Rootstock and Scion Cultivar Interact to Affect Apple Tree Performance: A Five-year Summary of the 1990 NC-140 Cultivar/Rootstock Trial[1]

NC-140[2]

Abstract

'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' apple scion cultivars on M.9 EMLA, B.9, Mark, O.3, and M.26 EMLA rootstocks in all combinations were planted in an NC-140-coordinated trial in 1990 at 17 locations throughout the U.S. and Canada. Tree performance was assessed from 1990 through 1994. M.26 EMLA was consistent across scion cultivar in its effects on tree performance. Relative to other rootstocks, M.26 EMLA resulted in a large tree, with low precocity, high yields, low yield efficiency, and large fruit. With 'Golden Delicious', 'Empire', and 'Rome' as scion cultivars, O.3 consistently resulted in a large tree with low precocity, high yields, moderate yield efficiency, and small fruit. With 'Jonagold', O.3 resulted in a moderately sized tree with moderate yields. With 'Jonagold', 'Empire', and 'Rome' as scion cultivars, M.9 EMLA resulted in a moderately sized tree with low precocity, high yield, moderate yield efficiency, and large fruit. With 'Golden Delicious', M.9 EMLA resulted in low yields and low yield efficiency. Across all scion cultivars, B.9 produced a small tree, with high precocity, low yields, high yield efficiency, and large fruit. Mark also was consistent in its effect across scion cultivars, producing a small tree, with high precocity, low yields, high yield efficiency, and small fruit.

Although studies have compared the effects of various rootstocks on apple tree performance (e.g., 7, 8, 10), few have focused on the interaction between rootstock and scion. In the few studies that have, relative effects of rootstocks differed for different cultivars in some cases. For example, Ferree et al. (5) found that 'Mollies Delicious' trees on MM.106 were 28% smaller than those on M.7 and that 'Mutsu' trees on MM.106 were 185% larger than those on M.7. Westwood et al. (13), in a study including seven cultivars on M.9 EMLA, M.9, or M.27 EMLA, found that the differences among the rootstock effects were largest for the most vigorous scions and smallest for the least vigorous scion cultivars. Czynczyk and Omiencinska (4) found different relative effects of 12 rootstocks with 'Spartan', 'Lobo', or 'Empire' as the scion cultivar. Schupp (12) showed that 'Pioneer Mac' and 'Ginger Gold' trees on M.26 were larger than those on Mark; whereas, 'Marshall McIntosh' and 'Empire' trees on Mark were larger than those on M.26. He also found that 'Marshall McIntosh' and 'Pioneer Mac' trees on Mark were more yield efficient than those on M.26, but 'Ginger Gold' and 'Empire' trees were similarly yield efficient on these two rootstocks.

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[2]Coauthors are listed in Table 1.

In this study, four cultivars were selected to represent somewhat different growth habits ranging from spur-type and basitonic 'Empire' to tip-bearing and acrotonic 'Rome'. These trees were propagated on the five rootstocks found most promising in previous NC-140 plantings (8, 10). The objective was to compare performance of these rootstocks with different scion cultivars grown over a wide range of environments. Reported here are the results after five growing seasons.

Materials & Methods

'Smoothee Golden Delicious', 'Nicobel Jonagold', 'Empire', and 'Law Rome' scion cultivars were bench grafted onto M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA rootstocks during the winter of 1989 by Stark Bro's Nurseries (Louisiana, MO). Trees were grown in Selma, CA during the 1989 season, dug in the fall, and stored until the spring of 1990.

Seventeen sites were included in this study. Cooperators and locations are listed in Table 1. Trees were planted in a randomized complete block/split plot design at each location, with scion cultivar as the whole plot and rootstock as the split plot. Five -six replications were included at each site. Overall, the experiment was a split-split plot design, with site serving as the whole plot, cultivar as the split plot, and rootstock as the split-split plot. Experimental units were individual trees.

Trees were planted in late winter to early spring of 1990 (specific date was appropriate to the specific planting site) with the graft union 5 cm above the soil surface. Trees were staked and managed as slender spindle (6). Pest, fertility, and water management were per local recommendations.

Trunk circumference of each tree was measured each October. Tree height and canopy spread were measured in October 1994. The number of flower clusters per tree was counted in 1991 and 1992. Trees were defruited in 1991. Total yield per tree was assessed each year from 1992 through 1994. Each year, 25 fruit were selected randomly from each tree and weighed to determine average fruit size. Root suckers were counted and removed each August.

Data collection and analyses were organized by the Massachusetts site cooperator. Analyses of variance were conducted by the GLM procedure of SAS (SAS Institute, Cary, NC). Fruit size data were subjected to analysis of covariance, with crop load as the covariate. In cases where significant interactions existed, the sums of squares were partitioned among levels of one main factor within each level of the other. Mean separation was applied to the levels of one factor within each level of the other factor involved in the interaction. All mean separation was by Duncan's New Multiple Range Test ($P = 0.05$).

