list of possible rootstock choices on the basis of desirable horticultural traits (lack of suckering, need for support, etc.) for the specific site and the management system desired. Further results from current and future NC-140 rootstock trials will increase our understanding of these interactions and will improve our ability to use these models as an aid to making rootstock recommendations for specific sites.

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Abnormalities in 'Starkspur Supreme Delicious' on Nine Rootstocks in the 1980-81 NC-140 Cooperative Planting

NC-140[1]

Abstract

'Starkspur Supreme Delicious' on MAC.24, OAR 1, M.7 EMLA, M.26 EMLA, O.3, M.9 EMLA, M.9, Mark, and M.27 EMLA were planted at 27 sites in the United States and Canada in 1980-81. During the 10 years of the trial, biotic and abiotic abnormalities occurred. Some were confined to one location while others were more widespread. An outbreak of fire blight (*Erwinia amylovora* Burr) developed in the Virginia trial. Although there was no significant effect of rootstock on the severity of infection initiated in the scion, tree losses varied with rootstock. Tree losses ranged from 67% and 50% on M.26 EMLA and O.3, respectively, to 0 to 20% for the other rootstocks. In Arkansas, Internal Bark Necrosis occurred; trees on M.27 EMLA and Mark were most severely affected, followed by M.26 EMLA and O.3. The least affected trees were on OAR 1. A growth proliferation occurred on essentially all Mark rootstocks in 7 locations. A swelling was located on the rootstock shank, at the ground line and below, with no apparent relationship to the bud union.

[1]Cooperators shown in Table 1.

Introduction

In addition to tree size control, precocity, and yield, other aspects of rootstock performance are important. This paper summarizes data and observations made by several researchers involved with the 1980/81 NC-140 Cooperative Rootstock Planting (14). The primary emphasis of this paper is on fire blight, internal bark necrosis, and a growth proliferation on the rootstock shank, each of which occurred at one or more of these plantings.

Apple cultivars vary widely in their susceptibility to fire blight [*Erwinia amylovora* (Burr)]. After an extensive literature review, Van der Zwet and Keil (20) reported the 'Delicious' is most often classified as resistant to fire blight. Of the rootstocks used in

Table 1. Cooperators and site locations.

State	Cooperator(s)	Planting Location
AR	C. R. Rom and R. C. Rom	Fayetteville
CA	W. C. Micke and R. H. Tyler	Watsonville
IL	D. B. Meador	Urbana
MT	N. W. Callan	Corvallis
OH	D. C. Ferree	Wooster
PA	L. D. Tukey	University Park
VA	J. A. Barden and K. S. Yoder	Blacksburg
WA	B. H. Barritt	Wenatchee

the 1980/81 NC-140 trial, Van der Zwet and Keil (20) classified their susceptibility to fire blight as follows: M.7, light; M.27, moderate; M.9, severe; and M.26, very severe. Both Mark and O.3 have M.9 parentage and both have fire blight susceptibility similar to M.9 (6, 15). Susceptibility of MAC.24 and OAR 1 to fire blight is not well defined.

An unknown apple disease reported in an Arkansas Experiment Station bulletin in 1912 (9) was eventually identified and described by Berg and Clulo (2, 3) as internal bark necrosis (IBN), manganese toxicity, or apple measles. Ferree and Thompson (7) indicated that IBN is related to low soil pH and that symptoms appear early in the life of the tree, late in the growing season, and on wood which is one-year-old or older. Monus and Toth (11) recently suggested an association of IBN symptom development with anaerobic soil conditions. There are numerous reports of varying cultivar susceptibility; Ferree and Thompson (7) and Cooke (5) indicated that genetic factors are involved. Lehova (10) reported that trees on M.7 had more IBN than those on M.4 rootstocks.

Since the early years of widespread propagation and testing of the Mark (MAC.9) rootstock, it has become apparent that this rootstock is subject to a growth proliferation on the rootstock shank (1, 15). Neither the exact cause nor the long term effects of this proliferation on tree growth and cropping are known (1).

