

Blossom-end Rot Incidence of Tomato as Affected by Irrigation Quantity, Calcium Source, and Reduced Potassium

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Abstract. ‘Equinox’ tomatoes (*Lycopersicon esculentum* Mill.) were grown during the springs of 2001 and 2002 with black polyethylene-mulch and drip irrigation on an Arredondo fine sand in Gainesville, Fla., to study the influence of water quantity, Ca source, and reduced K on incidence of blossom-end rot (BER), marketable fruit yield, and fruit and leaf Ca concentration. Tensiometers were used to schedule irrigation in main plots when the soil matric potential reached 10 or 25 kPa. Subplot nutritional treatments were no added Ca, Ca(NO₃)₂, Ca thiosulfate, CaCl₂, CaSO₄, and K rate reduced by 50%. Interactions between year and treatment were significant. During 2001, total marketable yields were higher with Ca(NO₃)₂ or CaCl₂ compared to plants that received Ca thiosulfate and were higher from plants irrigated at 10 kPa than irrigated at 25 kPa. Number and weight of BER fruit were lower with Ca(NO₃)₂ and reduced K than with no added Ca and CaSO₄. Leaf and fruit Ca concentrations were generally higher with Ca(NO₃)₂ compared to all other nutritional treatments. Leaf and fruit Ca concentrations were generally higher from plants irrigated at 10 kPa than at 25 kPa. The reduction of NH₄⁺-N, by the supply of N as NO₃⁻, and the addition of supplemental Ca reduced the incidence of BER, and increased the leaf and fruit Ca concentrations. During 2002, marketable yields were higher with CaSO₄ than with CaCl₂ and reduced K. Weight and number of BER fruit were lower with irrigation at 10 kPa than at 25 kPa. Leaf and fruit Ca concentrations were higher or similar from plants that received Ca(NO₃)₂ than with all other nutritional treatments. During the 2002 season, rainfall was less and temperatures and daily evapotranspiration (ET) were higher than in the 2001 season. In the 2002 season, 3.28 × 10⁶ L·ha⁻¹ of irrigation was applied as compared to 1.58 × 10⁶ L·ha⁻¹ in 2001. With an average Ca concentration of 76 mg·L⁻¹ in the irrigation water, much more Ca was applied during the higher ET 2002 season. With the higher transpiration and temperature, water uptake and hence, Ca uptake were increased. During both seasons, the lowest Ca concentration was observed at the blossom end of the fruit and the highest Ca at the stem end of the fruit. Fruit Ca concentrations were lower and BER was 5 times higher in the lower ET, higher rainfall (lower irrigation) 2001 season compared to the higher ET, lower rainfall (higher irrigation) 2002 season. These data support that BER was a symptom of Ca deficiency and this deficiency was aggravated by high rainfall, low ET, and the resulting reduced irrigation applied and reduced Ca uptake.

Blossom-end rot (BER) of tomato is a problem that was first described as black-rot (Galloway, 1888). BER is a common physiological disorder that occurs on tomato, pepper (*Capsicum annuum* L), eggplant (*Solanum melongena* L.), and watermelon [*Citrullus lanatus* (Thunb.) Matsun & Nakai] that is common in all the tomato-producing areas of the world and has been shown to create losses up to 50% (Geraldson, 1955). BER is caused by many factors but the underlying cause of this disorder is an inadequate amount of Ca in the blossom-end of the fruit (Ho et al., 1995; Kitano et al., 1999; Saure, 2001). The first evidence of Ca involvement in BER was discovered by Raleigh and Chucka (1944), who showed that whenever the Ca content of the fruit was below 0.20%, BER generally occurred. Previous studies have shown

that BER is not caused by one single factor but by a combination of one or more factors intensifying the effect, including: high Mg, Na, NH₄⁺, and/or K concentration (Geraldson, 1955); accelerated growth rate (Marcelis and Ho, 1999; Saure 2001); low water availability (Franco et al., 1999); low soluble soil Ca (Kirby and Pilbeam, 1984); and high (Kreij, 1996) and low transpiration (Paiva et al., 1998a). Inadequate amounts of Ca for plant growth are rare in most soils; thus, a Ca deficiency is usually the result of poor distribution of Ca in relation to demand, antagonistic effects of other elements, and/or low plant transpiration (Keiser and Mullen, 1993).