Results & Discussion

Tree Survival. Rootstock and scion cultivar did not interact to affect tree survival; however, the effects of rootstock and the effects of scion on tree survival varied significantly from site to site. In AR, CO, GA, IA, MA, ME, PA, UT, and VA there were no significant differences in tree survival associated with rootstock (Table 2). In IN, KS, KY, MI, OH, Quebec, and TN, however, rootstock affected tree survival. Specifically, trees on M.9 experienced the lowest survival at these eight sites, and trees on M.26 experienced the highest survival. Trees on B.9 had the lowest survival compared to

those on other rootstocks in IN and TN, and trees on Mark had the lowest survival in MI, OH, and KY. Trees on O.3 experienced the lowest survival in IN, OH, and Quebec.

In AR, CO, GA, IA, KS (Wichita), KY, MA, ME, PA, UT, and VA, there were no significant differences in tree survival associated with scion cultivar (Table 3). In IN, KS (Manhattan), MI, OH, Quebec, and TN, however, scion cultivar affected tree survival. Across these six sites, 'Empire' and 'Golden Delicious' experienced relatively high survival, and 'Rome' experienced low survival. Jonagold' tree survival was extremely low in MI and TN.

Over all sites, rootstock did not affect survival (Table 2), but scion cultivar did (Table 3). Specifically, the greatest survival was experienced by 'Golden Delicious' and 'Empire,' and the lowest was experienced by 'Rome'. 'Jonagold' was intermediate.

Tree Size and Root Suckering. Rootstock and scion cultivar interacted to affect tree size (Table 4). For all cultivars, M.26 EMLA had the greatest trunk cross-sectional area (TCA). The smallest TCAs were of trees on B.9 or Mark; trees on B.9 were larger than those on Mark only for 'Jonagold'. Trees on M.9 EMLA and those on O.3 were intermediate in size, with 'Golden Delicious' and 'Empire' trees on O.3 having greater TCA than those on M.9 EMLA. 'Jonagold' and 'Rome' trees on O.3, however, had similar TCA to corresponding trees on M.9 EMLA.

Tree height and canopy spread were affected similarly by rootstock and scion cultivar (Table 4). Specifically, the tallest and widest trees were on M.26 EMLA, but 'Rome' trees on M.9 EMLA and those on O.3 were similar in size to those on M.26 EMLA. 'Golden Delicious' trees on O.3 were similar in size to those on M.26 EMLA. 'Empire' trees on O.3 were taller and had greater canopy spread than those on M.9 EMLA. 'Jonagold' trees on O.3, however, were shorter and had a smaller canopy spread than those on M.9 EMLA. The shortest trees with the smallest canopy spread were on Mark or B.9. For each scion cultivar, trees on B.9 were significantly taller and had a greater canopy spread than trees on Mark.

The general trends among rootstock effects that were measured in this study, i.e. decreasing size from M.26 EMLA to O.3 to M.9 EMLA to B.9 to Mark, generally conform to those measured previously (7, 8, 10). The most significant deviation from this trend (that which likely resulted in the significance of the interaction of rootstock and scion cultivar) was with 'Jonagold' on O.3. 'Jonagold' trees on O.3 were smaller than would have been expected. The reason for this response is unclear but may be the result of some degree of incompatibility between 'Jonagold' and O.3.

Over all rootstocks, 'Jonagold' trees had the greatest TCA, and 'Empire' trees had the smallest TCA (Table 4). 'Rome' and 'Golden Delicious' trees were the tallest. 'Empire' trees had the greatest canopy spread, and 'Rome' trees had the smallest.

Over all scion cultivars, Mark and O.3 resulted in the greatest amount of root suckering (Table 5). In the 1980 NC-140 Apple Rootstock Trial (8), MAC-9 (Mark is a virus indexed MAC-9) and O.3 produced the greatest numbers of root suckers among the four rootstocks that were also included in this trial (M.9 EMLA, MAC-9, M.26 EMLA, and O.3). An interaction, however, also existed between rootstock and scion cultivar on root-sucker production. With 'Golden Delicious' or 'Jonagold' as scions, trees on Mark produced more root suckers than trees on the other rootstocks, and no differences existed among the other rootstocks. Rootstock had no effect on root suckering with 'Rome' as the scion. For 'Empire', Mark and O.3 resulted in similar amounts and the most root suckering. M.26 EMLA resulted in the least root suckering, and both M.9 EMLA and B.9 resulted in intermediate

levels.

It is unclear why 'Rome' generally reduced suckering and why 'Empire generally increased suckering, particularly of O.3. The hormonal conditions which result in the tip-bearing habit of 'Rome' also may affect shoot induction on roots. Furthermore, the hormonal conditions which result in the spur-type spreading habit of 'Empire', may induce shoot growth in the roots. Interestingly, Autio and Southwick (3) found that suckering was less for a spur-type 'McIntosh' strain when compared to a strain with a standard growth habit. Additionally, it is unclear why root suckering of O.3 was enhanced by 'Empire' than for the other rootstocks.

