# Nitrogen Nutrition of Tomato Plants and Susceptibility of the Fruit to Bacterial Soft Rot

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## ABSTRACT

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Incidence of bacterial soft rot following wound inoculation was used to measure the influence of different plant fertilization treatments on the susceptibility of tomato fruit to *Erwinia carotovora* var. *carotovora*. The fertilizers were either banded or broadcasted. The susceptibility of the fruit was increased when the banded nitrogen (N) was doubled while the potassium (K) in the band remained constant. No consistent increases in susceptibility occurred, however, when both the N and the K in the band were doubled or when N was applied as broadcasted $NaNO_3$, $NH_4NO_3$, $Ca(NO_3)_2$, or $KNO_3$. Fruit from the various broadcast treatments were either as susceptible as or more resistant than those from the nonsupplemented N and K treatments. Increased resistance was not consistently associated with any of the supplements. Tissue N, K, and Ca were not correlated with fruit susceptibility. The N and K in the fruit tissue were not correlated with the amounts of those elements applied, but differences in tissue N, K, and Ca were found between treatments. The fruit from the Ca-amended treatments usually had higher Ca.

*Additional key words*: *Lycopersicon esculentum*, postharvest decay.

Florida tomato growers have long been aware of a relationship between nitrogen (N) fertilization and fruit quality. Excessive N was believed responsible for fruit with excessive softness and susceptibility to cracking, bruising, and postharvest decay. Side-dresses or topdresses with N, however, usually were required to obtain maximum yields and fruit size. Experimentally, poor quality fruit were associated with N side-dresses, temporary calcium (Ca) deficiencies, and heavy rains (4–9). Percolation of rainwater through fertilizer bands either leached salts into the root zone (resulting in a competitive inhibition of Ca uptake) or, with heavier rainfall, leached Ca out of the root zone (12). In either instance, the plant was deficient at least temporarily in Ca, and as a result, the fruit were softer, more likely to develop blossom end rot, and to be lost during postharvest handling.

The need for side-dresses or topdresses as well as the leaching problems associated with those practices was eliminated when the plastic mulch system was adapted to tomato culture. In this system, a thin sheet of plastic covers a raised bed of soil. Water needed for plant growth moves into the root zone either horizontally and upward in the seep-irrigation system or downward through holes cut in the surface of the plastic in other systems. In either type of water movement, most leaching is prevented. The upward movement of water in the bed, however, could also result in reduced Ca uptake. The salts from the fertilizer accumulate in areas near the fertilizer band. Plant roots develop extensively in these areas, permitting competitive inhibition of Ca uptake. The chances of this inhibition are increased if high-analysis fertilizer (those with a high percentage of essential elements) containing N and K only are used; such fertilizers do not contain Ca from superphosphate, nor do they contain the gypsum filler ($CaSO_4$) used in some low-analysis fertilizers.

We studied the relationship between susceptibility to postharvest decay in tomato fruit and fertilization practices, especially the use of high N in the full-bed mulch system. *Erwinia carotovora* var. *carotovora* (Jones) Dye was selected as the test organism, because bacterial soft rot has been the most important postharvest disease in Florida-grown tomatoes.

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## MATERIALS AND METHODS

**General cultural methods**. The soil was a Myakka fine sand having a spodic horizon. The hard pan layer ranged from 46–61 cm below the soil surface. Drainage/irrigation ditches were cut at about 12-m intervals. Moisture was maintained to the top of the plant beds by adding or removing water from the ditches as needed. Calcium as 4,480 kg/ha of dolomitic lime ($Ca{\cdot}Mg[CO_3]_2$) was applied once when the land was first cleared; this raised the pH from 4.5 to 6.5. Additional dolomite was applied whenever the pH dropped below 6.0. The soil was formed into beds 25–36 cm high by 91 cm wide. The spacing from bed center to bed center was 183 cm. Superphosphate was broadcast over the bed surface at 58 kg of P/ha. The superphosphate contained 205 g of Mg/kg and 75 g of FTE 503/kg (FTE 503 is a minor element mix [Ferro Corp., Cleveland, OH 44114] containing 3% B, 3% Ca, 18% Fe, 0.2% Mo, 7.5% Mn, and 7% Zn by weight). Fertilizers containing N and K were applied as two 5-cm wide bands on the bed surface except for about 56 kg/ha, which were broadcast on the bed surface. Each band was roughly 15 cm from the nearest plant row. The N and K fertilizers were composed entirely of $NH_4NO_3$ and $KNO_3$. Supplements to the fertilizers were broadcast on the bed surface between the plant rows. The plastic was laid after application of all chemicals. Holes were cut in the plastic for the tomato transplants. The holes were staggered in paired rows with 61 cm between row centers and between individual holes within each row.