The Ca concentration in the soil is usually ≈10 times that of K, but the uptake is usually lower for Ca (Kirby and Pilbeam, 1984). Ca²⁺ is a divalent ion and as ions increase in valence, uptake decreases (Marschner, 1997). Geraldson (1956) suggested excessive soluble K, Na, or NH₄⁺ (monovalent ions) caused decreased Ca uptake and increased incidence of BER in tomato. Locascio et al. (1991) showed that increasing K fertilization significantly reduced

Ca content of potato leaf and medulla tissue. When fertilizing with N, the use of NO₃⁻-N stimulates Ca uptake, as compared to NH₄⁺-N, which depresses Ca uptake (English et al., 1983).

Calcium movement through the plant and accumulation in fruit is correlated with transpirational movement of water (Keiser and Mullen, 1993). Rapidly growing transpiring leaves or stems that have a higher surface area than fruit transpire at a higher rate than fruit (Kirby and Pilbeam, 1984) and act as competing sinks with fruit for directional Ca flow and use (McLaughlin and Wimmer, 1999). Increasing plant tissue Ca concentration is more likely a result of altered flux of Ca in xylem sap (e.g., higher transpiration rate) rather than from increased Ca supply to the roots (Kleinhenz et al., 1999). Different environmental factors, such as temperature, humidity, and soil water content influence transpiration rates of the plant. Tadesse et al. (2001) showed that high relative humidity induced the incidence of BER and that low relative humidity reduced incidence of BER in sweet pepper. In this experiment, the incidence of BER and high relative humidity was significantly correlated with low Ca concentrations.

Even though Ca depends on water to get into and throughout the plant, not many studies have been performed to evaluate different irrigation quantities on the incidence of BER. In a study by Reid et al. (1996), incidence of BER was greater and tomato fruit Ca content was lower from plants that were not irrigated compared to irrigated plants. In an experiment by Franco et al. (1999), water stress (25 d after planting irrigation reduced by one-half until the end of the season) significantly increased the incidence of BER in drip-irrigated tomatoes.

Maximum relative growth rate of tomato fruit occurs at 12 to 15 d after anthesis (Saure, 2001). During this period of rapid cell expansion, Ca is essential to prevent BER. Deficiency of Ca is most disastrous during this period of rapid cell expansion in the fruit 1 to 3 weeks after anthesis (Willumsen et al., 1996). Many other researchers agree that the incidence of BER mostly occurs at about the second week after anthesis (Saure, 2001).

The objective of this study was to evaluate the influence of water quantity as controlled by tensiometers, Ca source, and reduced K on fruit yield, leaf and fruit Ca and K concentrations, and incidence of BER.

Materials and Methods

‘Equinox’ tomatoes were grown with black polyethylene-mulch and drip irrigation on an Arredondo (loamy, siliceous, hyperthermic Grossarenic Paleudults) fine sand at the Univ. of Florida Horticultural Unit in Gainesville during Spring 2001 to evaluate water quantity and Ca treatment on growth of tomato. The six nutritional treatments were: no added Ca, Ca(NO₃)₂ as sole drip N source (total Ca at 165 kg·ha⁻¹), Ca thiosulfate solution (CaS₂O₃·6.4% Ca) at 37.4 L·ha⁻¹ split into four applications applied through the drip system once a week from week 4 through 7 after transplanting (total

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Ca at 12 kg·ha⁻¹), CaCl₂ drip-applied once a week from week 1 through 10 after transplanting (total Ca at 82.5 kg·ha⁻¹), CaSO₄ applied preplant (total Ca at 592 kg·ha⁻¹), and K rate reduced by 50% from 168 to 84 kg·ha⁻¹ (with no added Ca). Water treatments were controlled with tensiometers used to automatically schedule irrigation by opening solenoid valves on demand when soil matric potential (kPa) reached threshold values of 10 (wetter) or 25 kPa (drier) (10 or 25 cb). Two tensiometers were installed per water treatment, one at a soil depth of 15 cm and the other at 30 cm, midway between the plants. The system was designed so that tensiometers monitored soil matric potential 3 times daily. Tensiometers were wired in parallel so that either one of the two could initiate an irrigation of 0.75 pan measured the previous week (Smajstrla and Locascio, 1996). Treatments were arranged in a randomized complete-block design with five replications in plots 1.8 m wide × 10.7 m long.