Precocity and Yield. As a measure of precocity, bloom density was assessed in 1991 (the second growing season) and 1992 (Table 6). In 1991, rootstock and scion cultivar did not interact to affect bloom density. Over all scion cultivars, B.9 resulted in the greatest bloom density, followed by Mark, M.9 EMLA, O.3, and M.26 EMLA. In 1992, an interaction occurred between rootstock and scion cultivar. For 'Jonagold' and 'Empire', Mark resulted in greater bloom density than all other rootstocks. For 'Jonagold', B.9 resulted in the next largest bloom density, and M.26 EMLA resulted in the lowest. For 'Empire', B.9 resulted in the next largest bloom density and more than the other rootstocks. 'Golden Delicious' trees on Mark and those on B.9 produced the greatest bloom density, higher than the other rootstocks. For 'Rome', the differences among rootstocks were less pronounced; Mark and B.9 resulted in the greatest bloom density, and M.9 EMLA and M.26 EMLA resulted in the lowest.

In 1991, over all rootstocks, 'Rome' trees had the greatest bloom density; 'Jonagold' and 'Empire' trees had the lowest (Table 6). In 1992, 'Golden Delicious' trees had the greatest bloom density, and 'Empire' trees had the lowest.

Fruit set was calculated in 1992, based on yield and fruit size (Table 7). Generally, fruit set per TCA was greatest for trees on Mark; however, 'Golden Delicious' trees on B.9 and those on O.3 set similar numbers of fruit to those on Mark. Also, 'Rome' trees on B.9 set similar numbers to those on Mark. Trees on M.26 EMLA and those on M.9 EMLA generally set the smallest number of fruit per TCA. 'Jonagold' trees on O.3 and those on B.9 and 'Rome' trees on O.3, however, set similar numbers to those of the corresponding scion cultivar on M.26 EMLA or M.9 EMLA. Over all rootstocks, 'Rome' and 'Golden Delicious' trees set the most fruit per TCA.

The effect of rootstock on set per 100 flower clusters also varied with scion cultivar (Table 7). Rootstock did not affect set per 100 clusters of 'Jonagold' or 'Rome' trees. 'Golden Delicious' trees on O.3 set greater numbers per 100 flower clusters than those on M.9 EMLA, and 'Empire' trees on O.3 set significantly more than those on Mark. Over all rootstocks, 'Rome' trees set the greatest number of fruit per 100 flower clusters, and 'Jonagold' trees set the fewest.

In 1994, trees on O.3 and those on M.26 EMLA yielded the most per tree (Table 8). 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA also yielded similarly to the corresponding scion cultivar on O.3 or M.26 EMLA. Lowest yields per tree in 1994 were obtained from trees on B.9 or Mark. 'Golden Delicious' trees on M.9 EMLA had similarly low yields. Cumulatively (1992-94), highest yields were obtained from trees on O.3 for 'Golden Delicious', 'Empire', and 'Rome' (Table 8). 'Jonagold' trees on O.3, however, yielded less than those on M.26 EMLA. Generally, similar yields were obtained from trees on M.26 EMLA and those on M.9 EMLA, except for 'Golden Delicious', where trees on M.9 EMLA yielded significantly less than those on M.26 EMLA. Trees on B.9 and

those on Mark yielded the least with all scion cultivars, but 'Golden Delicious' and 'Empire' trees on M.9 EMLA did not yield significantly more than the corresponding trees on Mark or B.9.

The general trend among rootstock effects on yield per tree were highest yields for trees on O.3, next highest and similar yields from trees on M.26 EMLA and those on M.9 EMLA, and lowest yields from trees on B.9 and trees on Mark. These results are comparable to those from other trials including these rootstocks (8, 10). The two important deviations from this trend, however, are for 'Golden Delicious' on M.9 EMLA and 'Jonagold' on O.3. Both combinations yielded much less than expected. The lower yields for 'Jonagold' on O.3 can be explained partially by the fact that trees were smaller than might otherwise be expected, but the reason for lower yields from 'Golden Delicious' trees on M.9 EMLA is not clear.

The greatest yield over all rootstocks in 1994 was obtained from 'Golden Delicious' and 'Rome' trees, and the lowest yield was obtained from 'Empire' trees. Cumulatively, the greatest yields were obtained from 'Rome' trees, and the lowest yields were obtained from 'Empire' trees.

