Boron Maintenance Sprays for Apple: Early-season Applications and Tank-mixing with Calcium Chloride

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Abstract. The recommendations for boron (B) sprays in deciduous tree fruit orchards have changed little over the past 50 years. We conducted two 3-year field studies evaluating the effect of two modifications to the existing recommendation for B maintenance sprays on apple (*Malus ×domestica*) tree nutritional status. A widely recommended Na polyborate-based commercial B spray product was used as the B source. Postbloom sprays of B applied at the recommended annual B maintenance rate of 0.56 kg·ha⁻¹ to ‘Scarlet Gala’ apple trees consistently increased fruit B concentration but had a weaker effect on leaf B concentration in early August, the recommended timing for sampling leaves for mineral element analysis. Applying half or all of the annual B maintenance rate in a spray at the pink flowering stage increased flower cluster and early-season leaf B concentrations as well as having positive effects on fruit and leaf B concentrations. The pink sprays increased flower cluster Na concentration but had no effect on leaf and fruit Na concentrations. In the second study, one-quarter of the annual B fertilizer requirement was tank-mixed with each of four biweekly CaCl₂ sprays applied starting in early June for bitter pit control. This treatment consistently increased ‘Scarlet Gala’ fruit B concentration but had a lesser effect on August leaf B concentration. It did not interfere with fruit Ca status, and increased both fruit and leaf Na concentrations. Leaf Na concentration in all treatments was substantially lower than levels associated with specific Na toxicity of deciduous fruit trees. The results of these experiments indicate that applying B sprays at the pink flowering stage timing and tank-mixing B with CaCl₂ sprays applied for bitter pit control are useful practices to enhance B spray efficacy and convenience of application.

Boron (B) deficiency is a widespread problem in apple orchards. Benson (1953) recommended annual maintenance sprays of Na polyborate compounds in Washington orchards to ensure that apple trees contained sufficient B for optimal tree growth and fruiting performance. Although timing was not considered critical for apple, application of a single spray at first to second cover timing was considered convenient and effective. Burrell (1960) validated this recommendation for New York apple orchards. Postharvest B sprays, which are so effective in controlling B deficiency-induced blossom blast of pear flowers (Batjer et al., 1953; Crandall et al., 1976), appear not to have been widely adopted for apple because their later harvest dates compromise spray logistics and efficacy. Maintenance B recommendations for apple later shifted to emphasize prebloom sprays to ensure that transitory low B status in flowers

did not limit fruit set (WSU, 1982), coupled with concern about the potentially deleterious effect of mid-summer B sprays on apple fruit storage quality (Wilcox and Woodbridge, 1942; Bramlage and Thompson, 1962). Current Washington guidelines include a recommendation for two B maintenance sprays, prebloom and at first or second cover timing, for apples grown on very sandy or calcareous soils (Smith, 2002).

Annual B sprays at petal fall or first cover timing are recommended for apples in the mid-Atlantic region, where internal cork associated with low fruit B is a major problem on local varieties (Pfeiffer, 1998). Stiles and Reid (1991) recommend annual B sprays at both pre- and postbloom timing for apple trees with low leaf B concentrations in New York but as supplements to soil application of B. Bramlage and Weis (1991) found the recommendations for Massachusetts, which were based solely on soil applications of B, to be inadequate and suggested adoption of the Stiles and Reid (1991) guidelines. Stover et al. (1999) found prebloom B sprays to sometimes increase cropping of winter-damaged ‘MacIntosh’ and ‘Empire’ apple trees in New York, and recommended their use on winter-damaged or otherwise light-cropping trees. All of these

researchers used or recommend Solubor (U.S. Borax, Valencia, Calif.), a Na polyborate-based powdered B spray product containing 20.5% B (w/w). There therefore appears to be reasonable congruence of B spray recommendations for apple throughout the United States. Variation likely reflects differences in cultivar requirements, soils, climate, and management practices. While there are numerous studies on soil applications and postbloom sprays of B to apple, the effect of B sprays applied at pink or pink plus postbloom timings on apple tree B status has not been evaluated.