**Experiments**. In the first test, three different rates of N were applied along with a single rate of K. The N treatments were 262, 394, and 526 kg/ha banded and 62.7, 66.1, and 69.4 kg/ha broadcasted, respectively. The K applied was 93.5 kg/ha broadcasted and 419.5 kg/ha banded.

In the second test, 128 or 257 kg of N/ha were banded along with 221 kg of K/ha. Each treatment received 12 kg of K/ha broadcasted. Two Ca compounds, $Ca(NO_3)_2$ and $CaCl_2$, were broadcasted to provide additional N along with added Ca and added Ca without additional N. The broadcasted treatment added 7, 13, 98, 177, or 183 kg of N/ha and 0, 135, 170, 200, 270, or 400 kg of Ca/ha.

In the third test, 139 kg of N and 224 kg of K or 287 kg of N and 462 kg of K were banded, respectively. Broadcast treatments included: 14 kg of K; 9, 93, 99, or 197 kg of N/ha; and 0, 135, or 200 kg of additional Ca/ha. The higher amounts of N were from 561 kg of $Ca(NO_3)_2$, $NaNO_3$, and $NH_4NO_3$/ha, respectively. The Ca was from $Ca(NO_3)_2$ and $CaCl_2$, respectively.

In the fourth test, 136 kg of N and 137 kg of K or 282 kg of N and 287 kg of K were banded, respectively. Broadcast treatments included 12 or 324 kg of K/ha; 10, 115, 131, or 139 kg of N/ha; and 0, 194, and 208 kg of additional Ca/ha. The higher amounts of N were from 808 kg/ha of $KNO_3$, $Ca(NO_3)_2$, and $NaNO_3$, respectively. The Ca was from $Ca(NO_3)_2$ and $CaCl_2$, respectively.

The fertilizers used in these tests were classified as high analysis. Most of the fertilizer was a primary plant food or element; thus the unnecessary salts found in lower analysis fertilizers were avoided. The following is a breakdown of the treatments in current 1978 U.S. agricultural terminology:

First test—12-0-25, 18-0-25, or 24-0-25 each banded at 2,087 kg/ha (1,950 lb/A) and broadcast at 56 kg/ha (50 lb/A) plus an additional 560 kg/ha (500 lb/A) of 10-10-10 per hectare was broadcast to each treatment; second test—12-0-25 or 24-0-25 each banded at 1,065 kg/ha (950 lb/A) and broadcast at 50 kg/ha (50 lbs/A) with and without broadcast treatments of 560 or 1,121 kg $CaCl_2$ or $Ca(NO_3)_2$/ha (= 500 or 1,000 lb/A); third test—16-0-31 banded at 869 or 1,793 kg/ha (= 775 or 1,600 lb/A) and broadcast at 56 kg/ha (50 lb/A) with and without broadcast treatments of $NaNO_3$, $NH_4NO_3$, $Ca(NO_3)_2$, or $CaCl_2$ each at 560 kg/ha (500 lb/A); fourth test—18-0-25 banded at 751 and 1,558 kg/ha (= 670 and 1,390 lb/A) and broadcast at 56 kg/ha (50 lb/A) with and without broadcast treatments of $NaNO_3$, $KNO_3$, $Ca(NO_3)_2$, or $CaCl_2$, each at 807 kg/ha (720 lb/A).

**Harvest and handling of fruit**. In each test, the fruit were hand harvested when approximately mature green, bulked within treatments, and divided into replicates with ten fruit each. Each fruit was wounded in four places with four pins held by a cork (1, 2). The pins were dipped into a $1 \times 10^6$ or $1 \times 10^7$ cells/ml suspension of *E. carotovora* var. *carotovora* (Florida isolates SR-1 [1] and SR-12 [2]) before each wound was made. The bacterial suspensions were prepared from nutrient-broth shake cultures 18–28 hr old. All inoculated fruit were stored at 21 C and about 90+% RH. Fruits with lesions were discarded after each observation to prevent secondary spread of the pathogen from infected fruit to healthy fruit.