Both in 1994 and cumulatively (1992-94), relative differences in yield efficiency among rootstocks varied from cultivar to cultivar (Table 9). For 'Golden Delicious', trees on B.9, Mark, or O.3 were more efficient than those on M.9 EMLA or M.26 EMLA. Rootstock did not affect 1994 yield efficiency of 'Jonagold' trees. 'Empire' trees on M.9 EMLA, B.9, Mark, or O.3 were more efficient than those on M.26 EMLA. 'Rome' trees on B.9 were more yield efficient than those on M.9 EMLA or M.26 EMLA. Cumulatively, for 'Golden Delicious', trees on Mark were the most efficient and those on M.9 EMLA or M.26 EMLA were the least efficient. For 'Jonagold' cumulatively, trees on B.9 or Mark were more yield efficient than those on M.9 EMLA, O.3, or M.26 EMLA. For 'Empire' cumulatively, trees on Mark were more efficient than those on M.9 EMLA or O.3, and trees on M.26 EMLA were the least yield efficient. For 'Rome' cumulatively, trees on B.9 were more efficient than trees on M.9 EMLA or O.3, and trees on M.26 EMLA were the least yield efficient.

The general trend over all scion cultivars showed trees on Mark and trees on B.9 to be the most yield efficient, followed by those on O.3, trees M.9 EMLA, and trees on M.26 EMLA in descending order. The most important deviation from this trend was for 'Golden Delicious' on M.9 EMLA. As suggested above, yields were lower than expected and this deviation was not the result of smaller trees than were expected. Previous work with M.9 EMLA with 'Delicious' as the scion cultivar (8) showed M.9 EMLA to be a very yield efficient tree.

In 1994 and cumulatively, across all rootstocks, 'Rome' and 'Golden Delicious' trees were the most efficient, and 'Jonagold' trees were the least efficient.

Fruit Size. The effects of rootstock on fruit size varied with year and scion cultivar (Table 10). In 1992, regardless of scion cultivar, trees on O.3 produced the smallest fruit. 'Golden Delicious' trees on M.9 EMLA, B.9, or M.26 EMLA produced larger fruit than trees on O.3, and 'Jonagold' trees on all other rootstocks produced larger fruit than those on O.3. 'Empire' trees on M.26 EMLA produced fruit similar in size to those from trees on O.3, both producing fruit smaller than those from trees on Mark. 'Rome' trees on M.9 EMLA produced larger fruit than trees on O.3. In 1993, rootstock did not affect 'Empire' fruit size. For 'Jonagold' and 'Rome', M.9 EMLA, B.9, and M.26 EMLA resulted in the largest fruit, and Mark and O.3 resulted in the smallest fruit. For 'Golden Delicious', O.3 and M.26 EMLA resulted in larger fruit than did Mark. In 1994, rootstock and scion cultivar did not interact, and over all scion cultivars, M.9 EMLA resulted in the largest fruit, followed by

B.9 and M.26 EMLA. Mark and O.3 resulted in the smallest fruit.

The general trend across the three years of measurement and the four scion cultivars suggested that M.9 EMLA results in the largest fruit, followed by B.9, M.26 EMLA, Mark, and O.3 in descending order. Previous studies (1, 2, 10) have suggested that M.9 EMLA, B.9, and M.26 EMLA can produce relatively large fruit. It was unexpected that O.3 would result in relatively small fruit, since Autio (1) showed that fruit from 'Delicious' trees on O.3 were among the largest in the 1980 NC-140 Apple Rootstock Trial in Massachusetts.

Over all rootstocks and all years, 'Rome' produced the largest fruit followed by 'Jonagold', which produced larger fruit than 'Golden Delicious'. The smallest fruit were harvested from 'Empire' trees.

Site Effects. Tree size varied dramatically from site to site (Table 11). Trees with the greatest TCA were found in KS, KY, and VA, and trees with the smallest TCA were found in MA, ME, MI,PA, CO, and Que. The tallest trees were in KS and KY, and the shortest trees were in ME, MI, and PA. Trees with the greatest canopy spread were in VA, KY, MA, PA and TN and those with the smallest spread were in Que, ME, PA, and MI. These variations from site to site correspond to the relative differences among sites in the previous NC-140 plantings (9, 11).

Root sucker production also varied from site to site (Table 11). Trees in VA, IA, KY and GA produced the most root suckers, while those in UT and Que produced the fewest.

Bloom density in 1991 was greatest in MI, OH, and VA and lowest in KS, UT, and AR (Table 12). In 1992, it was greatest in GA, MA, and VA and lowest in TN, KS, UT, AR, and IA. Set per TCA was greatest in 1992 in MA, GA, and VA and lowest in KS, TN, AR, and IN. Set per 100 flower clusters was greatest in MA, IA, ME, UT and VA and least in KS (Wichita), AR, and IN.

Yield per tree in 1994 was greatest in VA, MA, and OH and least in KS (Wichita), IA, and AR (Table 13). Cumulative yield per tree was highest in VA, OH, and MA and lowest in TN, Que, and AR. Yield efficiency in 1994 and cumulatively was highest in MA, MI, OH, and VA. Lowest yield efficiency values were recorded in 1994 in IA, UT, KS, and AR, and lowest cumulatively in TN, KS (Manhattan), and AR. These variations from site to site correspond to the relative differences among sites in the previous NC-140 plantings (9, 11).

