Journal American Pomological Society 55(3):138-145 2001

Location Affects Performance of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome Beauty' Apple Trees on Five Rootstocks Over Ten Years in the 1990 NC-140 Cultivar/Rootstock Trial[1]

W. R. Autio, J.L. Anderson, J.A. Barden, G.R. Brown, R.M. Crassweller,
P.A. Domoto, A. Erb, D.C. Ferree, A. Gaus, P.M. Hirst,
C.A. Mullins, and J.R. Schupp

Abstract

At 12 sites in the United States, trials were established in 1990 which included four apple (*Malus* X *domestica* Borkh.) cultivars ('Smoothee Golden Delicious', 'Nicobel Jonagold', 'Empire', and 'Law Rome Beauty') in all combinations on five rootstocks (M.9 EMLA, B.9, Mark, O.3, and M.26 EMLA). After ten growing seasons, rootstock and cultivar interacted significantly with location to affect trunk cross-sectional area (TCA), tree height, canopy spread, yield per tree, yield efficiency, and fruit size. Further, at many locations rootstock interacted significantly with cultivar to affect these parameters. In most cases, however, these interactions contributed minimally to the variability among rootstocks or among cultivars as they affected performance. Survival varied greatly by location, ranging from 43% in Kentucky to 100% in Massachusetts, Pennsylvania, and Virginia. Where tree loss occurred, more 'Rome' trees died than the other cultivars, and more trees on O.3 died than trees on the other rootstocks. Tree size also was affected by location, with TCA ranging from 48 cm^2 on average in Massachusetts to 131 cm^2 in Kansas. In general, largest trees were on M.26 EMLA, and the smallest were on Mark or on B.9. 'Jonagold' trees were consistently among the largest, and 'Empire' trees were among the smallest. Cumulative yield per tree (1992-99) ranged from 1.49 in Utah to 4.17 in Ohio, and the most yield efficient trees were those on B.9 and those on Mark. 'Jonagold' trees were consistently among the most yield efficient. Average fruit size (1992-99) ranged from 141 g in Tennessee to 224 g in Massachusetts. M.26 EMLA and M.9 EMLA generally resulted in the largest fruit, and Mark and O.3 resulted in the smallest. 'Rome' and 'Jonagold' fruit were consistently among the largest, and 'Empire' fruit were among the smallest.

Few researchers have studied the relative differences in tree performance caused by rootstock at different locations. One project (2) observed the effects of rootstock on similarly managed 'McIntosh' apple trees at ten locations exhibiting different soil-moisture conditions. Rootstock and location did not interact to affect TCA, but interacted to affect yield per tree and yield efficiency. Specifically, M.7A resulted in significantly greater yields per tree than did M.26, M.9/MM.106, and M.9/MM.111 only at dry locations. Trees on M.7A produced similar or lower yields at moderate and wet locations. Likewise, trees on M.7A were similarly yield efficient to trees on the other rootstocks at dry locations, but were significantly less efficient than the other trees at moderate and wet locations. M.9/MM.111 had similar yield efficiency to trees on M.9/MM.106 except on the wettest sites where trees on M.9/MM.106 were less efficient. It is important to have knowledge of this type of variation in performance when making recommendations to apple growers.

As part of the 1980 and 1984 NC-140 Apple Rootstock Trials, NC-140 (4, 6) reported location effects and presented performance of a number of rootstocks at different locations; however, little attention was paid to determining the significance of

[1]Massachusetts Agricultural Experiment Station Paper 3291. At participating state agricultural experiment stations, funding was provided by RRF NC-140. Further we wish to thank the International Dwarf fruit Tree Association for their financial support of this project and Stark Bro's Nurseries, Louisiana, MO for donating the trees.

the variation in rootstock performance caused by location factors. One reason for this lack of attention is the complexity of location-to-location differences, including soil, temperature, moisture, pests, and horticultural management.

