stocks had poor survival rates (only 30%). Variation due to date accounted for almost half of the variation in the model indicating that sampling date has a large effect on bud set.

To test whether origin of rootstock effects terminal bud set, a contrast was done. Two rootstock groups were formed: East Malling, Kent, England; or Poland and Russia combined. When categorized this way, there were no difference among the rootstocks. Therefore place of origin, at least with this set of rootstocks, is not a factor in terminal bud set.

M.26 EMLA set 90% of the terminal buds by the end of the sampling period. Forsline (2) found M.26 EMLA was tardy in acclimating but tolerated low mid-winter temperatures. Our results indicate that M.26 EMLA formed terminal buds at a fairly steady rate throughout the fall. Although we did not express our data on a rate basis, if total number of buds set is an indication of the beginning of acclimation, M.26 EMLA was not behind on any given date during the study compared to this group of rootstocks.

The results of this study suggest that rootstocks are able to affect the timing of terminal bud set of 'Starkspur Supreme Delicious' scions in a non-bearing orchard. Whether this in turn affects the time to vegetative maturity and the onset of acclimation remains to be determined.

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Blackheart Injury in 'Starkspur Supreme Delicious' on 15 Rootstocks in the 1984 NC-140 Cooperative Planting

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Abstract

Blackheart injury was evaluated at 25 cm above the soil surface on trees in the NC-140 'Starkspur Supreme Delicious' plantings located in Iowa (IA), Kansas (KS), Massachusetts (MA), Maine (ME), Missouri (MO), North Carolina (NC), Nova Scotia (NOS), New York (NY), Quebec (QUE), and Virginia (VA) after 10 years growth. Trees grown in IA, KS, MO and QUE exhibited the greatest amount of blackheart, whereas those grown in MA, NC, NOS, NY, and VA had the least amount of damaged xylem tissue. Overall, trees on B.9. P.2, P.16, and P.22 were more susceptible to blackheart injury than those on B.490, MAC.1, C.6, and MAC.39. Tracing the area of the discolored xylem and the total xylem area and then calculating the percent blackheart injury on a weight basis resulted in a better separation of injury among rootstocks than estimating blackheart by other methods.

Introduction

Blackheart injury is commonly observed in the xylem tissue of trees following exposure to low temperatures (13, 14, 19). Brown, discolored tissue in the xylem of branches or the trunk is the primary symptom of blackheart (14, 15, 17). Lack of vegetative growth has also been associated with blackheart injury (12). However, when <20% of the xylem is injured, the damage may not be apparent (17). with severe blackheart injury (>50% xylem discoloration), the affected tissue may not recover (17). Loss of productivity may also occur after blackheart injury, although it is not documented in the literature (13).

In an earlier study conducted by the NC-140 rootstock committee, blackheart injury in apple trees was not limited to sites that typically had very low temperatures (≤ -30°C) during winter (20). 'Starkspur Supreme Delicious' trees in rootstock trials at each test location (Ames, IA; Wooster, OH; Blacksburg, Frelighsburg, QUE.; and Crossville, TN) exhibited blackheart injury after ten years of growth. When blackheart injury was compared among rootstocks across all locations, M.7 EMLA trees had greater blackheart injury than M.26 EMLA, M.9, and O.3.