Site differences in fruit size varied somewhat from year to year (Table 14). In 1992, MA, VA, and OH produced the largest fruit, and KS (Wichita), Que, and TN produced the smallest. In 1993, MA, MI, and VA produced the largest fruit, and AR and TN produced the smallest. In 1994, GA, VA, MA, and IN produced the largest fruit, and KS and CO produced the smallest.

Conclusions

Clearly, five years are too few to make firm conclusions about the performance of these rootstocks with these cultivars. However, some statements can be made regarding the consistency of these rootstocks across scion cultivar in their effect on tree size, precocity, early yield and efficiency, and fruit size.

M.26 EMLA was relatively consistent in its effect on tree performance. Specifically, it resulted in a relatively large tree with low precocity, high yield, low yield efficiency, and large fruit in comparison with other rootstocks.

O.3 was consistent in its effect, except with 'Jonagold' as the scion cultivar. With the other scion cultivars, trees on O.3 were relatively large with low precocity, high yield, moderate efficiency, and small fruit in comparison with the other rootstocks in this trial. With 'Jonagold' as the scion cultivar, O.3 resulted in moderate tree size and moderate yield.

M.9 EMLA was consistent in its effect on 'Jonagold', 'Empire', and 'Rome'. Trees generally were moderate in size with moderate to low precocity, high yield, moderate efficiency, and large fruit. With 'Golden Delicious' as the scion cultivar, M.9 EMLA resulted in low yield and low efficiency compared to the other rootstocks.

B.9 consistently resulted in a small tree with high precocity, low yield, high yield efficiency, and large fruit compared with other rootstocks in the trial.

Mark consistently resulted in a small tree with high precocity, low yield, high yield efficiency, and small fruit compared with the other rootstocks.

At this point in the trial, B.9 appears to be the most promising rootstock. Its effects are consistent, it has high yield efficiency, and fruit size is relatively large.

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Table 1. Site locations and cooperators in the 1990 NC-140 Cultivar/Rootstock Trial.

Site	Planting location	Cooperator
AR	Fayetteville	Curt R. Rom
CO	Hotchkiss	Alvan Gaus
GA	Athens	Stephen C. Myers
IA	Ames	Paul A. Domoto
IN	West Lafayette	Richard A. Hayden
KS-Ma	Manhattan	Frank Morrison
KS-Wi	Wichita	Frank Morrison
KY	Princeton	Gerald R. Brown
MA	Belchertown	Wesley R. Autio
ME	Monmouth	James R. Schupp
MI	East Lansing	Ronald L. Perry
OH	Wooster	David C. Ferree
PA	University Park	Loren D. Tukey
Que	St. Jean sur Richelieu	Raymond L. Granger
TN	Crossville	Charles A. Mullins
UT	Logan	J. LaMar Anderson
VA	Blacksburg	John A. Barden

Table 2. Survival (% alive) after five growing seasons of trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of rootstock and site was significant, so rootstock means were separated within each site.[z]

Rootstock	AR	CO	GA	IA	IN	KS-Ma
M.9 EMLA	100 a	100 a	96 a	100 a	78 b	78 b
B.9	100 a	100 a	100 a	100 a	75 b	87 ab
Mark	96 a	91 a	96 a	100 a	100 a	96 a
O.3	96 a	100 a	96 a	96 a	79 b	100 a
M.26 EMLA	100 a	92 a	100 a	100 a	92 a	92 a

	KS-Wi	KY	MA	ME	MI	OH
M.9 EMLA	73 b	77 ab	100 a	--	66 ab	83 ab
B.9	100 a	89 a	100 a	100 a	78 a	92 a
Mark	100 a	71 b	100 a	90 a	59 b	75 b
O.3	100 a	79 ab	100 a	88 a	71 ab	71 b
M.26 EMLA	88 ab	83 ab	100 a	95 a	71 ab	79 ab

	PA	Que	TN	UT	VA	Over all sites
M.9 EMLA	100 a	81 ab	90 ab	100 a	100 a	90 a
B.9	100 a	94 a	73 b	100 a	100 a	93 a
Mark	100 a	94 a	91 ab	100 a	100 a	91 a
O.3	100 a	67 b	88 ab	100 a	100 a	90 a
M.26 EMLA	100 a	79 ab	96 a	100 a	100 a	92 a

[z] Mean separation among rootstocks within site by Duncan's New Multiple Range Test (P = 0.05).

