

Low Temperature Tolerance of 'Starkspur Supreme Delicious' on Nine Rootstocks in the Iowa 1980-1981 NC-140 Cooperative Planting¹

PAUL A. DOMOTO²

Abstract

'Starkspur Supreme Delicious' apple trees in the Iowa planting of the 1980-1981 NC-140 cooperative rootstock trial experienced three late-fall/early-winter freezes, and two freezes associated with fluctuating temperatures during four winters of the ten year study. All the trees on MAC.24 were killed following two consecutive winters during which freezes occurred in late-fall or early-winter. Trees on MAC.9 exhibited a high incidence of spur injury, and reduced vigor that may have been confounded by prior injury and poor growth of the cultivar on this rootstock. Shoot injury evaluations following two freezes suggested that trees on MAC.9 acclimate early but do not attain a high tolerance to low temperature stress in mid- or late-winter. Trees on OAR 1 exhibited a similar pattern of hardiness reported for M.7, but were more susceptible to late-fall/early-winter freezes than M.7 EMLA. Trees on O.3 appeared to be similar in hardiness to trees on M.26 EMLA.

In many apple producing areas, including Iowa, the low temperature tolerance of the rootstock or scion is one of the critical limiting factors affecting rootstock adaptability and acceptance. To evaluate more thoroughly new and untested rootstocks under a diversity of soil and climatic conditions, the NC-140 committee initiated a number of uniform rootstock and interstem plantings in which Iowa has participated (4, 5, 6). In 1980 and 1981, a uniform cooperative planting was established to evaluate the performance of 'Starkspur Supreme Delicious' on nine rootstocks in 27 apple producing areas of the United States and Canada. In a publication summarizing the early performance of the rootstocks in this test, it was reported

that the Montana and Minnesota plantings were eliminated by winter injury during the 1983-1984 winter (4). The Iowa planting sustained injury during that winter and in subsequent winters. This report summarizes the injury that occurred in the Iowa planting throughout the study.

Materials and Methods

As part of the NC-140 cooperative uniform apple rootstock trial to evaluate the performance of 'Starkspur Supreme Delicious' on nine rootstocks (O.3, M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, MAC.9, MAC.24, and OAR 1), five replications were established in 1980 at the Iowa State University Horticulture Station near Ames, Iowa, with an additional 5 replications established in 1981. Cultural requirements and data collection were conducted following uniform guidelines established by the NC-140 committee (4).

Trees in the Iowa planting exhibited symptoms of low temperature injury following the 1983-1984, 1985-1986, 1986-1987 and 1988-1989 winters. During the 1983-1984 winter low temperatures recorded were -29°C on 24 December, and -21°C on 9 March following almost a month with daytime temperatures above freezing. Other stressful temperatures recorded were -32°C on 19 December 1985; -20°C on 11 November 1986; and -27°C on 3 February 1989 following above freezing temperatures in Janu-

¹Received for publication . . . Journal Paper No. J-14408 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Project No. 2266, a contributing project to North Central Regional Project NC-140.

²Department of Horticulture, Iowa State University, Ames, Iowa 50011.

ary. Following these winters, injury symptoms were exhibited as the loss of spurs, or as reduced tree vigor and the eventual death of some trees.

Following the 1983-1984, 1985-1986, and 1986-1987 winters, dead or injured spurs were evident during bloom. After bloom both dead and living spurs were counted and the percentage of dead spurs per tree was determined. Symptoms of tree decline were evident following the 1983-1984 winter, and commencing in 1985, the symptoms were visually rated in August on a scale of 1 to 6: (1 = healthy foliage, no symptoms; 2 = leaves slightly off-color; 3 = leaves distinctly off-color, and/or vigor slightly reduced; 4 = vigor reduced with small, off-colored leaves; 5 = vigor greatly reduced with small, sparse leaves; 6 = dead tree).

