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Performance of 'Starkspur Supreme Delicious' on 9 Rootstocks at 27 Sites Over 10 Years

NC-140[1]

Abstract

In 1980-1981, 'Starkspur Supreme Delicious' trees on 9 rootstocks were planted at 27 sites in the United States and Canada according to guidelines established for cooperative testing by the NC-140 technical committee. Over the years, 7 plantings were removed because of excessive tree loss due to voles (NY), winter injury (MN, MT), or other factors (CO, MO, NC, SC). The following sites averaged less than 10% tree loss over the 10 years of the study: MA, OR, ONT, WA, WI and PA. Trees on M.7 EMLA survived well at all sites. IA lost all trees on MAC.24 to winter injury, while 8 sites had no losses with this rootstock. Based on trunk cross-sectional area (TCA), trees at the following sites were the largest: GA, IL, IN, ONT, CA and VA and smallest in WA, MA and QUE. Height of trees on M.26 EMLA and O.3 varied more than other rootstocks of comparable size (M.9 EMLA, M.9 and MAC.9). CA averaged much higher yield efficiencies than the other sites, because of high yield efficiencies on MAC.24, M.7 EMLA and OAR 1. Tree size in MA was small, but yields were high. Generally, trees in CA and MA had high production efficiencies as measured by yield/TCA. Production efficiencies were lowest in AR, IA and QUE. In addition to CA and MA, O.3 was very efficient in OR, ONT and WI.

Evaluations of potential apple rootstock and interstem systems have been made independently by researchers in many locations. Lack of common genetic materials, spacings, and handling procedures have made comparison of the results from these independent studies difficult. Because of lack of information growers have planted many scion/rootstock combinations at inappropriate spacings for their soils or poorly adapted to their area.

In order to develop comparable rootstock information, the NC-140 rootstock-scion committee initiated a series of test plantings to evaluate new and untested rootstock and interstem candidates by means of cooperative plantings. Through uniform cooperative testing a number of fruit growing areas, investigators could benefit from the knowledge of scion/rootstock performance under a range of soil types and climatic conditions as well as their own. Through the diversity of climatic conditions at various sites, it should be possible to expose scion/rootstock-combinations to a wide range of test conditions in a relatively short period of time.

Results of earlier NC-140 cooperative plantings have been published (2, 3, 4, 5). The test plantings reported here were established in 1980-1981 to compare performance of 9 different rootstocks with a common scion cultivar, 'Starkspur Supreme Delicious,' in 27 apple producing areas of the United States and Canada.

Materials and Methods

The cooperators and sites as well as the experimental design were described in the previous paper (4). The relative performance among sites will be compared in this paper.

The trees were exposed to -36°C in QUE and to -34°C in MN, IA, and WI (Table 1). The CA site had the mildest winter temperatures and generally the trees were not exposed to a killing frost in the fall. The trees were exposed to temperatures of 40°C and above at

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Table 1. Yearly maximum and minimum temperatures (°C) at each site.

