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Influence of Four Apple Cultivars on Five Dwarfing Rootstocks on Morphology of Two-Year-Old Limb Sections

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Abstract

Morphological characteristics on two-year-old stem sections of four apple cultivars on five dwarfing rootstocks (M.26 EMLA, O.3, M.9 EMLA, B.9, Mark) were measured in Wooster, OH, Manhattan, KS and Wichita, KS from 1994-1996. Location and year had the greatest influence on all the morphological characters. Rootstock had minor influence on morphological characters measured, while cultivar had a significant influence. Stem length of all cultivars and rootstocks was positively correlated to spur and shoot numbers. For most of the cultivars and rootstocks, yield was positively correlated with density for flowering spurs and negatively correlated with stem length. Consistently for all cultivars M.26 EMLA and O.3 produced the longest stems and had the most spurs/stem, while the opposite was true for MARK and B.9/ the data in this study supports the theory that rootstock controls total growth and cultivar controls distribution of growth. However, the cultivar rootstock interactions show that some rootstocks were able to cause slight changes in the distribution of growth of a given cultivar.

Rootstocks have long been known for their influence on tree size, yield and yield efficiency of apples (1,6,7). Warrington et al. (8) found that rootstock could influence spur characteristics of 'Delicious' and 28 'Delicious' strains demonstrated a positive relationship between spur density and yield efficiency. Hirst and Ferree (4) reported that shoot length of 'Starkspur Supreme Delicious' was affected by rootstock and number of spurs on a shoot was positively correlated with shoot length. The best predictor of precocity and productivity was shoot length or trunk cross-sectional area. In a greenhouse study Hirst and Ferree (3) reported that rootstock controlled total growth while scion mainly controlled distribution of growth.

The 1990 NC-140 cultivar rootstock planting compared five dwarf rootstocks on cultivars that ranged from a terminal bearer ('Rome Beauty'), to a spur type ('Empire') with 'Golden Delicious' and 'Jonagold' intermediate forms (Lespinase Class 3). The objective of this axillary study to the NC-140 study was to evaluate the influence of rootstocks on the morphological characteristics of two-year-old limb sections of apple cultivars with a range of growth habits. These morphological characters were related to yield to determine relative importance.

Materials and Methods

Four apple cultivars (Empire, Nicobel Jonagold, Smoothee Golden Delicious and Law Rome Beauty) on five dwarfing rootstocks (M.26 EMLA, O.3, M.9EMLA, B.9 and MARK) were planted in Wooster, OH, Manhattan, KS and Wichita, KS in 1990 as part of the NC-140 rootstock/cultivar planting (7). Unfortunately an epidemic of fireblight eliminated the 'Rome Beauty' from the Wooster site. The trees were planted 3 x 5.5m, staked, trained to a slender spindle with minimal pruning. Pest and soil management were according to local recommendations. This study was conducted for three years (1994-96) and 3-5 trees of each combination at each site were

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used for analysis. The three locations represent three different USDA hardiness zones (Wooster, OH - Zone 5, 155 frost-free days; Manhattan, KS - Zone 6A, 175 frost-free days; Wichita, KS - Zone 6B, 185 frost-free days).

Annually at bloom, 5 two-year-old stem sections from the periphery of each tree were randomly selected and the following measured: length, basal diameter, flowering spurs, vegetative spurs, short shoots (5-15 cm in length), long shoots (>15 cm in length). Total number of flower clusters per tree were counted at bloom and yield and trunk circumference measured annually. Treatments were arranged in a randomized complete block/split plot design at each location with cultivar as the whole plot and rootstock as the split plot with 5 individual tree replicates where possible. Data were analyzed using analysis of variance (MIXED procedure of SAS) and regression analysis (SAS Institute, Cary, NC).

Results

Significant differences occurred for locations and years for all morphological characters analyzed (Table 1). Cultivars differed for all factors except vegetative long shoot, while rootstock affected only flower density, flowering spurs/m and vegetative long shoots. The Wooster site tended to have more flowering spurs and short shoot density, but unfortunately flower clusters/tree and long shoots were not measured. As expected 'Empire' had more spurs and fewer short shoots than the other three cultivars. The morphology of 'Jonagold' and 'Golden Delicious' was very similar with the only differences being more vegetative short shoots in 'Golden Delicious' trees. MARK caused the greatest flower density/tree (flower clusters ÷ trunk area) and flowering spur/m stem. M.26EMLA trees had the lowest flower density per tree and flowering spurs/m and were the largest trees. Trees on M.26EMLA and M.9EMLA produced more vegetative long shoots than trees on B.9 and MARK, which had smaller trunk cross-sectional areas.