Table 3. Survival (% alive) after five growing seasons of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and site was significant, so cultivar means were separated within each site.[z]

Cultivar	AR	CO	GA	IA	IN	KS-Ma
Gold. Del.	100 a	100 a	97 a	100 a	87 ab	96 a
Jonagold	93 a	96 a	97 a	100 a	83 ab	79 b
Empire	100 a	97 a	100 a	100 a	93 a	97 a
Rome	100 a	93 a	96 a	97 a	77 b	92 ab

	KS-Wi	KY	MA	ME	MI	OH
Gold. Del.	100 a	79 a	100 a	87 a	76 a	97 a
Jonagold	96 a	80 a	100 a	88 a	83 a	77 b
Empire	99 a	87 a	100 a	100 a	90 a	93 a
Rome	82 a	73 a	100 a	95 a	25 b	53 c

	PA	Que	TN	UT	VA	Over all sites
Gold. Del.	100 a	95 a	100 a	100 a	100 a	95 a
Jonagold	100 a	63 b	96 a	100 a	100 a	90 b
Empire	100 a	94 a	82 ab	100 a	100 a	96 a
Rome	100 a	73 b	79 b	100 a	100 a	84 c

[z] Mean separation among cultivars within site by Duncan's New Multiple Range Test (P = 0.05).

Table 4. Tree size after five growing seasons of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. For each measurement, the interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious		Jonagold		Empire		Rome		Mean
				Trunk cross-sectional area (cm^2)					
M.9 EMLA	25.6	c	30.0	b	21.7	c	28.2	b	26.6
B.9	18.1	d	20.4	c	17.1	d	19.0	c	18.7
Mark	18.2	d	18.0	d	15.3	d	18.7	c	17.6
O.3	30.2	b	28.0	b	28.3	b	30.6	b	29.4
M.26 EMLA	33.9	a	39.2	a	32.4	a	33.3	a	34.7
Mean	25.3	b	27.2	a	23.1	c	25.9	b	
				Tree height (m)					
M.9 EMLA	2.5	b	2.5	b	2.5	c	2.7	a	2.5
B.9	2.4	c	2.2	c	2.2	d	2.4	b	2.3
Mark	2.2	d	2.0	d	2.0	e	2.2	c	2.1
O.3	2.6	ab	2.4	b	2.6	b	2.7	a	2.6
M.26 EMLA	2.7	a	2.7	a	2.8	a	2.7	a	2.7
Mean	2.5	a	2.4	b	2.4	b	2.5	a	
				Canopy spread (m)					
M.9 EMLA	2.5	b	2.7	b	2.7	c	2.6	a	2.7
B.9	2.3	c	2.4	d	2.4	d	2.3	b	2.3
Mark	2.1	d	2.2	e	2.2	e	2.1	c	2.1
O.3	2.7	a	2.5	c	2.9	b	2.7	a	2.7
M.26 EMLA	2.7	a	2.9	a	3.0	a	2.6	a	2.8
Mean	2.5	b	2.5	b	2.6	a	2.4	c	

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 5. Cumulative number of root suckers per tree after five growing seasons (1990-94) of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious		Jonagold		Empire		Rome		Mean
M.9 EMLA	0.1	b	0.4	b	1.5	b	0.5	a	0.7
B.9	0.7	b	0.7	b	2.0	b	0.3	a	0.9
Mark	2.5	a	2.0	a	4.0	a	0.8	a	2.3
O.3	1.0	b	0.2	b	4.0	a	1.0	a	1.6
M.26 EMLA	0.2	b	0.1	b	0.4	c	0.0	a	0.1
Mean	0.9	b	0.7	b	2.4	a	0.5	b	

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 6. Bloom density (flower clusters/cm^2 TCA) in 1991 and 1992 of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious		Jonagold		Empire		Rome		Mean	
				1991						
M.9 EMLA	3.5		1.3		2.2		4.1		2.7	bc
B.9	4.8		3.0		2.9		5.1		3.9	a
Mark	3.1		2.5		2.6		5.0		3.3	b
O.3	2.1		0.8		2.0		3.8		2.2	cd
M.26 EMLA	2.1		1.0		1.0		3.9		2.0	d
Mean	3.0	b	1.7	c	2.1	c	4.4	a		
				1992						
M.9 EMLA	10.0	b	6.6	bc	5.7	c	7.4	b	7.3	
B.9	14.3	a	8.0	b	8.7	b	9.4	a	10.0	
Mark	12.9	a	14.1	a	12.7	a	9.7	a	12.3	
O.3	8.8	b	6.2	bc	4.5	cd	8.5	ab	6.9	
M.26 EMLA	8.2	b	5.4	c	3.5	d	7.0	b	6.0	
Mean	10.6	a	8.1	b	6.9	c	8.4	b		