NC-140 trials expose rootstocks to a wide range of conditions to evaluate performance in the most thorough manner possible. However, it is not possible to control many factors across location. Acknowledging this problem, the objective of this portion of the 1990 NC-140 Cultivar/Rootstock Trial was to assess in a rigorous statistical manner the interaction of rootstock and location, cultivar and location, and rootstock and cultivar within location.

Materials and Methods

Details regarding the initiation of this trial were presented previously (7), and the specific details of data collection were reported in the first article of this series (1). Data collection and analyses were organized by the Massachusetts site cooperator. Analyses of variance were conducted with the MIXED procedure of the SAS software package (SAS Institute, Cary, NC). For the results presented in this article, cultivar, rootstock, location, and the interactions among these main effects were considered fixed effects. Differences among locations were significant for all measurements, and least-squares means were separated by Tukey's HSD (P = 0.05). For all measurements, the interactions location x rootstock, location x cultivar, and location x cultivar x rootstock, were significant. Because of the inherent differences in variance among sites and for ease of analysis, cultivar, rootstock, and cultivar-by-rootstock effects were analyzed individually by location. Differences among least-squares means of cultivars and among least-squares means of rootstocks were then assessed by Tukey's HSD (P = 0.05). In cases where significant interactions between cultivar and rootstock existed, the sums of squares for rootstock and the interaction were repartitioned into units representing the effects of rootstock within each cultivar utilizing the SLICE option of the LSMEANS statement. Where rootstock within cultivar was significant, a t test (P = 0.05) was used to separate rootstock means; however, a Bonferroni adjustment was applied prior to determining the significance of each pair-

Table 1. Survival, tree size, yield, and fruit size as affected by location after 10 years in the 1990 NC-140 cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Location	Tree survival (%)	Trunk cross-sectional area (cm^2)	Tree height (m)	Canopy spread (m)	Cumulative yield per tree (kg, 1992-99)	Cumulative yield efficiency (kg/cm^2TCA (1992-99)	Fruit size (g, 1992-99)
Colorado	97 a	63 cde	3.3 cd	3.0 cde	101 e	1.77 fg	182 de
Indiana	72 b	77 c	3.1 de	3.3 bc	115 de	1.68 fg	166 g
Iowa	97 a	75 c	3.5 bc	3.1 cd	97 e	1.51 g	188 d
Kansas	91 a	131 a	4.1 a	3.9 a	273 b	2.87 d	172 efg
Kentucky	43 c	81 bc	2.6 f	2.7 e	153 cde	2.26 ef	180 def
Maine	88 ab	49 de	2.9 ef	3.8 a	155 cd	3.25 c	187 d
Massachusetts	100 a	48 e	3.1 de	3.1 cd	183 c	3.97 ab	224 a
Ohio	73 b	82 bc	3.4 bc	3.3 bc	310 a	4.17 a	221 ab
Pennsylvania	100 a	62 cde	2.4 f	2.8 de	158 cd	2.64 de	170 fg
Tennessee	70 b	72 cd	3.1 de	3.0 cde	99 e	1.61 g	141 h
Utah	99 a	99 b	3.7 b	3.2 bc	128 de	1.49 g	210 bc
Virginia	100 a	101 b	3.7 b	3.4 b	340 a	3.58 bc	208 c

[z]Mean separation within columns by Tukey's HSD ($P = 0.05$).

Table 2. Survival (%) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	98 a	71 a	100 a	81 a	32 bc	—	100 a	75 a	100 a	74 a	100 a	100 a
B.9	100a	67 a	100 a	100 a	72 a	100 a	100 a	79 a	100 a	91 a	100 a	100 a
Mark	91 a	75 a	88 a	91 a	47 ab	80 a	100 a	75 a	—	91 a	100 a	100 a
O.3	100 a	63 a	96 a	96 a	13 c	77 a	100 a	58 a	100 a	43 b	92 a	100 a
M.26 EMLA	92 a	83 a	100 a	88 a	54 ab	95 a	100 a	75 a	100 a	71 a	100 a	100 a
Golden Delicious	100 a	67 b	100 a	100 a	39 b	90 a	100 a	90 a	100 a	91 a	100 a	100 a
Jonagold	97 a	67 b	90 a	90 a	25 b	82 a	100 a	73 a	100 a	73 ab	100 a	100 a
Empire	97 a	93 a	100 a	97 a	67 a	100 a	100 a	93 a	100 a	60 b	100 a	100 a
Rome	90 a	60 b	97 a	78 a	40 b	80 a	100 a	33 b	100 a	51 b	93 a	100 a

