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Performance of 'Braeburn', 'Golden Delicious' and 'Yataka Fuji' Apple on Mark and M.9 Rootstocks at Multiple Locations Across North America

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Abstract

The performance of three apple (*Malus × domestica* Borkh.) cultivars ('Braeburn', 'Gibson Golden Delicious' and 'Yataka Fuji') on two dwarfing rootstocks (M.9 T337 and Mark) was studied for five years at multiple sites across North America as part of a large international cultivar evaluation trial. The trees were trained as slender spindles, and arranged in a randomized block design at each site. Cultural practices followed regional commercial recommendations, except that no calcium was applied. The effect of rootstock on cultivar performance was examined. Whether trees were propagated on Mark or M.9 made no difference to cultivar comparisons of the number of days between bloom and maturity, nor fruit red color, soluble solids concentration, or length/ diameter ratio, but these measures were affected by location and/or location x cultivar interaction. Scion differences in bloom density ratings were consistent across all rootstocks and locations, with 'Braeburn' having the greatest bloom density, followed by 'Golden Delicious', and then 'Yataka Fuji.' Skin russet was unaffected by rootstock; 'Golden Delicious' had slightly more russet than 'Braeburn'. Rootstock affected flesh firmness consistently, with fruit from trees on Mark being about 0.27 kg firmer than on M.9. Rootstock differentially affected cultivar fruit size, flesh titratable acidity and yield efficiency. However, the cultivar x rootstock interaction effect was small compared to location differences for fruit size and yield efficiency, and its effect on fruit acidity was limited to one location. Rootstock influenced cultivar tree size (trunk cross-sectional area, tree height and spread), but the presence, direction and magnitude of the rootstock effect varied with location and cultivar. At sites and for scions where tree size differed significantly between rootstocks, trees on Mark tended to be larger than those on M.9 in sites with cold winters and smaller than on M.9 in southern sites. Rootstock also affected cumulative yield; the extent and direction of the effect varied with location but not cultivar. At the majority of locations, 'Golden Delicious' was more productive than 'Braeburn', but not more yield-efficient. At 13 of 19 locations, 'Golden Delicious' was more yield-efficient than 'Yataka Fuji'.

Introduction

In 1995, the first apple cultivar evaluation trial held under the auspices of the USDA NE-183 regional committee was planted at various sites across North America (10). The objectives of the trial were to assess regional adaptation of the new cultivars, to evaluate their profitability, and to measure their resistance to different pests and diseases.

Rootstocks are employed for their known effects on scion performance, such as size control. Significant differential effects of rootstock on scion have been noted in some trials (15, 17,18), but not others (5). Three cultivars in the trial ('Braeburn', 'Golden Delicious' and 'Yataka Fuji') were propagated on two different dwarfing rootstocks, M.9 T337 and Mark. The present paper in the series reporting the results of the 1995 NE-183 trial focuses on whether rootstock affects the conclusions drawn about cultivar performance. Full reports on the performance of these and other cultivars on M.9 appear elsewhere (7, 13).

[1]Agriculture and Agri-Food Canada contribution no. 2230. For locations of all authors, see Table 1.

Materials and Methods

All combinations of 'Braeburn', 'Golden Delicious' (Gibson strain) and 'Fuji' (Yataka strain) on M.9 T337 and Mark rootstocks were propagated by Adams County Nursery in Aspers, PA, USA. Trees were planted at the 19 sites shown in Table 1 in spring of 1995 at a 2.5 m x 4.3 m spacing with the bud union 5 cm above the soil line. Trees were supported and trained as slender spindles. Pest management, irrigation, and fertilization followed regional commercial practices at each site, except that no calcium was applied, in order to determine any cultivar propensities to calcium-related nutritional disorders. Trees were first cropped in year two or three, according to the local cooperator's judgment. Only fruit from king blooms were kept, and these were thinned to a spacing of 15 to 20 cm. In early years, all thinning was by hand, but as the trees grew, chemical plus hand thinning became necessary.

Trunk cross-sectional area (TCA) was calculated from circumference or diameter measurements taken after harvest in 2000 at 30 cm above the bud union. Tree height and maximum canopy spread (the latter being the average of two measurements at right angles to each other) were also recorded after harvest in 2000. The total yield of fruit (by weight) of each tree was recorded annually, and the figures summed for cumulative yield (CY). Cumulative yield was divided by TCA in 2000 to obtain cumulative yield efficiency (CYE). The day of the year when trees reached 90% king bloom ("date of full bloom") on spurs was noted annually, and the bloom density was rated on a 0 to 5 scale (0=no

Table 1. Locations and cooperators in the 1995 NE-183 apple cultivar trial.