	1981		1982		1983		1984		1985		1986		1987		1988		1989		Avg.	
Site	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
AR	36.1	-21.6	36.1	-20.5	38.0	-23.1	40.0	-26.0	39.4	-25.5	43.0	-18.0	38.0	-13.0	38.0	-25.0	37.0	-24.0	38.4	-19.0
CA	34.4	- 2.2	35.0	- 1.9	39.4	-12.7	36.7	- 1.1	24.5	3.6	32.2	- 2.2	41.1	- 2.8	34.0	- 4.0	32.0	- 6.0	34.4	- 2.1
GA	33.8	-16.1	32.2	-22.8	36.1	-17.2	32.2	-14.4	32.8	-26.7	36.1	-18.9	35.0	-12.2	38.0	-17.0	32.0	-11.0	34.5	-17.7
IL	33.3	-23.0	33.9	-30.6	37.2	-14.4	35.0	-28.9	33.9	-31.1	35.0	-23.9	38.0	-14.0	39.0	-23.0	35.0	-23.0	37.5	-23.6
IN	33.9	-21.7	33.6	-28.6	37.8	-17.2	34.0	-27.0	33.3	-31.1	34.0	-23.0	34.1	-25.8	39.1	-22.6	34.7	-21.5	30.9	-17.7
IA	34.5	-23.8	34.0	-33.3	38.1	-27.8	36.7	-30.6	38.3	-29.4	32.8	-32.2	35.6	-25.0	38.9	-30.0	36.5	-27.2	36.2	-28.9
KS	37.8	-23.3	38.9	-26.1	41.6	-19.4	41.0	-28.0	40.0	-25.0	39.0	-18.0	41.1	-16.1	35.0	- 9.0	39.4	-30.6	39.5	-20.2
KY	35.0	-19.4	35.6	-26.7	38.0	-10.0	37.0	-26.0	34.0	-27.0	38.0	-19.0	38.3	-16.1	39.4	-16.1	35.0	-11.7	36.3	-18.0
MA	34.0	-24.4	31.7	-24.0	34.4	-20.6	35.0	-27.2	31.1	-22.2	32.8	-20.6	36.0	-22.0	37.0	-30.0	34.0	-19.0	34.0	-23.3
MI	32.8	-26.1	32.2	-26.1	34.0	-17.0	32.2	-24.4	33.0	-26.6	33.0	-23.0			38.0	-26.0	33.0	-22.0	32.5	-23.9
OH	31.7	-23.3	30.0	-21.1	33.0	-17.2	31.1	-26.7	35.6	-28.3	33.3	-18.9	33.9	-20.0	40.0	-21.0	35.3	-16.0	33.6	-21.4
OR	43.8	- 4.0	38.1	-16.5	33.0	- 5.0	32.5	-12.0	36.5	— 8.4	35.0	-10.0	38.0	- 5.0	41.0	- 4.5	34.0	-14.0	36.9	- 7.7
ONT	32.4	-26.3	26.8	-10.9	34.0	-17.7	32.8	-24.4	25.7	-11.2	33.0	-23.6	35.0	-23.0	37.7	-20.7	32.6	-20.7	30.7	-18.5
PA	33.9	-22.7	32.8	-27.8	35.6	-20.6	32.8	-24.4	35.0	-21.2	32.8	-17.8	35.6	-26.7	39.0	-22.0	37.0	-18.0	35.2	-22.1
QUE	31.5	-36.0	33.0	-31.0	31.5	-26.5	30.5	-26.0	30.0	-28.0	29.0	-27.3	30.5	-27.5	36.0	-18.0	32.0	-27.0	31.5	-27.5
VA	34.3	-19.0	30.5	-24.6	37.2	-17.2	32.2	-22.2	32.2	-27.8	33.0	-23.0	35.0	-20.0	36.0	-18.0	31.0	-15.0	33.9	-16.9
WA	41.1	-15.8	38.6	-23.5	37.2	-14.4	39.7	-25.6	39.4	-20.0	39.4	-20.6	38.0	-14.0	25.0	-31.0	24.0	-36.0	29.1	-22.1
WI	31.6	-25.0	31.0	-34.0	34.4	-20.5	32.0	-30.0	32.0	-30.0	33.8	-23.8	35.6	-24.4	37.2	-23.9	33.8	-23.3	33.5	-26.1
MO	36.0	-24.0	37.2	-28.1	39.4	-16.7	40.0	-23.3	35.6	-26.1									47.1	-29.6
UT	38.8	-11.7	38.1	-23.0	37.8	-11.7	37.2	-22.2	38.3	-21.7	41.0	-16.0	35.0	-13.9	38.0	-15.0			38.0	-16.9
TN	33.0	-22.0	31.0	-27.0	36.0	-24.0	33.0	-24.0	34.0	-32.0	33.9	-21.7	34.0	-17.0	38.0	-18.0	32.0	-17.0	33.8	-23.5
MN	32.0	-30.0	36.0	-34.0	36.0	-24.0	34.0	-35.5											34.5	-30.0
NC	37.8	-15.6	34.4	-15.6	39.6	- 7.0	35.0	-15.0	36.4	-21.5									36.6	-14.9
MT	35.6	-29.4	33.9	-29.4	35.0	-20.0	35.0	-21.1	36.7	-28.4									35.2	-25.7
SC	37.2	- 1.7	35.0	-18.0	40.0	-11.0			36.0	-19.0									37.1	-12.4
CO	35.6	-14.4	35.6	-19.4	35.0	-16.0	35.0	-22.0	37.0	-24.0									35.6	-19.2