[z]Mean separation among rootstocks or among cultivars by Tukey's HSD ($P = 0.05$).

Table 3. Trunk cross-sectional area (cm^2) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	62 bc	103 ab	86 b	125 b	78 b	—	45 bc	88 b	70 b	89 ab	111 ab	114 b
B.9	49 cd	47 cd	48 c	114 b	51 bc	31 b	40 bc	54 c	47 c	67 b	74 c	61 c
Mark	34 d	45 d	41 c	39 c	35 c	44 ab	36 c	56 c	—	27 c	79 bc	70 c
O.3	69 b	75 bc	91 b	158 b	90 ab	57 ab	54 ab	94 ab	64 b	73 b	107 abc	118 b
M.26 EMLA	104 a	122 a	112 a	216 a	134 a	59 a	68 a	122 a	100 a	105 a	123 a	145 a
Golden Delicious	67 ab	81 a	78 a	124 ab	91 a	51 a	46 ab	89 a	70 ab	67 b	108 a	90 b
Jonagold	74 a	86 a	83 a	163 a	81 a	55 a	53 ab	92 a	73 ab	94 a	101 a	109 a
Empire	57 b	83 a	61 b	114 b	58 a	45 a	41 b	68 b	59 b	62 b	114 a	99 ab
Rome	56 b	64 a	82 a	121 ab	81 a	40 a	54 a	83 ab	78 a	66 b	72 b	108 a

[z]Mean separation among rootstocks or among cultivar by Tukey's HSD ($P = 0.05$).

Table 4. Tree height (m) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	3.5 b	3.7 a	3.9 a	4.2 b	2.8 ab	—	3.0 abc	3.6 a	2.6 ab	3.4 a	4.0 ab	3.9 a
B.9	3.2 b	2.5 c	3.1 b	4.0 b	2.3 bc	2.4 b	2.9 bc	3.0 b	2.5 b	3.2 a	3.3 bc	3.1 b
Mark	2.3 c	2.6 bc	2.7 c	2.8 c	2.0 c	2.6 b	2.6 c	3.0 b	—	2.3 b	3.2 c	3.1 b
O.3	3.3 b	3.1 ab	3.9 a	4.5 ab	2.6 abc	3.1 a	3.3 ab	3.5 a	2.5 b	3.2 a	4.0 ab	3.9 a
M.26 EMLA	4.0 a	3.5 a	4.0 a	5.1 a	3.0 a	3.1 a	3.5 a	3.6 a	2.8 a	3.5 a	4.2 a	4.2 a
Golden Delicious	3.4 a	3.5 a	3.7 a	4.3 a	2.5 ab	2.8 a	3.0 a	3.7 a	2.4 b	3.2 a	4.0 a	3.7 a
Jonagold	3.4 a	3.0 a	3.4 b	4.3 a	2.5 ab	2.9 a	3.2 a	3.2 b	2.4 b	3.2 a	3.7 a	3.7 a
Empire	3.2 a	3.1 a	3.2 b	4.0 a	2.3 b	2.8 a	2.8 a	3.3 ab	2.4 b	3.0 a	3.9 a	3.5 a
Rome	3.2 a	2.9 a	3.7 a	3.9 a	2.9 a	2.7 a	3.2 a	3.2 b	3.2 a	3.0 a	3.2 a	3.7 a

[z]Mean separation among rootstocks or among cultivar by Tukey's HSD ($P = 0.05$).

