

Application of CaCl₂ Sprays Earlier in the Season May Reduce Bitter Pit Incidence in ‘Braeburn’ Apple

Gerry Neilsen, Denise Neilsen, Shufu Dong, and Peter Toivonen

Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C. V0H 1Z0, Canada

Frank Peryea

Tree Fruit Research and Extension Center, Washington State University, 1100 North Western Avenue, Wenatchee, WA 98801

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Abstract. Calcium application trials were undertaken in a ‘Braeburn’ apple (*Malus × domestica* Borkh.) orchard with a history of bitter pit development at harvest. In 2000, an early season calcium chloride application strategy was compared with the unsprayed control and a late season application strategy. From 2001–03, the assessment of timing of calcium chloride sprays was extended by comparing effects of five weekly sprays applied during the growing season either early, middle, or late season. Other Ca application strategies tested included sprays of acidified calcium carbonate suspensions and soil application of calcium thiosulphate. In the first experiment, early application of calcium chloride reduced the occurrence of bitter pit at harvest and after 3 months cold air storage, despite having low harvest fruit Ca concentrations. Late sprayed fruit had a higher incidence of bitter pit. In the second experiment, the later calcium chloride was sprayed in the growing season, the higher the fruit Ca concentration at harvest. Despite this, no bitter pit was measured at harvest for 2 years for early and midseason calcium chloride spray regimes. In 2003, when Ca disorders were severe and fruit large, bitter pit was observed despite early season calcium chloride sprays. Soil calcium thiosulphate application and foliar sprays of acidified calcium carbonate suspensions failed to meaningfully augment harvest fruit Ca concentrations and affect bitter pit incidence.

The importance of achieving adequate Ca supply for optimising the quality of apple fruit has stimulated research in the major fruit growing regions of the world to increase fruit Ca concentration and thereby improve fruit quality. The preferred method to increase fruit Ca concentration has been via preharvest foliar Ca sprays, as indicated from numerous research reviews summarizing field trials from many regions (Bramlage et al., 1980; Terblanche et al., 1980; Vang-Petersen, 1980). Recommendations based upon this early research usually involves application of three to six sprays of soluble Ca salts (usually chloride or nitrate salts) throughout the growing season. Limited consideration has been given to time of Ca application since many spray rate application experiments have been confounded by application at different times (Le Grange et al., 1998b). Several laboratory studies using Ca⁴⁵ have indicated that the rate of penetration of Ca into the fruit decreases as fruit ages during the growing season (Michalezuk and Kubik, 1984; Schoenherr, 2001). Limited use

of this information has been made in the field despite a possibility of improving the effectiveness of Ca sprays, especially since the initial symptoms of apple physiological disorders have been reported to occur early in the fruit development stages (Simons et al., 1980). In a field trial where rate and timing of Ca sprays were not confounded, Mason (1979) found that three late-season sprays were more effective at increasing harvest fruit Ca concentration and reducing ‘Spartan’ breakdown than three early season sprays.

Cultivars are known to vary in their susceptibility to Ca-related disorders such as bitter pit (Ferguson and Watkins, 1989). ‘Braeburn’ is a cultivar originating from New Zealand with a known susceptibility to developing bitter pit on initial crops (Le Grange et al., 1998a) and with reported low fruit Ca concentrations (Broom et al., 1998). There is however limited information concerning the mineral nutrition of ‘Braeburn’ in different regions and much existing information has related to vigorous trees growing on nondwarfing rootstocks such as MM106 (Broom et al., 1998; Volz et al., 1994). Little is known concerning fruit Ca concentration of ‘Braeburn’ growing in high density orchards on dwarfing rootstocks in the Pacific Northwest of North America. Similarly there is little information to support or refute the use of new and largely untested Ca compounds that have been promoted for this cultivar.

For these reasons, Ca application experiments were undertaken in a high density ‘Braeburn’ apple orchard in the Pacific Northwest. By designing spray regimes that did not overlap in time, the effects of an early and late season spray regime (Expt. 1) and very early, midseason and late spray regimes (Expt. 2) could be compared.