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 7. Fruit set in 1992 of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
		Number of fruit per cm² TCA			
M.9 EMLA	1.1 b	0.9 b	1.1 b	1.3 b	1.1
B.9	2.1 a	1.0 b	1.5 a	2.1 a	1.7
Mark	2.0 a	1.9 a	1.9 a	2.1 a	2.0
O.3	1.7 a	0.9 b	0.9 bc	1.6 b	1.3
M.26 EMLA	0.9 b	0.7 b	0.7 c	1.3 b	0.9
Mean	1.5 a	1.1 b	1.2 b	1.7 a	
		Number of fruit per 100 flower clusters			
M.9 EMLA	15 b	12 a	22 ab	39 a	23
B.9	30 ab	12 a	19 ab	36 a	24
Mark	26 ab	8 a	16 b	32 a	21
O.3	32 a	17 a	30 a	32 a	28
M.26 EMLA	24 ab	12 a	21 ab	36 a	23
Mean	26 b	12 c	22 b	35 a	

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 8. Yield per tree (kg) in 1994 and cumulatively of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious		Jonagold		Empire		Rome		Mean
				1994					
M.9 EMLA	13.3	b	14.0	a	10.1	ab	17.2	a	14.0
B.9	13.3	b	9.9	b	8.7	b	13.4	b	11.3
Mark	11.7	b	8.4	b	8.4	b	12.7	b	10.3
O.3	17.8	a	12.9	a	11.7	a	18.4	a	15.2
M.26 EMLA	17.7	a	15.3	a	11.1	ab	16.8	a	15.2
Mean	15.0	a	12.1	b	10.0	c	15.6	a	
				Cumulative (1992-94)					
M.9 EMLA	26.0	c	26.9	ab	20.9	bc	34.6	b	27.7
B.9	25.2	c	21.6	c	18.5	c	28.8	c	23.7
Mark	26.0	c	20.9	c	19.2	c	27.3	c	23.3
O.3	37.9	a	25.7	b	25.9	a	37.8	a	32.0
M.26 EMLA	31.7	b	29.2	a	22.5	b	33.8	b	29.3
Mean	30.0	b	24.9	c	21.4	d	32.4	a	

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 9. Yield efficiency (kg/cm^2 TCA) in 1994 and cumulatively of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells. The interaction of cultivar and rootstock was significant, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious		Jonagold		Empire		Rome		Mean
				1994					
M.9 EMLA	0.56	b	0.48	a	0.56	a	0.63	bc	0.57
B.9	0.79	a	0.52	a	0.58	a	0.73	a	0.65
Mark	0.75	a	0.52	a	0.62	a	0.64	abc	0.63
O.3	0.71	a	0.48	a	0.55	a	0.65	ab	0.60
M.26 EMLA	0.60	b	0.44	a	0.43	b	0.55	c	0.51
Mean	0.69	a	0.49	c	0.54	b	0.64	a	
				Cumulative (1992-94)					
M.9 EMLA	1.06	c	0.91	b	1.07	b	1.24	b	1.09
B.9	1.47	b	1.11	a	1.20	ab	1.51	a	1.33
Mark	1.63	a	1.22	a	1.33	a	1.39	ab	1.39
O.3	1.42	b	0.92	b	1.11	b	1.30	b	1.19
M.26 EMLA	1.04	c	0.82	b	0.76	c	1.07	c	0.92
Mean	1.34	a	1.00	c	1.09	b	1.30	a	

[z] Mean separation among rootstocks within cultivar and among cultivars overall by Duncan's New Multiple Range Test (P = 0.05).

Table 10. Fruit size (g) in 1992, 1993, and 1994 of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome' trees on M.9 EMLA, B.9, Mark, O.3, or M.26 EMLA planted in 1990 as part of the NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells and crop load. The interaction of cultivar and rootstock was significant each year, so rootstock means were separated within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
		1992			
M.9 EMLA	177 a	221 a	153 ab	231 a	195
B.9	176 a	219 a	153 ab	225 ab	193
Mark	164 ab	213 a	159 a	224 ab	190
O.3	155 b	198 b	142 b	215 b	178
M.26 EMLA	169 a	225 a	146 b	221 ab	189
Mean	167 c	215 b	151 d	223 a	
		1993			
M.9 EMLA	163 ab	200 a	153 a	226 a	187
B.9	165 ab	195 a	150 a	227 a	184
Mark	161 b	183 b	147 a	214 bc	176
O.3	169 a	177 b	148 a	209 c	177
M.26 EMLA	172 a	194 a	149 a	220 ab	184
Mean	168 c	190 b	149 d	219 a	
		1994			
M.9 EMLA	163	225	156	233	196 a
B.9	167	204	156	231	190 b
Mark	158	193	149	225	181 c
O.3	174	190	150	217	183 c
M.26 EMLA	175	209	153	225	191 b
Mean	170 c	204 b	153 d	226 a	

[z] Mean separation among rootstocks within cultivar and year and among cultivars overall within year by Duncan's New Multiple Range Test (P = 0.05).