Location	Cooperator	Planting location
(AR) Arkansas	C. Rom	Fayetteville
(BC) British Columbia, Canada	C. Hampson	Summerland
(MA) Massachusetts	D. Greene, J. Clements	Belchertown
(ME) Maine	J. Schupp[1]/Renae Moran	Monmouth
(NC) North Carolina	J.D. Obermiller	Fletcher
(NJ) New Jersey	W. Cowgill, R. Belding	Pittstown
(NYG) New York	S. Brown	Geneva
(NYH) New York	E. Stover[2]/J. Schupp	Highland
(NYI) New York	I. Merwin	Ithaca
(OH) Ohio	D. Miller	Wooster
(ON) Ontario, Canada	J. Cline	Simcoe
(OR) Oregon	A. Azarenko	Corvallis
(PAB) Pennsylvania	G. Greene	Biglerville
(PAR) Pennsylvania	R. Crassweller	Rock Springs
(VT) Vermont	E. Garcia, L. Berkett	Burlington
(WA) Washington	B. Barritt	Wenatchee
(WI) Wisconsin	T. Roper	Sturgeon Bay
(WV) West Virginia	S. Miller	Kearneysville
(WVD) West Virginia, second	S. Miller	Kearneysville

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Table 2. P-values from the mixed-model analysis of variance for the main-factor effects and interactions of location, cultivar and rootstock on experimental response variables.

Response variable	Location (L)	Cultivar (C)	L x C	Rootstock (R)	L x R	C x R	L x C x R
Fruit diameter	0.004	0.964	0.085	0.049	0.176	0.003	0.910
Average fruit weight	< 0.001	0.013	0.156	0.644	0.319	< 0.001	0.923
Fruit length	< 0.001	0.004	0.112	0.488	0.242	0.003	0.820
Red overcolor	0.003	< 0.001	< 0.001	0.617	0.999	0.733	0.972
Length:diameter ratio	0.011	< 0.001	0.020	0.278	0.675	0.495	0.607
Russet rating	0.053	< 0.001	0.200	0.583	0.943	0.678	0.598
Flesh firmness	0.005	< 0.001	< 0.001	0.008	0.889	0.535	0.532
Soluble solids	0.416	< 0.001	0.001	0.105	0.081	0.090	0.093
Titratable acidity	< 0.001	< 0.001	< 0.001	0.307	0.244	0.024	0.647
Days to maturity	< 0.001	< 0.001	< 0.001	0.683	0.641	0.579	0.983
Final trunk girth	< 0.001	< 0.001	< 0.001	0.007	< 0.001	< 0.001	0.106
Height:spread ratio	< 0.001	< 0.001	< 0.001	< 0.001	0.004	0.088	0.232
Bloom rating	0.291	< 0.001	0.777	0.269	0.146	0.996	0.878
Cumulative yield	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.295	0.148
Cumulative yield efficiency	< 0.001	< 0.001	< 0.001	0.383	0.056	< 0.001	0.221

bloom, 1=a few clusters, 2=sufficient clusters for a partial crop, 3=sufficient clusters for a full crop, 4=more than sufficient clusters for a full crop, 5= "snowball" bloom).

Fruit were harvested when starch index reached 4 to 6 on the 8-point Cornell University generic starch-iodine index chart for apple (6). Data for a given cultivar-site-year were excluded from analysis if the mean starch index was outside the range of 3.5 to 6.5. Harvest date was recorded. "Days to maturity" was calculated as the difference between dates of full bloom and harvest. At harvest each year, ten fruit from each tree were sampled. The weight, diameter, and length of the composite sample, and the mean starch index, were noted. The soluble solids concentration (SSC, by temperature-compensated refractometer) and titratable acidity (TA, as % malic acid) were measured on a composite juice sample. Flesh firmness (without the peel) was measured by penetrometer using the standard 11.1 mm tip. The percentage of red overcolor was estimated visually, and fruit russet was rated (0=none, 1=up to 5% of fruit surface russeted, 2=5.1 to 10%, 3=10.1 to 15%, 4=15.1 to 20%, 5=over 20%).