the following sites: AR, CA, KS, MO, OH, UT, SC, and WA. In 1988, the east and mid-west experienced a drought and the usual high temperatures associated with it. Unfortunately, soil descriptive data were not available for the sites. The general relationships of environment to yield and survival of these trees will be discussed in companion papers.

Results and Discussion

A factor which may be of great significance is the survival and longevity of trees of different rootstocks. The planting in NY was lost the first year due to severe vole damage. In subsequent years, severe winter injury eliminated plantings in MN and MT (3). Plantings in CO, MO, NC and SC were also removed due to excessive tree loss. Of the remaining sites (Table 2), the following experienced rather severe tree losses over the 10 years of the study: GA (43%), IN (40%), TN (40%)M and AR (33%). Overall, the following sites averaged less than 10% tree loss over 10 years: MA, OR, ONT, WA WI and PA. All sites except IA and WA lost some O.3 trees with UT losing all trees on this rootstock. Trees on M.7 EMLA and OAR 1 survived well at all sites. No tree loss occurred with M.9 EMLA at the following sites: MA, MI, OR, WA and WI, while severe losses occurred in TN (90%) and GA (70%). Trees on M.26 EMLA survived well at all sites except VA, GA, and IN. The loss of M.26 EMLA in IN was the result of fireblight and phytophthora infections. Nine sites had 20% or less loss of trees on M.27 EMLA,

Table 2. Tree loss (%) over 10 years of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	Average
AR	30	10	0	20	50	30	50	50	60	33
CA	0	0	0	0	30	30	20	20	50	17
GA	30	0	0	70	80	70	70	30	40	43
IL	20	0	0	0	20	20	30	20	90	22
IN	30	10	0	40	70	50	50	70	40	40
IA	100	30	0	10	0	40	20	10	0	23
KY	20	0	10	20	50	30	50	10	40	26
MA	0	0	0	0	10	0	0	0	0	01
MI	30	0	10	10	50	0	10	0	10	13
OH	0	0	10	0	10	40	10	0	80	17
OR	0	0	0	0	10	0	10	0	0	02
ONT	0	0	0	0	20	10	0	0	0	03
PA	0	0	0	0	20	10	10	30	0	08
QUE	40	30	20	0	50	30	10	0	20	22
VA	0	0	0	70	50	10	10	20	10	19
WA	0	0	0	0	0	0	10	10	10	03
WI	10	0	0	0	20	0	0	0	20	06
Planted 1981										
UT	50	0	20	10	100	20	0	10	40	28
TN	10	30	0	10	80	90	20	50	70	40
Average	19.5	5.8	3.7	13.7	37.8	25.3	20.0	17.4	30.5	19

[z]Please see accompanying papers for further details on tree losses.

while the following states had significant losses with this rootstock: CA (50%), AR (60%), TN (70%), OH (80%), and IL (90%). Fourteen sites had 20% or less loss of trees on M.9, while 4 sites had losses of 50% or more. Trees on MAC.9 performed similarly to trees on M.9 with 14 sites having 20% or less loss and 3 losing 50% or more of their trees. AR and IN had similarly large losses of both of these rootstocks. IA lost all trees on MAC.24 to winter injury, while 7 other sites had no losses with this rootstock.

Much of the tree loss in many sites may have been the result of severe fluctuating and low mid-winter temperatures which occurred in the early 1980's (Table 1). The 5 sites with the greatest tree losses and a number of these that withdrew from the trial due to several losses were located in more southern or mid-western areas, areas which often experience relatively severe temperature fluctuations during the dormant season.

