Chapter 15

Fertilizer Applications for Correcting Micronutrient Deficiencies

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Increases in crop yields from application of B, Cu, Fe, Mn, Mo, and/or Zn occur in many parts of the world including numerous regions of the USA. There is growing awareness that micronutrient deficiencies may limit crop yields even though exceedingly small amounts are required by plants (Table 15–1). Various reasons can be provided to account for the current increased recognition of micronutrient needs in crop production. These include (i) improved soil test and tissue analysis methods for diagnosis of micronutrient deficiencies; (ii) accumulated data on crop responses to micronutrient applications on diverse soil types; (iii) micronutrient removal from long-term crop production; (iv) increased use of high-analysis fertilizers with low amounts of micronutrient impurities; (v) higher micronutrient requirements accompanying higher crop yields; (vi) less use of animal manures in crop production; and (vii) induction of micronutrient deficiencies by high P concentrations from long-term applications (Berger, 1962; Vitosh et al., 1981). Attention will be directed in this chapter toward correction of B, Cu, Fe, Mn, Mo, and Zn deficiencies in plants grown under diverse management regimes. Literature on Cl, Co, and Ni deficiencies also will be discussed.

I. BORON

Soil and environmental factors influencing B availability to plants are discussed in Ch. 11 of this book and in other reviews (Keren & Bingham, 1985; Gupta, 1972a; Gupta et al., 1985). Boron deficiencies in the USA occur on low-organic-matter, acid, sandy and silt loam soils, particularly in the South Atlantic and Pacific area states, although B deficencies were report-

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Table 15-1. Approximate micronutrient uptake for the production of high yields of alfalfa, corn, and soybean (Mengel, 1980).

Micronutrient	Nutrient uptake by		
	13.4 t alfalfa	9.4 t corn	4.0 t soybean
	kg ha^{-1}		
B	0.33	0.18	0.11
Cu	0.07	0.11	0.11
Fe	2.02	2.13	1.90
Mn	0.67	0.33	0.67
Mo	0.02	0.01	0.01
Zn	0.27	0.30	0.22

ed in 43 states (Sparr, 1970). Deficiencies are more prevalent during drouth and availabilities generally decrease when acid soils are limed. Most dicotyledons require more B than do monocotyledons. Vegetables of the *Cruciferous* and *Umbelliferous* families have a high B requirement and tolerate high B concentrations that are toxic to some other crops (Table 15-2). Crop yield and quality responses to B fertilization may not be consistent because of soil and other environmental interactions affecting B availability and plant growth.

A. Sources

The B concentrations of the common sources of B fertilizers are provided in Table 15-3. The Na borates are generally used for soil application, except Solubor® which is used for both soil and foliar applications because of its solubility. Boric acid has only received limited use. Borax is a popular water-soluble B fertilizer, but it readily leaches in sandy soils. Colemanite and B frits may be used successfully on soils subject to leaching losses if their particle size is small enough. Manures, sewage sludges, composts, waste effluents, and fly ash materials are also readily available B sources for plants, but B toxicity can be a problem at high application rates (Adriano et al., 1980; Kardos et al., 1977).

B. Application Methods and Rates

Soil applications and foliar spraying are the two principal methods of applying B. Boron fertilizers are mixed and applied with other fertilizer materials to correct potential B deficiencies for cultivated annual crops. Foliar sprays are used after these crops are established and for several perennial agricultural crops.

1. Soil Application

Selected field experiments in which different B rates were used are summarized in Table 15-4. Legumes and certain root crops required 2 to 4 kg B ha^{-1}, while lower rates were necessary for maximum yields in other crops to avoid toxicity problems.

Table 15-2. Relative sensitivities of selected crops to micronutrient deficiencies.

