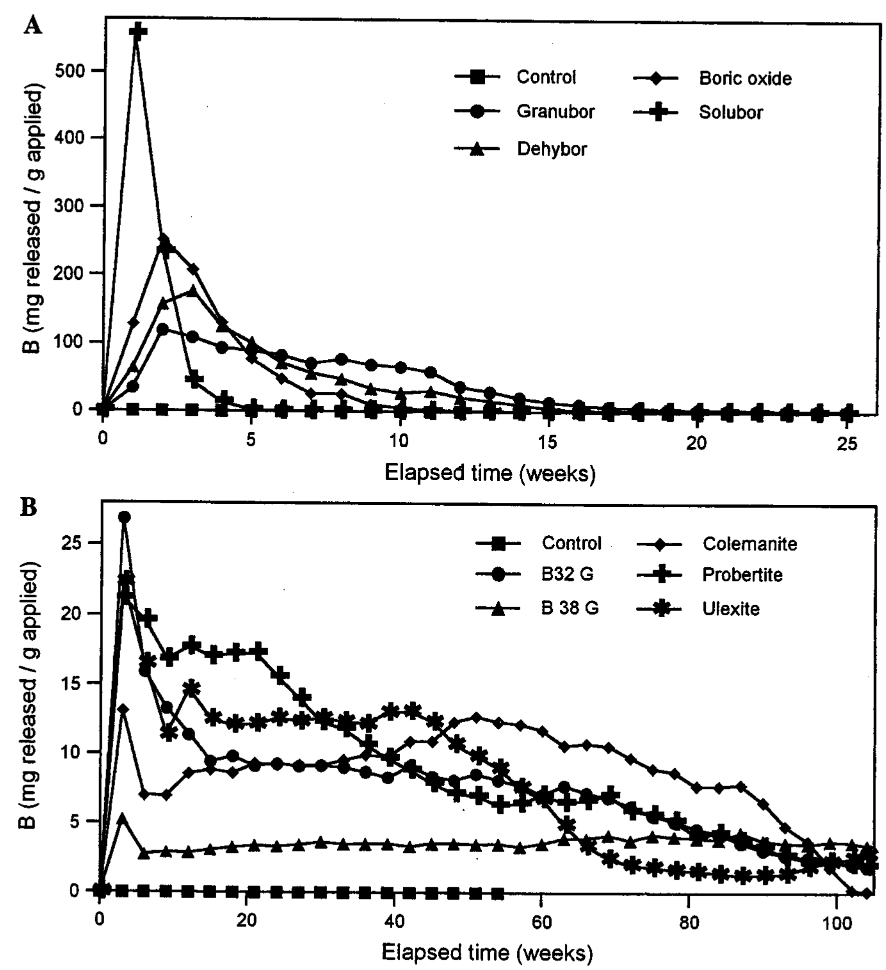

Fig. 1. Weekly release of boron (B) from soluble and controlled-release B fertilizers. (A) Release of B from soluble and short-term controlled-release products. (B) Release of B from longlasting products. Data are means from three replicate columns ± SE. Granubor, Solubor, and Dehybor are manufactured by U.S. Borax, Inc., Valencia, CA. B 32 G and B 38 G are manufactured by Frit Industries, Walnut Ridge, AR (1 $mg \cdot g^{-1}$ = 0.1%).