Table 11. Size and cumulative suckering at the end of the fifth growing season of trees at each site in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells.[z]

Site	Trunk cross-sectional area (cm^2)		Tree height (m)		Canopy spread (m)		Cumulative suckers per tree (1990-94)	
AR	23.4	e	2.3	e	2.3	de	0.6	ef
CO	18.1	f	2.4	de	2.3	de	1.6	bcd
GA	29.8	d	-		-		2.0	b
IA	23.4	e	2.4	de	2.3	de	3.2	a
IN	23.2	e	2.4	de	5.0	?	0.9	def
KS-Ma	41.4	b	2.9	b	2.5	bc	0.5	ef
KS-Wi	44.9	a	3.3	a	2.3	de	0.3	ef
KY	36.1	c	2.7	c	2.9	a	2.0	bc
MA	17.1	fg	2.4	de	2.7	b	0.7	def
ME	15.6	fg	2.1	f	2.2	e	0.8	def
MI	14.1	g	2.1	f	1.8	f	1.0	def
OH	27.9	d	2.4	de	2.4	cd	0.5	ef
PA	18.3	f	2.1	f	1.9	f	0.5	ef
Que	9.6	h	2.3	e	1.4	g	0.0	f
TN	22.7	e	2.5	d	2.6	bc	1.1	cde
UT	27.1	d	2.5	d	2.4	cd	0.1	f
VA	38.8	bc	2.5	d	3.1	a	3.5	a

[z] Mean separation within columns by Duncan's New Multiple Range Test (P = 0.05).

Table 12. Bloom density in 1991 and 1992 and fruit set in 1992 of trees at each site in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells.[z]

Site	Bloom density (clusters/cm² TCA)		Fruit set	
	1991	1992	Per cm² TCA	Per 100 flower clusters
AR	0.4 f	3.4 c	0.1 f	2 f
GA	-	20.6 a	3.0 b	30 c
IA	-	2.8 c	0.6 def	40 b
IN	-	0.5 d	0.0 f	0 f
KS-Ma	0.1 f	3.8 c	0.1 f	20 de
KS-Wi	2.0 de	4.9 c	0.4 ef	5 f
KY	3.9 b	9.6 b	1.1 cd	26 cd
MA	2.5 cd	19.3 a	5.8 a	51 a
ME	3.7 bc	8.4 b	1.5 c	36 bc
MI	5.4 a	-	-	-
OH	4.9 ab	-	-	-
TN	-	4.9 c	0.4 ef	13 ef
UT	0.8 ef	4.7 c	0.9 de	33 bc
VA	4.5 ab	19.3 a	2.9 b	32 bc

[z] Mean separation within columns by Duncan's New Multiple Range Test (P = 0.05).

Table 13. Yield in 1994 and cumulatively by the end of the fifth growing season from trees at each site in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells.[z]

	Yield per tree (kg)				Yield efficiency (kg/cm^2 TCA)			
Site	1994		Cumulative (1992-94)		1994		Cumulative (1992-94)	
AR	0.0	h	3.7	h	0.00	k	0.16	j
CO	6.6	efg	16.9	e	0.36	gh	0.98	ef
GA	22.2	c	41.6	d	0.80	d	1.53	d
IA	4.3	g	14.9	ef	0.21	ij	0.68	gh
IN	7.1	efg	14.8	ef	0.36	gh	0.84	fgh
KS-Ma	11.1	d	16.5	e	0.27	hi	0.41	i
KS-Wi	4.3	g	38.0	d	0.12	jk	0.93	f
KY	24.4	bc	40.3	d	0.69	de	1.18	e
MA	29.5	a	48.3	c	1.78	a	2.92	a
ME	8.6	def	14.8	ef	0.51	fg	0.90	fg
MI	22.6	bc	39.5	d	1.51	b	2.65	b
OH	26.0	b	55.3	b	0.94	c	2.06	c
PA	10.1	de	18.8	e	0.55	ef	1.05	ef
Que	4.7	fg	6.5	gh	0.48	fg	0.68	gh
TN	5.7	fg	10.0	fg	0.34	hi	0.59	hi
UT	4.7	fg	16.3	e	0.20	ij	0.69	gh
VA	32.4	a	66.0	a	0.93	c	1.89	c

[z] Mean separation within columns by Duncan's New Multiple Range Test (P = 0.05).

Table 14. Size (g) of fruit from each site in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing cells and crop load.[z]

Site	1992		1993		1994	
AR	--		116	i	--	
CO	185	c	170	gh	148	g
GA	185	c	204	d	233	b
IA	171	d	170	gh	176	e
IN	--		178	fg	208	c
KS-Ma	197	bc	195	de	157	fg
KS-Wi	166	cde	186	ef	158	fg
KY	201	b	193	e	188	d
MA	225	a	257	a	231	b
ME	185	c	177	fgh	165	ef
MI	183	c	227	b	189	d
OH	218	a	194	e	210	c
PA	--		176	fgh	175	e
Que	152	e	167	gh	162	f
TN	147	e	95	j	166	ef
UT	205	b	167	h	193	d
VA	223	a	214	c	251	a

[z] Mean separation within columns by Duncan's New Multiple Range Test (P = 0.05).