The 'Starkspur Supreme Delicious' scion used in this study is quite resistant to fireblight (*Erwinia amylovora*), but the rootstocks have variable resistance to fireblight. No positive verification of tree losses due to fireblight were noted except in VA and IN. If a fireblight susceptible scion such as 'Jonathan,' 'Rome Beauty,' 'Gala,' 'Granny Smith,' 'Fuji' or 'Jonagold' had been used, the results could be different, especially in some areas of the central

Table 3. Trunk cross-sectional area (cm^2) in 1989 of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	Means	LSD .05	C.V.
AR	123.0	104.0	85.6	83.8	44.9	51.2	45.0	28.0	11.9	64.2	21.8	57.3
CA	303.7	151.6	69.1	19.0	22.6	53.1	18.0	15.9	---	81.6	66.9	123.3
GA	284.3	164.4	142.1	96.3	78.0	38.3	22.5	27.6	9.5	95.6	42.5	92.8
IL	213.4	137.0	95.8	77.7	56.6	46.5	34.3	32.9	---	86.8	32.3	71.4
IN	226.9	120.9	132.2	86.7	61.7	60.6	27.5	38.5	7.8	84.7	32.6	79.4
IA	---	109.6	97.3	88.8	60.8	48.5	42.4	31.7	13.4	61.6	15.8	55.1
KY	174.9	92.9	72.9	72.8	46.2	39.3	42.4	18.7	7.9	63.0	25.6	79.1
MA	---	52.4	69.5	45.1	35.8	23.3	14.0	33.0	6.3	34.9	8.9	59.2
MI	116.1	67.7	78.7	58.5	38.6	31.8	25.1	23.3	11.9	50.2	14.0	66.2
OH	166.2	80.3	73.3	58.0	41.4	41.1	22.5	28.1	13.0	58.2	16.3	79.5
OR	143.5	55.1	105.7	84.2	40.7	40.0	37.5	34.3	10.4	61.3	18.4	68.4
ONT	233.5	84.2	122.8	94.5	73.0	58.7	37.7	27.7	12.7	82.7	21.9	80.0
PA	102.8	76.8	69.7	52.1	28.6	27.1	23.5	20.0	8.4	45.4	22.1	69.6
QUE	89.9	50.0	62.0	37.5	20.0	23.3	18.4	24.1	7.6	37.0	16.7	70.4
VA	219.0	111.3	137.4	64.1	46.0	51.6	35.8	33.7	11.4	78.9	25.6	83.3
WA	125.6	43.3	45.1	20.8	28.0	13.2	10.2	12.7	3.8	33.6	20.7	110.9
WI	180.9	81.1	87.3	84.7	34.0	40.2	26.9	36.3	13.6	65.0	17.8	78.9
Planted 1981												
UT	128.0	107.3	99.8	79.5	---	55.1	38.3	19.7	12.5	67.5	29.4	63.1
TN	99.1	88.0	88.0	77.6	42.3	30.8	24.6	38.3	12.0	55.6	17.0	58.3
Average	172.4a	93.6b	91.3b	67.5c	44.4d	40.7d	28.7de	27.6de	10.3e			
LSD	60.7	20.3	21.4	36.2	24.1	21.8	16.5	13.2	NS			
C.V.	37.8	36.4	29.4	34.8	36.6	32.4	35.4	27.6	27.6			

C.V. = Coefficient of variation, NS = nonsignificant; Average mean separation by Duncan's Multiple Range Test, .05%

states. The potential fireblight problem will be addressed in future studies now in the planning stages.

Based on trunk cross-sectional area (TCA), trees at the following sites were the largest: GA, IL, IN, ONT, CA, and VA. GA, CA, and VA have longer growing seasons with particularly long periods after harvest before killing frosts (Table 3) compared to many other sites. Especially fertile soils may account for more growth at other sites. Trees in WA, MA, and QUE were the smallest with the other sites intermediate. Although TCA for MAC.9 in MA was average, tree height (Table 4) and spread (Table 5) were relatively large. Trees on MAC.9 were precocious and particularly sensitive to overcropping. It appears that in many locations overcropping suppressed growth and ultimately resulted in the development of a small, senescent tree. In MA, overcropping did not significantly affect growth until the seventh growing season, and by that time trees on MAC.9 were nearly as large as trees on M.26 EMLA. The trees at WA were on a site with a replant problem. Winter injury likely contributed to the smaller tree size in QUE. The Ca site had the highest absolute variability as measured by LSD and also a high variability relative to the mean as measured by C.V. (coefficient of variation). IA, MA and TN stood out as having relatively low variation by either measure. The C.V. values for each rootstock across all sites showed that there was not much