Preharvest Ca sprays often are applied to reduce the likelihood of bitter pit development in apple (Conway et al., 2002). Multiple Ca sprays are applied, usually commencing in early June (Bramlage, 1994; Smith, 2002). Food or spray-grade Ca chloride has proven to be the preferred Ca source because of its high effectiveness and low cost. Adding B to early-season preharvest Ca sprays would be a convenient and cost-cutting way to apply postbloom B provided it did not create excessive fruit B. Calcium and B interact in a number of ways, the outcome of which is difficult to predict. Pfeiffer (1998) warned against premixing Solubor and CaCl₂, stating that B precipitation can occur. Chemical reaction of Solubor, a highly soluble Na polyborate-based compound, with CaCl₂ may produce a Ca borate precipitate of lower solubility, which could reduce dissolved Ca and B concentrations in the spray solution and possibly interfere with plant uptake of both elements from a tank-mixed foliar spray. Formation of mixed Ca-Na borates and then Ca borates of varying mineralogy is favored with increasing Ca²⁺ activity in aqueous CaO–NaO–B geochemical systems (Christ et al., 1967). Colwell and Cummings (1944) found that the dissolution rate of Ca metaborate solid was so slow that months of reaction were required to achieve near-complete dissolution. The kinetics of the converse reaction, de novo formation of Ca borate minerals, either directly in a tank-mixed Solubor and CaCl₂ spray or, more likely, as the spray dries on plant surfaces after application, and its potential effect on phytoaccumulation of Ca or B have not been studied.

The potentially adverse geochemical reaction may be counterbalanced by a beneficial effect of added B on intra-plant transport of Ca. Shear and Faust (1970) reported that boric acid sprays enhanced Ca movement into leaves of apple seedlings grown in solution culture. Postbloom B sprays enhanced fruit and leaf Ca of field-grown apple trees in some cases (Dixon et al., 1973; Wojcik et al., 1999) but had little or no effect in others (Dunlap and Thompson, 1959; Wightman et al., 1970). Lidster et al. (1978) reported that boric acid added to CaCl₂ sprays had no effect on fruit Ca or on the incidence of breakdown in ‘Spartan’ apples, but did not measure fruit B concentrations.

Citrus, nut, and stone fruit trees are particularly sensitive to specific Na toxicity, which usually is associated with sprinkler irrigation with high Na water (Maas, 1986). Because Solubor contains Na, there has been a question about whether foliar sprays of Solubor

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application can increase apple tree Na status to levels that may induce specific Na toxicity. We are aware of no studies that have examined this issue.

The purpose of the current study was to evaluate the effect of possible refinements in B maintenance spray practices on apple tree B, Ca, and Na status. One field study examined the effect of early-season Solubor spray timing (pink flowering stage, postbloom, and split between pink and postbloom). The second field study evaluated the effect of tank-mixing Solubor with CaCl_2 sprays applied for bitter pit control.

Materials and Methods

The two experiments were conducted from 1997–99 on ‘Scarlet Gala’/EMLA.26 apple trees in a mixed ‘Fuji’ and ‘Gala’ apple orchard located in Wenatchee, Wash. The orchard was planted in Mar. 1992 on a Cashmont gravelly sandy loam (coarse-loamy, mixed, mixed mesic Aridic Haploxerolls). The trees were planted at a 2-m (in-row) $\times$ 4.6-m (between-row) spacing (1104 trees/ha) and were supported by a single overhead wire/metal conduit trellis system. The trees were irrigated using under-tree microsprinklers located between every other tree. Herbicides were used to maintain a weed-free strip within the tree rows. Fruits were chemically and hand-thinned, pesticides applied, and fertilizers other than B and Ca applied according to commercial practice (Smith, 2002). The experimental orchard was chosen because previous leaf B analyses indicated marginally low B status. Visual symptoms of B deficiency did not appear on any of the trees at any time. The incidence of bitter pit was inconsequential, appearing randomly on only a few fruits in the entire orchard.