	Sensitivity to micronutrient deficiency†					
Crop‡	B	Cu	Fe	Mn	Mo	Zn
Alfalfa	High	High	Medium	Medium	Medium	Low
Asparagus	Low	Low	Medium	Low	Low	Low
Barley	Low	Medium	High	Medium	Low	Medium
Bean	Low	Low	High	High	Medium	High
Blueberry	Low	Medium	--§	Low	--	--
Broccoli	Medium	Medium	High	Medium	High	--
Cabbage	Medium	Medium	Medium	Medium	Medium	--
Carrot	Medium	Medium	--	Medium	Low	Low
Cauliflower	High	Medium	High	Medium	High	--
Celery	High	Medium	--	Medium	Low	--
Clover	Medium	Medium	--	Medium	Medium	Low
Cucumber	Low	Medium	--	Medium	--	--
Corn	Low	Medium	Medium	Medium	Low	High
Grass	Low	Low	High	Medium	Low	Low
Lettuce	Medium	High	--	High	High	Medium
Oat	Low	High	Medium	High	Low	Low
Onion	Low	High	--	High	High	High
Parsnip	Medium	Medium	--	Medium	--	--
Pea	Low	Low	--	High	Medium	Low
Peppermint	Low	Low	Low	Medium	Low	Low
Potato	Low	Low	--	High	Low	Medium
Radish	Medium	Medium	--	High	Medium	--
Rye	Low	Low	--	Low	Low	Low
Sorghum	Low	Medium	High	High	Low	High
Spearmint	Low	Low	--	Medium	Low	Low
Soybean	Low	Low	High	High	Medium	Medium
Spinach	Medium	High	High	High	High	--
Sudan grass	Low	High	High	High	Low	Medium
Sugar beet	High	Medium	High	Medium	Medium	Medium
Sweet corn	Medium	Medium	Medium	Medium	Low	High
Table beet	High	High	High	High	High	Medium
Tomato	Medium	Medium	High	Medium	Medium	Medium
Turnip	High	Medium	--	Medium	Medium	--
Wheat	Low	High	Low	High	Low	Low

† Based on data from Robertson et al. (1981), Robertson and Lucas (1981), Vitosh et al. (1981), Alloway and Tills (1984), and Fenster et al. (1984).

‡ Asparagus (*Asparagus officinalis*); blueberry (*Vaccinium corymbosum*); broccoli (*Brassica oleracea botrytis*); parsnip (*Pastinaca sativa*); peppermint (*Mentha piperita*); radish (*Raphanus sativa*); rye (*Secale cereale*); spearmint (*Mentha spicata*); sudan grass (*Sorghum vulgare sudanese*); turnip (*Brassica rapa* var. *rapa*).

§ Inadequate available data to categorize into low, medium, or high sensitivity groups.

Boron fertilizers are generally broadcast and incorporated prior to seeding crops not planted in rows; e.g., legumes, rape (*Brassica napus*), and grasses (Gupta, 1984; Plank & Martens, 1974; Nuttall et al., 1987; Monson & Gaines, 1986). Once established, broadcast applications are also recommended for these crops (Rehm et al., 1987; Gerwing et al., 1988). Broadcast applications are particularly effective around trees and grapevines (*Vitis vinifera* L.) on coarser-textured soils (Boswell et al., 1980; Hopmans & Flinn, 1984).

Table 15-3. Boron sources used for correcting B deficiencies in plants.†

Source	Formula	B, g kg^{-1}‡
Boric acid	H_3BO_3	170
Boron frits	Fritted glass	20–60
Borax	$Na_2B_4O_7 \cdot 10H_2O$	110
Colemanite	$CaB_6O_{11} \cdot 5H_2O$	100
Sodium pentaborate	$Na_2B_{10}O_{16} \cdot 10H_2O$	180
Sodium tetraborate: Borate-45	$Na_2B_4O_7 \cdot 5H_2O$	140
Borate-65	$Na_2B_4O_7$	200
Solubor® §	$Na_2B_4O_7 \cdot 5H_2O$ + $Na_2B_{10}O_{16} \cdot 10H_2O$	200

† Data from Murphy and Walsh (1972), Keren and Bingham (1985), Gupta (1979a), and Gupta et al. (1985).
‡ Approximate concentration.
§ Solubor is partially dehydrated borax.

Boron concentrations in rutabaga (*Brassica napobrassica*) leaf tissue were greater when B was applied in fertilizer bands compared with similar B rates broadcast (Gupta & Cutcliffe, 1978). Banding 1.12 kg B ha^{-1} resulted in higher B concentrations than broadcasting 2.24 kg B ha^{-1}. Similar results are reported by Touchton and Boswell (1975a, b) for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. Boron application sometimes improve crop quality and economic yields, but not total yields (Gupta & Cutcliffe, 1978; Hemphill et al., 1982; Morrill et al., 1977). Boron should neither be placed in contact with the seed nor should broadcast rates be used when banding because of potential toxicity problems.