Table 5. Canopy spread (m) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	3.2 ab	3.7 a	3.4 a	3.9 b	2.9 a	—	3.1 bc	3.3 ab	3.0 b	3.1 a	3.5 a	3.6 a
B.9	2.7 b	2.8 bc	2.8 b	3.9 b	2.5 ab	3.4 b	3.0 bc	2.9 b	2.8 b	3.0 a	3.0 ab	3.0 b
Mark	2.0 c	2.5 c	2.3 c	2.6 c	2.1 b	3.5 b	2.8 c	3.0 b	—	2.1 b	2.8 b	2.9 b
O.3	3.2 ab	3.4 ab	3.4 a	4.2 ab	2.7 ab	4.0 ab	3.3 ab	3.5 a	3.0 b	3.2 a	3.4 a	3.7 a
M.26 EMLA	3.6 a	3.9 a	3.6 a	4.8 a	3.1 a	4.1 a	3.5 a	3.8 a	3.2 a	3.4 a	3.5 a	3.9 a
Golden Delicious	2.9 a	3.1 a	3.1 ab	3.7 a	2.6 a	3.9 a	3.3 a	3.4 ab	3.0 b	2.9 ab	3.4 ab	3.3 b
Jonagold	2.9 a	3.1 a	3.2 a	3.9 a	2.6 a	4.1 a	3.2 ab	3.1 b	2.9 b	3.3 a	3.2 ab	3.4 ab
Empire	3.0 a	3.7 a	2.9 b	3.9 a	2.6 a	3.9 a	3.0 b	3.2 ab	2.8 b	3.0 ab	3.5 a	3.5 ab
Rome	3.1 a	3.3 a	3.2 a	4.0 a	2.7 a	3.2 b	3.1 ab	3.6 a	3.3 a	2.8 b	2.9 b	3.6 a

[z]Mean separation among rootstocks or among cultivar by Tukey's HSD ($P = 0.05$).

Table 6. Cumulative yield per tree(kg, 1992-99) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	109 ab	144 a	112 a	265 ab	153 ab	—	186 abc	344 a	176 ab	99 a	162 a	398 ab
B.9	90 bc	95 bc	91 b	239 b	134 bc	106 b	162 bc	254 b	142 b	111 a	131 a	268 c
Mark	67 c	68 c	75 c	185 b	88 c	152 a	155 c	251 b	—	49 b	64 b	243 c
O.3	120 a	133 ab	115 a	321 a	169 ab	189 a	217 a	327 ab	178 a	108 a	152 a	358 b
M.26 EMLA	122.a	142 a	92 b	345 a	203 a	158 a	199 ab	371 a	189 a	129 a	139 a	434 a
Golden Delicious	126 a	141 a	109 a	271 ab	181 a	151 a	172 b	365 a	145 b	129 a	153 a	291 b
Jonagold	81 b	97 bc	81 b	251 b	155 a	174 a	184 b	275 b	114 b	106 ab	123 a	360 a
Empire	48 c	96 c	98 a	236 b	131 a	134 a	154 b	260 b	108 b	82 ab	110 a	293 b
Rome	151 a	132 ab	101 a	325 a	130 a	147 a	225 a	340 ab	318 a	79 b	134 a	417 a

[z]Mean separation among rootstocks or among cultivar by Tukey's HSD ($P = 0.05$).