At each location, the trees were arranged in a randomized block design. All data were analyzed with the SAS statistical software program (SAS Institute, Cary, NC), using the MIXED procedure. Location, cultivar and rootstock, and their interactions, were considered fixed effects. Replication nested within location, year, and interactions of year with the fixed factors were considered random effects. The best-fitting variance structure for the repeated measures across years was selected for the final analysis to compare levels of the fixed factors. Means were separated with multiple t tests where each test used a significance level of 0.05. No LSD can be given because all comparisons have different standard errors. Only two to three sites collected fruit quality data for 'Yataka Fuji' on both rootstocks, producing a very unbalanced data set. Therefore 'Yataka Fuji' was dropped from the fruit quality analyses, but all three cultivars were analyzed for the other response variables.

Results and Discussion

Although the three-way interaction was not significant for any of the response variables, all were affected by one or more of the main effects and/or the two-way interactions (Table 2). The discussion below therefore centers on how location, cultivar and rootstock interacted.

Fruit size. All three measures of fruit size were affected by the location main effect and cultivar x rootstock interaction (Table 2). Average fruit weight was the most sensitive measure for detecting location differences. The range in values between the two extreme locations (BC and PAB or PAR) was 121 g for fruit weight, 1.4 cm for diameter and 1.8 cm for length (Table 3). Location effects on fruit size were larger than cultivar x rootstock effects, where the ranges were 29 g for fruit weight, 0.2 cm for diameter and 0.3 cm for length (Table 4).

The pattern of interaction between cultivar and rootstock was not the same for the three measures of fruit size (Table 4). Average fruit weight of 'Braeburn' was higher on Mark than on M.9, but for 'Golden Delicious' the reverse was true. Fruit diameter was smaller on 'Golden Delicious'/ Mark than any other combination. In previous large-scale trials, rootstock x cultivar interaction has affected average fruit weight (1,15). Mark has repeatedly been found to reduce fruit size of the scion cultivar (1,4,5,11,15). The greater fruit size of 'Braeburn' on Mark than M.9 may have been related to crop load. On average, the crop load (number of fruit/TCA) was significantly higher on 'Braeburn'/M.9 than any other combination (data not shown).

External appearance of fruit. Of the three aspects of fruit external appearance measured (percentage red color, russet and length/diameter ratio), none was affected by rootstock (Table 2). As anticipated, 'Golden Delicious' had less red color than 'Braeburn'

Table 3. Generalized least-squares means for location for average fruit weight, diameter, length and russet rating of 'Braeburn' and 'Golden Delicious.[z]

Location	Fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)	Russet rating[y]
BC	284 a	8.45 a	8.17 a	0.94
NJ	236 b	8.23 ab	7.54 abc	1.67
NYI	232 bc	8.01 abc	7.79 ab	n.d.
NYH	224 bcd	7.62 bcd	6.88 cde	0.67
ME	219 b-e	7.78 a-d	7.25 bcd	n.d.
MA	218 b-e	n.d.[x]	n.d.	n.d.
VT	208 b-e	7.71 bcd	6.93 cde	0.41
WV	201 b-f	7.48 cd	6.61 de	1.17
NYG	195 b-f	7.64 bcd	6.88 cde	n.d.
WVD	195 b-f	7.31 d	6.40 e	1.47
WI	183 c-f	7.45 cd	6.93 cde	0.75
ON	181 c-f	7.32 cd	6.73 cde	0.91
PAB	171 ef	7.22 d	6.37 e	0.97
PAR	163 f	7.09 d	6.42 e	n.d.

[z] Within column, mean separation by t test at the 5% level.
[y] Rating scale: 0=none, 1=up to 5%, 2=5.1 to 10%, 3=10.1 to 15%, 4=15.1 to 20%, 5=over 20% of fruit surface affected
[x] n.d .= no data

Table 4. Generalized least-squares means for cultivar x rootstock for average fruit weight, fruit length and fruit diameter.[z]

Cultivar	Rootstock	Fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)
Braeburn	M.9	210 b	7.63 a	6.85 b
Braeburn	Mark	222 a	7.71 a	6.99 b
Golden Delicious	M.9	207 b	7.71 a	7.16 a
Golden Delicious	Mark	193 c	7.50 b	6.97 b

[z] Means within a column followed by the same letter are not significantly different at the 5% level.

at nearly all sites (Table 5). The difference in red color for a given cultivar among locations was striking. At PAB, less than 50% of the fruit surface of 'Braeburn' was red, compared to over 80% at NJ, ON, PAR and WI. At 5 of 8 locations, 'Golden Delicious' had over 10% red color.