One day prior to the 11 November 1986 freeze (-20°C), the stage of defoliation was rated on a scale of 0 = no defoliation to 10 = complete defoliation. To evaluate injury following the freeze, one-year-old shoots were sampled approximately one-week after the freeze when the ambient temperature was above 5°C . Four terminal shoots per tree were collected from scaffolds in the east and west (between-row) sectors, and placed in a greenhouse under intermittent mist for two weeks to promote enzymatic browning of injured tissue. After two weeks, each shoot was divided into terminal, middle and basal portions, sectioned tangentially near the midpoint of each section, and visually rated for injury following the scale developed by Holubowicz *et al.* (2) [1 = no visible xylem injury; 2 = slight (10-30%) xylem injury; 3 = considerable (30-50%) xylem, cambium, bark and buds]. Basal shoot sections exhibited no injury and were not included in the analysis. Terminal bud development on the collected shoots was rated on a scale of 1 to 3 as an assessment of shoot maturity (1 = poorly developed, diameter less than subtending shoot; 2 = developed but

small, diameter approximately the same as the subtending shoot; 3 = well developed, diameter greater than the subtending shoot). At the end of the 1987 growing season, the percentage of dead trunk bark was calculated relative to the trunk circumference at the site of greatest injury between the graft union and the lowest scaffold. Following the 3 February 1989 freeze shoots were again collected and evaluated for injury following the same procedure used following the November 1986 freeze.

The data following each winter were subjected to analysis of variance and means were separated by least significant difference (LSD) test. Simple correlations were performed on the data related to shoot injury following the 11 November 1986 freeze.

Results

Following the December 1983 freeze (-29°C), some spurs sampled in mid-January exhibited injury to the xylem tissue subtending the bud, and the trees were exposed to a second freeze in March (-21°C) following almost a month of above freezing temperatures. After bloom, the greatest spur loss occurred on MAC.9 trees, but did not differ from OAR 1 trees (Table 1).

Table 1. Percentage of dead spurs and vigor rating of 'Starkspur Supreme Delicious' apple trees following the 1983-1984 winter.

| Rootstock | Percent dead spurs | Tree vigor ² |
|-----------|--------------------|-------------------------|
| MAC.24 | 5.2 b ^y | 1.0 b |
| OAR 1 | 6.4 ab | 1.0 b |
| M.7 EMLA | 4.6 b | 1.0 b |
| M.26 EMLA | 3.3 b | 1.0 b |
| O.3 | 3.4 b | 1.0 b |
| M.9 EMLA | 3.4 b | 1.1 b |
| M.9 | 3.0 b | 1.0 b |
| MAC.9 | 9.3 a | 2.3 a |
| M.27 EMLA | 2.4 b | 1.2 b |

²Rated in August, 1985; scale 1 (healthy) to 6 (dead).

^yMean separation by LSD at the .05 level.

During the growing season, trees of MAC.9 exhibited moderate to severe symptoms of reduced vigor. These symptoms remained evident in August 1985 (Table 1). Tree loss consisted of one tree on OAR 1 which failed to leaf out in 1984, and one tree on MAC.9 that continued to decline over a period of two years.

In the spring after the December 1985 freeze (-32°C) 'Starkspur Supreme Delicious' trees on MAC.9 had greater spur loss than on MAC.24, O.3, M.7 EMLA, M.26 EMLA, M.9 EMLA, and OAR 1, but was not different from M.9 or M.27 EMLA (Table 2). When rated for vigor in August, trees on MAC.24 exhibited the greatest symptoms of decline followed by MAC.9. Trees on O.3 exhibited no symptoms of injury.

On the day prior to the 11 November 1986 freeze (-20°C), trees on MAC.9 M.9 EMLA, M.27 EMLA, M.9 O.3 were more defoliated than trees on MAC.24, M.7 EMLA and OAR 1 (Table 3). Based upon the terminal bud development of the shoots collected following the freeze, shoots from trees on M.27 EMLA, and MAC.9 were the most mature. Shoots from M.9 trees were more mature than on M.26 EMLA and MAC.24 trees, but were not differ-

ent from O.3 and M.9 EMLA. Shoots from trees on OAR 1 and M.7 EMLA were the least mature. Shoot injury was greatest on OAR 1, M.7 EMLA, MAC.24, and M.26 EMLA with no differences between the other rootstocks. Highly significant correlations were found between the stage of shoot maturity and shoot injury ($r = -.72$), and between the stage of defoliation and shoot maturity ($R = -.55$), and shoot injury ($r = -.44$).