Materials and Methods

General

In 1980 and 1981, 'Starkspur Supreme Delicious' apple trees on M.27 EMLA, M.9, M.9 EMLA, Mark (MAC.9), M.26 EMLA, O.3, OAR 1, M.7 EMLA, and MAC.24 were planted at 27 sites in the United States and Canada. The experimental design was a randomized complete block with 10 replications. In most locations, 5 replications were planted in 1980 and 5 replications in 1981. At some sites, all 10 replications were set in 1981. More detailed descriptions are presented in NC-140 (14).

During the 9-10 years of data collection in these plantings, observations were made on various aspects of tree performance. After the 1989 growing season several cooperators removed the trees and examined below-ground as well as the aerial tree structure.

Fire blight–Virginia

During mid-June to early July 1987, an outbreak of fire blight occurred in the planting at Blacksburg, VA. Infections were first observed about 6-8 weeks after full bloom and it is unlikely that open flowers were the point of entry. Strikes were apparent on most of the trees in the planting and many trees had rootsuckers which also had strikes. No control measures were

taken. In early October, prior to leaf fall, each tree was rated on a scale of 1 to 5 as follows: 1, no fire blight strikes; 2, 1-5 strikes; 3, 6-10 strikes; 4, 11-20 strikes; and 5, 21 or more strikes. Tree deaths occurring between July 1987 and October 1988 were very likely caused by fire blight. The tree death data were compared by Chi Square for the comparison of proportions from many samples (8).

Internal Bark Necrosis–Arkansas

Samples of the Linker loam soil collected at a depth of 2.5-20 cm. indicated an average soil pH of 4.9 in 1982 and 4.8 in 1983. The pH samples from 2.5-20 cm and 20-45 cm depths were 4.9-5.4 in 1987 and 4.7-5.2 in 1988. Organic matter levels ranged from 0.6-1.0%.

Typical symptoms of internal bark necrosis (IBN) were first observed in late 1982. Subjective observations were made during the spring in 1983-1987 and 1989 using a scale of 1-5. From 1983-1986 a rating of 5 indicated an IBN severity leading to tree death. In 1987 and 1989 the rating scale was revised to a system relating to IBN effects on tree growth and productivity. A rating of 5 indicated serious reductions in fruit production, and some shoot death, but no tree death. In the formative years, IBN symptom expression was greatest on the trunks and scaffolds; after 1985, symptom expression was primarily on one or 2-year-old growth. Data were analyzed by general linear models procedures of SAS (18).

Growth proliferation on rootstock shank–multistate

As trees in the 1980/81 NC-140 plantings were removed, cooperators were encouraged to evaluate the severity of growth abnormalities on the rootstock shank. Each tree was rated as to the presence or absence of the growth proliferation as well as the percent of the trunk circumference affected. Since some cooperators chose not to destroy their trees after 10 years and other did not take data, we report results for 7 states.

Results and Discussion

Fire blight–Virginia

The ratings of fire blight severity in 1987 in Virginia did not differ among trees on the 9 rootstocks (Table 2). Tree losses due to fire blight in 1987 and 1988, however, were strongly influenced by the rootstock. Losses of trees on M.26 EMLA and O.3 were 67 and 50%, respectively (Table 2). Losses of trees on other rootstocks ranged from 0 to a high of 20% on Mark. There have been reports of the rootstock affecting fire blight severity, but these have usually been with young trees (4, 13, 19). In such cases, earlier flowering on precocity-inducing rootstocks has coincided with an outbreak of fire blight. Scions on rootstocks such as M.26 which induce earlier flowering have therefore shown more infections than those on more vigorous rootstocks (4).

Table 2. Effects of rootstock on the severity of fire blight [*Erwinia amylovora* (Burr.)] infections in 'Starkspur Supreme Delicious' trees in 1987 and tree death due to fire blight in 1987 and 1988 (Virginia), NC-140 1980-81 planting.