Length/diameter ratio (L/D ratio) was analyzed as a measure of fruit elongation. Of the 12 locations where a comparison was possible, L/D ratio of the cultivars differed at 8, and at all these sites 'Braeburn' had a lower ratio (was rounder) than 'Golden Delicious' (Table 5). The magnitude of the cultivar difference varied from location to location, but in general was not very large. Rootstock had no effect on L/D ratio.

Skin russet was the only fruit quality variable unaffected by factor interaction in this study (Table 2). Location and cultivar affected the amount of russet on fruit, but rootstock had no influence. 'Golden Delicious' had a little more skin russet than 'Braeburn' (mean ratings 1.1 and 0.9 respectively). The *P*-value for location was close to 0.05 (Table 2). NJ, WV and WVD all had mean russet ratings greater than one (Table 3).

Internal fruit quality. Flesh firmness was affected by the interaction of location and cultivar, and by rootstock (Table 2). Fruit from trees on Mark rootstock was about 0.27 kg firmer than from trees on M.9. At ON and NJ, flesh firmness of the two cultivars did not differ, but at all other sites, 'Braeburn' was firmer than 'Golden Delicious' (Table 5). The size of the cultivar difference varied from location to location, and tended to be greatest at some of the cooler sites (e.g. ME, VT, BC), where 'Braeburn' may not have matured fully.

The SSC of the fruit was affected by location x cultivar interaction (Table 2). The SSC in the fruit juice was lower for 'Braeburn' than 'Golden Delicious' at all but three sites (Table 5). In NJ and WV, the two cultivars did not differ significantly. 'Braeburn' had unusually high SSC in ON, the only location where 'Braeburn' had greater SSC than 'Golden Delicious'.

The response pattern of TA was complex. Three-way means are presented because this variable was affected by both location x cultivar and rootstock x cultivar interactions (Tables 2 and 6). Cultivar differences did not occur at all sites, but where they did, 'Braeburn' was more acidic than 'Golden Delicious'. Only one site found a rootstock effect: NYG reported higher TA for 'Braeburn'/Mark than 'Braeburn'/M9 (Table 6).

Days to maturity. Rootstock had no effect on days to maturity (Table 2). Cultivars differed, and the pattern of response varied among locations. 'Braeburn' took longer to mature than either of the other two cultivars at 11 of 15 sites, but not at WV, WI or VT (Table 7). In ON, 'Braeburn' took longer to mature than 'Yataka Fuji' but not 'Golden Delicious'. The range in days to maturity among locations was 13 days for 'Yataka Fuji', 22 days for 'Golden Delicious' and 38 days for 'Braeburn'. 'Braeburn' took longer to mature in some of the warm sites (AR, NC, NJ) than in cool ones (ME,VT, WI). The initiation of fruit ripening in response to climatic conditions may be an interesting area for further study.

Table 5. Generalized least-squares means for cultivar x location for red color, length/diameter ratio, firmness and soluble solids, with the associated P-values for the difference between cultivars within location.

	Red over color (%)			Length/diameter ratio			Flesh firmness (kg)			Soluble solids (%)		
Location	Braeburn	Golden Del.	P -value	Braeburn	Golden Del.	P -value	Braeburn	Golden Del.	P -value	Braeburn	Golden Del.	P -value
BC	75.6	7.2	< 0.001	0.96	0.97	0.097	9.89	6.99	< 0.001	13.0	15.2	< 0.001
MA	72.0	15.5	< 0.001	0.90	0.93	0.003	9.48	7.39	< 0.001	13.0	14.2	0.004
ME	-	-	-	0.91	0.95	0.003	10.21	7.44	< 0.001	11.8	15.4	< 0.001
NJ	83.5	3.7	< 0.001	-	0.93	-	9.43	8.30	0.130	13.1	15.8	0.128
NYG	-	-	-	0.89	0.92	< 0.001	9.16	7.26	< 0.001	14.0	15.0	0.006
NYH	-	-	-	0.89	-	-	9.21	-	-	15.0	-	-
NYI	-	-	-	0.97	0.97	0.636	9.66	7.85	< 0.001	13.8	15.6	< 0.001
ON	83.5	14.8	< 0.001	0.87	0.95	< 0.001	7.39	7.21	0.762	18.1	15.8	0.005
PAB	36.5	18.2	0.067	0.87	0.89	0.006	10.25	8.80	< 0.001	13.8	14.5	0.034
PAR	81.9	4.6	< 0.001	0.89	0.93	0.033	-	-	-	14.1	16.6	0.001
VT	77.8	16.6	< 0.001	0.87	0.93	< 0.001	9.16	6.62	< 0.001	13.0	15.8	< 0.001
WI	84.1	18.5	< 0.001	0.95	0.92	0.182	9.71	7.35	< 0.001	12.3	15.0	< 0.001
WV	61.9	-	-	0.88	0.91	0.005	8.80	7.44	< 0.001	13.8	14.1	0.548
WVD	60.6	-	-	0.88	0.89	0.124	8.12	7.39	0.015	13.7	14.8	0.005