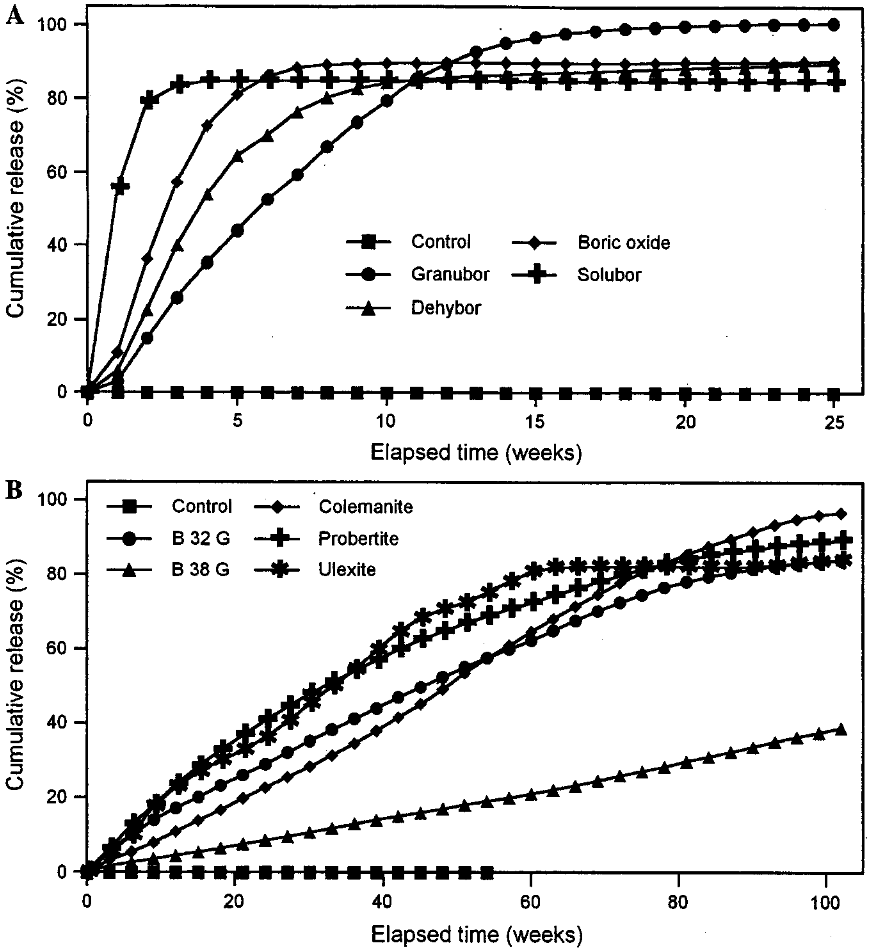

Fig. 2. Cumulative percent release of boron (B) from soluble and controlled release B fertilizers. (A) Release of B from soluble and short-term controlled-release products. (B) Release of B from longlasting products. Data are means from three replicate columns ± SE. Regression equations for these curves are shown in Table 2. Granubor, Solubor, and Dehybor are manufactured by U.S. Borax, Valencia, CA. B32 G and B38 G are manufactured by Frit Industries, Walnut Ridge, AR.

Table 2. Equations for cumulative percent release curves for nine soluble and controlled-release boron fertilizers

Product	Equation	R^2	*P*
B32 G[y]	$y = 0.98 + 1.90x\ln x$	0.994	0.0001
B38 G[y]	$y = 2.14 + 0.078x\ln x$	0.998	0.0001
Colemanite	$y = -0.747 + 1.036x$	0.992	0.0001
Probertite	$y = -8.133 + 10.16x^{0.5}$	0.989	0.0001
Ulexite	$y = -0.518 + 2.55x^{0.5}\ln x$	0.994	0.0001
Granubor[z]	$y = -15.74 + 28.44x^{0.5}$	0.961	0.0001
Dehybor[z]	$y = -10.69 + 30.82x^{0.5}$	0.944	0.0001
Boric oxide	$y^{-1} = 0.011 + 0.126e^{-x}$	0.989	0.0001
Solubor[z]	$y = 88.2–87.94e^{-x}$	0.998	0.0001

[z]Manufactured by U.S. Borax, Valencia, CA.
[y]Manufactured by Frit Industries, Walnut Ridge, AR.

smaller releases continuing up to week 13 (Figs. 1A and 2A). After week 2, Granubor released at a linear rate until approximately weeks 11 or 12 (Figs. 1A and 2A). It continued to release at lower rates until approximately week 16, when it was nearly exhausted. Ultimately, Granubor released 100% of its B (Fig. 2A).