Table 7. Cumulative yield efficiency (kg/cm^2 TCA, 1992-99) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	1.80 a	1.54 ab	1.39 b	2.96 bc	2.33 ab	—	4.21 a	4.24 ab	2.56 b	1.25 b	1.55 b	3.62 bc
B.9	2.07 a	2.15 a	1.99 a	3.16 b	2.88 a	3.63 a	4.21 a	5.07 a	2.99 a	1.65 ab	2.12 a	4.41 a
Mark	2.04 a	1.56 ab	2.00 a	4.47 a	2.67 ab	3.39 ab	4.34 a	4.70 a	—	2.10 a	1.33 b	3.77 ab
O.3	1.75 a	1.84 ab	1.30 b	2.20 bc	1.79 ab	3.35 ab	4.16 a	3.52 bc	2.77 ab	1.60 ab	1.41 b	3.04 c
M.26 EMLA	1.24 b	1.27 b	0.84 c	1.68 c	1.57 b	2.82 b	3.05 b	3.19 c	1.85 c	1.22 b	1.89 b	3.06 c
Golden Delicious	2.04 b	1.99 a	1.61 b	2.69 a	2.16 a	3.12 a	3.79 ab	4.38 a	2.24 b	2.19 a	1.66 ab	3.32 a
Jonagold	1.22 c	1.21 b	1.16 c	2.47 a	2.32 a	3.23 a	3.63 b	3.42 a	1.68 b	1.17 b	1.49 ab	3.58 a
Empire	1.01 c	1.38 b	1.87 a	2.98 a	2.83 a	3.12 a	4.25 ab	4.25 a	1.91 b	1.40 ab	1.01 b	3.46 a
Rome	2.85 a	2.11 a	1.38 bc	3.43 a	1.69 a	3.72 a	4.32 a	4.52 a	4.35 a	1.49 ab	1.93 a	3.95 a

[z]Mean separation among rootstocks or among cultivar by Tukey's HSD ($P = 0.05$).

Table 8. Fruit size (g, 1992-99) as affected by cultivar, rootstock, and location in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Cultivar/Rootstock	Colorado	Indiana	Iowa	Kansas	Kentucky	Maine	Mass.	Ohio	Penn.	Tenn.	Utah	Virginia
M.9 EMLA	184 ab	174 a	197 a	181 ab	178 a	—	230 ab	223 ab	174 a	147 a	224 a	214 a
B.9	180 ab	169 ab	184 c	169 b	182 a	187 a	221 bc	224 a	174 a	145 a	216 a	211 ab
Mark	168 b	160 bc	178 c	152 c	172 a	185 a	219 c	218 ab	—	132 a	191 b	203 bc
O.3	181 ab	156 c	186 bc	175 ab	170 a	184 a	218 c	211 b	166 b	132 a	206 ab	198 c
M.26 EMLA	195 a	175 a	195 ab	182 a	187 a	187 a	233 a	229 a	176 a	148 a	217 a	213 ab
Golden Delicious	155 b	154 c	181 c	167 c	162 b	167 b	192 c	222 b	163 b	136 bc	204 b	185 c
Jonagold	201 a	179 b	192 b	199 a	211 a	222 a	262 b	260 a	195 a	166 a	230 a	230 b
Empire	156 b	142 d	152 d	138 d	131 c	144 c	170 d	191 c	136 c	116 c	183 c	164 d
Rome	213 a	191 a	228 a	184 b	208 a	210 a	272 a	211 b	196 a	145 ab	227 a	252 a

[z]Mean separation among rootstocks or among cultivars by Tukey's HSD ($P = 0.05$).

wise comparison (i.e., P = 0.005 was used as the critical value to declare significance).

Results and Discussion

Tree Survival. Survival varied greatly with location. Specifically, all or nearly all trees survived in Colorado, Iowa, Massachusetts, Pennsylvania, Utah, and Virginia; however, only 43%, 70%, 72%, and 73% survived in Kentucky, Tennessee, Indiana, and Ohio, respectively (Table 1). Dramatic tree loss was due primarily to fireblight infection. At locations where trees were lost, cultivar effects were similar to those reported by Autio et al. (1) for the trial overall. With the exception of Tennessee, 'Empire' trees survived to a greater extent than 'Rome' trees (Table 2). Only at two locations did rootstock affect tree loss, and rootstock effects were similar to those reported for the overall trial (1) (Table 2). Trees on O.3 survived to a lesser extent than those on B.9. Within a number of sites, cultivar and rootstock interacted to affect survival, but results were not consistent and trends were not discernable (data not shown).