The soil was disked and 0.9-m-wide beds, 1.8 m apart, were formed. Beds were fumigated with 362 kg·ha⁻¹ methyl bromide, 131 kg·ha⁻¹ chloropicrin mix, and covered with 0.0038-cm-thick black polyethylene mulch on 29 Feb. 2001. Fertilizer was applied at 225–25–168–34–45 kg·ha⁻¹ N–P–K–S–micro-nutrient. A preplant application of 40% N and K and all other nutrients were broadcast and incorporated into beds. The remaining 60% of the N and K was applied through the drip system once a week for 10 weeks, starting 8 d after transplanting (DAT). Fertilizer sources

for preplant-applied nutrients were NH₄NO₃, triple-super phosphate, KCl, MgSO₄, and FTE-503 (Frit Industries, Ozark, Ala.). Double-wall drip tubing (Chapin Twinwall, Watertown, N.Y.), with emitters 30.5 cm apart with a delivery rate of 62 mL·m⁻¹·min⁻¹, was placed 7.5 to 10 cm from the bed center.

Tomatoes were transplanted 0.5 m apart on 13 Mar. 2001 and were overhead-irrigated when needed for a week until established. Soil samples were taken 51 DAT and analyzed for Ca and K with Mehlich-I procedures (Page et al., 1982). Recently matured whole leaves (eight per plot) and green fruit ≈2 cm in size (three per plot) were harvested 57 DAT and ripe fruit (four per plot) were harvested 90 DAT. All fruit were equally divided into stem-end, middle, and blossom end.

Leaf and fruit tissue were dried in a forced-air drier at 70 °C. The K and Ca concentrations were determined by dry ash procedure using 500-mg samples ashed at 500 °C for 10 h, diluted in 50 mL of 1 M HCl, and analyzed by inductively coupled plasma spectrophotometer (ICPS) (Kalra, 1998). Fruit were harvested 84, 92, and 99 DAT at the mature green to red stage. BER fruit were separated and remaining fruit graded into extra large (>73 mm in diameter), large (64–73 mm), and medium (58–63 mm) sizes of marketable fruit and weighed (USDA, 1976).

The above 2001 study was duplicated in 2002 where all treatment combinations and cultural practices were similar to Spring 2001 except for some factors described below.

Planting date was 19 Mar. 2002 and fruit were harvested 77 and 90 DAT at the mature green to red stage. Data were statistically analyzed by analysis of variance using SAS version 8.02 and Duncan's procedure (SAS Institute, 2002).

Results and Discussion

The 2001 and 2002 seasons were 99 and 90 d in length from transplant to the final harvest, respectively (Table 1). Average minimum and maximum temperatures were higher in 2002 than 2001. Daily evapotranspiration (ET) values of 0.46 cm in 2002 were significantly higher than 0.43 cm in 2001, with rainfall at 0.35 cm per day in 2001 and significantly lower at 0.10 cm per day in 2002. With the lower rainfall and higher transpiration rate in 2002, there was much more dependence on the drip irrigation system to supply water during 2002 compared to 2001 (Table 2) when drip irrigation averaged 15.8 cm in 2001 and 32.8 cm in 2002. Interactions between year, water treatment, and nutritional treatment were significant; thus, most data are presented by year.

During 2001, total marketable yields were significantly higher from plants that received Ca(NO₃)₂ or CaCl₂, compared with plants that received Ca thiosulfate (Table 3). With an increase in irrigation from 25 to 10 kPa, total marketable fruit yield increased from 35.0 to 63.1 t·ha⁻¹. This was expected because 10 kPa is recommended for this soil type for tomatoes in Florida and 25 kPa is considered stressful. In a 4-year study by Smajstrla and Locascio (1996), in one of the 4 years and in the 4-year average there was a linear increase in marketable yield with irrigation at 20, 15, and 10 kPa. During 2002, irrigation quantities were 34.4 cm with 10 kPa and 31.21 cm with 25 kPa and total marketable yield was unaffected by water treatment. In past work, maximum yields were produced with water quantities between 0.5

Table 1. Season length, average daily evapotranspiration (ET), average daily rainfall, and average minimum and maximum temperatures, Spring 2001 and 2002.

Year	Season length (d)	Avg daily ET (cm)	Avg daily rainfall (cm)	Avg min temp (°C)	Avg max temp (°C)
2001	99	0.43	0.35	13.1	27.7
2002	90	0.46	0.10	15.3	29.3
Significance		*	**	**	**

ns, *, **Nonsignificant or significant at $P = 0.10$ and 0.01 , respectively.

Table 2. Quantity of water applied through irrigation system, rainfall, and evapotranspiration (ET) 1 through 13 weeks after transplanting, Spring 2001 and 2002.