Expt. 1. Boron spray timing. A randomized complete-block experiment was established in the orchard using five blocks each containing four plots of adjacent four ‘Scarlet Gala’ apple trees (two within-row and two in an immediately adjacent row). The experimental plots were separated by at least two guard trees (in-row) and by two guard rows (between-rows). The four experimental treatments were assigned randomly to the four plots within each block. The four trees of each plot comprised the sampling unit, from which composite plant tissue samples were collected and analyzed for mineral element concentrations.

The total B application rate in all B treatments was 0.51 g/tree per season (0.56 kg/ha per season), which is the recommended B maintenance rate (Smith, 2002). Solubor was used as the B source. The four treatments were applied annually in 1997–99. They were: water sprayed control; 100% of B applied at the pink flowering stage (about mid-April); 100% of B applied postbloom at second cover spray timing (early to mid-June); and 50% of B applied at pink and the remaining 50% postbloom. Solutions of Solubor were prepared separately for each experimental plot in 2 to 4 L of tap water and applied by backpack sprayer. The trees were sprayed to drip, which required solution volumes of 2 L/plot for the pink spray and

4 L/plot for the postbloom spray. To ensure that all trees received equal amounts of spray water during the going season, tap water only was sprayed on the 100% Pink trees at the postbloom timing (4 L/plot), and on the 100% Postbloom trees at pink timing (2 L/plot).

Eight flower clusters (comprised of flowers and fruiting spur leaves) were sampled randomly from each plot (two per tree) at full bloom in 1998–99, composited by plot, freeze-dried without washing, and ground in a Wiley mill. This protocol was adopted because delicate portions of the flower clusters do not survive the washing procedure. Its use means that measured B and Na concentrations in flower clusters from trees receiving Solubor sprays at the pink flowering stage may be biased by the probable presence of Na polyborate spray residues on the plant tissue surfaces. Comparison with the control treatment provides a quantitative estimate of the contribution of the treatment sprays on total B and Na concentrations. Given the high rate of absorption of B and Na by growing leaf tissue (Maas, 1986; Shu et al., 1994), we anticipate that internal B and Na concentrations will be positively related to total concentrations in the unwashed flower clusters. Twenty early-season leaf samples were collected from each plot (five per tree) in late May/early June of 1997–99, immediately before the postbloom B spray application. Twenty mid-season leaves were randomly sampled from each plot (five per tree) in early Aug. 1997–99, $\approx$ 2 months after the postbloom sprays. All leaves were sampled from mid-shoot positions of current season’s shoots angled $\approx 45^\circ$ from the vertical. The leaf samples from each sample timing were composited by plot, washed, oven-dried at 85°C , ground in a Wiley mill, and analyzed for Ca, B, Na, N, P, K, Mg, S, Zn, Fe, Cu, Mn, Fe, and Al. Nitrogen was determined by wet-digestion followed by assay using Kjeldahl distillation and titration. The other elements were determined by dry ashing, dissolution of the ash in HNO_3 , and assay by inductively coupled plasma atomic emission spectroscopy. Eight fruits were sampled randomly from each experimental plot (two per tree) at commercial harvest timing in late August of each year. Each fruit sample was cut longitudinally into quarters, and seeds and stems were removed. Two opposing quarters were freeze-dried. The skin and core tissue of the two remaining quarters were excised and the residual cortical tissue was freeze-dried. The freeze-dried fruit tissue samples were ground in an agate mortar, and analyzed for Ca, B, and Na as previously described. All leaf and fruit tissue samples were washed in 0.5% (v/v) Liquinox solution (Alconox, New York, NY), followed by tap water and distilled water rinses, prior to processing for analysis. All plant tissue concentrations are expressed on a dry mass basis.

Expt. 2. Tank-mixing with calcium chloride. A second randomized complete-block experiment was established in the same orchard using five blocks each containing two plots of four ‘Scarlet Gala’ apple trees (two within-row and two in an immediately adjacent row). The two experimental treatments were as-

signed randomly to the two plots within each block. The four trees of each plot comprised the sampling unit, from which composite plant tissue samples were collected and analyzed for mineral element concentrations.