Rootstock	Fire blight rating October, 1987[z]	Tree death (%) 1987 and 1988[y]
MAC.24	2.0	0 b[x]
OAR 1	2.1	0 b
M.7 EMLA	2.2	0 b
M.26 EMLA	2.2	67 a
O.3	1.8	50 a
M.9 EMLA	2.0	0 b
M.9	2.2	10 b
Mark	1.7	20 b
M.27 EMLA	1.7	0 b
	n.s.	

[z]Fire blight rating scale: 1, no fire blight strike; 2, 1-5 strikes; 3, 6-10 strikes; 4, 11-20 strikes; 5, 21 or more strikes.
[y]Cumulative tree losses due to fire blight as % of total trees.
[x]Mean separation by Duncan's Multiple Range Test, .05 level.

Rootstocks rated as very susceptible to fire blight include M.26 (17, 20) and O.3 (6). Consequently, an attempt was made to identify the point of entry of the fire blight organism into the trees on M.26 EMLA and O.3 which died. Of the 6 trees on M.26 EMLA, 3 had rootsuckers and of these, 2 had fire blight strikes on the rootsuckers. All 5 trees on O.3 which died had strikes on rootsuckers. All M.26 EMLA trees had burr knots on the above-ground rootstock. It is proposed that entry of the fire blight bacteria occurred partially through rootsuckers but that entry through burr knots was also likely in M.26 EMLA. This hypothesis is supported by data from Rom (16).

This experience in Virginia confirms that fire blight can be a very serious problem with susceptible rootstocks, even when the scion cultivar may be resistant. Commercially, all available means to minimize fire blight infections should be used. In addition to bactericides, susceptible rootstocks should be planted with only a short (2-3 cm) section of rootstock above the soil line to minimize the formation of burrknots. Rootsuckers must also be controlled. Although Virginia was the only location with a serious outbreak of fire blight in these trials, the problem may have been greater if a more fire blight-susceptible scion cultivar had been used.

Internal Bark Necrosis-Arkansas

Trees on M.27 EMLA and Mark exhibited the greatest severity of IBN symptoms while those on M.26 EMLA and O.3 ranked next in severity (Table 3). IBN severity on trees with M.9 and M.9 EMLA rootstocks increased over time. The least susceptible trees were those on OAR 1 rootstocks.

At the termination of the study in 1989, all surviving trees, with the exception of 3 on OAR 1 rootstocks, showed some manganese phytotoxicity. Fifty percent of the trees with M.27 EMLA and 40% with Mark had died from IBN (Table 4). Mortality, when it occurred, came early in the life of the orchard.

Root absorption of Mn from the acid soil, in which this planting was placed, was a common characteristic of all rootstocks evaluated. Being a 'Delicious' sport, 'Starkspur Supreme

Table 3. Ratings of internal bark necrosis (IBN) symptom expression on 'Starkspur Supreme Delicious' on nine clonal apple rootstocks (Arkansas), NC-140 1980-81 planting.

	IBN rating in the following years					
Rootstock	1983[z]	1984[z]	1985[z]	1986[z]	1987[y]	1989[y]
MAC.24	1.1b[x]	1.2c	2.0cd	1.8cd	2.3bc	2.7c
OAR 1	1.0b	1.1c	1.1d	1.1d	1.0d	1.3d
M.7 EMLA	1.1b	1.3c	2.0cd	1.8cd	2.6abc	2.8c
M.26 EMLA	2.5a	2.4b	2.9abc	2.1c	3.3abc	3.3bc
O.3	1.5b	2.7b	2.6abc	2.0c	2.9abc	3.7abc
M.9 EMLA	1.0b	1.3c	2.2cd	2.6bc	2.6bc	3.9abc
M.9	1.3b	1.9bc	2.5bc	3.2ab	3.2abc	4.2ab
Mark	2.9a	3.8a	3.6a	3.7a	3.5ab	4.5a
M.27 EMLA	3.1a	4.4a	3.7a	3.2ab	3.8a	3.6abc