Week	Water quantity (cm)							
	2001				2002			
	Irrigation quantity		Rainfall	ET	Irrigation quantity		Rainfall	ET
	Water treatment				Water treatment			
10 kPa	25 kPa	10 kPa	25 kPa	10 kPa	25 kPa	10 kPa	25 kPa	
1	---	---	10.00	1.97	---	---	0.05	2.59
2	0.1	0.1	2.05	2.21	0.3	0.2	0.18	2.86
3	0.1	0.1	2.29	2.40	0.2	0.2	0.05	2.61
4	0.2	0.2	0.00	2.63	0.2	0.2	0.81	2.56
5	0.4	0.4	0.71	3.06	1.0	0.7	0.03	3.42
6	1.6	0.4	0.25	3.03	3.5	1.2	0.00	3.42
7	1.5	0.6	1.52	2.87	4.2	2.9	0.00	3.84
8	2.1	1.3	1.14	3.10	6.6	4.9	0.00	3.73
1–8 Total	6.0	3.2	17.96	21.27	15.9	10.3	1.12	25.03
Year mean	4.6				13.1			
9	2.3	1.8	0.03	3.22	1.3	3.5	2.21	3.16
10	3.2	3.8	0.00	3.65	5.5	5.3	0.00	3.50
11	2.9	2.0	4.14	3.74	6.0	5.4	1.96	3.75
12	3.0	0.8	0.89	3.51	2.4	1.7	2.40	2.87
13	2.1	0.6	7.74	3.16	3.4	5.0	0.28	3.68
9–13 Total	13.5	8.9	12.80	17.28	18.5	21.0	6.85	16.96
Total	19.5	12.1	30.78	38.55	34.4	31.2	7.98	41.99
Year mean	15.8				32.8			

Table 3. Main effects of nutritional treatment and water treatment on total marketable yield and total weight and number of blossom-end-rot (BER) fruit, Spring 2001 and 2002.

	Marketable yield (t·ha ⁻¹)	
	Year	
	2001	2002
Nutritional treatment		
No added Ca	44.5 ab ^z	78.9 ab
Ca(NO ₃) ₂	50.4 a	79.0 ab
Ca Thiosulfate	36.9 b	78.6 ab
CaCl ₂	50.3 a	75.2 b
CaSO ₄	40.9 ab	84.2 a
½ KCl	44.5 ab	71.1 b
Water treatment		
10 kPa	57.4 a	76.8 a
25 kPa	31.8 b	78.9 a
	BER wt (t·ha ⁻¹)	
	Year	
	2001	2002
Nutritional treatment		
No added Ca	9.7 a	1.5 a
Ca(NO ₃) ₂	6.5 b	1.0 a
Ca Thiosulfate	9.8 a	1.1 a
CaCl ₂	8.1 ab	1.7 a
CaSO ₄	9.7 a	1.1 a
½ KCl	6.7 b	1.3 a
Water treatment		
10 kPa	5.6 b	1.0 b
25 kPa	11.2 a	1.6 a
	BER no. (1000s/ha)	
	Year	
	2001	2002
Nutritional treatment		
No added Ca	86.6 a ^z	10.1 a
Ca(NO ₃) ₂	50.5 c	7.8 a
Ca Thiosulfate	78.0 ab	8.3 a
CaCl ₂	64.6 abc	12.3 a
CaSO ₄	89.5 a	7.9 a
½ KCl	58.1 bc	9.0 a
Water treatment		
10 kPa	43.6 b	6.6 b
25 kPa	98.9 a	11.8 a

^zMean separation (in column) by Duncan's multiple range test.

and 1.0 pan (Locascio and Smajstrla, 1996). In 2002, fruit yields were higher from plants that received CaSO₄ than from plants that received CaCl₂ or reduced K. This suggests the K rate was below the plants' requirements for optimal fruit production, and the reduction in K application in the higher irrigation 2002 season than in 2001 caused a reduction in marketable yield (Locascio et al., 1997). During the latter half of the drier 2002 season, the plants demand for water was high compared to earlier in the season. Marketable yield was considerably higher in 2002 compared to 2001. These differences were attributed to higher minimum and maximum temperatures and less BER fruit during the 2002 season.

During 2001, numbers of BER fruit were lower from plants that received Ca(NO₃)₂ than from plants that received all other nutritional treatments except CaCl₂ and reduced K, and was lower from plants that received reduced K compared to plants that received no added Ca or CaSO₄ (Table 3). Weights of BER fruit were lower with Ca(NO₃)₂ or reduced K compared to plants that received no added Ca, Ca thiosulfate, or CaSO₄. These results suggest that reducing NH₄⁺-N, supplying N as NO₃⁻, and adding supplemental Ca reduced the incidence of BER. In a study by DeKock et al. (1982) BER percentages were significantly higher with NH₄⁺-N than with NO₃⁻-N. There is a competition between cations for root

absorption sites, and monovalent cations (K⁺ and NH₄⁺) are absorbed more readily than divalent cations (Ca²⁺) (Marschner, 1997). Reducing the amount of K⁺ and NH₄⁺ in soil reduced the incidence of BER in 2001. Geraldson (1956) showed excessive K⁺ or NH₄⁺ caused an increase in the prevalence and severity of BER.