Materials and Methods

A block of ‘Braeburn’ apple trees (*Malus × domestica* Borkh) on the dwarfing rootstock, M9, planted in April 1998 at a 3-m (between row) × 1.25-m (within row) spacing was used to undertake Ca experiments. Trees were trained as slender spindles, each tree supported by a post and grown in 2-m-wide herbicide strips maintained by several annual applications of glyphosate. By the cessation of the experiment in 2003, tree height ranged from 1.5 to 2.0 m. Trees were irrigated from about 1 May to 1 Oct each year via two 4 L·h⁻¹ pressure-compensating drip emitters located 0.5-m either side of the tree within the row. Irrigation was applied to meet daily requirements based on water demand as estimated by the previous day’s evaporation from an atmometer (ET Gage Co., Loveland, Colo.) linked through a datalogger (CR10X; Campbell Scientific, Logan, Utah) to irrigation controls. Throughout the experimental period, trees were fertigated with potassium nitrate (13N–0P–37K) for a 6-week period commencing in early June at a constant irrigation solution N-concentration of 112 mg·L⁻¹. Annual fertilizer application rates ranged from 30 to 40 g N/tree and 84 to 100 g K/tree during the study. Otherwise the block was managed following standard commercial recommendations to achieve fruit production (British Columbia Ministry of Agriculture and Food, 1998). The experimental site was located on a Skaha loamy sand (Witneben, 1986), an Aridic Haploxeroll (Orthic Brown), extensively planted to orchards or vineyards in southern British Columbia.

In the first fruiting year (1999) a small yield of apples comprising 1.9 kg of fruit per tree, averaging 245 g in size, was measured in the ‘Braeburn’ block. Bitter pit surface symptoms were observed on 29% of all fruit at the time of harvest, confirming the susceptibility to bitter pit as reported for light cropped ‘Braeburn’ (Le Grange et al., 1998a). A randomized complete block experiment was established in the subsequent year (2000) to compare the effectiveness of early-mid and late season timing of CaCl₂ application to augment fruit Ca and prevent the possible development of bitter pit. Treatments included 1) an unsprayed control; 2) early CaCl₂ involving five weekly sprays applied mid-June to mid-July; and 3) late CaCl₂ (current standard industry recommendation) involving five weekly sprays applied end of August to end of September. Calcium chloride sprays were applied to runoff at about 1800 L·ha⁻¹ at a concentration of 0.5% w/v CaCl₂ [as ClorClear (34.5% Ca w/v); Sego International Inc., Portland, Ore.]. Each treatment consisted of a three-tree plot replicated six times.

In the subsequent 3 years (2001–03) an

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experimental design was established and maintained each on the same trees with the following treatments: 1) an unsprayed control; 2) early season 0.5% w/v ClorClear CaCl₂ involving five weekly sprays commencing the first week of June and ceasing the first week of July; 3) midseason 0.5% w/v ClorClear CaCl₂ involving five weekly sprays commencing the week after the last early season CaCl₂ spray and ceasing the first week of August; 4) late season 0.5% w/v ClorClear CaCl₂ involving five weekly sprays commencing the week after the last midseason CaCl₂ spray and ceasing the second week of September; 5) Micronoshade powdered calcium carbonate slurry (Columbia River Carbonates, Woodlawn, Wash.) applied as an 18.75 mL·L⁻¹ suspension acidified with 5 g·L⁻¹ citric acid and containing 25 g Ca/L. Five weekly sprays were applied at the same time as late season CaCl₂ in 2001–02 and at the same time as early season CaCl₂ in 2003; and 6) Micronoshade dry calcium carbonate applied as a 2.5% (w/v) calcium carbonate suspension, acidified with 5 g·L⁻¹ citric acid comprising five weekly sprays applied annually with the same amount of Ca and timing as treatment 5. A seventh treatment was initiated in 2002 and involved spray application to the soil surface in a 2 × 5-m plot area centred on the tree row of the three-tree plot of calcium thiosulphate (Thio Cal, 6% Ca w/w, density 1.039 kg·L⁻¹, Best Sulfur Products, Fresno, Ca) at a rate of 1,120 L·ha⁻¹ on 7 June 2002 and again on 26 May 2003. Each treatment consisted of three-tree plots replicated six times. All foliar treatments were applied to runoff. Application volumes across all treatments averaged 2,050 L·ha⁻¹ in 2001, 2,160 L·ha⁻¹ in 2002 and 2,180 L·ha⁻¹ in 2003, increasing in response to greater tree canopy volume over time.