Following bloom in 1987, trees on MAC.24 had the greatest percentage of dead spurs (Table 4). This was followed by MAC.9, while M.27 EMLA and OAR 1 were not different from MAC.9 or the other rootstocks. During the growing season, trees on MAC.24 exhibited severe symptoms of decline. By August, when the trees were rated for vigor, all 'Starkspur Supreme Delicious' scions on MAC.24 were dead while the rootstock suckers remained alive. Trees on OAR 1, MAC.9 and M.27 EMLA exhibited less vigor than trees on M.26 EMLA, M.9 and M.9 EMLA, while trees on O.3 and M.7 EMLA exhibited intermediate injury symptoms. Trunk bark injury at the

Table 2. Percentage of dead spurs and vigor rating of 'Starkspur Supreme Delicious' apple trees following the 1985-1986 winter.

| Rootstock | Percent dead spurs | Tree vigor ^z |
|-----------|--------------------|-------------------------|
| MAC.24 | 1.6 d ^y | 3.3 a |
| OAR 1 | 5.0 bcd | 1.2 cd |
| M.7 EMLA | 2.3 d | 1.1 d |
| M.26 EMLA | 3.6 cd | 1.1 d |
| O.3 | 2.0 d | 1.0 d |
| M.9 EMLA | 4.9 bcd | 1.2 cd |
| M.9 | 7.2 abc | 1.3 cd |
| MAC.9 | 11.0 a | 2.3 b |
| M.27 EMLA | 8.3 ab | 1.7 c |

^zScale 1 (healthy) to 6 (dead).

^yMean separation by LSD at the .05 level.

Table 3. Defoliation, shoot maturity, and shoot injury ratings of 'Starkspur Supreme Delicious' apple trees in relation to the 11 November 1986 freeze.

| Rootstock | Defoliation ^z | Maturity ^y | Shoot injury ^x |
|-----------|--------------------------|-----------------------|---------------------------|
| MAC.24 | 5.0 cd ^w | 2.2 c | 2.0 a |
| OAR 1 | 3.3 d | 2.0 d | 2.1 a |
| M.7 EMLA | 4.8 d | 2.0 d | 2.1 a |
| M.26 EMLA | 6.0 bc | 2.2 c | 2.0 a |
| O.3 | 6.9 ab | 2.3 bcd | 1.5 b |
| M.9 EMLA | 7.1 ab | 2.5 bc | 1.4 b |
| M.9 | 7.1 ab | 2.6 b | 1.5 b |
| MAC.9 | 7.3 a | 2.9 a | 1.3 b |
| M.27 EMLA | 7.1 ab | 3.0 a | 1.3 b |

^zScale 0 (no defoliation) to 10 (complete defoliation).

^yScale 1 to 3: 1 = terminal bud poorly developed, 2 = terminal bud developed but small, 3 = terminal bud well developed.

^xScale 1 (no visible xylem injury) to 5 (complete kill).

^wMean separation by LSD at the .05 level.

Table 4. Percentage of dead spurs, vigor rating, and percentage of dead trunk bark on 'Starkspur Supreme Delicious' apple trees following the 1986-1987 winter.

| Rootstock | Percent dead spurs | Tree vigor ^z | Percent dead bark |
|-----------|---------------------|-------------------------|-------------------|
| MAC.24 | 88.3 a ^y | 6.0 a | 100.0 a |
| OAR 1 | 8.0 bc | 2.3 b | 26.8 b |
| M.7 EMLA | 5.4 c | 1.5 cd | 17.1 bc |
| M.26 EMLA | 4.6 c | 1.1 d | 3.8 d |
| O.3 | 3.5 c | 1.4 cd | 8.9 cd |
| M.9 EMLA | 5.5 c | 1.2 d | 3.3 d |
| M.9 | 5.0 c | 1.1 d | 4.0 d |
| MAC.9 | 16.5 b | 2.2 b | 0.0 d |
| M.27 EMLA | 12.7 bc | 2.0 bc | 2.3 d |

^zScale 1 (healthy) to 6 (dead).