Fruit from the last two tests were analyzed for N, K, and Ca in the fruit wall. Tissue analysis has been considered a valid method for detecting Ca deficiencies (9). Five fruit from each treatment in the third test and six in the fourth test were sliced into strips about 3 cm wide. The locular and placental tissues were removed, and the remaining wall tissue was dried at 90 C for about 5 days. Portions of the wall tissue were ashed and analyzed for K and Ca through standard techniques of flame spectrophotometry by the Soil Chemistry Laboratory at the University of Florida, Gainesville. The total N in the dried tissue was estimated by the Kjeldahl method.

Decay was expressed by the percentage of fruit with lesions at stated intervals after inoculation. Percentage data were transformed before being analyzed. Treatments were compared for either percentage of fruit with lesions or content of Ca, N, and K by the Duncan's new multiple range test at $P = 0.05$.

## RESULTS AND DISCUSSION

Fruit from the two higher N treatments were more susceptible to *E. carotovora* var. *carotovora* than those from the lower N treatments (Table 1). The difference in total N between the lowest N treatment, 325 kg/ha, and the intermediate N treatment, 460 kg/ha, was 135 kg/ha. This was also the difference in total N between the intermediate and high N treatments, but the fruit of those two treatments were not different in susceptibility at $P = 0.05$. Thus, either the highest N treatment represented overfertilization, or the N effect on susceptibility to *E. carotovora* var. *carotovora* occurred only in the lower range of N fertilization.

In the second test, the total N applied was lowered so that the range was 135–440 kg of N/ha as compared with the 325–595 kg/ha used earlier. In addition, a different source of N was applied, $Ca(NO_3)_2$. The higher N fertilization was associated with greater susceptibility only when the banded N was doubled from 128 kg/ha to 257 kg/ha. Increasing the N applied by either 177 or 183 kg of N/ha through broadcast application of $Ca(NO_3)_2$, however, did not increase the susceptibility of the fruit as compared with the respective no-$Ca(NO_3)_2$ control treatments (Table 2). This did not seem to be due to the Ca in the $Ca(NO_3)_2$, as only one of the four $CaCl_2$ treatments resulted in more resistant fruit as compared with the respective no-Ca control treatments. One of the lower $Ca(NO_3)_2$ treatments also was associated with a significant decrease in susceptibility ($P = 0.05$) as compared with its control treatment, but unfortunately, the plants in the other low $Ca(NO_3)_2$ treatment were lost.

In two separate tests, increasing the N in the fertilizer band twofold was associated with a significant increase in susceptibility of the fruit to bacterial soft rot. In the second test, a greater than twofold increase in N applied by broadcast application of $Ca(NO_3)_2$ did not produce a similar effect. Thus, the association of N fertilization with susceptibility of tomato fruit to *E. carotovora* var. *carotovora* did not seem to be caused strictly by higher total N, but may have included a fertilizer placement effect.

In the third test, the two genotypes planted reacted differently to the same banded fertilizer treatment (Table 3). Fruit from MH-9 plants were more susceptible, while those from MH-1 plants were as susceptible as those in the respective control treatments. None of the treatments involving broadcasted N resulted in greater susceptibility as compared with the respective control treatments. On the contrary, each of the supplements to the 2X banded

TABLE 1. Average[a] percentage of tomato fruit from different fertilizer treatments[b] with visible lesions 3 and 6 days after being artificially wound inoculated with two concentrations (cells/ml) of *Erwinia carotovora* var. *carotovora*, spring 1971

| Total N applied (kg/ha) | Percentage of fruit with lesions per days after inoculation and cells/ml | | | |
|---|---|---|---|---|
| | 3 days | | 6 days | |
| | $10^6$ (%) | $10^7$ (%) | $10^6$ (%) | $10^7$ (%) |
| 325 | 7 b[c] | 12 b | 35 b | 52 b |
| 460 | 13 a | 31 a | 57 a | 71 a |
| 595 | 16 a | 38 a | 64 a | 84 a |

[a]Average of ten 10-fruit replicates, five from Walter plants and five from Breeding Line 2432-1-1.
[b]Banded treatments = 419.5 kg of K/ha and either 262, 294, or 526 kg N/ha, respectively. Broadcast treatments = 62.7, 66.1, and 69.4 kg of N/ha, respectively, and 93.5 kg of K/ha.
[c]Each value not followed by the same letter was significantly different at $P = 0.05$.