The two treatments were applied annually in 1997–99. The four trees in each plot were sprayed using a backpack sprayer with 4 L of CaCl_2 solution only or CaCl_2 tank-mixed with Solubor, which was sufficient volume to spray the trees just to drip. Foliar-grade CaCl_2 (Leaf Life Cal-Quik, 34% Ca, Crop Protection Services, Pasco, Wash.) was used as the Ca source and tap water as the water source. For the B-containing treatment, Solubor was added to the CaCl_2 solution just prior to application. The Ca application rate was 2.07 g/tree (equivalent to 2.29 kg·ha $^{-1}$ per spray, consistent with commercial practice). The B application rate was either 0 or 0.127 g B/tree per spray (equivalent to 0.14 kg·ha $^{-1}$ per spray, one quarter of the recommended annual B maintenance rate). The first spray was applied in late May or early June of each year. The three subsequent sprays were applied biweekly, with minor adjustments for weather conditions. By early- to mid-July of each year, the B-treated trees had received their full annual B maintenance requirement equally distributed between the four CaCl_2 sprays.

Twenty leaves were sampled randomly from each experimental plot (five per tree) in early Aug. 1997–99, at least one month after the last spray, and in May 1998–99, before the first spray of each season. Eight fruits were sampled randomly from each experimental plot (two per tree) at commercial harvest timing in late August of each year. Leaf and fruit sampling criteria, processing, and analysis were as described in the B spray timing section.

Statistical analysis. The SAS computer program was used for statistical analysis (SAS, 1999). The main treatment effect on all response variables in each experiment was statistically evaluated on a by-year basis using analysis of variance (ANOVA) for a randomized complete-block experimental design. Duncan’s multiple range test was used to separate treatment means found significantly different by ANOVA. Statistical significance was defined at $P \leq 0.05$.

Results and Discussion

Expt. 1. Boron spray timing. Fruit mass was unaffected by B spray treatment and, averaged across treatments, was 190, 174, and 197 g in 1997–99, respectively. The B sprays had no strong or consistent effects on plant tissue concentration of elements other than B and Na. Significant effects were observed for early-season leaf N concentration ($P = 0.030$) in 1997; flower cluster Mg ($P = 0.026$) and Zn ($P = 0.044$) concentrations in 1998; and mid-summer leaf Ca concentration ($P = 0.046$) in 1999, where only the 100% Postbloom spray increased leaf Ca concentration relative to the control. These significant main treatment effects appear to be random statistical events.

Applying all of the B at pink timing substantially increased flower cluster B and early leaf B

concentrations in all years (Table 1). Applying half of the B at pink timing increased flower cluster B concentration to levels intermediate between the control and the 100% Pink sprays, but increased early-season leaf B concentration in only one of three years. Flower cluster and early-season leaf B concentrations did not differ between the control and the 100% Postbloom treatment in any year. Because these tissues in these two treatments were sampled before any B sprays were applied, their B content would have been governed by remobilization and transport of stored B within the tree. The lack of difference between the two treatments suggests that the B sprays failed to appreciably enhance overall tree B status during the course of the experiment. Numerous reports indicate that flower B concentration is generally indicative of B status of deciduous fruit trees (Crandall et al., 1976; Callan et al., 1978; Hanson, 1991a; Nymora et al., 1997).

Leaf B concentrations in the experimental trees were lower than the desirable range of 25–50 mg·kg⁻¹ (Tukey and Dow, 1979). All of the B-containing treatments increased August leaf B concentration by similar amounts in 1997; however, the main effect for the B spray treatments was less definitive in 1998 and 1999, becoming significant only at $P = 0.099$ and 0.128. Bramlage and Thompson (1962) and Khalil and Thompson (1965) also found that early-season Solubor sprays substantially increased apple leaf B concentration immediately after spray application; however, leaf B concentration thereafter declined until there was little or no observable effect of the sprays later in the growing season. Similarly, Crandall et al. (1976) reported that Solubor sprays applied at pink timing or in May failed to increase mid-August leaf B concentration in pear, while July sprays were effective. The likely mechanism for the weak influence of the B sprays on leaf B concentration is rapid export of spray-derived B out of leaves and into subtending tissues (Hanson, 1991b; Perica et al., 2001; Shu et al., 1994). Boron is phloem-mobile in sorbitol-rich species such as apple (Brown and Hu, 1996).