Table 4. Tree height (cm) in 1989 of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	Means	LSD .05	C.V.
AR	409	367	348	320	268	301	286	162	160	291	40.1	29.2
CA	528	381	309	125	190	155	153	157	---	250	58.7	57.5
GA	539	445	433	408	300	225	192	186	125	317	48.0	45.5
IL	411	362	338	324	291	289	256	216	---	311	41.7	19.8
IN	438	394	375	289	187	244	178	200	105	268	49.4	42.4
IA	---	314	316	295	280	255	240	201	142	255	23.0	23.6
KY	402	327	298	298	232	247	247	175	135	262	39.0	30.6
MA	---	361	402	335	305	276	239	264	174	294	31.0	24.6
MI	386	333	347	319	234	254	234	197	162	274	35.0	27.6
OH	490	367	257	284	271	256	203	192	125	283	45.0	38.7
OR	410	308	415	345	291	272	257	243	133	297	27.0	29.4
ONT	554	373	540	462	354	305	248	174	148	351	71.0	42.2
PA	309	303	317	291	225	230	205	181	139	244	---	26.0
QUE	346	302	316	266	160	209	218	216	158	244	43.0	27.8
VA	522	436	474	337	312	313	250	268	161	341	38.0	33.9
WA	372	254	294	172	208	148	145	150	90	204	48.0	43.4
WI	394	304	329	288	195	204	178	198	130	247	25.0	34.8
Planted 1981												
UT	411	385	388	385	---	339	262	167	145	310	43.0	34.0
TN	463	403	423	397	333	244	242	258	150	324	50.0	32.5
Average	434a	354b	369b	313c	258d	251d	223de	200e	140f			
LDS .05	77	43	73	80	81	55	61	36	31			
C.V. -	16.3	14.0	17.7	24.6	21.6	19.8	17.5	18.0	15.3			

C.V. = Coefficient of variation, NS = nonsignificant; Average mean separation by Duncan's Multiple Range Test, .05%

difference relative to their mean among rootstocks. Absolute variation across sites of TCA for MAC.24 was very large and for M.9 and MAC.9 was relatively small. This was not entirely due to absolute tree size because the rootstocks producing the next largest trees, OAR 1 and M.7 EMLA, had similar LSD values which were only a third of the value for MAC.24.

Generally, tree height (Table 4) and tree spread (Table 5) followed the pattern of relative sizes shown by TCA. Height of trees on M.26 EMLA and O.3 varied more relative to the mean than other rootstocks of comparable height (M.9 EMLA, M.9 and MAC.9). At most sites, trees on M.9 EMLA and O.3 could be handled from the ground, but in ONT and VA tree height exceeded 3 m. At all sites, trees on M.27 EMLA, M.9 and MAC.9 could be easily handled from the ground. The greatest difference (337 cm) in tree height occurred with M.26 EMLA being very short in CA (125 cm) and very tall in ONT (462 cm). The next greatest difference between sites occurred with large-size trees on M.7 EMLA (283 cm) and MAC.24 (245 cm).

Since trees were spaced 3.5 x 5.5 m, tree spread was not influenced greatly by tree competition with most rootstocks. However, trees on MAC.24 exceeded 3.5 m on all sites except UT. Trees on OAR 1 had an upright growth habit and this characteristic resulted in less spread than M.7 EMLA at all sites except VA, IL, and CA. Heavy crops in CA in the last couple of years may been caused increased spread. If ranges in tree density were calculated using natural tree spread at 10 years of