Tree size. TCA and tree height/spread ratio were recorded as alternate measures of scion vigor. They were significantly influenced by all three main effects, and TCA was influenced by all possible two-way interactions (Table 2). TCA is highly correlated with above ground tree size (3,11,12). For TCA, rootstock x cultivar interaction was only significant at 4 of 19 sites: MA, OH, WA and WVD (Table 8). At these sites, the TCA of one or more scions was larger on one rootstock than the other, but the larger trees were sometimes on M.9 and sometimes on Mark, depending on location. In a study with a large number of different dwarf rootstocks at a single location in WA, Barritt et al. (5) found no significant rootstock x scion effect on TCA. However rootstock x scion interaction significantly affected TCA in ME (17) and in a large national trial (1). At the other 15 sites, rootstock x scion interaction was not significant; at 8 of these, TCA was also similar between rootstocks. At AR and WV, TCA on M.9 was larger than on Mark, and at ME, NYH, ON, VT and WI, it was smaller. 'Braeburn' tended to be less vigorous (have smaller TCA) than the other two cultivars, but this was not true at 8 of the 19 locations (Table 8).

The effects of cultivar and rootstock on height/spread ratio were not the same at all locations (Table 2). Cultivar and rootstock

Table 6. Generalized least-squares means for the three-way interaction of location, cultivar and rootstock on titratable acidity of 'Braeburn' (Brae.) and 'Golden Delicious' (Golden Del.) fruit flesh.

	Titratable acidity (%)				*P*-value at location for rootstock difference:		*P*-value at location for cultivar difference:	
Location	Brae/ M9	Brae/ Mark	Golden Del. M9	Golden Del. Mark	for Braeburn	for Golden Del.	on M.9	on Mark
BC	1.21	n.d.[z]	0.89	0.93	-	0.584	< 0.001	-
NYG	0.82	1.01	0.62	0.67	0.005	0.386	0.002	< 0.001
NYI	0.79	0.79	n.d.	n.d.	0.972	-	-	-
PAB	0.72	0.74	0.54	0.53	0.760	0.946	0.010	0.003
WV	0.58	0.60	0.58	0.51	0.705	0.253	0.973	0.187
WVD	0.51	0.60	0.58	0.51	0.088	0.324	0.307	0.108

[z] n.d. = no data

did not interact with each other, however. At 10 of 16 locations, rootstock effects were not significant (Table 9). Where rootstocks did differ, height/spread ratio was always greater on M.9 than on Mark. At 9 of 16 locations, height/spread ratio of cultivars did not differ (Table 9). At the other 7 sites, the response pattern varied. Height and spread two-way means were examined in an attempt to shed further light on the response (data not shown). At 10 of 16 locations, the tree height of all cultivars was about the same on both rootstocks, and at 12 of 16 sites, so was canopy spread. Where tree height differed, trees on M.9 were taller than on Mark at 5 sites, but at NYH the reverse was true (not shown). In AR and WV, canopy spread was greater on M.9 than Mark, and in ME and VT it was smaller. In relative terms, tree spread varied more with location than did tree height.