The primary objective of the present study was to evaluate blackheart injury

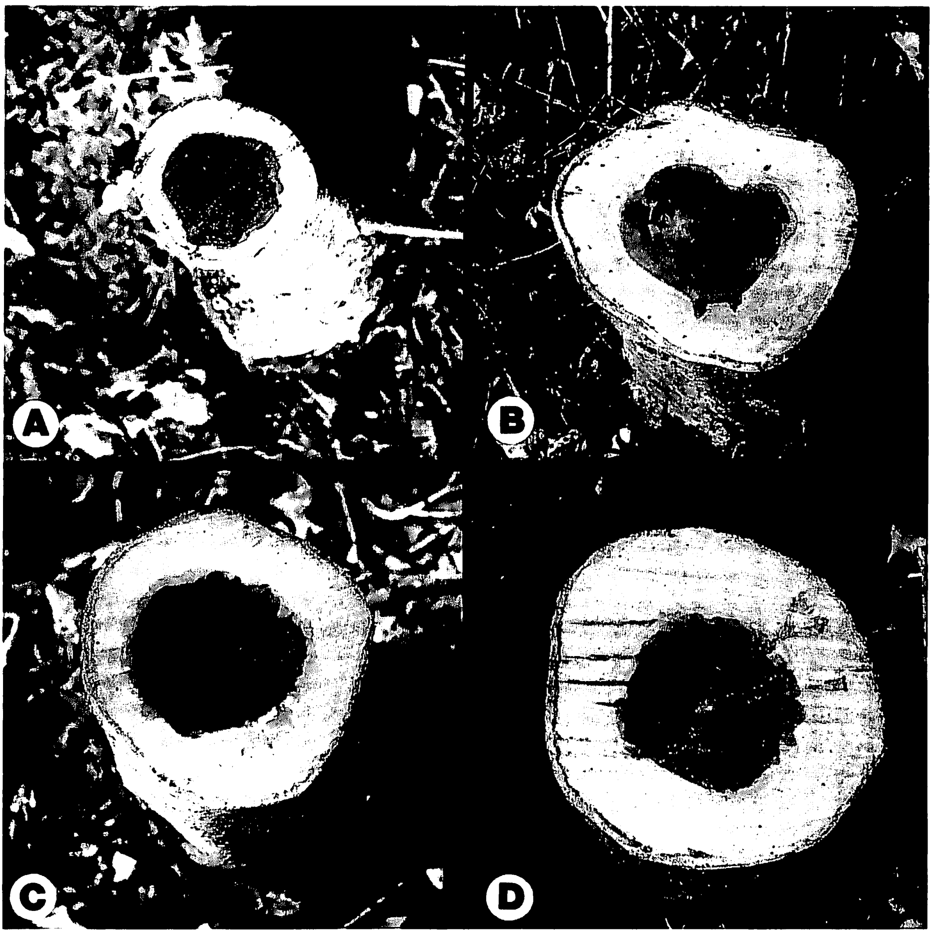

Figure 1. Blackheart injury at 25 cm from the soil surface in 'Starkspur Supreme Delicious' on A) P.22, B) seedling, C) M.4, and D) MAC.1 trees grown in MO.

in fifteen apple rootstocks budded with 'Starkspur Supreme Delicious' in the 1984 NC-140 cooperative trials located in IA, KS, MA, ME, MO, NC, NY, NOS, QUE, and VA. Three methods of assessing blackheart were also compared. In IA the susceptibility of one-year-old shoots of trees was also evaluated after three low temperature episodes.

Materials and Methods

Trees for these plantings were established in 1984 and maintained at Ames, IA; Manhattan, KS; Belchertown, MA; Monmouth, ME, New Franklin, MO;

Table 1. Minimum monthly temperatures (°C) at 10 locations from November 1984 through February 1993.[y]

	Year	IA	KS	MA	ME	MO	NC	NOS	NY	QUE	VA
November	1984	-11	-7	-8	-7	-7	-10	-7	-7	-13	-11
December	1984	-18	-14	-11	-21	-14	-12	-19	-11	-24	-14
January	1985	-29	-24	-18	-20	-26	-27	-18	-22	-25	-28
February	1985	-24	-24	-21	-24	-26	-12	-23	-18	-28	-13
November	1985	-19	-12	-5	--	-8	-4	-10	-4	-10	-6
December	1985	-32	-22	-16	--	-23	-16	-16	-16	-27	-22
January	1986	-27	-18	-21	--	-18	-19	-21	-19	-27	-23
February	1986	-27	-16	-16	--	-20	-12	-19	-17	-23	-17
November	1986	-20	-16	-11	-13	-14	-9	-11	-10	-12	-13
December	1986	-25	-13	-15	-17	-11	-9	-16	-13	-20	-12
January	1987	-23	-13	-21	-24	-21	-15	-21	-17	-23	-20
February	1987	-13	-12	-22	-23	-9	-11	-18	-25	-28	-11
November	1987	-7	-7	-9	--	-7	-7	-11	-12	-15	-8
December	1987	-17	-14	-19	--	-16	-7	-15	-18	-22	-11
January	1988	-27	-21	-30	--	-20	-20	-22	-21	-29	-18
February	1988	-30	-23	-19	--	-26	-15	-23	-19	-24	-17
November	1988	-12	-8	-7	-17	-7	-5	-6	-5	-9	-5
December	1988	-19	-12	-19	-23	-14	-10	-18	-24	-23	-15
January	1989	-16	-12	-18	-23	-10	-8	-20	-18	-26	-9
February	1989	-27	-22	-15	-21	-25	-12	-20	-16	-24	-12
November	1989	-17	-11	-16	-17	-12	-7	-11	-11	-15	-8
December	1989	-31	-15	-22	-23	-30	-17	-21	-19	-27	-23
January	1990	-13	-7	-11	-18	-10	-7	-16	-12	-21	-7
February	1990	-20	-16	-21	-23	-11	-8	-24	-19	-19	-14
November	1990	-14	-7	-6	-7	-2	-8	-5	-6	--	3
December	1990	-27	-22	-12	-14	-18	-16	-13	-14	--	-11
January	1991	-28	-21	-20	-24	-18	-17	-21	-21	--	-13
February	1991	-20	-11	-15	-22	-16	-19	-17	-17	--	-17
November	1991	-22	-16	-6	-10	-21	--	3	-18	--	-9
December	1991	-20	-11	-15	-20	-13	--	-15	-16	--	-11
January	1992	-23	-15	-19	-23	-13	-8	-19	-17	--	-14
February	1992	-12	-9	-21	-24	-9	-10	-22	-19	--	-9
November	1992	-14	-9	-7	-14	-6	-8	-12	-6	--	-8
December	1992	-20	-16	-14	-23	-13	-7	-18	-14	--	-11
January	1993	-23	-17	-17	-26	-13	-6	-28	-14	--	-8
February	1993	-28	-21	-22	-32	-19	-9	-23	-22	--	-14