^yMean separation by LSD at the .05 level.

end of the 1987 growing season was greatest on MAC.24. Trees on OAR 1 had greater bark injury than trees on O.3, M.9, M.26 EMLA, M.27 EMLA or MAC.9, but did not differ from M.7 EMLA. Trees on MAC.9 did not have any bark injury. Injury suffered during this freeze eventually resulted in the loss of two trees on OAR 1.

Following the 3 February 1989 freeze (-27.2°), shoots collected from trees on M.7 EMLA exhibited greater injury than shoots from M.26 EMLA trees (Table 5). Shoots collected from trees on the other rootstocks exhibited intermediate injury. No spur injury was evident following bloom. In August, trees of OAR 1 and MAC.9 exhibited greater symptoms of reduced vigor than trees on O.3 and M.26 EMLA.

Discussion

Winter injury of apple trees has been associated with late-fall/early-winter freezes during the period of acclimation, or during deacclimation induced by fluctuating temperatures in late-winter/early-spring. During this study, trees in the Iowa planting were exposed to three stressful freezes that occurred during the period of acclimation and two freezes associated with deacclimation and fluctuating temper-

atures. Tree loss that could be attributed to low temperature injury during a specific winter included one tree each of OAR 1 and MAC.9 following the 1983-1984 winter, and 2 trees of OAR 1 and all the trees on MAC.24 following the 1986-1987 winter.

Based on the spur loss and tree vigor ratings following the 1985-1986 and 1986-1987 winters, it was evident that trees on MAC.24 were slow to acclimate in late-fall/early-winter (Tables 2 and 4). This was also evident from the defoliation, maturity, and shoot injury data for the 11 November 1986 freeze (Table 3). In another planting where the rootstocks were grown without a cultivar scion, MAC.24 trees were almost totally defoliated prior to the freeze and suffered no shoot injury. Previously, it was reported that trees on this rootstock were the largest and relatively slow coming into production (4). Based upon these results, it is suggested that the poor tolerance of trees on MAC.24 to early freezes was associated with tree vigor and a delay in the acclimation process.

Trees on MAC.9 consistently exhibited a high percentage of spur loss and reduced tree vigor following each winter (Tables 1, 2, 4, 5). Associating this injury with either late-fall/early-winter or fluctuating temperature stress is

Table 5. Shoot injury and vigor rating of 'Starkspur Supreme Delicious' apple trees following the 3 February 1989 freeze.

| Rootstock | Shoot injury ^z | Tree vigor ^y |
|-----------|---------------------------|-------------------------|
| OAR 1 | 1.6 ab ^x | 1.9 a |
| M.7 EMLA | 1.7 a | 1.5 ab |
| M.26 EMLA | 1.2 b | 1.0 b |
| O.3 | 1.4 ab | 1.0 b |
| M.9 EMLA | 1.3 ab | 1.5 ab |
| M.9 | 1.3 ab | 1.3 ab |
| MAC.9 | 1.6 ab | 1.8 a |
| M.27 EMLA | 1.5 ab | 1.6 ab |

^zScale 1 (no visible xylem injury) to 5 (complete kill).

^yScale 1 (healthy) to 6 (dead).

^xMean separation by LSD at the .05 level.

complicated by the fact that the trees were exposed to both types of freezes during the 1983-1984 winter, and the severity of the injury suffered during the winter probably confounded the injury in subsequent freezes. Another factor that may have influenced spur injury was the tendency for 'Starkspur Supreme Delicious' to "runt out" on this rootstock when cropped heavily (4).