Table 5. Canopy spread (cm) in 1989 of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	Means	LSD .05	C.V.
AR	382	325	335	315	269	303	278	141	114	274	58	32.7
CA	472	326	314	127	190	143	175	123	---	234	63	53.4
GA	386	240	278	250	238	192	125	171	83	218	45	40.8
IL	439	321	308	303	324	273	246	219	---	304	50	21.7
IN	403	318	345	261	334	324	238	218	74	279	104	34.4
IA	---	278	282	279	259	233	218	179	116	230	26	25.5
KY	406	306	321	299	251	259	244	161	102	261	47	34.2
MA	---	339	383	338	297	262	187	253	95	269	40	34.6
MI	364	277	297	300	261	239	217	204	123	253	46	27.1
OH	443	333	347	316	290	296	230	231	150	293	47	28.5
OR	357	292	378	325	269	278	234	267	151	283	54	23.9
ONT	519	281	451	378	374	331	262	206	109	323	54	38.7
PA	273	269	287	250	195	199	183	150	78	209	112	32.5
QUE	358	240	293	255	212	229	221	202	96	234	47	30.3
VA	511	429	423	325	324	299	253	276	139	331	39	33.4
WA	416	244	304	202	254	168	163	143	63	217	64	47.2
WI	406	278	322	304	231	261	227	234	141	267	31	27.6
Planted 1981												
UT	337	279	304	299	---	269	219	142	113	245	32	32.9
TN	385	326	339	312	258	251	220	245	141	275	34	26.7
Average	403a	300c	332b	286c	268cd	253d	218e	198e	111f			
LSD .05	88	53	70	74	87	89	70	42	30			
C.V.-	15.3	14.8	14.3	19.2	18.2	20.1	17.1	23.6	24.6			

C.V. = Coefficient of variation, NS = nonsignificant; Average mean separation by Duncan's Multiple Range Test, .05%

Table 6. Cumulative yield (kg/tree) over 10 years of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	Means	LSD .05
AR[w]	115.9	55.8	99.8	100.8	62.6	89.4	69.0	27.6	14.8	70.6	38.0
CA[y]	1363.3	611.8	440.4	95.4	161.5	92.0	130.3	100.7	---	374.4	57.0
GA	328.7	116.0	125.4	133.3	196.0	64.3	41.0	90.6	14.8	123.3	94.7
IL[y]	50.4	78.6	105.0	148.9	161.5	172.9	109.9	117.1	---	118.0	38.8
IN[w]	179.4	150.0	230.1	245.5	178.3	223.0	104.0	126.7	12.0	161.0	NS
IA	---	59.0	89.2	102.4	99.3	75.2	77.4	60.4	27.5	73.8	35.9
KY[y]	150.9	70.9	145.4	142.7	85.8	113.7	86.5	41.8	20.6	95.3	51.3
MA[w]	---	122.3	282.3	242.2	213.1	158.5	76.9	189.5	34.7	164.9	54.0
MI	62.4	54.0	98.6	99.9	112.0	86.3	71.7	78.0	22.8	76.1	30.2
OH[y]	267.9	113.4	214.3	181.9	167.7	172.3	97.7	136.5	66.0	157.5	67.6
OR	345.6	152.7	370.2	257.6	182.8	154.3	130.3	180.0	40.6	201.5	86.0
ONT[y]	455.8	199.2	383.2	321.0	298.3	289.8	165.0	128.6	44.3	253.9	37.8
PA[y]	21.4	60.3	69.7	77.3	42.8	59.7	38.8	36.6	7.1	45.9	17.6
QUE	27.7	22.4	33.4	36.9	45.2	40.1	29.7	34.8	11.0	31.2	18.7
VA[y]	177.9	153.5	190.9	205.7	154.6	136.3	108.2	149.4	36.1	145.8	113.5
WA	123.0	51.8	108.2	48.0	72.6	31.0	24.8	25.3	7.3	54.6	33.6
WI	323.6	163.9	284.9	291.8	149.9	183.5	126.3	159.4	49.0	192.4	69.0
Planted 1981											
UT	17.0	21.0	99.0	99.6	---	103.5	69.1	55.7	28.8	61.7	32.7
TN	65.6	45.3	73.5	113.1	56.0	80.6	71.8	57.6	24.3	65.2	19.8
Average[z]	241.0a	119.1bcd	186.5ab	153.4abc	136.2bc	122.7bcd	85.5cd	95.8bcd	27.1d		
LSD	265.4	87.3	90.6	72.2	69.9	41.5	31.0	31.0	36.1		