[z]Trees were planted in spring 1984. IA = Iowa, KS = Kansas, MA = Massachusetts, ME = Maine, MO = Missouri, NC = North Carolina, NOS = Nova Scotia, NY = New York, QUE = Quebec, VA = Virginia.

Fletcher, NC; Kentville, NOS; Geneva, NY; Frelighsburg, QUE; and Blacksburg, VA; according to the guidelines established by the NC-140 committee (9). 'Starkspur Supreme Delicious' was the scion budded onto the following rootstocks at all locations: B.9, M.4, M.7 EMLA, M.26 EMLA, MAC.1, MAC.39, P.1, P.22, and a domestic seedling. Due to the limited number of trees at planting, additional rootstocks, including Ant.313, B.490, C.6, P.2, P.16, and P.18, were planted in IA, MA, NC, QUE, and VA. At each site, minimum air temperatures were recorded daily. In November 1993, blackheart injury was recorded for all surviving trees at each location, except QUE, where blackheart was evaluated in 1991. Trees were cut 25 cm above the soil surface to expose a cross-section of the trunk. The percentage of blackheart injury was determined by measuring the diameter of the xylem at the widest point and then taking a second diameter measurement at a 90 angle from the midpoint of the first measurement. Similar measurements were recorded for the discolored xylem tissue exhibiting blackheart injury. Diameters of the discolored xylem and the total xylem were then averaged and the area of the blackheart injury as a percent of the total xylem area was calculated using the formula for a circle.

Additional measurements were obtained from trees grown in ME and MO to compare the methods of determining blackheart injury. For one method, the outline of the discolored xylem and total xylem of trees were traced and measured with leaf area meters (LI-COR, Lincoln, NE). The area of the blackheart injury was then calculated as a percent of the total xylem area. For another method, the discolored xylem and total xylem were also traced on paper, cut out, and then weighed. The percent blackheart injury was then calculated on a weight basis. Data from all trials were subjected to analysis of variance and means were separated by a least significant difference (LSD) test.

Table 2. Percent blackheart injury of 'Starkspur Supreme Delicious' on 15 rootstocks planted in the 1984 NC-140 cooperative rootstock trial at 8 locations.[z]