The overall picture that emerges from the various measures of scion vigor is as follows. Trees were about the same size on both rootstocks at many sites, but in some of the locations with cold winters (e.g. ME, VT, WI), trees on Mark were bigger than on M.9, and in two of the southernmost locations (WV, AR), the reverse was true. One possible explanation is slight winter damage to the M.9 rootstock, especially if soils were dry going into winter. Reasons for the poor performance of Mark in AR and WV were not identified. Previous rootstock trials have found M.9 and Mark to have similar vigor control at many locations (11,14). Mark is known to be sensitive to drought stress (8,16), and tree size on Mark has varied from as small as on M.27 (9) to as large as on M.26 (17,18). Autio et al. (2) recently reported trees to be more vigorous on Mark than on M.9 in ME, MA and NS. Actual fifth-year TCA values reported there for ME and MA were also similar to those in the present study. Factors other than climate also affect the

Table 7. Generalized least-squares means for the number of days from bloom to maturity for three cultivars at different locations.[z]

	Days to maturity		
Location	Braeburn	Golden Del.	Yataka Fuji
AR	180 a	150 b	144 b
BC	174 a	147 b	139 c
MA	159 a	143 b	139 b
ME	154 a	140 b	138 b
NC	175 a	153 b	136 c
NJ	183 a	158 b	149 c
NYH	171 a	151 b	149 b
NYI	166 a	153 b	136 c
ON	161 a	159 a	145 b
PAB	164 a	146 b	138 c
PAR	165 a	142 b	142 b
VT	154 a	150 ab	141 b
WI	145 a	140 a	136 a
WV	167 a	162 a	148 b
WVD	169 a	162 b	148 c

[z] Means followed by the same letter within location (across row) are not significantly different by t test at the 5% level.

relative vigor of trees on Mark and M.9.

Bloom ratings. Bloom rating was affected only by cultivar (Table 2). Scion differences were consistent across all locations and both rootstocks. Mean bloom ratings were 4.3 for 'Braeburn', 3.5 for 'Golden Delicious' and 2.6 for 'Yataka Fuji'; each of these figures is significantly different from the other two. These results are consistent with observational data. 'Braeburn' is a cultivar with a marked tendency to "snowball" bloom at many locations. 'Yataka Fuji' is a sport of 'Fuji', a cultivar with a high propensity for biennial bearing. 'Yataka Fuji' did seem to share this tendency, in at least some locations in this trial.

Productivity. Rootstock affected yield at only five sites (Table 10). In four of these, CY was greater on Mark than on M.9, but in WV the opposite was true. Cumulative yield was strongly affected by location. The range in yield between the two extreme locations was 70.8 kg for 'Yataka Fuji', 67.9 kg for 'Golden Delicious', and 64.8 kg for 'Braeburn' (Table 10). Overall means indicated that the three cultivars all differed significantly in CY, with 'Golden Delicious' having the highest yield and 'Braeburn' the lowest. The cultivar yield patterns were consistent for both rootstocks, but were not consistent across locations (Tables 2 and 10). In 17 of 19 locations, 'Golden Delicious' was more productive than 'Braeburn', and at 15 locations, 'Yataka Fuji' and 'Braeburn' did not differ significantly in yield (Table 10). Only two locations found no yield difference among the three cultivars.

CYE relates yield to tree size. Cultivars differed in CYE at 15 of 19 locations (Tables 2 and 11). The greater CY of 'Golden Delicious' over 'Braeburn' was proportionate to its greater tree size in most cases, as the two cultivars had similar CYE at most sites (Table 11). Averaged over all locations, 'Golden Delicious' was the most yield-efficient of the three cultivars, and 'Yataka Fuji' the least, but this pattern was not true everywhere (Table 11).

The CYE of the scions also varied between rootstocks (Table 2). The CYE of 'Braeburn' was significantly higher on M.9 (2.31 kg/cm^2 TCA) than on Mark (1.85 kg/cm^2 TCA), but the opposite was true for 'Golden Delicious' (2.55 kg/cm^2 TCA on Mark, 2.27 kg/cm^2 TCA on M.9). The CYE of 'Yataka Fuji' was unaffected by rootstock (1.73 kg/cm^2 TCA on Mark, 1.68 kg/cm^2 TCA on M.9). Scion x rootstock effects on CYE were also reported in multi-site trials with a large range of rootstock vigor (1,15).

Conclusions

Location had the most profound effect on nearly all response variables. In this large-scale apple cultivar evaluation trial, "location" encompassed climatic, edaphic and management effects, so the reasons for differences in tree performance among locations were difficult to determine. Future

Table 8. Generalized least-squares means for trunk cross-sectional area (cm^2) after fifth growing season as affected by location, cultivar and rootstock.

