External and Internal Blotchy Ripening and Fruit Elemental Content of Trickle-irrigated Tomatoes as Affected by N and K Application Time

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Abstract. Tomatoes (*Lycopersicon esculentum* Mill.) were grown on polyethylene-mulched beds of an Arrendondo fine sand during two seasons to evaluate the effects of trickle irrigation-applied N and/or K, percentages of trickle-applied nutrient(s) (50%, 75%, and 100%), and schedules of nutrient application (variable, 2% to 12.5% of total amount weekly, or constant, 8.3% of the total amount weekly) on the occurrence of fruit external and internal blotchy ripening and fruit mineral nutrient concentration. Trickle-applied fertilizer was injected into the irrigation water weekly during the first 12 weeks of each season. External and internal blotchy ripening were less severe with trickle-applied N supplied as N + K or N than with preplant-applied N. Trickle-applied N + K or N resulted in higher fruit concentrations of N, P, K, Ca, and Mg than with all preplant-applied N. Internal fruit quality improved slightly as the trickle-applied percentage of N and/or K increased from 50% to 100%, but significant differences in exterior quality were not obtained. Internal fruit quality was higher early in the season than late in the season during both years, but this response was not associated with fruit elemental concentration. The weekly schedule of nutrient injection had no significant effect on fruit quality or fruit elemental concentration. Highest yields of high-quality fruit were obtained with 50% trickle-applied N + K.

Irregular or defective ripening of tomato fruit, known as blotchy ripening, has been recognized as a serious problem for some time (Beweley and White, 1926). Both external and internal pericarp may be blemished. External blotchy ripening is important to the tomato industry because of the difficulty in marketing blemished fruit (Agricultural Marketing Service, 1973). The presence of blotchy areas, especially on the fruit shoulder, reduces the value of whole-packed, canned tomatoes primarily because of the difficulty in removing the peel from affected portions of the fruit; discoloration is of secondary importance (Winsor and Massey, 1958). This disorder has been reported in many parts of the world including the United States (Geraldson, 1960; Minges and Sadik, 1964; Picha and Hall, 1981), Canada (Collin and Cline, 1966; Matsumoto and Hornsby, 1974), and the United Kingdom (Winsor and Massey, 1958). Most plantings in New York State were affected by blotchy ripening (Cornell Cooperative Extension, 1986).

The three types of abnormal coloration of portions of red-ripe pericarp referred to in the literature as external blotchy ripening are: 1) virtually colorless through yellow-orange-green discolored areas that vary in size and shape, have well-defined margins, and are found especially near the shoulder; 2) a less-distinct discoloration in which vascular bundles are observed within the outer pericarp wall; and 3) a (near) ringing of the stem scar by a yellow band (Minges and Sadik, 1964). Internally, the disorder is characterized by a white discoloration of the normally red-ripe pericarp and septa. The texture of blotchy-ripened areas may be uncharacteristically hard for the degree of fruit ripeness.

The role of mineral nutrition (especially K), temperature, sunlight, and genetics on the incidence of external (Beweley and White, 1926; Geraldson, 1960; Matsumoto and Hornsby, 1974;

White, 1938) and internal (Agricultural Marketing Service, 1973) blotchy ripening has been reported. Increasing the K rate from 0 to 745 kg·ha⁻¹ resulted in an increase in pericarp and leaf K concentrations in spring and fall crops, but neither form of the disorder was eliminated even at the highest K rate (Picha and Hall, 1981). The dissimilar susceptibility of four cultivars to blotchy ripening was not associated with differences in the K concentration of either tissue. The N and K concentration of tissue exhibiting yellow shoulder was reported to be lower than the concentration in normal red-ripe tissue (Picha, 1987). A decrease in the incidence of exterior blotchy ripening of trickle-irrigated tomatoes was reported as the K : N ratio increased from 0.8 to 2.1:1 (Winsor et al., 1961).

The objective of this study was to determine the effects of trickle-applied N and/or K, percentages of trickle-applied nutrient(s) (50%, 75%, and 100%), schedules of nutrient application (variable, 2% to 12.5% weekly, and constant, 8.3% weekly), and harvest period on the exterior and interior quality, and the elemental concentration of tomatoes.

Materials and Methods

'Sunny' tomatoes were grown as described previously (Dangler and Locascio, 1990). Ten breaker-stage, small (115 g) fruits per plot were obtained at the early, midseason, and late harvests in 1984 and 1985. Each fruit was selected from a different plant. To reduce the possibility of selecting tomatoes with solar injury, fruit were sampled from areas shaded from direct sunlight. Fruit were washed in a 125-ppm solution of chlorine (hypochlorite) and stored at 21C. After storage for ≈7 days, red-ripe fruit were rated for external and internal blotchy ripening using the following scale: 1) blotch-free; 2) 1% to 5% of the fruit surface blotchy; 3) 6% to 25% blotchy; 4) 26% to 50% blotchy; and 5) > 50% blotchy (Picha and Hall, 1981). Following the rating for external blotchy ripening, each fruit was cut across the equatorial plane, then rated for internal blotchy ripening. Opposite polar quarters of each fruit were pooled, then pureed in a blender. Homogenate subsamples were weighted, dried at 70C, and ground to a particle diameter of <0.6 mm. Prepared fruit tissue was stored in polyethylene scintillation vials and redried for 72 hr.