TABLE 2. Average[a] percentage of Florida MH-1 tomato fruit from different fertilizer treatments[b] with visible lesions 8 days after artificial wound inoculation with *Erwinia carotovora* var. *carotovora* at $10^7$ cells/ml, fall 1971

| N applied (kg/ha) | | Ca supplement | |
|---|---|---|---|
| Banded | Broadcasted | (kg/ha) | % Decay |
| 128 | 7 | 0 | 65 bc[e] |
| 128 | 7 | 200[d] | 68 bc |
| 128 | 7 | 400[d] | 58 c |
| 128 | 177 | 270[e] | 70 abc |
| 257 | 13 | 0 | 90 a |
| 257 | 13 | 200[d] | 68 bc |
| 257 | 13 | 400[d] | 70 abc |
| 257 | 98 | 135[c] | 55 c |
| 257 | 183 | 270[e] | 88 ab |

[a]Average of four 10-fruit replicates.
[b]Banded treatments included 221 kg of K; broadcast treatments, 12 kg of K.
[c]From $CaCl_2$, agricultural grade.
[d]From $Ca(NO_3)_2$ (15% N).
[e]Values not followed by the same letter were significantly different at $P = 0.05$.

treatment resulted in significantly ($P = 0.05$) reduced susceptibility as compared with the no-supplement control.

In the fourth test, again doubling the banded N and K had no effect on the susceptibility of the fruit to *E. carotovora* var. *carotovora* (Table 4). In addition, none of the supplements were associated with a significant increase in susceptibility. Thus, additional N at the rates used here could be broadcasted on plant bed surfaces without resulting in fruit of increased susceptibility to bacterial soft rot. In addition, there was no effect due to form of N. In the third test, the broadcast treatment of $NH_4NO_3$ did not increase fruit susceptibility as compared with either the control treatments or the nitrate-only supplemental treatments even though slightly more N was supplied in the $NH_4NO_3$ application.

Finally, in the third and fourth tests, use of the applied N, K, and Ca by the plants was monitored through determination of the content of those elements in fruit wall tissues. The amounts of those minerals varied significantly ($P = 0.05$) among the tests, but none of the changes could be correlated with differences in susceptibility. Tissue Ca was higher in the fruit from the $CaCl_2$ and $Ca(NO_3)_2$ treatments than in those from the other treatments. The failure of the higher Ca to correlate with greater resistance could be explained by the fact that total Ca was measured rather than pectate-bound Ca, which previously was associated with plant resistance to certain pathogens that produce pectolytic enzymes (3). Nevertheless, the higher levels of Ca in the fruit tissues meant that the plants were using the Ca from the $Ca(NO_3)_2$ and $CaCl_2$. On the other hand, the concentrations of N and K in the fruit tissues were not correlated with the amounts of those elements applied.

In summary, increasing the N applied to tomato plants can increase the innate susceptibility of the fruit to *E. carotovora* var. *carotovora*. Thus, N fertilization of tomato plants affects bacterial soft rot of the fruit just as it affects many other plant diseases (10,13). This conclusion partially agrees with that of Segall et al (11) who reported that increased susceptibility resulted from supplementary applications of $Ca(NO_3)_2$ or $KNO_3$. In the cultural system used here, however, the method of application of the N fertilizer seemed to have a greater impact on fruit susceptibility than did the amount or form of the N applied. Banded fertilizer treatments, especially those in which the N/K ratio was increased (tests 1 and 2), were associated with significant increases in fruit susceptibility. Some of the tomato genotypes used here, however, responded differently to the same fertilizer treatment (test 3). Thus, other genotypes may react somewhat differently to these fertilizer treatments than did the genotypes used here.

TABLE 3. Incidence[a] of bacterial soft rot among inoculated tomato fruit of two genotypes from different fertilizer treatments and average concentrations of N, K, and Ca in walls of those fruit, spring 1972