Each year at commercial harvest (25, 30, 29, and 21 Oct., 2000–03) number and weight of harvested fruit were measured. Crops were generally light on these young trees, averaging 34, 44, 42, and 21 apples per tree, 2000–03 respectively. A frost at bloom greatly reduced the 2003 crop. A randomly selected 10-apple subsample from all plots was evaluated for flesh firmness, titratable acidity (TA), and soluble solids concentration (SSC). Flesh firmness was determined with a Baullaf penetrometer (11.1-mm-diameter tip, Lake City Technical Products Ltd., Kelowna, B.C.). Soluble solids concentration in the juice was measured with a refractometer and TA was determined by titration of juice with 0.1 M NaOH to an 8.1 pH end point. Juice was obtained from sectors taken from each apple in the 10-fruit subsample.

From 2000–02 an additional 20 fruit subsample was used to evaluate incidence of disorders (from slight to severe) at harvest. These fruit were randomly collected from the outside of the middle third of the canopy from all treatment trees. The inherent difficulties of making precise estimates of low incidence disorders, such as bitter pit, have recently been discussed by Le Grange et al. (1998b) for 'Braeburn' and are compounded by identification of substantial variation in mineral content of 'Braeburn' on the outside of the canopy (Volz et al., 1994). For these reasons the bitter pit

incidence values generated for this study, when observations are made on only 15% to 20% of the total fruit, should be considered estimates based upon relative comparisons of similar type samples among treatments. In 2003, with a light crop, all harvested fruit were used to estimate incidence of harvest disorders. In 2000 only, an additional 20-apple random sample was evaluated for incidence of disorders, 7 d after ripening at 20 °C, following air storage at 0 °C for 90 d. Incidence and severity of disorders were visually assessed for each apple. Disorders observed throughout the study included bitter pit and lenticel pit (originating in the lenticels) which were classified as slight (one to eight pits), moderate (less than one-third of the cortex) or severe (more than one-third of the cortex affected). Core browning occurred and was classified as slight (one or two areas up to 2 cm wide), moderate, or severe (area affected the same as for pitting disorders). Watercore was assessed in 2003 as slight (small areas around the seed cavity and vascular bundles), moderate (<25% of cortex) or severe (>25% of the cortex).

A random sample of 25 fruit was also selected each year at harvest from each treatment and replicate and rinsed under running, distilled water and then air-dried. Stem tissue and seeds were removed and opposite, unpeeled quarters were cut from each fruit. In 2000, these fruit were blended with 1.5 times their weight of distilled water. A 150 mL subsample was further homogenized with a high-speed tissue homogenizer. A weighed 9-mL subsample of homogenized slurry was digested in 5.4 mL of concentrated H₂SO₄ containing Na₂SO₄ (1.8 g), Cu (0.36 mL 25% CuSO₄ solution), and Se (0.67 g·L⁻¹) at 380 °C for 1 h. Calcium, Mg and K were determined in these extracts via atomic absorption spectrophotometry with concentrations expressed on a fresh weight (FW) basis. Nitrogen in the digest was determined through the formation of an ammonium-salicylate complex and P was determined through the formation of a phosphomolybdenum blue complex (Technicon Autoanalyzer II Industrial Method No. 334-74A/A; Technicon, Elmsford, N.Y.). Commencing with the 2001 harvest, the opposite sectors described above were freeze dried and ground. A 0.5-g sample was dry ashed at 475 °C and dissolved in 10 mL of 1.2 M HCl before determination of P, Ca, Mg and K by inductively coupled argon plasma spectrophotometry. Nitrogen was determined on another 0.5-g sample by N dry combustion (Leco, St. Joseph, Mich.).

Analysis of variance (ANOVA) was performed on all fruit data as a randomized

complete-block design with the number of treatments appropriate to the year. Data were analyzed separately by year since treatment number varied over years. All statistical analyses were undertaken using the general linear model (GLM) procedure (SAS Institute, 1989). Treatment means were separated using Duncan's multiple range test at the level of probability indicated.