During 2001, the number of BER fruit decreased from 98,900 to 43,600/ha and weight of BER fruit decreased from 11.2 to 5.6 t·ha⁻¹, for plants irrigated at 25 and 10 kPa, respectively (Table 3). During Spring 2002 there was no effect of nutritional treatment on number or weight of BER fruit. With an increase in irrigation from 25 to 10 kPa, the number and weight of BER fruit increased significantly from 6,600 to 11,800/ha and 1.0 to 1.6 t·ha⁻¹, respectively. During both years, the number and weight of BER fruit were lower from plants irrigated at 10 kPa compared to plants irrigated at 25 kPa. These results are consistent with a report by Franco et al. (1999), where the occurrence of BER was lower with a higher quantity of irrigation. Since plant Ca moves with the transpiration stream through the xylem to growing fruit, soil water content is very important for Ca uptake (Hanger, 1979; Kitano et al., 1999).

During 2002, the amount of water applied with the 10 and 25 kPa treatments were 34.4 and 31.2 cm, respectively. The differences in

the treatment totals were much less compared to the 2001 season. These data suggest that the effect of water treatment during the 2002 season on BER would be minimal. The maximum relative growth rate of tomato fruit occurs at 12 to 15 d after anthesis (Saure, 2001), the period where Ca is essential to prevent BER. Eight weeks after transplanting was the time that 2-cm fruit were sampled. Comparing water application quantities at 8 weeks after transplanting, the 10 and 25 kPa treatments received 15.9 and 10.3 cm of water, respectively. These differences accounted for the increased incidence of BER from plants irrigated at 25 kPa compared to plants irrigated at 10 kPa, during the 2002 season.

There were considerably more BER-affected fruit during the 2001 season compared to the 2002 season. During the second season there were higher minimum and maximum temperatures, which increase plant transpiration and therefore increase water and Ca uptake from the soil. Average daily rainfall decreased from 0.35 to 0.10 cm and total rainfall decreased from 34.9 to 6.1 cm during the 2001 and 2002 seasons, respectively. With minimal rainfall during the 2002 season, more irrigation water was applied. During the 2001 season, 19.5 cm of water was applied with the 10 kPa treatment and 12.1 cm of water was applied with the 25 kPa treatment. The average Ca concentration in irrigation water was 75.6 ppm, so the 10 kPa and 25 kPa treatment received an additional 147 and 90 kg·ha⁻¹ of Ca, respectively. During the 2002 season, 34.4 cm of water was applied with the 10 kPa treatment and 31.2 cm of water was applied with the 25 kPa treatment. The average Ca concentration in the irrigation water was 76.4 ppm, so with the 10 and 25 kPa treatment received, an additional 262 and 238 kg·ha⁻¹ of Ca was applied, respectively. This increase in irrigation water from the 2001 to the 2002 season additionally provided an average of 115 and 148 kg·ha⁻¹ of Ca with the 10 and 25 kPa treatments in the 2002 season, respectively. Although Ca nutritional treatments had no effect on the incidence of BER in 2002, probably the higher amount of added Ca provided by irrigation at 10 kPa than 25 kPa reduced the incidence of BER with irrigation at 10 kPa.

During 2001, 57 DAT leaf Ca concentrations were higher with Ca(NO₃)₂ compared to plants that received other nutritional treatment (Table 4). In Spring 2002, 57 DAT leaf Ca concentrations were higher with Ca(NO₃)₂ compared to plants that received no added Ca and Ca thiosulfate. Leaf Ca concentrations were unaffected by water treatment during 2001 and 2002 but were nearly twice as high in 2002 when transpiration rate was higher than in 2001. During both years, leaf K concentrations were lower from plants that received reduced K than with all other nutritional treatments, and K concentrations were unaffected by water treatment.

The Ca concentrations of 2-cm fruit sampled 57 DAT during 2001 from plants that received Ca(NO₃)₂ were higher than with no added Ca, Ca thiosulfate, and CaSO₄ (Table 5). The Ca con-

Table 4. Main effects of nutritional treatment and water treatment on leaf dry weight Ca and K concentrations sampled 57 d after transplanting (DAT), Spring 2001 and 2002.