Rootstock	IA	KS	MA	ME	MO	NC	NOS	NY	QUE	VA	Avg[y]
Seedling	42.1	41.2	11.6	22.8	37.8	1.5	15.4	15.9	47.2	10.8	21.5
P.18	37.9	--	13.1	--	--	0.4	--	15.9	52.5	12.3	24.1
Ant.313	40.5	--	11.8	29.8	--	3.2	--	17.5	49.4	12.5	23.4
B.490	36.0	--	11.0	20.9	--	0.9	--	13.5	47.9	9.8	20.2
MAC.1	38.9	43.5	8.0	17.9	33.4	3.0	16.7	12.4	42.5	8.4	19.3
M.4	37.9	40.9	16.0	29.5	28.7	4.6	27.7	11.8	45.1	18.1	22.5
M.7 EMLA	36.6	41.8	9.3	44.7	36.4	0.0	10.9	14.6	44.0	10.8	21.8
P.1	39.1	47.0	13.9	30.1	40.0	5.4	20.6	20.2	41.6	14.4	23.4
M.26 EMLA	31.3	36.8	17.3	32.1	48.0	22.0	7.3	12.4	35.0	13.3	23.7
C.6	30.1	--	10.2	24.3	--	6.0	--	14.7	44.2	14.4	20.5
MAC.39	29.7	46.1	8.7	19.4	40.1	17.2	4.6	9.7	38.6	10.4	20.5
B.9	36.7	56.7	13.5	35.2	45.3	15.0	12.5	19.0	42.0	24.6	26.4
P.2	37.6	--	8.8	19.3	--	25.8	--	15.0	41.1	28.9	25.6
P.16	31.5	--	15.2	--	--	--	--	10.7	44.7	28.7	26.9
P.22	43.5	32.4	12.8	27.1	55.7	11.5	5.2	10.3	46.7	35.2	28.0
LSD (0.05)	5.5	8.6	NS	NS[z]	NS	11.5	NS	7.5	NS	9.8	4.2

[z]Blackheart injury was determined by averaging the diameters of the discolored xylem (measured in two directions) and the diameters of the total xylem of each tree and then calculating the area of the blackheart injury as a percent of the total xylem area. IA = Iowa, KS = Kansas, MA = Massachusetts, ME = Maine, MO = Missouri, NC = North Carolina, NOS = Nova Scotia, NY = New York, QUE = Quebec, VA = Virginia.

[y]Avg = mean injury from sites that had all 15 rootstocks. Data from KS, MO, and NOS not included in this mean.

Results and Discussion

Low temperature extremes were recorded at most locations in January and December 1985, February 1988, and December 1989 (Table 1). Another severe low temperature episode occurred in IA, KS, and MO in early November 1991 before trees were acclimated. After a period of moderate rainfall and warm temperatures in late October, which prolonged vegetative growth, the temperature fell rapidly from 2°C to -11°C in MO and many fruit trees in commercial orchards were injured. From 1984 through 1993, the sites that generally recorded the coldest temperatures were IA, MO, and QUE.

Blackheart injury was observed in trees at all sites (Table 2). The greatest blackheart damage (>36%) occurred in trees grown in IA, KS, MO, and QUE. ME trees averaged 27% blackheart, whereas those grown in MA, NC, NOS, NY, and VA had the least amount of damaged xylem tissue (< 17%).

In IA, seedling, Ant.313, P.1, and P.22 trees had greater blackheart injury than M.26 EMLA, C.6, MAC.39, and P.16 trees. Although P.22 had >42% of the xylem discolored in the trunk when measured in 1993, the terminal shoots of these trees had very little damage after low temperature episodes in November 1986, February 1989, and November 1992 (Table 3). When early freezes occurred in Iowa in November 1986 and 1992, terminal shoots of seedling, P.18, M.4, and M.7 EMLA trees exhibited greater tissue injury than those of C.6, B.9, P.2, P.16, and P.22 trees. Following a low temperature episode in February 1989, terminal shoots of seedling, MAC.1, and M.4 trees were more susceptible to cold injury than M.26 EMLA, MAC. 39, B.9, P.2, P.16, and P.22 shoots. Additionally, B.9 shoots had less tissue injury than those on all other rootstocks.

In KS, trees on P.1 and B.9 had more blackheart injury than those on M.26 EMLA and P.22 (Table 2). However, only three trees on P.22 survived in 1993 and were measured. There was no evidence that mortality was associated with disease in these trees. Although the reason for tree loss is unknown, P.22 trees had the poorest survival of any of the rootstocks planted in Kansas (9).

Many of the trees grown in NC had minimal blackheart injury (Table 2). Trees on M.26 EMLA and P.2 had greater blackheart than those on seedlings, P.18, Ant.313, B.490, MAC.1, M.4, M.7 EMLA, P.1, and C.6. Blackheart injury was not observed in any of the M.7 EMLA trees.

In NY, the percentage of discolored xylem tissue in trees of all root stocks was ≤ 20% (Table 2). Apparently, the low temperature (-25°C) recorded in February 1987 did not cause a large amount of xylem injury in trees. By fall 1993, P.1 and B.9 trees had more blackheart than those on MAC.39, P.16, and P.22. However, there was a 70% loss of P.22 trees at this location (9). In the VA planting, trees on B.9, P.2, P.16, and P.22 had greater blackheart injury than those of all other rootstocks, except M.4.