Results and Discussions

Experiment 1 (2000). Fruit Ca concentration, incidence and severity of bitter pit at harvest and after 90 days cold air storage were affected by foliar spray regime in 2000, the third growing season for this experimental block (Table 1). Fruit size was unaffected by treatments. Despite a moderate fruit size, averaging 186 g, over all treatments, unsprayed (control) fruit had a low fruit Ca concentration of 3.8 mg Ca/100 g FW and an estimated 25% of fruit affected by bitter pit at harvest, with similar proportions of fruit exhibiting bitter pit after cold storage. Five sprays applied closer to harvest (weekly from 25 Aug. to 22 Sept.) significantly increased fruit Ca concentration relative to unsprayed control fruit. The early season Ca spray regime however had no measurable bitter pit at harvest or after storage (Table 1). At harvest but not after storage, incidence and severity of bitter pit was reduced by the early relative to the late season Ca spray regime.

Whole fruit Ca concentrations of 3.8 mg Ca/100 g FW at harvest were associated with high incidence of bitter pit disorder which had developed on the tree prior to harvest. Although the inexact relationships between harvest fruit Ca concentration and bitter pit incidence is well recognized (Perring and Pearson, 1986), it is noteworthy that Ca concentration of 'Braeburn' fruit severely affected by bitter pit was less than 4 mg/100 g FW which has been cited as a critical quality threshold for apple fruit (Nielsen and Nielsen, 2003). The successful elimination of bitter pit by sprays that commenced as early as 22 June and were completed by 20 July differs from recommendations that foliar Ca sprays are most effectively applied late in the season when the fruit target is larger (Vang-Petersen, 1980).

Our results imply that fruit Ca concentration is increased most by late sprays but this did not result in the lowest incidence of bitter pit. Timing of Ca application appeared to be more critical than amount of Ca absorbed in order to reduce the development of bitter pit on the tree. A question arises as to how effective

Table 1. Effects of early and late season Ca-sprays on 'Braeburn' fruit Ca concentration at harvest and incidence and severity of bitter pit disorder at harvest and 7 out of 90 d after cold air storage at 0 °C, 2000.

Treatment	Fruit Ca (mg/100 g fresh wt)	Bitter pit (harvest)		Bitter pit (storage)	
		Incidence ^a	Severity ^b	Incidence ^a	Severity ^b
1. Control (no Ca)	3.8 b	0.25 a	1.87 a	0.23 a	1.65 a
2. Early Ca	4.4 b	0.00 c	0.00 b	0.00 b	0.00 b
3. Late Ca	5.9 a	0.12 b	1.45 a	0.08 b	0.67 b
Significance	***	**	**	*	**

^aIncidence ranges from none (0.00) to all fruit (1.00) affected.

^bFruit classified as slight (1), moderate (2), or severely (3) affected by disorder.

***Significantly different at $p = 0.05$, 0.01 , or 0.001 , respectively.

Table 2. Average fruit Ca concentration at harvest and estimated incidence of bitter pit as affected by Ca treatment, 2001–03.

Treatment	Fruit Ca (mg/100g fresh wt)			Incidence ^a of bitter pit		
	2001	2002	2003	2001	2002	2003
1. Control (no Ca)	3.6 b	3.4 d	3.5	0.02b	0.12a	0.36 a
2. Early season foliar CaCl ₂	3.3 bc	3.7cd	3.4	0.00 b	0.00 c	0.06 d
3. Midseason foliar CaCl ₂	4.2 a	4.9b	3.3	0.00 b	0.00 c	0.09 cd
4. Late season foliar CaCl ₂	4.4 a	5.7a	3.8	0.03 b	0.02 bc	0.15 bcd
5. Soil Ca applications	NA ^x	3.5d	3.2	NA ^x	0.10 a	0.24 abc
6. Foliar CaCO ₃ suspension ^y	2.8 c	4.0cd	3.8	0.15 a	0.08 ab	0.26 ab
7. Foliar Micronoshade ^y	3.1 bc	4.3c	3.9	0.10 ab	0.02 bc	0.24 abc
Significance	****	****	NS	*	**	**

^aIncidence ranges from none (0.00) or all sampled fruit (1.00) affected.

^yApplied late season, 2001–02 and early season, 2003.

^xNA = treatment not applied 2001.

NS,*,**,**Nonsignificant or significantly different at $p = 0.05, 0.01, \text{ or } 0.0001$, respectively.

Table 3. Soluble solids, firmness and titratable acidity of 'Braeburn' apple at commercial harvest as affected by Ca treatment, 2001–03.