[z]IBN rating scale used in 1983-1986: 1, no IBN symptoms; 2, mild symptoms; 3, moderate symptoms; 4, severe symptoms; 5, symptoms causing tree death.
[y]IBN rating scale used in 1987 and 1989: 2, no IBN symptoms; 2, mild symptoms; 3, moderate symptoms; 4, severe symptoms; 5, seriously reduced production, some shoot death, but no tree death.
[x]Mean separation within columns by Duncan's Multiple Range Test, .05 level.

Table 4. Tree mortality and extent of internal bark necrosis (IBN) symptom expression of 'Starkspur Supreme Delicious' on nine clonal apple rootstocks (Arkansas), NC-140 1980-81 planting.

	Tree Mortality (%)[z]						Trees Showing IBN (%)					
Rootstock	1983	'84	'85	'86	'87	'89	1983	'84	'85	'86	'87	'89
MAC.24	0	0	0	0	0	0	20	20	30	40	60	100
OAR 1	0	0	0	0	0	0	0	10	10	10	10	70
M.7 EMLA	0	0	0	0	0	0	10	40	60	60	80	100
M.26 EMLA	10	10	10	10	10	10	80	90	100	100	100	100
O.3	0	0	0	0	0	0	20	70	70	100	100	100
M.9 EMLA	0	0	0	0	0	0	0	30	90	100	100	100
M.9	0	0	0	0	0	0	30	50	80	100	100	100
Mark	20	30	30	30	40	40	80	100	100	100	100	100
M.27 EMLA	40	40	40	40	40	50	100	100	100	100	100	100

[z]Cumulative tree loss. Losses other than to IBN, not considered.

Delicious' is known to be an IBN susceptible cultivar (7, 13). Symptom expression was greatest with the most dwarfing rootstocks, frequently resulting in early tree death. While not fatal with the more vigorous rootstocks, symptom expression increased with tree age. Based on subjective evaluation, IBN became deleterious to tree growth and production as these trees matured. Lehova (10) reported the susceptibility of M.7 to IBN. Our data show that M.7 EMLA is significantly less susceptible to IBN than most of the other rootstocks in this study.

This research points out that, when grown in soils of low pH, clonal dwarfing rootstocks can exacerbate IBN symptoms in susceptible apple cultivars. It likewise reaffirms the need to adjust soil pH prior to setting an orchard.

Growth proliferation on rootstock shank

Cooperators in 7 states collected data on growth proliferations on the rootstock shank as trees were removed at the end of 10 years (Fig. 1). In all of these sites trees on Mark exhibited growth abnormalities on the rootstock shank; in all but Pennsylvania, 100% of the Mark rootstocks were affected (Table 5). One cooperator noted swelling on older roots. No abnormalities were found on other rootstocks at any of the 7 sites. The conspicuous swelling of the rootstock shank at the below the soil line usually extended completely around the rootstock, and had a gnarled surface (Fig. 1, 2, 3). The diameter of the swelling was up to twice that of the above-ground portion of the rootstock shank. Where roots were removed, the shanks had a club-like appearance (Figs. 1, 3). There

Table 5. Effect of rootstock on growth proliferation on rootstock shank of 10-year-old 'Starkspur Supreme Delicious' trees in several states, NC-140 1980-81 planting.