	Leaf concn (g·kg ⁻¹)			
	Year			
	2001		2002	
	Ca	K	Ca	K
Nutritional treatment				
No added Ca	12.8 b ^z	24.6 a	20.4 bc	27.8 ab
Ca(NO ₃) ₂	16.5 a	25.7 a	24.1 a	25.3 b
Ca thiosulfate	12.7 b	25.2 a	19.7 c	27.8 ab
CaCl ₂	14.2 b	25.0 a	23.4 ab	30.0 a
CaSO ₄	14.2 b	23.8 a	23.4 ab	28.5 ab
½ KCl	14.1 b	18.8 b	23.7 a	21.3 c
Water treatment				
10 kPa	13.7 a	24.4 a	22.3 a	26.9 a
25 kPa	14.5 a	23.3 a	22.5 a	26.6 a

^zMean separation (in column) by Duncan's multiple range test.

Table 5. Main effects of nutritional treatment and water treatment on 2 cm fruit dry weight Ca and K concentrations sampled 57 d after transplanting (DAT), Spring 2001 and 2002.

	2-cm Fruit concn (g·kg ⁻¹)	
	Year	
	2001	2002
	Ca	K
Nutritional treatment		
No added Ca	0.99 bc ^z	36.0 a ^z
Ca(NO ₃) ₂	1.12 a	35.5 a
Ca thiosulfate	0.83 d	36.3 a
CaCl ₂	1.05 ab	36.9 a
CaSO ₄	0.90 cd	35.9 a
½ KCl	1.06 ab	31.6 b
Fruit section		
Stem end	1.58 a	31.6 c
Middle	0.74 b	35.1 b
Blossom end	0.65 c	39.5 a
Water treatment		
10 kPa	1.08 a	35.4 a
25 kPa	0.90 b	35.3 a

^zMean separation (in column) by Duncan's multiple range test.

centrations of fruit decreased significantly from the stem-end section to the blossom-end section. The Ca concentrations of 2-cm fruit from plants irrigated at 10 kPa were higher than from plants irrigated at 25 kPa. The K concentrations of 2-

2001 and Ca concentrations in 2002 of 2-cm fruit sampled 57 DAT were affected by an interaction between nutritional treatment and water treatment (Table 6). During 2001 with irrigation at 10 kPa, the K concentrations of 2-cm fruit from plants that received reduced K were lower than with other nutritional treatments. With irrigation at 25 kPa, the K concentrations of fruit with reduced K were lower than with Ca(NO₃)₂, CaCl₂, and CaSO₄. With both water treatments, the K concentrations increased significantly from the stem-end section to the blossom-end section. With irrigation at 10 kPa, the Ca concentrations of 2-cm fruit from plants that received CaCl₂ were higher than with Ca thiosulfate and CaSO₄. With irrigation at 25 kPa, the Ca concentrations of 2-cm fruit from plants that received Ca(NO₃)₂ were higher than with no added Ca, Ca thiosulfate, and CaCl₂. During both years the Ca concentration was nearly 3 times higher in the stem-end than blossom-end and were almost 2 times higher in 2002 than 2001.

During 2001 the Ca concentrations of ripe fruit sampled 90 DAT were affected by interactions between water treatment and nutritional treatment (Table 7). With irrigation at 10 kPa, the Ca concentrations of fruit from plants that received Ca(NO₃)₂ were higher than with other nutritional treatments. When irrigated at 25

cm fruit sampled 57 DAT during 2001 from plants that received reduced K were lower than with other nutritional treatments. The K concentrations were unaffected by water treatment and increased significantly from the stem-end section to the blossom-end section.

The K concentrations in

kPa, the Ca concentrations of ripe fruit from plants receiving any form of additional Ca were higher than with no added Ca. Fruit Ca concentrations decreased 2- to 3-fold from the stem-end section to the blossom-end section with both water treatments.

During 2002, the Ca concentrations of ripe fruit 90 DAT were not affected by nutritional treatment or water treatment (data not presented). The Ca concentrations were higher (1.91 g·kg⁻¹) in the stem-end section of the fruit compared to the middle (1.07 g·kg⁻¹) or blossom-end (1.91 g·kg⁻¹) fruit sections, and were higher than ripe fruit in 2001. The K concentrations of ripe fruit were higher during 2002 compared to 2001 (Table 8). The K concentrations were lower from plants that received reduced K than with other nutritional treatments. The K concentrations were unaffected by water treatment and, in contrast to Ca concentrations, increased for the stem-end section to the blossom-end section.