The fritted B (B32 G and B38 G) and B-containing minerals (colemanite, probertite, and ulexite) all released at much slower rates than the products containing sodium borates or boric acid. B38 G released B at a very slow linear rate for the entire length of the experiment (104 weeks) (Figs. 1B and 2B). Less than 40% of the B in this product was released during that period. On the other hand, B32 G released at a more rapid rate during the first 15 weeks and then linearly through approximately week 65 (Figs. 1B and 2B). In contrast with B38 G, B32 G ultimately released ≈84% of its B during the 104-week experiment.

Of the three B-containing minerals tested, colemanite released linearly from week 6 through 87 and ultimately released ≈97% of its B during the 104-week experiment (Figs. 1B and 2B). Probertite released at a slightly faster rate than colemanite during the first 36 weeks, but more slowly thereafter (Fig. 1B). After 104 weeks, probertite had released ≈90% of its B (Fig. 2B). After the first 3 to 6 weeks of relatively rapid release, ulexite released at a rather uniform rate until approximately week 45 (Fig. 1B). After that time, its release rate dropped off rapidly to virtually nothing after ≈60 weeks (Figs. 1B and 2B). Over the course of 104 weeks, ≈84% of the B in ulexite was recovered in our leachates (Fig. 2B).

Discussion

As expected, our results demonstrated that soluble B sources such as Solubor can be quickly leached through sand and would have to be applied frequently at low rates to provide similar availability to controlled-release sources. In high rainfall areas such as south Florida, palms growing in field nurseries or landscapes are often fertilized every 3 months with complete fertilizer products containing controlled-release nitrogen, potassium, and magnesium (Broschat, 2005). Controlled-release B sources such as Granubor have release curves that would be suitable for blending with other elemental sources that have 3-month longeveties. In areas where more soluble fertilizers are used, faster-release B sources such as boric oxide or Dehybor might be preferable for blending.

If B fertilizers are to be applied alone rather than blended with other components, then the longer-term products such as B32 G, colemantite, probertite, or ulexite may be useful for preventing B deficiencies. Inclusion of these very slow-release B sources into blended complete fertilizers that are applied at 3-month intervals or other relatively short intervals could result in an accumulation of B in the soil in the long term, potentially to toxic levels. Whereas B toxicity from soluble sources such as Solubor can be alleviated by heavy leaching, such leaching would be relatively ineffective in reducing B toxicities caused by excessive application of long-term controlled-release B fertilizers (Nable et al., 1997). The release curves presented here should be useful in determining safe reapplication intervals. However, additional research is needed with these products to determine optimum application rates for various crops and environments.

One additional benefit of some of these controlled-release B fertilizers is their granular particle size. When powdered B sources are blended into granular complete fertilizers, the powder quickly settles out, resulting in low B concentrations in fertilizer at the top and excessive amounts at the bottom of the container. Of the products tested, Granubor, B32 G, and B38 G have granules similar in size to other commonly used nitrogen, phosphorus, and potassium sources and would be suitable for blending with them. Boric oxide, Dehybor, colemanite, and probertite have fine granules or crystals and are less well suited for blending. Solubor and the ulexite that we tested are fine powders and are unsuitable for blending. The more rapid release of ulexite than of probertite and colemanite is likely the result of the finer particle size of the ulexite (Table 1) (Mortvedt, 1994; Wear and Wilson, 1954).

In summary, the release rates of most of the materials tested were fairly linear until ≈80% of their B content had been released. They represent a wide range of release rates, with Solubor releasing the fastest followed by boric oxide, Dehybor, Granubor, probertite and ulexite, B32 G, Colemanite, and B38 G, the latter releasing less than 40% of its B during the 2-year study. Particle sizes for Granubor, B32 G, and B38 G are suitable for blending with other granular fertilizers; however, the fine particle size of the other products may limit their use to separate applications.

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