Treatment	Firmness (N)			Titratable acidity (mg malic acid/100 mL juice)		
	2001	2002	2003	2001	2002	2003
1. Control (no Ca)	98	96	103 c	880 bc	1048 a	1046
2. Early season foliar CaCl ₂	98	101	111 a	867 c	922 b	986
3. Midseason foliar CaCl ₂	95	97	110 a	831 c	886 b	1057
4. Late season foliar CaCl ₂	101	94	108 ab	969 ab	899 b	976
5. Soil Ca application	NA ^y	96	108 ab	NA ^y	974 a	1085
6. Foliar CaCO ₃	104	96	106 bc	996 a	957 ab	1031
7. Foliar Micronoshade ^z	102	96	105 bc	974 ab	961 ab	1051
Significance	NS	NS	**	**	*	NS

^zApplied as late season, 2001–02 and early season 2003.

^yNA = treatment not applied (NA) 2001.

NS,*,**Nonsignificant or significantly different at $p = 0.05 \text{ or } 0.01$, respectively.

sprays applied earlier in the season would be against bitter pit in 'Braeburn' fruit.

Experiment 2 (2001–03): Fruit Ca concentration. Fruit in Expt. 2 were much larger than in Expt. 1, but fruit size was not affected by treatment (data not shown). Fruit N, P, K, Mg and B at harvest were generally not affected by treatment (data not shown). Fruit Ca concentration was significantly affected by treatments in 2001–02 but not in 2003 when frost had reduced yield and fruit were largest, averaging above 300 g for some treatments. In 2001–02, timing of CaCl₂ sprays directly affected fruit Ca concentration (Table 2). Application of five CaCl₂ sprays early in the growing season (primarily June) failed to increase fruit Ca concentration above that of unsprayed fruit, whereas five CaCl₂ sprays applied late in the season (after mid-August) generally resulted in fruit with the highest Ca concentration. Spraying liquid calcium thiosulphate within the tree row on the soil surface in early spring did not increase fruit Ca concentration in the two years this treatment was applied. Similarly spray application of acidified suspensions of calcium carbonate and Micronoshade generally did not increase fruit Ca concentration (relative to control) regardless of whether sprays were applied late (2001–02) or early (2003) in the growing season. An exception was 2002 when fruit sprayed with Micronoshade had higher fruit Ca than unsprayed fruit.

Maximum Ca concentration in fruit at harvest occurred after multiple calcium chloride sprays were applied later in the season. These results are consistent with Expt. 1 and with previous research on 'Spartan', for which Ca concentration was much higher in fruit receiving three late (Sept.) than three early

(July) CaCl₂ sprays (Mason, 1979). Despite young fruit having skin more permeable to Ca (Schoenherr, 2001), the minimal increases in Ca concentration of fruit sprayed early (before middle or late season) is an indication of the importance of fruit size (surface area) to amount of Ca absorbed by a fruit. The ineffectiveness of soil Ca applications in improving fruit Ca status is consistent with research indicating gypsum and lime application to soils barely affected fruit Ca concentrations and were less effective for this purpose than foliar applications (Van der Boon, 1980). Increased Ca concentration of fruit has been reported after application of 81g Ca/tree when added with irrigation (fertigated) as calcium nitrate to a coarse-textured soil over a four week period (Nielsen et al., 1993). In our study, an annual liquid application of calcium thiosulphate which applied 35 g Ca/tree to the surface of the soil over 2 years was ineffective at increasing fruit Ca concentration. This may reflect the inefficiency of one-time surface applications of Ca over the whole tree row when trees are drip-fertigated, which induces a proliferation of roots in a small volume of soil near the drip emitters (Nielsen et al., 1997). The ineffectiveness of late season foliar application of acidified calcium carbonate solutions for increasing fruit Ca concentrations confirms production practices in many areas (e.g., British Columbia Ministry of Agriculture and Food, 1998) that recommend use of calcium chloride which has superior cuticular penetration ability and a low point of deliquescence (Schoenherr, 2001).