Plants that received Ca(NO₃)₂ had either the highest or were equivalent to the highest leaf, 2-cm fruit, and ripe fruit Ca concentrations than with all other nutritional treatments during both seasons. These results suggest that reducing NH₄⁺-N by the supply of N as NO₃⁻ and adding supplemental Ca increases leaf and fruit Ca concentrations. Klougart (1980) found that the NO₃ source of Ca was better than Cl or SO₄ sources in nutrient solution for ensuring high concentrations of Ca uptake in tulips. Kleinhenz et al. (1999) showed that soluble Ca sources [e.g., Ca(NO₃)₂] increased Ca concentrations in nonperidermal potato tissue compared to CaSO₄, suggesting it was due to the lower solubility of CaSO₄. The Ca concentrations of leaves, 2-cm, and ripe fruit from plants that received reduced K sampled during the 2002 season were similar to the treatments that promoted the highest Ca concentrations. This suggests that reducing K inputs increases the uptake of Ca.

The Ca concentrations of 2-cm and ripe fruit stem-end sections were higher than the blossom-end sections during both seasons. The Ca concentrations of mid-fruit section were generally intermediate or statistically the same

Table 6. Interaction of nutritional treatment and water treatment on 2-cm fruit dry weight Ca and K concentrations sampled 57 d after transplanting (DAT), Spring 2001 and 2002.

	2-cm fruit concn (g·kg ⁻¹)			
	Year			
	2001		2002	
	K		Ca	
	Water treatment		Water treatment	
	10 kPa	25 kPa	10 kPa	25 kPa
Nutritional treatment				
No added Ca	40.2 a ^z	38.1 ab	1.73 abc ^z	1.43 bc
Ca(NO ₃) ₂	38.3 ab	39.3 a	1.80 ab	1.89 a
Ca thiosulfate	38.2 ab	38.4 ab	1.55 bc	1.39 c
CaCl ₂	40.0 a	39.4 a	1.83 a	1.41 c
CaSO ₄	37.9 b	39.5 a	1.52 c	1.71 ab
½ KCl	33.0 c	36.8 b	1.74 abc	1.69 ab
Fruit section				
Stem end	35.4 c	36.4 c	3.03 a	2.78 a
Middle	37.6 b	38.3 b	1.08 b	1.03 b
Blossom end	40.7 a	41.1 a	0.97 b	0.95 b

^zMean separation (in column) by Duncan's multiple range test.

Table 7. Interaction of nutritional treatment and water treatment on dry weight ripe fruit Ca concentrations divided into stem-end, middle, and blossom-end, sampled 90 d after transplanting (DAT), Spring 2001.

	Ripe fruit Ca concn (g·kg ⁻¹)	
	Water treatment	
	10 kPa	25 kPa
Nutritional treatment		
No added Ca	1.18 b ^z	0.84 c
Ca(NO ₃) ₂	1.40 a	1.05 a
Ca thiosulfate	1.20 b	1.08 a
CaCl ₂	1.16 b	0.98 ab
CaSO ₄	1.08 b	1.10 a
½ KCl	1.15 b	0.86 bc
Fruit section		
Stem end	1.74 a	1.52 a
Middle	0.99 b	0.77 b
Blossom end	0.86 c	0.67 c

^zMean separation (in column) by Duncan's multiple range test.

Table 8. Main effects of year, nutritional treatment, irrigation treatment, and fruit section on dry weight ripe fruit K concentration sampled 90 d after transplanting (DAT), Spring 2001 and 2002.

	Ripe fruit K concn (g·kg ⁻¹)
Year	
2001	29.2 b ^a
2002	31.5 a
Nutritional treatment	
No added Ca	29.9 a
Ca(NO ₃) ₂	31.0 a
Ca thiosulfate	30.8 a
CaCl ₂	32.1 a
CaSO ₄	30.8 a
½ KCl	27.6 b
Water treatment	
10 kPa	29.9 a
25 kPa	30.8 a
Fruit section	
Stem end	28.1 c
Middle	30.2 b
Blossom end	32.7 a

^aMean separation (in column) by Duncan's multiple range test.

as the blossom-end section of the fruit. Frost and Kretschman (1989) divided cucumbers into four equal transverse sections and found a Ca gradient existed within the fruit. The proximal peduncle portion contained the highest concentration of Ca, while the distal section contained the lowest. In a study by Tadesse et al. (2001), sweet pepper fruit blossom-end sections had lower Ca concentrations than the stem-end sections of the fruit.