Based upon defoliation tests for determining vegetative maturity and artificial freezing tests conducted during acclimation, Fernandez (1) reported that MARK (MAC.9) apple rootstocks were able to acclimate early and tolerate below average seasonal temperatures. In artificial freezing tests conducted on 2-year-old wood sampled in early December from the Missouri planting of the study, Warmund and Slater (7) reported that 'Starkspur Supreme Delicious' wood sampled from MAC.9 trees had greater xylem injury than that M.7 EMLA, M.9 EMLA, and M.26 EMLA trees. In this study, shoot injury of the same cultivar on MAC.9 following the 11 November 1986 freeze was less than on OAR 1, M.7 EMLA, MAC.24, and M.26 EMLA, and not different from M.27 EMLA, M.9 EMLA, O.3, or M.9 (Table 3). Following the 3 February 1989 freeze, although only M.7 EMLA had statistically greater shoot injury than M.26 EMLA, the MAC.9 shoot injury rating was more similar to M.7 EMLA than M.26 EMLA (Table 5). Artificial freezing tests of rootstock shoots have shown M.7 to have a low tolerance to freezing temperatures throughout the winter, while M.9 and Robusta 5 have good tolerance early but are susceptible to low temperature stress following mid- and late-winter thaws (2). Malling 26 and MM.106 were found to be tardy in acclimating, but to have good low temperature tolerance from mid-winter into spring. Shoot injury ratings of M.7 EMLA, M.9 EMLA, M.26 EMLA, and M.9 following the 11 November 1986 and 3 February 1989 freezes tend

to support these findings. The ratings also suggest that OAR 1 responds similarly to M.7, while MAC.9, O.3, and M.27 EMLA behave similarly to M.9. Based upon the reports by Fernandez (1), and Warmund and Slater (7), and the results from this study, it appears that MAC.9 induces early acclimation of the scion, but the scion does not attain a high tolerance to low temperature stress during mid- or late-winter.

Tree vigor ratings during the 1989 growing seasons showed that trees on O.3 and M.26 EMLA exhibited no symptoms of low temperature injury. It was reported that blackheart was less severe in the trunks of trees on M.26 EMLA and O.3 than on OAR 1, MAC.9, M.7 EMLA, and M.27 EMLA in the Iowa planting with a similar trend evident in Quebec (8). This suggests that O.3 and M.26 EMLA have good overall hardiness when tested under field conditions.

Literature Cited

1. Fernandez, G. E. 1987. Acclimation of Mark apple rootstocks under natural conditions in Minnesota. M. S. Thesis, Hort. Sci. Dept., Univ. of Minnesota.
2. Forsline, P. L. 1983. Winter hardiness of common New York apple varieties and rootstocks as determined by artificial freezing. Proc. N.Y. State Hort. Soc. 128:20-42.
3. Holubowicz, T., J. N. Cummins, and P. L. Forsline. 1982. Responses of malus clones to programmed low-temperature stresses in late winter. J. Amer. Soc. Hort Sci. 107:492-496.
4. NC-140. 1987. Growth and production of 'Starkspur Supreme Delicious' on nine rootstocks in the NC-140 cooperative planting. Fruit Var. J. 41:31-39.
5. NC-140. 1990. Early performance of 'Starkspur Supreme Delicious' on 16 rootstocks in the NC-140 cooperative planting. Fruit Var. J. 44:225-235.
6. Simmons, R., R. Hayden, P. Domoto, F. Morrison, W. Lord, R. Perry, M. Warmund, E. Stang. 1986. NC-140 1976 Cooperative apple interstem planting. Fruit Var. J. 40:108-115.
7. Warmund, M. R. and J. V. Slater. 1988. Hardiness of apple and peach trees in the NC-140 rootstock trials. Fruit Var. J. 42:20-24.
8. Warmund, M. R., D. C. Ferree, P. A. Domoto, J. A. Barden, C. A. Mullins, and R. L. Granger. 1991. Blackheart injury in 'Starkspur Supreme Delicious' on nine rootstocks in the 1980-1981 NC-140 cooperative planting. Fruit Var. J. 45:(4)219-223.