Table 3. Injury ratings of one-year-old shoots of 'Starkspur Supreme Delicious' on various rootstocks planted in Ames, IA 1n 1984.[z]

Rootstock	Nov. 1986	Feb. 1989	Nov. 1992
Seedling	2.10	1.75	2.30
P.18	2.45	1.73	2.43
Ant. 313	2.34	1.69	1.90
B.490	1.95	1.70	1.97
MAC.1	1.75	1.75	2.30
M.4	2.31	1.75	2.30
M.7 EMLA	2.40	1.55	2.28
P.1	2.08	1.63	1.78
M.26 EMLA	1.50	1.38	2.07
C.6	1.36	1.43	1.55
MAC.39	1.85	1.25	1.83
B.9	1.43	1.00	1.45
P.2	1.29	1.25	1.71
P.16	1.50	1.25	1.30
P.22	1.25	1.25	1.10
LSD (0.05)	0.37	0.34	0.43

[z]Rating scale = 1 (no oxidative browning in xylem) to 5 (100% browning injury).

Rootstocks did not differ in blackheart injury in MA, ME, MO, or NOS when the percent blackheart injury was calculated from the diameters of the discolored xylem. The reason for the lack of significance among rootstocks at these locations may be attributed to the method of estimating blackheart injury. When tracings of the discolored tissue and the total xylem area were obtained from trees grown in ME and MO and were used to calculate the percent blackheart, there were statistical differences in injury among rootstocks (Table 4). With this method, M.7 EMLA and B.9 trees exhibited more blackheart injury than MAC.1, MAC.39, and P.2 trees in the ME planting. When methods of measuring blackheart injury ratings were compared from tracings in MO, the calculation based on tracing weight of the discolored tissue as a percent of the tracing weight of the total xylem area provided a greater separation of injury among rootstocks ($P = 0.007$) than that based on the area of the tissue as measured by the leaf area meter ($P = 0.01$). When injury in MO was measured by the weight of the tracings, trees on P.22 had greater blackheart than those on M.4, MAC.1, and B.9 (Table 4, Fig. 1).

To compare blackheart injury among sites, data were pooled from all sites that had fifteen rootstocks (Table 2). Trees on B.9, P.2, P.16, and P.22 were more susceptible to blackheart injury than those on B.490, MAC.1, C.6, and MAC.39.

Various methods have been used to evaluate the susceptibility of apple rootstocks to low temperature injury Several researchers (3, 5, 14) have evaluated injury by subjecting root stocks to controlled freezing tests in the laboratory to simulate low temperature episodes in the field. In one study, where various rootstocks were exposed to 3, 5, or 10°C for 10 days in January or in February, B.9 rootstocks deacclimated more rapidly than M.9, P.2, P.22, and M.26 (3). Other researchers (4, 11) evaluated tree and scion survival in the field following extremely cold winters. In field observations in Poland, P.2 and P.22 trees had greater resistance to low temperatures than P.1 and P.16 (4, 22). Based upon the results of laboratory and field studies, Quamme (14) ranked the "winter hardiness" of several apple rootstocks by the following classification: Antonovka seedling, B.9, P.2, P.22, and P.18 were very hardy; M.26, MM.111, P.1 were moderately hardy; M.4, M.9, MM.106 and P.16 were tender; and M.7 was very tender.

Some researchers (14, 18) have reported that the rootstock did not influence the low temperature tolerance of the scion. In British Columbia, Quamme (14) found that B.9, B.490, M.4, M.9, and O.3 did not affect the

Table 4. Percent blackheart injury calculated from tracings of the discolored xylem and total xylem area of trees grown in Maine (ME) and Missouri (MO).