In contrast to leaves, the B concentration in whole fruits and fruit cortical tissue was enhanced by all of the B spray timing treatments. There were occasional but inconsistent differences between the B spray treatments. Chamel and Andreani (1985) concluded that uptake of B through the skin of apple fruit was limited but sufficient to detectably increase B concentration throughout the fruit. Field experiments also indicate that foliar B sprays can appreciably and consistently increase apple fruit B concentration (Bramlage and Thompson, 1962; Burrell, 1960; Burrell et al., 1956; Dixon et al., 1973; Khalil and Thompson, 1965; Wojcik et al., 1999; Yogaratnam and Johnson, 1982).

Boron concentration was lower in the fruit cortical tissue than in whole fruit samples, as observed in other studies (Burrell et al., 1956; Peryea and Drake, 1991; Wightman et al., 1970). Fruit corking caused by B deficiency appears to be controlled by maintaining whole-fruit B concentrations above 10 mg·kg⁻¹ dry

Table 1. Average B concentrations in leaf and fruit tissue of 'Gala' apple trees sprayed annually with 0.51 g of B as Solubor per tree (0.56 kg·ha⁻¹) at pink flowering stage, postbloom, or equally split between pink and postbloom timings, 1997–99.

Year	Tissue	B spray timing				
		Water control	100% Pink	100% Postbloom	50% Pink + 50% Postbloom	Prob. ^z
		(B concn, mg·kg ⁻¹ dry mass)				
1997	Leaf, early June ^y	12.4 a ^x	18.9 b	12.4 a	18.2 b	0.0359
	Leaf, early August ^w	18.0 a	27.5 b	27.8 b	22.0 ab	0.0247
	Fruit cortex, at-harvest	12.5 a	22.0 b	23.4 b	23.0 b	<0.0001
	Whole fruit, at-harvest	16.2 a	29.2 b	31.7 b	29.7 b	<0.0001
1998	Flower cluster, full bloom ^y	26.7 a	183.1 c	35.6 a	122.6 b	0.0001
	Leaf, late May ^x	15.1 a	23.7 c	18.1 ab	21.4 bc	0.0010
	Leaf, early August ^w	14.0	18.5	19.2	21.0	0.0990
	Fruit cortex, at-harvest	10.6 a	21.7 b	25.4 c	22.7 b	<0.0001
1999	Whole fruit, at-harvest	12.3 a	24.1 b	29.1 c	26.1 b	<0.0001
	Flower cluster, full bloom ^y	35.2 a	274.6 c	43.1 a	130.6 b	0.0001
	Leaf, late May ^x	17.6 a	28.3 b	20.2 ab	24.9 ab	0.0798
	Leaf, early August ^w	17.0	21.9	20.4	21.2	0.1280
	Fruit cortex, at-harvest	8.9 a	19.7 c	17.9 b	18.3 bc	<0.0001
	Whole fruit, at-harvest	10.5 a	20.6 b	18.2 b	20.0 b	<0.0001

^zLevel of probability that within-row treatment means are significantly different.

^yLeaves sampled ≈6 weeks after the pink sprays and immediately before postbloom sprays.

^xWithin-row treatment means followed by different letters are significantly different by Duncan's multiple range test ($P = 0.05$).

^wLeaves sampled ≈2 months after the postbloom sprays.