The B contained in fly ash, scrubber and sewage sludges, municipal composts, and wastewater effluents is readily available to plants (Plank & Martens, 1974; Adriano et al., 1980; Kardos et al., 1977). A wide range of B concentrations exists among, as well as within, these materials. The B availability from these materials when broadcast is similar to that from traditional

Table 15-4. Rates of B application for correction of B deficiencies of various crops.

Crop	B source	B rate, kg ha^{-1} Range	Optimum	Application method	Reference
Alfalfa	$Na_2B_4O_7$	1.12–4.48	2.24	Broadcast	Gupta, 1984
Alfalfa	Fly ash	1.7–3.4	1.7	Broadcast	Plank & Martens, 1974
Cole crops	$Na_2B_4O_7$	–	0.45	Banded	Gupta & Cutcliffe, 1975
Grape	Solubor	0.38–3.05	0.76	Broadcast	Boswell et al., 1980
Pine tree†	$Na_2B_4O_7 \cdot 10H_2O$	5.7–17.0	5.7	Broadcast	Hopmans & Flinn, 1984
Rapeseed	H_3BO_3	0–2.8	1.4	Broadcast	Nuttall et al., 1987
Soybean	$Na_2B_4O_7 \cdot 5H_2O$	0.28–2.24	1.12	Broadcast	Touchton & Boswell, 1975b
Strawberry†	$Na_2B_4O_7$	0.56–2.24	1.12	Broadcast	Blatt, 1982
Sugarbeet	Solubor	2.2–6.6	2.2	Banded	Voth et al., 1979
Table beet	Solubor	3.4–6.7	3.4	Broadcast	Hemphill et al., 1982

† Pine tree (*Pinus radiata* D. Don); strawberry (*Fragaria ananassa*).

B fertilizer materials (Table 15-3). Boron toxicity and crop yield reductions can occur at B application rates greater than those recommended (Walker & Dowdy, 1980; Purves & Mackenzie, 1973; Ransome & Dowdy, 1987).

2. Foliar Application

Foliar sprays are widely used on perennial crops such as nuts, vines, and fruit orchards because they have consistently produced better results than soil applications. Hanson and Breen (1985) and Shrestha et al. (1987) found that spring spray applications of 300 to 600 mg B L^{-1} on hazelnut (*Corylus americana* Marshall) and prune (*Prunus domestica*) trees increased fruit set and B concentrations in plant tissues. Environmental conditions appear to have more influence on a spring application than on a fall application after petal fall.

Foliar applications of B to annual crops are superior to broadcast applications, and equivalent or slightly more effective than banded applications (Touchton & Boswell, 1975a, b; Gupta & Cutcliffe, 1978). A general foliar spray with B is recommended on peanut (*Arachis hypogaea* L.) at early bloom (Hill & Morrill, 1974; Donohue et al., 1979). Effective foliar application rates are 10 to 50% of that required by the broadcasting method, although repeated applications may be necessary because of B immobility. Phytotoxicity may be a problem at higher application rates.

C. Residual Effects of Boron Application

Boron fertilizers have a longer residual effect on high silt and clay soils compared with that on sandy soils. Lower solubility materials also have more residual effects. Foliar-applied materials on perennial crops usually show no residual effects during the year following applications, whereas soil applications do. A broadcast application of 2 kg B ha^{-1} as Borate-65 on a loam soil provided sufficient B for 2 yr of alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.) (Gupta, 1984). High application rates, 4 to 8 kg B ha^{-1}, on soils susceptible to leaching losses were not toxic to later cereal and bean (*Phaseolus vulgaris* L.) crops (Gupta & Cutcliffe, 1982, 1984). Annual applications of 1.2 to 3.6 kg B ha^{-1} on crimson clover (*Trifolium incarnatum* L.) for 4 yr did not adversely affect subsequent B-sensitive crops, even though B had accumulated in the profiles of the heavier-textured soils (Wear, 1957).

D. Toxicity Effects of Boron

Indigenous concentrations of B in virgin soils are generally not sufficient to cause B toxicity, except in arid and semiarid regions where salts accumulate. Boron toxicity from irrigation waters is usually caused by B salts concentrating in the soil via evapotranspiration processes. Some wastewater effluents contain sufficient B to be toxic when applied to satisfy evapotranspiration demand (Kardos et al., 1977).