Location	*P*-value for root x scion at that location	For all scions			For both rootstocks[z]		
		M.9	Mark	*P*-value	Braeburn	Golden Del.	Yataka Fuji
AR	0.108	31.1	19.6	< 0.001	17.4 b	29.4 a	29.3 a
BC	0.960	11.4	15.7	0.116	8.0 b	15.4 a	17.3 a
MA	0.020[y]	13.4	24.9	< 0.001	15.5	21.7	20.3
ME	0.251	12.2	27.3	< 0.001	20.2	21.4	20.2
NC	0.649	32.6	28.3	0.063	22.2 b	35.8 a	33.3 a
NJ	0.059	32.7	34.6	0.482	22.1 b	41.7 a	37.2 a
NYG	0.859	15.6	19.7	0.134	13.2 b	18.7 ab	21.0 a
NYH	0.340	16.1	21.7	0.036	12.6 b	20.4 a	23.6 a
NYI	0.739	25.8	25.5	0.907	17.3 b	28.8 a	30.8 a
OH	0.008[y]	33.6	32.4	0.620	26.7 b	33.5 a	38.9 a
ON	0.720	11.3	17.5	0.032	10.3	16.6	16.3
OR	0.093	24.2	26.0	0.511	19.0 b	30.1 a	26.3 a
PAB	0.682	15.5	14.2	0.581	11.1 b	16.4 ab	17.0 a
PAR	0.827	30.7	34.1	0.199	22.9 b	37.5 a	36.7 a
VT	0.991	10.6	19.0	0.007	10.9	16.5	17.0
WA	0.034[y]	15.4	17.4	0.512	13.8	20.0	15.4
WI	0.955	9.4	17.4	0.003	9.3	15.7	15.3
WV	0.266	45.8	37.6	0.014	26.2 b	46.9 a	52.0 a
WVD	< 0.001[y]	41.8	28.8	< 0.001	22.2 b	42.3 a	41.2 a

[z] Means followed by no letter or the same letter within a row (at one location) are not significantly different by t test at the 5% level.
[y] For these locations it is appropriate to study the three-way means rather than the two-way means shown here. See text.

studies aimed at explaining the reasons for large location effects could provide interesting scientific insights into the tree's physiological responses. Rootstock had no influence on cultivar comparisons of SSC, L/D ratio, skin russet, or red color, nor did it affect days to maturity or bloom rating. Rootstock did affect fruit firmness; the effect was consistent across locations and cultivars, but its magnitude was small relative to location differences. Rootstock had a differential effect on cultivars with respect to fruit size, but again, its influence tended to be smaller than those of cultivar and location main effects. Rootstock greatly influenced tree size and cumulative yield. Of most concern, the rootstock effect on tree size and fruit yield differed in direction as well as magnitude among locations or cultivars. The present paper is limited in scope, consisting of only two dwarfing rootstocks and two or three cultivars, followed over five years. In some previous studies, rootstock effects on scion performance that appeared important after five years (15) later dissipated (1). It would probably be simplest to use a single rootstock in future large trials screening for

Table 9. Generalized least-squares means for height/spread ratio after fifth growing season as affected by location, cultivar and rootstock.

	For all scions[z]		For both rootstocks[z]		
Location	M.9	Mark	Braeburn	Golden Del.	Yataka Fuji
AR	1.06	1.19	1.12	1.13	1.12
BC	1.78 A	1.45 B	2.00 a	1.57 b	1.28 c
ME	1.03 A	0.80 B	0.96	0.96	0.81
NC	1.30	1.23	1.29	1.25	1.24
NJ	1.15 A	0.94 B	1.29 a	0.95 b	0.91 b
NYG	1.00	0.96	1.10 a	0.98 ab	0.87 b
NYH	1.07	1.13	1.21	1.05	1.04
OH	1.04	1.04	0.96 b	1.18 a	0.99 b
ON	1.18	1.09	1.26 a	1.13 ab	1.02 b
OR	1.33	1.27	1.44 a	1.31 a	1.14 b
PAB	1.44	1.40	1.50	1.34	1.41
PAR	1.05	1.01	1.04	1.05	1.00
VT	1.32 A	1.10 B	1.28	1.22	1.13
WA	1.70 A	1.50 B	1.78 a	1.43 b	1.58 ab
WV	1.12	1.12	1.08	1.11	1.17
WVD	1.30 A	1.06 B	1.18	1.20	1.17

[z] Means followed by no letter or the same letter within a row are not significantly different at the 5% level by t test. Capital and lower case letters denote separate analyses for rootstocks and scion cultivars.

cultivar adaptation. However, if that rootstock is poorly adapted in certain areas, re-testing the most promising new cultivars on the region's best-adapted rootstock may have merit, particularly as some of the characteristics most affected by rootstock (such as yield) are of economic importance for commercial producers.