The significant interactions between cultivar and rootstock for the morphological characters are shown in Figure 1. The average length of the two-year-old stem on trees on M.26EMLA, O.3 and M.9EMLA was longer that trees on B.9 and MARK (Fig. 1A). Stem length on B.9 and MARK was similar except on 'Rome Beauty' where B.9 was longer that MARK. Spur number was highest on 'Empire' and lowest on 'Rome Beauty' with 'Jonagold' and 'Golden Delicious' intermediate and similar (Fig. 1B). Rootstock had no influence on spur number of 'Jonagold', 'Golden Delicious', and 'Rome 'Beauty'. However, M.26EMLA and O.3 had more spurs per stem on 'Empire' trees than B.9 and MARK.

Rootstock did not influence the density of flowering spurs on 'Empire', but with 'Jonagold' trees on M.9 had a lower density of flowering spurs than trees on B.9 and MARK (Fig. 1C). 'Golden Delicious' trees on M.26EMLA had a lower density of flowering spurs than B.9 or MARK.

We calculated correlation coefficients between yield per tree and the morphological factors in an attempt to see if relationships existed (Table 2). Yield for each of the cultivars had relationships with most of the morphological factors, while rootstock seemed related to length of the two-year-old branch, but not strongly related to the other factors. Correlating the morphological factors with the cultivar/rootstock interaction means shows a strong relationship for length of the two-year-old stem for 'Empire' trees on all rootstocks, while with 'Jonagold' the relationship was limited to B.9 and MARK and for 'Rome Beauty' all rootstocks except MARK. Stem length of 'Golden Delicious' had no relationship on any of the rootstocks, but all rootstocks had a strong relationship with flowering spurs/m for this cultivar.

Since this study had so many significant factors (site, year, cultivar and rootstock) and corresponding interactions that influenced the results, we calculated the percentage of the treatment sums of squares that was attributed to each (Table 3). More than 50% of all factors, except flowering

Table 1. Effect of location, year, cultivar, and rootstock on density of flowering and vegetative spurs, flower clusters, short shoots, and long shoots on 2-year-old apple stems on trees planted in 1990.

Effect	Flower density clusters/TCSA	Flowering spurs/m	Vegetative spurs/m	Flowering short shoots/m	Vegetative short shoots/m	Flowering long shoots/m	Vegetative long shoots/m
Location							
Wooster	–	12.9	6.9	2.73	1.03	–[z]	–[z]
Manhattan	4.73	11.2	9.5	1.13	1.18	1.20	0.81
Wichita	8.14	8.5	12.2	0.37	0.58	0.13	0.43
LSD (P=0.05)	0.87	1.1	1.0	0.21	0.27	0.33	0.20
Year							
1994	–	5.6	9.7	1.07	1.33	1.31	1.34
1995	8.98	17.9	7.4	1.50	0.37	0.41	0.19
1996	3.89	9.1	11.6	1.66	1.09	0.28	0.31
LSD (P=0.05)	0.80	1.0	0.9	0.19	0.25	0.36	0.22
Cultivar							
Empire	8.01	15.3	11.7	0.46	0.69	0.21	0.62
Jonagold	7.41	8.7	7.8	1.83	0.70	0.91	0.69
Golden Delicious	5.44	8.7	9.1	1.95	1.39	0.82	0.79
LSD (P=0.05)	1.02	0.9	0.9	0.20	0.20	0.25	NS
Rootstock							
M.26EMLA	4.76	9.8	10.3	1.27	0.97	0.72	0.75
O.3	6.11	10.2	9.5	1.41	0.99	0.83	0.61
M.9EMLA	6.33	10.4	9.3	1.49	0.99	0.70	0.89
B.9	6.80	11.7	9.4	1.45	0.84	0.55	0.51
MARK	8.17	12.3	9.2	1.43	0.86	0.52	0.32
LSD (P=0.05)	0.96	0.8	NS	NS	NS	NS	0.21
F significance							
Location (L)	***	***	***	***	*	***	*
Year (Y)	***	***	***	***	***	*	***
Cultivar (C)	***	***	***	***	***	***	NS
Rootstock (R)	***	***	NS	NS	NS	NS	**
L x Y	***	***	***	*	NS	**	NS
L x C	*	***	NS	***	**	***	NS
L x R	***	NS	NS	***	NS	NS	*
L x C x R	**	NS	NS	**	NS	**	NS
Y x C	NS	*	***	**	**	*	*
Y x R	NS	**	*	NS	***	***	NS
Y x L x C	NS	***	***	NS	***	NS	*
Y x L x R	**	***	***	***	*	***	NS
Y x C x R	NS	***	***	*	***	**	**
C x R	NS	*	NS	NS	NS	NS	NS
L x Y x C x R	NS	***	**	**	*	***	*

[z] Long shoot data were not collected from the trees in Wooster in 1995 and 1996.