^yFlower clusters sampled at full bloom, ≈1 week after the pink sprays.

mass basis (Haller and Batjer, 1946). Apple fruit quality also can be impaired by high levels of B. While 'Delicious' and 'Golden Delicious' apples appear to tolerate elevated fruit B concentration (Latimer and Percival, 1943; Peryea and Drake, 1991), sensitive varieties such as 'Jonathan', 'MacIntosh', and 'Elstar' begin to show increased internal breakdown, rots, and firmness loss at whole-fruit B concentrations ≥30 mg·kg⁻¹ (Bramlage and Thompson, 1962; Wilcox and Woodbridge, 1942; Wojcik et al., 1999). Regardless of timing, the B sprays in the current study appear to have effectively increased whole-fruit B concentration to desirable levels.

No leaf Na data are reported for 1997 because the Na concentration was below the instrumental limit of detection of 60 mg·kg⁻¹. Equipment improvements substantially lowered the limit of detection in 1998–99. Ap-

plying all or half of the B as Solubor at pink timing substantially increased flower cluster Na concentration, with the latter treatment being intermediate in effect (Table 2). The sample preparation procedure does not allow determination of how much of the spray-derived flower cluster Na had actually penetrated into the plant tissue. Solubor spray timing had no effect on early-season leaf Na or fruit Na concentrations. The 100% Postbloom spray increased August leaf Na concentration in 1999 but not in 1998. Leaf Na concentration in all years was substantially lower than the 2500 to 5000 mg·kg⁻¹ range associated with specific Na toxicity in tree crops (Ayers and Wescot, 1976).

Expt. 2. Tank-mixing with calcium chloride. Fruit mass was unaffected by adding B to the CaCl₂ and, averaged across treatments, was 189, 170, and 193 g in 1997–99, respec-

Table 2. Average Na concentrations in leaf and fruit tissue of 'Gala' apple trees sprayed annually with 0.51 g B as Solubor per tree (0.56 kg·ha⁻¹) at pink flowering stage, postbloom, or equally split between pink and postbloom timings, 1997–99.

Year	Tissue	B spray timing				
		Water control	100% Pink	100% Postbloom	50% Pink + 50% Postbloom	Prob.
		----- (Na concn, mg·kg ⁻¹ dry mass) -----				
1997	Fruit cortex, at-harvest	10.6 ^y	10.8	11.4	11.4	0.9594
	Whole fruit, at-harvest	9.0	11.2	13.8	11.8	0.1643
1998	Flower cluster full bloom ^x	11.6 a	193.1 c	13.2 a	114.8 b	0.0001
	Leaf, late May ^w	7.3	8.1	8.0	7.9	0.4421
	Leaf, early August ^y	22.4	25.2	30.6	26.3	0.1365
	Fruit cortex, at-harvest	71.9	68.0	54.2	60.6	0.7208
1999	Whole fruit, at-harvest	43.8	53.2	56.9	48.1	0.9250
	Flower cluster, full bloom ^x	22.3 a	259.5 c	23.6 a	121.6 b	0.0001
	Leaf, late May ^w	21.1	23.7	23.9	22.5	0.6959
	Leaf, early August ^y	17.0 a	19.3 a	34.3 b	23.8 a	0.0012
	Fruit cortex, at-harvest	32.8	39.4	42.0	51.4	0.4577
	Whole fruit, at-harvest	83.4	77.2	66.1	61.8	0.6087

^zLevel of probability that within-row treatment means are significantly different.

^xWithin-row treatment means followed by different letters are significantly different by Duncan's multiple range test ($P = 0.05$).

^yFlower clusters sampled at full bloom, ≈1 week after the pink sprays.

^wLeaves sampled ≈6 weeks after the pink sprays and immediately before postbloom sprays.

^yLeaves sampled ≈2 months after the postbloom sprays.

Table 3. Average Ca, B, and Na concentrations in leaf and fruit tissue of 'Gala' apple sprayed annually commencing in late May with four biweekly sprays of CaCl₂ with and without tank-mixed B (2.07 g CaCl₂ with/without 0.127 g B per tree), 1997–99.