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Table 10. Generalized least-squares means for cumulative yield (kg) as affected by location, cultivar and rootstock.

	For all scions[z]		For both rootstocks[z]		
Location	M.9	Mark	Braeburn	Golden Del.	Yataka Fuji
AR	21.4	24.1	11.3 b	32.1 a	24.8 ab
BC	37.8	46.8	24.3 c	60.4 a	42.2 b
MA	31.8 B	56.6 A	34.5 b	60.8 a	37.4 b
ME	23.1 B	49.0 A	31.9	42.8	33.5
NC	42.1	42.7	27.1 c	59.0 a	41.1 b
NJ	58.5 B	72.4 A	51.5 b	93.5 a	51.4 b
NYG	46.0	54.1	24.5 c	70.4 a	55.2 b
NYH	22.2	26.4	19.4 b	34.7 a	18.9 b
NYI	69.4	78.5	59.5 b	93.6 a	68.6 b
OH	57.4	61.3	50.8 b	71.2 a	56.0 b
ON	20.7	30.5	20.6 ab	34.5 a	21.7 b
OR	81.8	86.4	76.1	87.8	88.5
PAB	19.1	17.4	11.4 b	25.6 a	17.7 ab
PAR	28.6	33.0	19.6 b	41.0 a	31.6 ab
VT	27.7 B	42.7 A	20.4 b	53.4 a	31.8 b
WA	37.0	38.0	22.6 b	54.0 a	35.9 b
WI	22.7	32.9	18.1 b	38.9 a	26.4 b
WV	71.0 A	56.4 B	55.6 b	85.5 a	49.9 b
WVD	67.6	59.2	60.7 b	84.4 a	45.0 c

[z] Means followed by no letter or the same letter within a row are not significantly different by t test at the 5% level. Capital and lower case letters denote separate analyses for rootstocks and scion cultivars.

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Table 11. Generalized least-squares means for cumulative yield efficiency (cumulative yield,kg/final trunk cross-sectional area, cm^2) for three cultivars at different locations, averaged over two rootstocks.

Location	Braeburn[z]	Golden Del.	Yataka Fuji
AR	0.65	1.29	0.80
BC	3.20 b	3.98 a	2.45 c
MA	2.45 ab	2.79 a	1.94 b
ME	1.75	2.10	1.94
NC	1.31	1.73	1.29
NJ	2.39 a	2.31 a	1.42 b
NYG	2.04 c	3.93 a	2.79 b
NYH	1.50 a	1.69 a	0.82 b
NYI	3.46 a	3.28 a	2.31 b
OH	2.08 a	2.09 a	1.53 b
ON	2.00 a	2.14 a	1.33 b
OR	4.09 a	2.95 c	3.41 b
PAB	1.03 b	1.74 a	1.08 b
PAR	0.85	1.11	0.86
VT	1.98 b	3.20 a	2.00 b
WA	1.93 b	2.79 a	2.41 ab
WI	2.14 ab	2.56 a	1.77 b
WV	2.06 a	1.94 a	1.02 b
WVD	2.55 a	2.23 a	1.18 b

[z] Means followed by no letter or the same letter within a row are not significantly different by t test at the 5% level

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Tree Age at Planting, Root Manipulation, and Trickle Irrigation Affect Growth and Cropping of Apple Trees

'Queen Cox'/M.9 trees were more precocious when planted as 2-yr-old trees than when planted as 1-yr-old trees, even though there were no differences in height or branch length at planting. The 2-yr-old trees had larger root systems than the 1-yr-old trees at planting, however. As the trees aged, those planted as 1-yr-old trees were more vigorous, and produced higher cumulative yields than those planted as 2-yr-old trees. Annual root pruning reduced shoot growth, canopy volume and final tree weights. In some seasons, root pruning increased flowering, fruit set and yield efficiency. Planting of trees in semi-permeable fabric membranes suppressed shoot growth and tree size, but to a lesser extent than root pruning. Root restriction increased fruit set and yield and also improved the grades of fruit produced. Trickle irrigation increased shoot growth and tree size, but had minimal effects on fruit set and yield. From Webster, A.D., S.P. Vaughan, A.S. Lucas, J.E. Spencer, and C.J. Atkinson. 2003.J. Hort. Sci Biotech. 78:680-688.