Rootstock	% Blackheart injury (cm²)[z] ME	% Blackheart injury (cm²)[z] MO	% Blackheart injury (g)[y] MO
Seedling	23.6 (0)	36.5	36.9
Ant. 313	24.7 (0)	--	--
B.490	21.6 (0)	--	--
MAC.1	20.2 (0)	28.6	32.0
M.4	31.3	29.0	29.0
M.7 EMLA	41.3 (30)	31.4	34.0
P.1	32.2 (0)	38.4	49.6
M.26 EMLA	32.1 (0)	45.6	42.5
C.6	26.8 (30)	--	--
MAC.39	17.5 (90)	41.7	47.4
B.9	35.1 (0)[x]	34.9	30.0
P.2	20.0 (60)	--	--
P.22	23.2 (40)	47.5	50.0
LSD (0.05)	14.2	15.0	17.8

[z]Blackheart injury was determined by tracing the outline of the discolored xylem and the total xylem and obtaining their area using a leaf area meter. The area of the blackheart injury was then calculated as a perent of the total xylem area.
[y]Blackheart injury was determined by tracing the outline of the discolored xylem and the total xylem and obtaining their weight. The percent blackheart injury was then calculated on a weight basis.
[x]Value in parentheses is the percent tree loss in ME in November 1993.

susceptibility of 'Starkspur Supreme Delicious' to low temperature injury. In contrast, others (3, 6, 8, 16, 20, 21) have reported an effect of the rootstock on the scion. Rootstocks, such as M.26 and MM.106 (20) retarded acclimation in the fall, whereas Mark induced early acclimation (Hoover, Warmund, unpublished data). In the present study, results from IA indicated that terminal shoots of B.9, C.6, P.2, P.16, and P.22 trees had less tissue injury than those on P.18, M.7 EMLA, M.4, and seedling trees after exposure to severe low temperatures in November 1986 and 1992. The reason that B.9 and other trees grown in British Columbia did not influence the susceptibility of the scion to low temperature injury may be that trees were most likely exposed to different temperature extremes preceding evaluations and the length of exposure may have varied. Crop load prior to low temperature stress can also have an influence on hardiness (2, 7).

The blackheart measured in the 'Starkspur Supreme Delicious' trees was apparently an indication of sub-lethal xylem injury. This confirms earlier work in which trees with <50% xylem injury recovered from the low temperature injury (17). The greatest percentage of blackheart injury was observed in P.22 trees grown in MO (Fig. 1). Although >50% of the xylem of P.22 trees exhibited blackheart (Table 4), these trees produced fruit and increased in trunk cross-sectional area annually (Warmund, unpublished data).

It is interesting to note that the four most dwarfing rootstocks included in this study (10) had a large percentage of blackheart injury when data were analyzed across all states. However, MAC.39 and C.6 trees, which were slightly less dwarfing than B.9 (10), had significantly less blackheart injury than B.9, P.22, P.2, and P.16 trees. Seedling trees, which were the largest in the trial, did not differ in blackheart injury from C.6 or MAC.39 trees. Based on these results, a clear relationship between tree vigor and blackheart can not be established. Tree mortality also is not apparently related to blackheart injury in the surviving trees. In ME, all tree losses were attributed to low temperature injury (Table 4). However, MAC.39 trees in ME had high mortality (90%), but relatively little blackheart injury (18%) when measured on a weight basis (Table 4). Moreover, B.9 trees had 100% survival, but exhibited a relatively high percentage of blackheart injury (35%).

In spite of the apparent lack of association between blackheart injury and tree size or mortality, the comparison of blackheart injury among trees on various rootstocks at the termination of the NC-140 trial is a useful assessment of trunk damage caused by low temperature injury. As trees acclimate in the field in the fall, tissue hardening begins in the terminal shoots and proceeds downward. The portion of the trunk near the soil surface is the last part of the tree to harden. Thus, the lower part of the trunk is the least cold tolerant portion of the tree and is a sensitive indicator of low temperature injury (1).

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Performance Potential and Stability of 15 Apple Rootstocks as Affected by North American Growing Sites Over the Period 1984-1993[1]

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Abstract

Stability analysis models were developed by the method of joint linear regression for the cumulative performance of 15 apple rootstocks evaluated in replicated trials in 29 sites located across North America over a period of 10 years. Stability analysis provides a simple graphical basis to compare rootstocks based both on mean performance and on the stability, or consistency, of that performance across sites for a given trait. Models were developed for cumulative tree growth (based on trunk cross-sectional-area), cumulative yield per tree. and cumulative yield efficiency (yield per trunk cross sectional-area). Rootstocks followed a trend varying from low mean potential with high stability across sites, to high mean potential with low stability across sites for all three performance variables. However, no rootstock demonstrated a simultaneous improvement in both mean potential and stability of tree performance in contrast to models developed previously for the 1980-1989 NC-140 apple rootstock trial.

Introduction

Apple tree growth habit, fruit yield and fruit quality are strongly affected by choice of rootstock (2, 3, 14), making rootstock selection a critical aspect

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