	Trees showing growth proliferation (%)						
Rootstock	CA	IL	MT	OH	PA	VA	WA
MAC.24	---	0	0	0	0	0	0
OAR 1	---	0	0	0	0	0	0
M.7 EMLA	---	0	0	0	0	0	0
M.26 EMLA	0	0	0	0	0	0	0
O.3	0	0	0	0	0	0	0
M.9 EMLA	0	0	0	0	0	0	0
M.9	0	0	0	0	0	0	0
Mark	100	100	100	100	86	100	100
M.27 EMLA	---	0	0	0	0	0	0

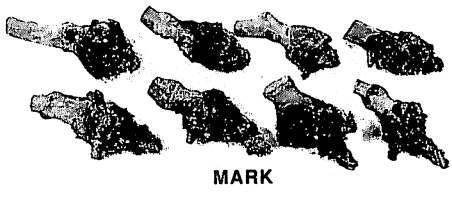

Figure 1. Shanks from 'Starkspur Supreme Delicious'/Mark with roots removed. Trees were dug after 10 years in the orchard (Wooster, OH).

Figure 2. Shanks of 'Starkspur Supreme Delicious'/Mark dug after 9 years in the orchard, Blacksburg, VA. (See Figure 3 for other views of same tree.)

was no apparent relationship between the swelling and burrknots which also occurred on Mark above the ground line (see Fig. 2) or with the graft union which was kept 2-5 cm above the soil line. Some researchers noted that the affected Mark rootstocks exhibited extensive fine root development from the swollen area. One cooperator the roots originating from the enlarged shank as having nodules.

The major symptoms exhibited on Mark appeared to be somewhat similar to those of two bacterial diseases, crown gall and hairy root. Crown gall, incited by *Agrobacterium tumefaciens*, causes galls on the rootstock shank and roots and occasionally on the stem (12). Hairy root, caused by *Agrobacterium rhizogenes*, induces extensive proliferation of adventitious roots (12). In some cases, both crown gall and hairy root can occur in the same tree (12).

Figure 3. Shanks of 'Starkspur Supreme Delicious'/Mark dug after 9 years in the orchard, Blacksburg, VA. (See Figure 2 for tree prior to root removal.)

The exact cause of the growth proliferation on the shank of Mark rootstocks remains unclear. Although these symptoms are somewhat similar to both crown gall and hairy root, isolation of these organisms was not attempted in any of the trees described herein. Clarification of the exact cause and long term effects of this growth proliferation deserves attention by both plant pathologists and pomologists.

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Blackheart Injury in 'Starkspur Supreme Delicious' on Nine Rootstocks in the 1980-1981 NC-140 Cooperative Planting

WARMUND, M. R., D. C. FERREE, P. DOMOTO, J. A. BARDEN, C. A. MULLINS, AND R. L. GRANGER

Abstract

Blackheart was measured at 25 cm above the soil surface in trees in the NC-140 'Starkspur Supreme Delicious' plantings located in Iowa, Ohio, Quebec, Tennessee, and Virginia after at least ten years of growth. Trees at all five locations exhibited blackheart injury. However, trees grown in Iowa, under the coldest climatic conditions, had the greatest amount of blackheart. Trees grown in Ohio and Quebec were intermediate in blackheart injury, while those grown in Tennessee and Virginia, under mild winter conditions, had less injury. Overall, M.7 EMLA and OAR.1 trees had greater blackheart injury than M.9 and Ottawa 3 (O.3) trees. All MAC.24 trees were killed in Iowa in 1986 due to a November freeze and all M.27 EMLA trees in Ohio were dead by the spring of 1989 due to severe frost heaving conditions.

Introduction

Blackheart is a type of winter injury in which xylem ray parenchyma cells are killed and vessel elements are occluded, but the cambial tissue remains uninjured (22). The typical symptom of blackheart is xylem browning, which is the result of the supercooled fraction of intracellular water freezing in the ray parenchyma cells (18, 19). Steinmetz (21) reported that if 50% or more of the parenchyma cells are killed, branches are not likely to remain alive, but if 20% or less are injured, recovery will generally occur. Thus, even though these injured trees may exhibit xylem browning internally, they may appear uninjured or produce limited vegetative growth in subsequent growing seasons (15). Blackheart injury has also been associated with a loss of productivity, although this has not been documented in the literature (18).

Blackheart is a common problem in many genera of woody plants in both temperate and sub-tropical regions of