| Genotype | Banded fertilizer rate[b] | Broadcasted amendment | Total N applied (kg/ha) | | Tissue analysis (mg/g dry wt)[d] | | | Decay incidence (%) |
|---|---|---|---|---|---|---|---|---|
| | | | Banded | Broadcasted[c] | N | K | Ca | |
| MH-1 | 1X | ... | 139 | 9 | 20.36 b[e] | 45.0 abc | 1.3 d | 7 d |
| | 2X | ... | 287 | 9 | 20.36 b | 43.7 bcd | 1.1 d | 4 d |
| MH-9 | 1X | ... | 139 | 9 | 24.8 ab | 48.8 ab | 1.9 abc | 14 bcd |
| | | $NaNO_3$ | 139 | 99 | 24.2 ab | 46.8 ab | 1.6 abcd | 14 bcd |
| | | $NH_4NO_3$ | 139 | 197 | 24.5 ab | 49.5 ab | 1.5 abcd | 20 bc |
| | | $Ca(NO_3)_2$ | 139 | 93 | 28.2 a | 50.1 ab | 2.1 a | 26 ab |
| | | $CaCl_2$ | 139 | 9 | 21.4 b | 53.5 a | 2.1 ab | 4 d |
| | 2X | ... | 287 | 9 | 24.6 ab | 42.6 bcd | 1.4 cd | 41 a |
| | | $NaNO_3$ | 287 | 99 | 24.3 ab | 35.5 d | 1.8 abc | 17 bcd |
| | | $NH_4NO_3$ | 287 | 197 | 21.4 b | 39.9 cd | 1.2 d | 16 bcd |
| | | $Ca(NO_3)_2$ | 287 | 93 | 23.0 ab | 36.3 d | 2.1 ab | 20 bcd |
| | | $CaCl_2$ | 287 | 9 | 21.1 b | 39.9 cd | 1.5 bcd | 17 bcd |

[a] Average percentage (seven 10-fruit replicates) of fruit with lesions at 7 days after wound inoculation of mature green fruit with suspension of $10^6$ cells/ml of *Erwinia carotovora* var. *carotovora*.
[b] Banded fertilizer included 224 (1X) or 462 (2X) kg of K/ha.
[c] In addition to indicated amounts of N, broadcasted Ca amendments $Ca(NO_3)_2$ and $CaCl_2$ provided 135 and 200 kg of Ca/ha, respectively.
[d] Average of five fruit per treatment.
[e] All values within each column not followed by same letter were significantly different at $P = 0.05$.

TABLE 4. Incidence[a] of bacterial soft rot following inoculation of breeding line MH-11 tomato fruit from different fertilizer treatments and average concentrations of N, K, and Ca found in walls of those fruit, spring 1973

| Banded fertilizer rate | Broadcasted amendment | Total N applied (kg/ha)[b] | | Tissue analysis (mg/g dry wt)[c] | | | Decay incidence (%) |
|---|---|---|---|---|---|---|---|
| | | Banded | Broadcasted | N | K | Ca | |
| 1X | ... | 136 | 10 | 17.0 b[d] | 52.3 ab | 1.4 d | 33 a |
| | $NaNO_3$ | 136 | 139 | 20.4 ab | 54.1 a | 1.7 bcd | 7 c |
| | $KNO_3$ | 136 | 115 | 22.1 ab | 52.8 ab | 1.7 bcd | 18 a |
| | $Ca(NO_3)_2$ | 136 | 131 | 22.2 ab | 50.9 ab | 2.1 a | 28 a |
| | $CaCl_2$ | 136 | 10 | 19.7 ab | 48.4 ab | 2.0 ab | 20 ab |
| 2X | ... | 282 | 10 | 19.1 ab | 46.2 b | 1.6 cd | 26 a |
| | $NaNO_3$ | 282 | 139 | 23.7 a | 50.9 ab | 1.9 abcd | 23 a |
| | $KNO_3$ | 282 | 115 | 21.2 ab | 48.0 ab | 1.5 d | 20 a |
| | $Ca(NO_3)_2$ | 282 | 131 | 23.2 a | 46.3 b | 1.9 abc | 20 a |
| | $CaCl_2$ | 282 | 10 | 21.7 ab | 46.7 b | 1.8 abcd | 7 bc |

[a] Average percentage of fruit (ten 10-fruit replicates) with lesions at 6 days after wound-inoculation of mature-green fruit with suspension ($1 \times 10^6$ cells/ml) of *Erwinia carotovora* var. *carotovora*.
[b] Banded fertilizer included 137 (1X) or 287 (2X) kg of K/ha. In addition to indicated amounts of N, broadcasted amendments $KNO_3$, $Ca(NO_3)_2$, and $CaCl_2$ provided 312 kg of K, 194 kg of Ca, and 208 kg of Ca, respectively.
[c] Average of six fruit per treatment.
[d] All values within each column not followed by same letter were significantly different at $P = 0.05$.

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