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Additional tissue preparation for nutrient analyses of leaf and shoot tissue was performed as described by Dangler and Locascio (1990).

The experimental design was a split-split-split plot arranged in a randomized complete-block design with four replications. Main-plot treatments were years and subplot treatments were factorial combinations of trickle-applied N and/or K, percentages of trickle-applied nutrient(s) (50%, 75%, and 100%), and schedules for nutrient application (variable, 2% to 12.5% weekly, and constant, 8.3% weekly). Harvest period was analyzed as a sub-subplot treatment.

Results and Discussion

The occurrence of blotchy ripening was low during the 2 years but was influenced significantly by year, trickle-applied nutrient, percentage of trickle-applied nutrient, and time of harvest, but not weekly schedule of nutrient application (Table 1). External blotchy ripening was slightly less severe in 1985 than in 1984, while the difference in internal blotchy ripening was more substantial, but in the reverse direction. Interior blotchy ripening was a more-severe blemish than exterior blotchy ripening in these and in other studies (Picha and Hall, 1981).

In both years, external and internal blotchy ripening were less severe with trickle-applied N + K than with either N or K trickle-applied individually. Also, blotchy ripening was less severe with trickle-applied N than with trickle-applied K (all N preplant-applied) (Table 1).

The trickle-applied- percentage of nutrients had no effect on external blotchy ripening but had a small significant effect on interior blotchy ripening (Table 1). Internal blotchy ripening

decreased linearly from a rating of 3.2 to 3.0 as the percentage of trickle-applied nutrients was increased from 50% to 100%.

Harvest period and year interacted in their effects on interior and exterior fruit quality (Table 2). In 1984, exterior blotchy ripening was less severe at midseason than at the early and late harvests; but in 1985 exterior blotchy ripening was less severe at the early and late harvests than at midseason. In both years, interior quality was consistently better earlier in the season than at the late harvest.

Higher fruit N, P, K, Ca, and Mg concentrations were obtained with trickle-applied N + K and N than with trickle-applied K (Table 1). Fruit K concentrations obtained with trickle-applied N + K and N were 4.40% and 4.11%, respectively, whereas the K concentration with trickle-applied K was 3.99%. Trickle-applied N was, therefore, more important than trickle-applied K for uniform fruit ripening and improved marketability of tomatoes, even though the ripening response appeared to be associated with an increase in fruit K concentration. Results of previous work showed a reduction in the severity of blotchy ripening with an increase in fruit (Picha and Hall, 1981) or leaf (Corey et al., 1986; Ozbun et al., 1967; Winsor et al., 1961) K concentration. The higher fruit K concentration obtained with trickle-applied N + K than with trickle-applied N or K in the studies reported here could not be explained by an increase in plant growth because shoot fresh and dry weights were not significantly affected by the trickle-applied nutrient treatment (data not shown). The fruit K concentrations (4.77% and 3.55%, mean values in 1984 and 1985, respectively) were higher than concentrations reported with similar amounts of preplant-applied fertilizer K ($\approx$ 2.5% to 3.5% K) (Picha and Hall, 1981; Picha, 1987).

Table 1. Main effects of year, trickle-applied nutrient(s), percentage of nutrient(s) trickle-applied, schedule of nutrient application, and harvest period on tomato fruit quality and composition.

Treatment	Fruit characteristic ^z							
	Blotchy ripening rating ^y		Mineral concn (%)					Dry wt (%)
	External	Internal	N	P	K	Ca	Mg	
Year (Yr)								
1984	1.9	2.9	2.91	0.63	4.77	0.17	0.25	4.0
1985	1.7	3.4	2.99	0.44	3.55	0.14	0.21	4.5
Significance	*	**	NS	***	***	**	***	***
Nutrients applied								
N + K	1.6 c	2.8 c	3.00 b	0.54 a	4.40 a	0.16 b	0.23 a	4.3 a
N	1.8 b	3.1 b	3.06 a	0.55 a	4.11 b	0.17 a	0.23 a	4.2 b
K	2.0 a	3.5 a	2.79 c	0.51 b	3.99 c	0.14 c	0.21 b	4.3 a
Trickle-applied (%)								
50	1.8	3.2	2.86	0.53	4.14	0.14	0.22	4.3
75	1.9	3.1	2.99	0.54	4.23	0.16	0.23	4.2
100	1.7	3.0	3.00	0.53	4.13	0.17	0.22	4.1
Significance	NS	L***	Q*	NS	Q*	L*	Q*	L*
Schedule								
Variable	1.8	3.1	2.99	0.53	4.18	0.16	0.23	4.2
Constant	1.8	3.2	2.92	0.53	4.15	0.16	0.22	4.2
Significance	NS	NS	NS	NS	NS	NS	NS	NS
Harvest period (H)								
Early	1.7 b	3.0 b	2.95	0.54 a	4.32 a	0.17 a	0.23 a	4.1 c
Mid	1.7 b	2.9 b	2.94	0.55 a	3.99 c	0.16 a	0.22 b	4.2 b
Late	1.8 a	3.5 a	2.97	0.51 b	4.19 b	0.15 b	0.22 b	4.4 a
Yr $\times$ H significance	***	***	***	***	***	***	***	***