The NC-140 Technical Committee (3) reported similar variability in tree survival in the 1980 NC-140 Apple Rootstock Trial. Survival ranged from 99% at some locations to only 57% at others. At locations where tree loss occurred, O.3 consistently exhibited the poorest survival.

Tree size. Tree vigor was affected significantly by location. Trees in Kansas, Virginia, and Utah had the largest TCA after 10 years, and those in Massachusetts and Maine had the smallest TCA (Table 1). Similar differences among these locations were noted in the NC-140 report on the 1984 NC-140 Apple Rootstock Trial (6).

Rootstock interacted significantly with location to affect TCA; however, the relative differences among rootstock (Table 3) were similar to those reported by Autio et al. (1) for the trial overall. Specifically,

M.26 EMLA resulted in the largest trees. O.3 and M.9 resulted in similar TCA and generally smaller trees than did M.26 EMLA. The smallest trees were those on B.9 and Mark. Other studies (2, 8, 9) reported similar relative effects of rootstock on vigor regardless of location. In this study, the only notable effect of location was the relative difference between the smallest trees and the largest trees. Locations with the overall smallest trees tended to have a smaller relative range in TCA then did locations with the overall largest trees.

Cultivar also interacted significantly with location to affect TCA (Table 3). Differences were somewhat inconsistent, but generally, 'Jonagoldi'trees were among the largest in each location, and 'Empire' trees were among the smallest. Only Utah deviated from this general trend, with 'Empire' trees being among the largest at that location.

Although the interaction of rootstock and cultivar as it affected TCA was statistically significant within a number of locations (data not shown), the relative differences among rootstocks were consistent and similar to those reported here and by Autio et al. (1) for the trial overall.

Location affected tree height and canopy spread (Table 1), and rootstock and cultivar interacted with location to affect height and spread (Tables 4 and 5). These effects were similar to those reported above for TCA; however, pruning and training appeared to compress differences.

Yield per tree. Greatest cumulative (1992-99) yields per tree were obtained in Virginia and Ohio, and the lowest were obtained in Colorado, Iowa, and Tennessee (Table 1). Similar relative differences among locations were reported by NC-140 for the 1984 NC-140 Apple Rootstock Trial (6).

Both rootstock and cultivar interacted significantly with location to affect yield per tree. Although the interaction of location with rootstock was statistically significant, differences were consistent with those reported for the trial overall (1). Trees on M.26 EMLA, O.3, and M.9 EMLA yielded the most, and those on B.9 and Mark yielded the least per tree (Table 6). Cultivar differences were somewhat less consistent across location (Table 6). Generally, however, 'Rome' trees were among the highest yielding, and 'Empire' trees were among the lowest. Yield of 'Rome' trees in Pennsylvania was two-to-three times more than other cultivars, a much more pronounced difference than measured at other locations.

As with tree size, rootstock and cultivar interacted significantly to affect yield per tree at some locations (data not shown); however, general rootstock effects were consistent and similar to those reported for this trial overall (1).

Yield efficiency. Cumulatively (1992-99), the most yield efficient trees were in Ohio and Massachusetts, and the least efficient trees were in Utah, Iowa, and Tennessee (Table 1). Again, these relative differences in location were similar to those reported by NC-140 (6).

Both rootstock and cultivar interacted with location to affect efficiency; however, little deviation from the overall effects of rootstock and cultivar (1) were seen. Specifically, trees on Mark and those on B.9 were consistently among the most yield efficient, and trees on M.26 EMLA were the least (Table 7). 'Rome' trees were consistently among the most yield efficient, and 'Jonagold' trees were consistently among the least efficient (Table 7). Rootstock also interacted with cultivar at a number of locations to affect yield efficiency (data not shown) but results did not deviate from the general effects reported here and for the trial overall (1).