[z]Mean separation by Duncan's Multiple Range .05%.
[y]Fruit load adjusted by thinning either chemically or by hand.
[w]Fruit was not thinned.

age as the in-row spacing, and spread + 2.5 m as between row spacing, the following ranges in tree density t/ha would be appropriate for the following rootstocks based on this study: O.3, 513-1196 t/ha; M.7 EMLA, 316-666 t/ha; M.9 EMLA, 537-1782 t/ha; M.26 EMLA, 421-2092 t/ha; M.27 EMLA, 1652-5076 t/ha; M.9, 681-2136 t/ha; MAC.9, 688-2182 t/ha; MAC.24, 250-700 t/ha; and OAR 1, 350-850 t/ha.

It can be seen from these density ranges, which vary as much as 3-fold within each rootstock and wide ranges in tree mortality that cooperative testing is important to show the differences and allow growers to select optimum rootstock/scion combinations and planting distances based on site results similar to their own soil and climatic conditions. Barritt (1) suggests that 988-2964 trees/ha (400-1200 t/a) are appropriate densities for modern intensive orchard systems in WA. At sites with the weakest growth and given better than average expectations of tree survival the following rootstocks appear to have the most promise for intensive systems such as slender spindle, trellis and central axe with spur-type 'Delicious' as the scion: O.3, M.9 EMLA, M.26 EMLA, M.9 and MAC.9. M.27 EMLA probably would be too small to be productive on sites with the weakest growth. On sites that produced the most vigorous trees, tree density would need to be reduced or additional training techniques employ-

Table 7. Cumulative yield/trunk cross-sectional area (kg/cm²) over 10 years of 'Starkspur Supreme Delicious' apple trees on 9 rootstocks in the NC-140 rootstock trial planted in 1980-81.

Site Planted 1980	MAC.24	OAR 1	M.7 EMLA	M.26 EMLA	O.3	M.9 EMLA	M.9	MAC.9	M.27 EMLA	LSD
AR	0.96	0.52	1.18	1.16	1.57	1.77	1.57	0.57	1.44	0.49
CA	4.19	4.34	6.41	4.83	6.95	3.79	7.24	6.30	---	---
GA	1.08	0.67	1.68	1.37	2.54	1.72	1.81	3.24	1.43	0.73
IL	0.26	0.57	1.30	2.06	2.87	3.70	3.14	3.48	---	0.58
IN	0.87	0.87	1.61	3.36	3.34	3.99	4.34	3.89	1.31	---
IA	---	0.49	0.89	1.11	1.63	1.45	1.81	1.89	1.99	0.35
KY	0.84	0.73	1.97	1.96	1.81	2.89	2.34	2.20	2.42	0.55
MA	---	2.30	4.03	5.36	6.09	6.76	5.48	5.62	6.10	1.54
MI	0.56	0.78	1.28	1.75	2.88	2.77	2.87	3.38	2.68	0.61
OH	1.51	1.35	2.93	3.26	3.91	4.16	4.28	5.06	5.06	2.52
OR	2.36	2.93	3.57	3.13	4.65	3.88	4.12	5.52	3.82	1.17
ONT	1.96	2.34	3.11	3.42	4.17	4.98	4.37	4.58	4.29	0.85
PA	0.20	1.27	1.67	2.04	2.77	3.75	1.60	2.12	0.90	---
QUE	0.30	0.43	0.55	1.03	2.44	1.83	1.57	1.45	1.31	0.89
VA	0.73	1.42	1.45	3.25	3.33	3.63	3.97	4.47	3.32	0.95
WA	1.06	1.16	2.35	2.31	2.53	2.34	1.85	1.98	1.88	0.72
WI	1.68	2.02	3.23	3.44	4.29	4.38	4.66	4.42	3.56	0.55
UT	0.13	1.33	1.03	1.73	---	1.98	1.92	2.84	2.35	---
TN	0.78	0.53	0.84	1.51	1.27	2.59	2.93	1.90	2.00	0.48
Average[z]	1.15c	1.37c	2.16bc	2.53ab	3.28ab	3.28ab	3.25ab	3.43a	3.39a	
LDS	0.73	1.55	1.06	0.98	2.96	1.61	1.99	1.39	0.58	