NS, *, **, *** Nonsignificant or significant at P≤ 0.05, 0.05, or 0.001, respectively

Table 2. Correlation coefficients between yield/tree (kg) and spur, short shoot and long shoot number and density of flowering spurs, short shoots and long shoots and stem length on 2-year-old apple stems on trees planted in 1990.

Effect	Spur number	Short shoot number	Long shoot number	Flowering spurs/m	Flowering short shoots/m	Flowering long shoots/m	Stem length (cm)
Location[z]							
Wooster	0.07	0.21**	—[y]	-0.02	0.21**	—[y]	0.08
Manhattan	0.13	-0.16*	-0.34***	0.32***	-0.06	-0.29***	-0.22**
Wichita	-0.12	-0.16**	-0.31***	0.30***	-0.01	-0.29***	-0.47***
Year							
1994	0.08	0.42***	0.40***	0.05	0.28***	0.29***	0.20**
1995	0.20**	0.30***	0.27***	0.01	0.26***	0.25***	0.36***
1996	0.03	0.02	0.16*	-0.16	0.04	0.16*	0.08
Cultivar							
Empire	-0.06	-0.17**	-0.21**	0.21***	-0.11	-0.15*	-0.29***
Jonagold	0.06	0.13	-0.14	0.18*	0.23**	-0.13	-0.23**
Golden Delicious	0.44***	0.16*	-0.15	0.53***	0.14*	-0.18*	-0.04
Rome[x]	0.07	-0.04	-0.19*	0.23**	0.06	-0.16	-0.35***
Rootstock							
M.26EMLA	0.12	0.17*	-0.13	0.35***	0.22	-0.13	-0.23**
O.3	-0.06	0.09	-0.18*	0.13	0.16*	-0.13	-0.35***
M.9EMLA	-0.02	0.02	-0.19	0.14	0.06	-0.14	-0.27**
B.9	-0.15	-0.04	-0.27**	0.04	0.12	-0.24**	-0.50***
MARK	-0.02	0.04	-0.19	0.30***	0.04	-0.26**	-0.38***
Cultivar X Rootstock							
Empire							
M.26EMLA	-0.05	-0.26	-0.20	0.50***	-0.17	-0.15	-0.42**
O.3	-0.22	-0.03	-0.18	0.13*	0.15	-0.08	-0.47***
M.9EMLA	-0.12	-0.30	-0.26	0.36**	-0.26	-0.08	-0.38***
B.9	-0.18	-0.15	-0.27	0.06	-0.13	-0.21	-0.47***
MARK	-0.30*	-0.18	-0.43*	0.11	-0.15	-0.41*	-0.53***
Golden Delicious							
M.26EMLA	0.43**	0.34*	-0.10	0.62***	0.33*	-0.16	0.07
O.3	0.51***	0.25	-0.13	0.52***	0.24	-0.12	0.002
M.9EMLA	0.32*	0.09	-0.16	0.53***	0.07	-0.16	-0.25
B.9	0.29	0.13	-0.17	0.60***	0.13	-0.24	-0.22
MARK	0.47***	-0.04	-0.29	0.61***	-0.02	-0.38*	-0.23
Jonagold							
M.26EMLA	0.03	0.33*	-0.16	0.25	0.48**	-0.14	-0.32
O.3	0.06	0.03	-0.11	0.15	0.03	-0.09	-0.27
M.9EMLA	0.34	0.42*	-0.04	0.17	0.35	-0.10	0.23
B.9	-0.16	-0.16	-0.36	0.16	0.38*	-0.26	-0.65***
MARK	-0.30	-0.04	-0.16	0.26	0.06	-0.22	-0.50***
Rome[x]							
M.26EMLA	0.12	-0.03	-0.15	0.42*	-0.02	-0.15	-0.43*
O.3	-0.03	0.04	-0.30	0.35*	0.21	-0.26	-0.55***
M.9EMLA	0.16	-0.07	-0.29	0.52*	0.12	-0.24	-0.63**
B.9	-0.15	-0.25	-0.33*	0.20	-0.02	-0.28	-0.68***
MARK	0.0005	-0.06	-0.23	0.27	0.006	-0.22	-0.35

[z] For location effects and interactions the Rome data was removed

[y] Long shoot data were not collected from the trees in Wooster in 1995 and 1996.