^zMean separation in columns by Duncan's multiple range test at $P = 0.05$. Absence of letter indicates no significance.

^yExternal and internal blotchy ripening ratings were 1) blotch-free; 2) 1% to 5% blotchy; 3) 6% to 25% blotchy; 4) 26% to 50% blotchy; and 5) >50% blotchy.

NS,*,**,* Main effects or interactions were nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively. Significant responses to percentage of nutrients trickle-applied were linear (L) or quadratic (Q).

Table 2. Interaction of year and harvest period on tomato fruit quality and composition.

Harvest	Fruit characteristic ^z							Dry wt (%)	
	Blotchy ripening rating ^y		Mineral concn (%)						
	External	Internal	N	P	K	Ca	Mg		
				1984					
Early	2.0 a ^y	2.8 b	2.83 b	0.62 b	5.08 a	0.19 a	0.24 b	3.9 b	
Mid	1.6 b	2.6 c	2.87 b	0.66 a	4.60 b	0.17 b	0.25 a	4.1 a	
Late	2.1 a	3.2 a	3.04 a	0.59 b	4.64 b	0.15 c	0.25 a	4.1 a	
				1985					
Early	1.5 b	3.2 b	3.07 a	0.46 a	3.55 b	0.14 a	0.21 a	4.3 b	
Mid	1.9 a	3.2 b	3.00 a	0.43 b	3.37 c	0.15 a	0.21 a	4.3 b	
Late	1.6 b	3.8 a	2.89 b	0.43 b	3.74 a	0.13 b	0.20 b	4.7 a	

^zMean separation in columns by Duncan's multiple range test at $P = 0.05$.

^yExternal and internal blotchy ripening ratings were 1) blotch-free; 2) 1% to 5% blotchy; 3) 5% to 25% blotchy; 4) 26% to 50% blotchy; and 5) >50% blotchy.

Consistent patterns of fruit nutrient accumulation at the various harvest periods were not obtained. Unlike nutrient accumulation throughout the season, the elemental K concentrations at the harvest periods could not be associated with fruit quality.

Although significant differences in fruit dry weight percentages were obtained among harvest periods, the relationship between this characteristic and fruit quality or fruit nutrient concentration was not evident. Results of previous work showed that the dry-matter content of blotchy-ripened whole fruit (Winsor and Massey, 1958) and yellow-shoulder tissue fruit (Picha and Hall, 1981) was lower than the dry-matter content of red-ripe fruit.

Fruit quality and nutrient concentration were not significantly affected by the weekly schedule of fertilizer application. It appeared that high-quality fruit was obtained as long as small portions of the total N and K were supplied to the plant late in the season, because there were no significant differences in quality between the constant and variable application schedules, and the effect of increasing the percentage of trickle-applied nutrients from 50% to 100% was small.

The mean total marketable yield at the early harvest decreased linearly from $\approx 25.4 \text{ t} \cdot \text{ha}^{-1}$ to $16.3 \text{ t} \cdot \text{ha}^{-1}$ as the percentage of trickle-applied N + K or N increased from 50% to 100% (Dangler and Locascio, 1990). Similar responses were obtained for yields of large fruit at the midseason and total harvest periods. Since highest yields were associated with 50% trickle-applied N + K and N, and the results of the fruit quality study reported here indicate high exterior and interior fruit quality was obtained with trickle-applied N + K (no interaction with trickle-applied percentage), the results of these studies taken together indicate the greatest yield of high-quality fruit was obtained with 50% trickle-applied N + K.

Although the average fruit evaluated in these studies was not severely blotched, marketable fruit should be blotch-free. Therefore, the small, significant differences in the severity of internal and external blotchy ripening (10% to 20%) obtained by manipulating the time of N and K fertilizer applied through the trickle system can significantly affect tomato marketability. Highest fruit quality was obtained with 50% to 100% trickle-applied N + K. The elemental concentration, especially K, was greater in higher quality fruit than in blotchy fruit. Higher internal fruit quality was obtained early rather than late in the season. Results of the ripening study reported here, and a tomato

yield study reported elsewhere, indicate that highest yield of high-quality fruit was obtained with 50% trickle-applied N + K.

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