[z]Mean separation by Duncan's Multiple Range .05%.

ed to reduce growth. The percentage difference from the site with the highest calculated trees/ha to the lowest was 80% for M.26 EMLA and ranged from 53-59% for the other rootstocks. It is recognized that canopy spread would be reduced by tree-to-tree competition or training in an intensive orchard situation thus rendering some of these rootstocks adaptable to intensive plantings at more sites. However, since many cultivars would have more vigor than 'Starkspur Supreme Delicious,' it is clear that new rootstocks with greater size control will be needed particularly on sites that induce the most growth. Conversely, in areas where certain rootstocks are poorly adapted and unacceptable tree losses can occur, selection of a more vigorous rootstock with good survival characteristics such as M.7 EMLA will necessitate modification of both tree density and training system to approach more intensive orchard system densities.

Generally, cumulative yield/tree followed tree size with the largest trees, on MAC.24, producing almost eight times the yield of the smallest trees on M.27 EMLA (Table 6). CA averaged much higher yields per unit trunk area than other sites because of high yields on MAC.24, M.7 EMLA, and OAR 1 compared to other sites. CA reported that trees on M.7 EMLA produced better than OAR 1 in the early years, but appeared to "runt out," while OAR 1 continued to maintain good shoot growth. Trees in WA and QUE did not grow well, resulting in very low yields. Tree size in MA was also rather small, but yields were relatively high, par-

ticularly with O.3 and MAC.9. Of the 17 original plantings, those in CA and MA had by far the highest yield efficiencies: 5.51 and 5.21 Kg/cm^2 TCA, respectively (Table 7). Plantings n Ont. OR, OH, WI had yield efficiencies of 3.5-3.8. Sites with the lowest yield efficiencies were AR, Que, IA. The unusually heavy cropping in MA is at least partially explained by the lack of any fruit thinning. Most plants were thinned chemically or by hand. Trees on the larger rootstocks MAC.24, OAR 1 and M.7 EMLA were much more efficient in CA than any other site, but in general, the least efficient overall.

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Long-Term Performance Potential and Stability Across 10 Environments for Nine Apple Rootstocks Tested in the 1980-81 NC-140 Trial[1]

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Abstract

Nine apple rootstocks grafted with 'Starkspur Supreme Delicious' were evaluated in 19 sites over 10 years by the NC-140 Regional Project as a randomized complete block with 10 replications at each site. Effect of site on rootstock trunk cross-sectional-area (TCSA), cumulative yield per tree (Yc), and cumulative yield efficiency (YEc = Yc/TCSA) were evaluated. Rootstock differences in average performance and in stability of performance across environments (mean and slope through the mean across sites) were evaluated by stability analysis. MAC.24 had highest mean Yc and TCSA with the lowest stability, giving this rootstock the highest predicted Yc and TCSA in best sites, and lowest in poor sites. M.27 EMLA was the opposite, with low potential and high stability in Yc and TCSA. M.27 EMLA and MAC.9 had high potential and low stability in YEc, OAR 1, M.7 EMLA, and especially MAC.24 were the opposite, and O.3 and M.26 were average in both respects for YEc. M.9 had high potential YEc with average stability, while M.9 EMLA was unique in having both high potential and high stability in YEc.

Introduction

The relative ranking of yield, growth, and other performance variables of perennial tree fruit selections have frequently been determined in evaluations conducted at a single site (2). However, environment x genotype interactions have rarely been evaluated in perennial crops (8), and never in tree fruit. We know that apple trees grow larger and produce greater yields in good sites relative to poor sites, and that there is a wide range of apple rootstock effects on tree size and productivity within a site. The assumption is often made that these rootstock effects vary on an absolute base among sites, but not on a relative base (no significant rootstock x environment interaction). However, in many annual

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