[x] Data were not collected from the Rome trees in Wooster.

*, **, *** Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Percentage of total treatments sum of squares due to main effects and interactions for various vegetative and flowering characteristics taken from 2-year-old apple stems in the NC-140 1990 planting in Ohio and Kansas.

	Stem length	Short shoot number	Long shoot number	Flower density	Flowering spurs/m	Vegetative spurs/m	Flowering short shoots/m	Flowering long shoots/m
Location (L)	9.2***	62.5***	19.7**	27.9***	6.3***	31.1***	57.2***	27.5***
Year (Y)	79.2***	4.4**	34.9***	41.5***	56.9***	26.1***	4.4***	10.7*
Cultivar (C)	3.2***	23.7***	23.8***	1.1***	26.9***	20.0***	28.6***	36.3***
Rootstock (R)	5.1***	0.9**	4.0***	0.4***	1.7***	0.5	0.1	0.8**
L x Y	0.4**	0.1	3.9	19.7***	4.1***	8.3***	0.7	5.7**
L x C	0.4**	4.4***	7.9***	1.8*	1.0***	0.7	6.0***	7.1***
L x R	0.4***	0.7***	1.2*	4.2***	0.1	0.2	0.5***	1.1
L x C x R	0.0	0.1**	0.5**	0.3**	0.0	0.2	0.1**	0.5**
Y x C	0.8**	1.8**	0.7	0.5	0.7*	6.0***	1.1**	2.9**
Y x R	0.2***	0.1	0.6	0.6	0.3**	0.8*	0.1	2.3***
Y x L x C	0.2***	0.3*	0.3	0.2	0.5***	3.5***	0.1	1.2
Y x L x R	0.1***	0.2***	0.7	0.9***	0.3***	0.8***	0.2***	2.1***
Y x C x R	0.1***	0.1***	0.5***	0.1	0.2***	0.5***	0.1*	0.3**
C x R	0.1*	0.1	0.4	0.1	0.3*	0.5	0.1	0.4
L x Y x C x R	0.0	0.0	0.0	0.0	0.1***	0.1**	0.0	0.6***

*, **, *** Significance of original F values at $P \leq 0.05$, 0.01, or 0.001, respectively.

long shoots (37%) was attributed to site and year effects. The percentage attributed to rootstock was small (<6%) for all morphological factors. Cultivar accounted for 20% or more of all factors except stem length and flower density. The highest percentage (above 7%) accredited to interactions were as follows: 19.7% L x Y flower density; 8.3% L x Y vegetative spurs/m; 7.9% L x C long shoot number; 7.1% L x C flowering long shoots.

Discussion

The differences based on location and year were expected because the three locations were in different hardiness zones, weather zones varied from site to site and year to year, and the trees were grown on different soil types. In particular, M.9 EMLA and MARK have been reported to have different rooting densities when exposed to different soil types, (2). A study examining spur characteristics of 'Delicious' apple strains at two locations reported wide variation, at both sites within and between spur and standard types, for density of spurs (8). Interestingly, spur number and density of flowering spurs were either not correlated or weakly correlated with yield and yield efficiency. In a study reported by Hirst and Ferree (4), 'Starkspur Supreme Delicious' trees were grown on 17 rootstocks over six years and the correlation coefficients for the relationship between yield and spur number ranged from a low of 0.46 at the beginning of the study to a high of 0.80 at the end of the study, and density of spurs was always negatively correlated with yield. Their data clearly showed an increasing trend between yield and spur number, which became stronger as the trees aged. The lack of trends or strong relationships due to location or year in this study between yield or yield efficiency and spur number or density of flowering spurs is probably because the data were combined for differ-