Fruit Size. The largest fruit on average (1992-99) were harvested from plantings in Massachusetts and Ohio, and the smallest were harvested in Tennessee (Table 1). Both rootstock and cultivar interacted with location to affect fruit size. Rootstock effects, however, were relatively consistent and similar to those reported for the trial overall (1). Specifically, M.26 EMLA and M.9 EMLA resulted consistently in fruit in the largest category, and Mark and O.3 resulted consistently in fruit in the smallest

category (Table 8). Cultivar differences, likewise were consistent from location to location. 'Rome' and 'Jonagold' trees produced the largest fruit, and 'Empire' trees produced the smallest (Table 8). Significant interactions between rootstock and cultivar at a number of locations did not show deviation from these general effects (data not shown).

Conclusions

The results reported for the overall study conducted over 12 locations throughout the U.S. suggest that the relative importance of the interaction of cultivar and rootstock was low (1). When these results were studied further with particular attention paid to the location differences, the relative importance of the interactions of location and rootstock, location and cultivar, and rootstock and cultivar within location were all low. As noted in the previous article in this series (1), earlier NC-140 studies utilizing these rootstocks with 'Delicious' as the cultivar (4, 5) predicted relative performance adequately. Thus, future cooperative trials should compare only one cultivar. It also can be inferred from these results that a relatively small number of sites is necessary to assess rootstock effects. This study did not, however, include locations with dramatically different climatic conditions. Greater interactions between rootstock and location may have been seen if more divergent locations were included, as observed by Autio et al. (2) with a range of soil-moisture conditions. When planning future rootstock trials, more attention should be paid to obtaining locations expressing the full breadth of climatic conditions experienced within the apple-growing regions of North America. Few sites would be necessary within any given category of climatic condition.

Literature Cited

1. Autio, W.R., J.L. Anderson, J.A. Barden, G.R. Brown, R.M. Crassweller, P.A. Domoto, A. Erb, D.C. Ferree, A. Gaus, P.M. Hirst, C.A. Mullins, and J.R. Schupp. 2001. Performance of 'Golden Delicious', 'Jonagold', 'Empire' and 'Rome' apple trees on five rootstocks over ten years in the 1990 NC-140 Cultivar/Rootstock Trial. J. Amer. Pom. Soc. 55: in press.
2. Autio, W.R., W.J. Lord, and P.L.M. Veneman. 1990. Rootstock and site influence performance of 'McIntosh' apple trees. HortScience 25:1219-1221.
3. NC-140. 1991. Performance of 'Starkspur Supreme Delicious' on 9 rootstocks at 27 sites over 10 years. Fruit Var. J. 45:200-208.
4. NC-140. 1991. Performance of 'Starkspur Supreme Delicious' apple on 9 rootstocks over 10 years in the NC-140 Cooperative Planting. Fruit Var. J. 45:192-199.
5. NC-140. 1996a. Performance of the NC-140 Cooperative Apple Rootstock Planting: I. Survival, tree size, yield and fruit size. Fruit Var. J. 50:6-11.
6. NC-140. 1996b. Performance of the NC-140 Cooperative Apple Rootstock Planting II: A 10-year summary of TCA, yield and yield efficiency at 31 sites. Fruit Var. J. 50:11-18.
7. NC-140. 1996c. Rootstock and scion cultivar interact to affect apple tree performance: A five-year summary of the 1990 NC-140 Cultivar/Rootstock Trial. Fruit Var. J. 50:175-187.
8. Parry, M.S. 1977. Field comparisons of M.26 and other dwarfing apple rootstocks on a diversity of sites. J. Hort. Sci. 52:59-73.
9. Rogers, W.S. 1946. Growth and cropping of apple trees on Malling rootstocks on five soil series. J. Pomology 22:209-226.

'Golden Delicious' - Self Fertilization

'Golden Delicious' is considered self compatible. However, considering fruit set levels and number of seeds the self-fertilization potency in 'Golden Delicious' is less than 10% of the cross-fertilization potency. The presence of S2 and S3 ribonuclease bands suggests that the gametophytic SI Rnase rejection mechanism is active. From Schneider et al 2001 J. Hort.Sci & Biotech76(3):259-263.