Temperature, daily ET, and fruit Ca concentrations were higher and rainfall was lower in 2002 compared to 2001. Both high temperature and low rainfall causes lower humidity. In a study by Tadesse et al. (2001), lower relative humidity promoted the uptake and accumulation of Ca into the blossom-end portion of sweet pepper compared to uptake with a higher relative humidity. With higher ET, more water moves through the plant and since Ca moves with the transpiration stream, more Ca moves into the plant and fruit. Quintana et al. (1999) suggested differences in bean Ca concentration from year to year were due to variations in rainfall, temperature, and other environmental factors. In the study, beans that had higher Ca concentrations were grown during the season that was higher in temperature.

Ripe fruit K concentrations were higher during 2002 than in 2001 (Table 8). Leaf, ripe fruit, and 2-cm fruit K concentrations from plants that received reduced K had the lowest fruit K concentrations compared to fruit with other nutritional treatments, except 2-cm fruit during 2001 with irrigation at 25 kPa, where they were similar. Locascio et al. (1997) also found linear increases in K fertilization generally led to linear increases in tomato leaf K concentration.

Nutrient concentrations of soils samples, taken 51 DAT during 2001 and 2002, are presented in Table 9. Soil K concentrations were lower from plots that received reduced K compared with other nutritional treatments. Soil Ca concentrations were higher from plots that received CaSO₄ compared with other nutri-

Table 9. Main effects of nutritional treatment and water treatment on soil K and Ca concentrations sampled 51 d after transplanting (DAT), spring 2001 and 2002.

	Soil (mg·kg ⁻¹)	
	K	Ca
Year		
2001	103.5 a	357.1 b
2002	89.2 b	393.2 a
Nutritional treatment		
No added Ca	109.5 a	332.6 cd
Ca(NO ₃) ₂	100.5 a	412.2 b
Ca thiosulfate	114.1 a	296.2 d
CaCl ₂	99.3 a	362.3 bc
CaSO ₄	99.6 a	503.7 a
½ KCl	55.1 b	343.8 cd
Water treatment		
10 kPa	84.9 b	370.9 a
25 kPa	107.8 a	379.4 a

^aMean separation (in column) by Duncan's multiple range test.

tional treatments, and Ca concentrations with Ca thiosulfate were lower than with Ca(NO₃)₂ or CaCl₂. Water treatment had no effect on soil Ca concentrations. Plots irrigated at 10 kPa had a lower K concentration than with irrigation at 25 kPa. Soil Ca concentrations were higher and the K concentrations were lower in 2002 compared to 2001. These differences most likely increased Ca uptake by the plant.

The incidence of BER was not completely alleviated by treatments used in this study; these effects may be due to the limited capacity of the plant to regulate the internal distribution of Ca, in particular the continued flow towards organs with low ET and rapid growth such as fruit (Franco et al., 1994). In this study leaf and fruit Ca concentrations were generally higher in the 2002 season compared to the 2001 season, due to application of more Ca containing irrigation water, higher daily ET, and lower soil K concentrations. Paiva et al. (1998b) in a greenhouse study showed an increase in fruit transpiration was more effective in increasing fruit Ca concentrations than increasing Ca concentration in the substrate.

The lowest Ca concentration was observed at the blossom-end of fruit from plants irrigated at 25 kPa during the 2001 season, which had over 5 times the amount of BER compared to the 2002 season. These data indicate that BER was a symptom of Ca deficiency and this deficiency was aggravated by low ET and the low amount of irrigation water supplied in 2001. During 2002, incidence of BER was unaffected by nutritional treatment. Plants irrigated at 10 kPa had less incidence of BER compared to plants irrigated at 25 kPa. The 2002 season had higher temperatures, higher ET, much less rainfall, and hence, higher Ca uptake by the plants, compared to 2001. Due to the reduced rainfall in 2002, much more Ca containing irrigation water was applied during the 2002 season. This suggests that when irrigation water is high in Ca and there is minimal rainfall and high ET, additional Ca fertilization may not be necessary to reduce the incidence of BER.

With increasing restrictions on water and fertilizer use, prevention of BER may become

even more difficult. Interactions of mineral elements in the soil and in the plant together with synergistic and antagonistic effects are constantly new problems that call for the researcher's attention (Gunes et al., 1998). Most research on relationships between water and nutrients on tomato BER has been conducted in greenhouses. Field research has been limited. With tomato production in a sandy soil, it was essential to maintain soil matric potential at 10 kPa compared with 25 kPa to decrease incidence of BER, particularly in seasons with high rainfall and low ET.

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