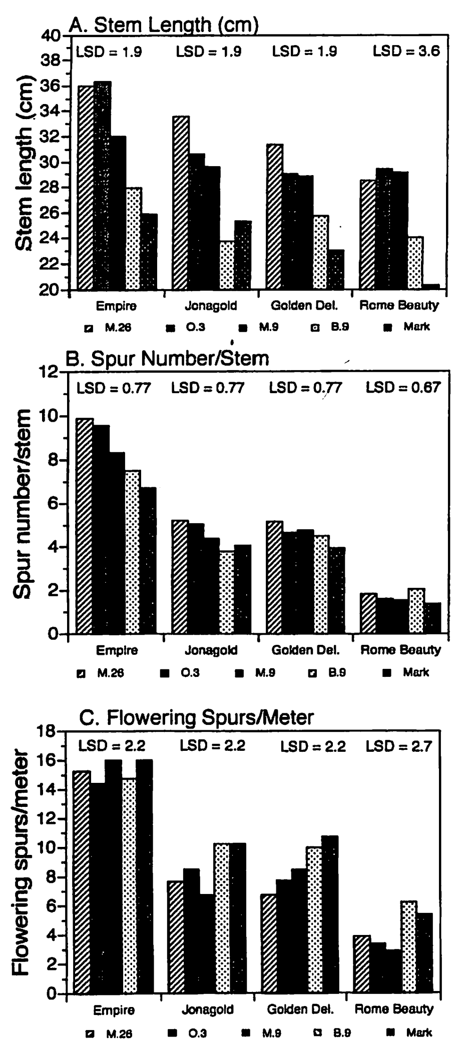

Figure 1. Morphological characteristics of two-year-old stems where the interaction between cultivars and rootstock was significant: stem length (A), spur number/stem (B), flowering spurs/meter (C).

ent cultivars. Correlation coefficients in Table 2 show a strong relationship of yield and density of flowering spurs for 'Golden Delicious' and no relationship with 'Jonagold' with the other cultivars in between (Table 2).

Cultivar differences were also expected because they were originally chosen for the NC-140 project based on their growth habit (7). 'Empire' is a spur type cultivar, 'Rome Beauty' is primarily a tip-bearing type tree and 'Golden Delicious' and 'Jonagold' are intermediate in their growth habits. As expected, two-year-old stem sections from 'Empire' trees had much higher spur densities than branches on trees of the other cultivars in the study. Compared with 'Empire', the two-year-old branch segments of 'Golden Delicious' and 'Jonagold' were shorter with fewer spurs and more short and long shoots. The smallest trees were produced by 'Empire' probably because they had a high spur density and only produced a few short and long shoots resulting in the trees being more compact. In a study where 21 spur and 14 standard 'Delicious' strains were compared, on average the spur trees were smaller. The smallest correlation coefficients for the relationship between stem length and spur number were for the 'Rome Beauty' trees. Because 'Rome Beauty' is a terminal bearing cultivar with few spurs, one would not expect stem length and spur number to be very strongly correlated. In contrast, 'Empire' being of spur-type habit, had a stronger relationship between stem length and spur number than the other cultivars. Most of the morphological correlations with yield and yield efficiency were low with the exception of flowering spur density or spur number for 'Golden Delicious' and stem length for 'Rome Beauty'. Overall, 'Rome Beauty' had the strongest relationship between stem length and yield or yield efficiency. The longer the stem length, the lower the yield or yield efficiency. B.9 and MARK resulted in a stronger negative relationship of stem length and yield than the other rootstocks with 'Jonagold'. This correlation indicates that some rootstocks were able to cause slight changes in the distribution of growth for a given cultivar.

For each of the cultivars there was variation among rootstocks for the characters evaluated. However, by examining the correlation data for the strongest relationships between yield and yield efficiency and the morphological characteristics, certain variables seem to be more important. The variables that had the strongest relationships with yield and yield efficiency were stem length , spur number, and flowering spurs and short shoot density. The relationship between stem length and yield or yield efficiency was negative indicating that trees with short stem lengths are more productive. The cultivars differed in which variables were the most important. For 'Empire' and 'Rome Beauty' the strongest relationships with yield and yield efficiency were for stem length or flowering spur density. For 'Golden Delicious' spur number and flowering spur density had the strongest relationships with yield and yield efficiency and for 'Jonagold' stem length and flowering short shoot density had the strongest relationships. In a six year study where 'Starkspur Supreme Delicious' was evaluated on 17 rootstocks the strongest relationships were between yield and yield efficiency and stem length, spur number, and flower number (4).

The high amount of treatment variation associated with year and location effects and the low amount accounted for by rootstock effects indicates that evaluation over multiple years and locations is necessary to accurately evaluate rootstocks for the variables followed in this study. However, because cultivar effects were larger that year or location effects for spur number and density of spurs and short shoots, vegetative short shoots and flowering long shoots these variables could be accurately evaluated on a given year at a given location . Comparison of just the variation accounted for by cultivar and rootstock effects indicates that total growth, yield, and yield efficiency are largely controlled by rootstock and distribution of flowering and vegetative spurs and short shoots and flowering long shoots are primarily scion controlled. These results basically corroborate earlier reports (3,5) that concluded rootstock controls total growth and distribution of growth was mainly controlled by cultivar. However, close examination of each cultivar-rootstock interaction reveals that some rootstocks were able to cause slight changes in the distribution of growth for a given cultivar.

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