Year	Tissue	Ca concn (mg·kg ⁻¹) ^z			B concn (mg·kg ⁻¹) ^z			Na concn (mg·kg ⁻¹) ^z		
		Spray treatment			Spray treatment			Spray treatment		
		Ca	Ca+B	Prob. ^y	Ca	Ca+B	Prob. ^y	Ca	Ca+B	Prob. ^y
1997	Leaf, early August ^w	1.17	1.19	0.641	17.0	22.3	0.005	NA ^v	NA	NA
	Fruit cortex, at-harvest	189	207	0.212	10.5	18.4	0.002	13	34	0.001
	Whole fruit, at-harvest	334	312	0.389	14.1	25.6	0.002	16	39	0.024
1998	Leaf, mid-May ^x	0.98	0.95	0.777	13.5	18.5	0.018	8	8	0.916
	Leaf, early August ^w	1.60	1.68	0.197	14.2	18.9	0.099	26	39	0.002
	Fruit cortex, at-harvest	398	387	0.700	11.2	24.9	<0.001	104	121	0.689
1999	Whole fruit, at-harvest	624	564	0.324	12.6	27.7	<0.001	71	105	0.020
	Leaf, mid-May ^x	0.64	0.66	0.230	19.2	21.8	0.384	28	25	0.558
	Leaf, early August ^w	1.31	1.62	0.030	17.8	21.3	0.069	33	61	0.001
	Fruit cortex, at-harvest	278	288	0.444	9.4	17.7	0.005	64	101	0.017
	Whole fruit, at-harvest	406	442	0.439	9.9	18.2	0.003	82	113	0.034

^zAll concentrations are on a dry mass basis.

^yLevel of probability that treatment means for each variable are significantly different.

^xLeaves sampled immediately before the first spray.

^wLeaves sampled ≈1 month after the last spray.

^vNot applicable.

tively. Adding B to the CaCl₂ sprays had no effect on leaf Ca concentration in the first 2 years and increased leaf Ca concentration in the third year (Table 3). There was no effect on fruit Ca concentration in any year. Even though the experimental fruit were large for 'Gala', likely lowering Ca concentration due to biomass dilution, fruit Ca concentrations were high enough to minimize risk of bitter pit development (Pavan et al., 1986). If formation of a Ca borate precipitate did occur in the tank-mixed spray, it was not of sufficient magnitude to reduce Ca phytoavailability. There also was no definitive evidence for B-enhanced phytoaccumulation of Ca.

Boron addition substantially increased leaf, whole fruit, and fruit cortical tissue B concentration, with the effect on the latter two variables being particularly strong. A residual effect of the previous season's B spray on May leaf B concentration was observed in 1998 but not in 1999. Leaf B concentration in the CaCl₂-only treatment would be considered inadequate; adding B increased it to the marginally sufficient level (Tukey and Dow, 1979). Whole-fruit B concentration was marginally adequate in the CaCl₂-only treatment; adding B increased it to optimal levels.

Leaf Na concentration in all years was substantially lower than levels associated with specific Na toxicity (Ayers and Wescot, 1976).

Conclusions

The results of the current study indicate that applying all or half of the annual B maintenance spray at the pink flowering stage substantially enhances flower cluster and early leaf B concentrations. Solubor applied at the pink flowering stage, postbloom, or split between pink and postbloom timings, or tank-mixed with CaCl₂ sprays applied for bitter pit control, failed to consistently increase leaf B concentration measured at the commercial sample timing of early August. The sprays did consistently increase fruit B concentration to desirable levels, indicating that the recommended annual B maintenance rate of 0.56 kg·ha⁻¹ was adequate

for supplying tree B needs even though its effect on leaf B concentration was variable. These results confirm that fruit B concentration is a more sensitive index for assessing tree B status than is leaf B concentration. Fruit cortical samples and whole fruit samples appear to be equally satisfactory for assessing the effect of B sprays on tree B status. The amount of Na supplied by Solubor applied at recommended B fertilization rates was too low to create risk of specific Na toxicity. Tank-mixing Solubor with CaCl₂ sprays did not compromise fruit Ca status; hence, the practice appears to be a safe and convenient means of applying B for nutritional maintenance purposes.

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