Experiment 2: Fruit disorders at harvest. At commercial harvest fruit disorders observed on 'Braeburn' apple in the experimental block included bitter pit (all 3 years), lenticel pit and

core browning (2 years each) and water core (1 year). Of these disorders, only bitter pit was differentially affected by experimental Ca treatments. In 2 years (2002–03) bitter pit incidence was lower for fruit receiving foliar CaCl₂ applications, regardless of timing when compared to unsprayed (control) fruit (Table 2). Other Ca applications via the soil or as sprays of acidified calcium carbonate suspensions were ineffective. Foliar application of Micronoshade resulted in lower bitter pit incidence relative to unsprayed fruit in 1 of 3 years (2002). Each year, the lowest incidence of bitter pit was observed after application of CaCl₂ early in the season. No bitter pit was observed after early and midseason CaCl₂ applications in 2001–02.

It is not surprising that bitter pit incidence was reduced by foliar application of calcium chloride, a generally recommended industry therapy (Vang-Petersen, 1980). It was, however, noteworthy that sprays applied earliest in the season (primarily June) were as effective as they were despite their limited ability to increase fruit Ca concentration at harvest. It has been difficult to define the optimum moment for Ca application to fruit from historical spray experiments which often compare treatments overlapping in time (Le Grange et al., 1998b). Our study with treatments applied at specific times suggest that bitter pit, which developed on the tree for these 'Braeburn' apples, has an early season origin which benefits from timely application of small amounts of Ca applied by early season foliar sprays. A field experiment by Michalezuk and Kubik (1989), involving Ca⁴⁵ application to individual 'Jonathan' apples found early season applications were preferentially allocated to flesh, core and

seeds, whereas late season applications were transferred mainly to the apple peel. The known deterioration of xylem functionality early in the growing season for 'Braeburn' (Drazeta et al., 2004), which inhibits subsequent Ca inflow to the fruit, may induce a Ca deficit within the 'Braeburn' fruit which can be reduced by Ca application early in the growing season. It is also of interest that lenticel pitting, a skin surface disorder, of highest incidence in 2003, occurred on 18% of early sprayed fruit and only 4% of late sprayed fruit (data not shown). The application of Ca to the soil early in each growing season however did not reduce bitter pit incidence of 'Braeburn' consistent with known limitations of soil applications to cure Ca deficiency for other cultivars (Ferguson and Watkins, 1989).

Experiment 2: Fruit quality. Fruit firmness at harvest was affected by experimental treatments only in the last year of the study (2003) (Table 3). In 2003, firmer fruit relative to unsprayed control fruit were measured for treatments involving five foliar CaCl₂ treatments, regardless of timing. Firmness was also relatively increased in the fruit which had received two years of soil thiosulphate application despite Ca concentration being unaffected by this treatment. This suggests that in general Ca additions are not an important factor affecting 'Braeburn' fruit firmness. Soluble solids were unaffected during the 3-year study (data not shown). Fruit titratable acidity was affected by treatments in the first 2 years of the experiment. In 2001, fruit acidity was reduced at harvest for fruit receiving early and midseason CaCl₂ or CaCO₃ based materials. In 2002, all CaCl₂ sprayed fruit had reduced acidity relative to unsprayed fruit (control, soil Ca treatment).

Foliar applications of CaCl₂, which most affected the occurrence of bitter pit, had few consistent effects on other quality characteristics of harvested 'Braeburn' fruit. This parallels findings previously reported for Ca-treated 'Golden Delicious' apples both at harvest and after cold storage (Nielsen et al., 1985). The tendency for minor reductions in harvest fruit acidity associated with increased Ca has previously been associated with foliar Ca application for apple (Benavides et al., 2001). Early season CaCl₂ sprays had no clear negative consequences to harvest fruit quality when compared to standard late season CaCl₂ applications.

Conclusions

The cumulative results of this research indicate young 'Braeburn' apple trees have an insufficient supply of Ca early in the season for lightly cropped trees and would benefit from spray application of CaCl₂ at this time. Five weekly sprays of CaCl₂ commencing the first week of June, were as effective as a similar regime of CaCl₂ sprays applied in late season, at reducing bitter pit incidence, despite minimal impact on whole fruit Ca concentration at harvest. Achieving fruit with maximum Ca concentration at harvest, as might be the goal for optimising fruit storage quality where no obvious Ca disorders are present, is best achieved by applying CaCl₂ close to harvest. Early season applications of Ca thiosulphate directly to the soil and early or late foliar applications of acidified calcium carbonate compounds are ineffective strategies.

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