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

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

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Abstract

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

Introduction

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

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crops, there is a strong genotype x environment interaction, or phenotypic plasticity, so that the relative ranking of genotypes changes as site potential changes (1, 7).

The NC-140 1980-1981 apple rootstock trial (5, 6) provides the first extensive opportunity to determine if apple rootstock x site interactions are significant. The ideal rootstock would be one that combined high potential with high stability across environments. Models comparing potential and environmental stability of growth and yield characteristics among rootstocks would provide an improved basis to make rootstock recommendations to growers.

Materials and Methods

The apple rootstocks O.3, M.7 EMLA, M.9, M.9 EMLA, M.26 EMLA, M.27 EMLA, MAC.9, MAC.24, and OAR 1 were budded in a commercial nursery with the scion cultivar 'Starkspur Supreme Delicious.' Ten replications of each rootstock were planted at each site in 1980-1981 in a randomized complete block design, and were evaluated over 10 years by NC-140 Regional Project cooperators at locations in 27 states and provinces across North America (5, 6). EMLA status indicates that these rootstocks are free from known latent viruses. 'Starkspur Golden Delicious'/M.26 and 'Macspur'/M.26 trees were included as pollinizers. Uniform planting and management practices were coordinated by the NC-140 Technical Committee (5, 6).

Plantings in eight of the sites were removed due to excessive tree loss from winter injury, vole damage, and other causes (5, 6). Some tree losses also occurred in the 19 sites that were retained for the duration of the study (6). Our analysis of rootstock performance potential and stability was based on the surviving trees in the final 19 sites.

Methods of analyzing cultivar differences in performance potential at an average site and differences in stability of performance across sites have been developed by plant breeders (1, 7). The method of "joint regression analysis" developed by Findlay and Wilkinson (4) provides a straight forward approach to comparing performance potential and stability of phenotypes across a range of sites. The analysis is commonly used for comparison of yield, but it can be used to evaluate environmental stability of any trait (1). We used this method in separate analyses of three long-term performance variables for nine rootstocks in this study: TCSA measured in 1989, Yc over 1980-1989, and YEc calculated as Yc/TCSA.

In the method of joint linear regression, a seperate linear regression line is determined for the performance of each rootstock across all sites. The average performance (TCSA, Yc, or YEc) of a given rootstock in a given site (Y axis value), is plotted against the average performance of all rootstocks in that site (X axis value). The average performance of all rootstocks within a site is termed the "site index" (SI) and is a measure of the overall potential of that site for the single performance variable being considered. the linear model obtained when a number of sites are considered describes the change in average performance of the rootstock with change in SI. Two characteristics of these models are useful in comparing rootstocks. First, rootstock "average potential" is defined as the average Y value for the rootstock at the average SI (that is, grand mean for the rootstock vs. grand mean over all rootstocks). The second characteristic of interest is the slope of the regression line through the average potential point. This slope is related to the environmental stability of the rootstock, (that is, the rootstock x environment interaction). Rootstocks with slopes less than 1.0 (flatter slopes) have greater stability, and rootstocks with slopes greater than 1.0 (steeper slopes) have less stability, relative to the average stability over all rootstocks in the test (slope = 1.0).

Results and Discussion

Site index. The 19 sites in this study provided a considerable range in SI, with SI values for Yc, TCSA, and YEc ranging from 50% to 180% of the mean SI over all sites (Table 1). SI values of Yc and YEc tended to vary in the same order across sites, with a linear correlation between these SI variables of r = 0.82 (significant at 0.1% level), but these variables were not well correlated with TCSA across sites. The relations among Yc, TCSA, and YEc are quite different when comparing sites than when comparing means of these same variables across rootstocks. In the case of rootstocks, Yc and TCSA generally vary together and are both inversely related to YEc (Table 2, 3, 4).

Cumulative yield per tree. All regressions of rootstock mean Yc within site on Yc SI's were significant at the 5% level (Table 2). Rootstock stability of Yc across locations decreased as Yc potential at the mean SI increased, with the exception of OAR 1. Mean Yc of OAR 1 was 8% below the population mean, but this rootstock had the second steepest slope (not stable) after MAC.24. MAC.24 had the highest mean Yc and lowest stability, while M.27 EMLA displayed the opposite characteristics. The combined effects of mean potential and stability resulted in MAC.24 having the poorest predicted Yc at the worst site (SI = 31 kg/tree) and the highest Yc at the best site (SI = 374 kg/tree). M.27 EMLA was lowest in Yc across the entire range in SI.

Table 1. Mean yield, trunk size, and yield efficiency by test site (Site Index), arranged in descending order by cumulative yield.

Site	Cumulative yield per tree (kg)	Trunk cross-sectional-area (cm^2)	Yield efficiency ($kg\ cm^{-2}$)
Planted 1980:			
California	374 (maximum)	82	5.5 (maximum)
Ontario	255	83	3.7
Oregon	202	61	3.8
Wisconsin	192	65	3.5
Indiana	166	85	3.9
Massachusetts	165	35	5.2
Ohio	158	58	3.5
Virginia	146	79	2.8
Georgia	136	96 (maximum)	1.7
Illinois	118	87	2.2
Kentucky	95	63	1.9
Michigan	76	50	2.1
Iowa	74	62	1.4
Arkansas	71	64	1.2 (minimum)
Washington	55	34 (minimum)	1.9
Pennsylvania	46	45	1.8
Quebec	31 (minimum)	37	1.2 (minimum)
Planted 1981:			
Utah	170	68	5.1
Tennessee	65	56	1.6
Mean	134	64	2.8

Table 2. Yield per tree, cumulative over the period 1980-1989.

Rootstock	Mean yield over sites^z (kg)	Yield stability over sites^y (slope)	r^x	Predicted cumulative yield extremes (kg)^w Worst site	Best site
MAC.24	+103	3.20 L	.88°°	-97	1003
M.7 EMLA	+ 57	1.33 L	.94°°	53	507
M.26 EMLA	+ 25	.55 M	.56°°	101	289
O.3	+ 3	.58 M	.72°°	76	276
M.9 EMLA	- 6	.46 M	.55°°	80	238
OAR 1	- 11	1.36 L	.90°°	-19	449
MAC.9	- 33	.41 M	.62°°	58	198
M.9	- 43	.37 M	.72°°	52	180
M.27 EMLA	- 92	.32 M	.61°°	9	118
Overall mean:	134	1.00			

^zMeans expressed as difference from the overall mean; "+" = better than average, "-" = worse than average.
^yM = more stable than average, L = less stable than average.
^xr is significant at the 5% (°°) level.
^wWorst site SI = 31 kg, best site SI = 374 kg.

Trunk cross-sectional-area. Regressions of the means of rootstock TCSA within site on SI for each site were significant at the 5% level for slopes of 0.58 or greater (Table 3). Among the very flat slopes, M.9 (b = 0.22) and M.27 EMLA (b = 0.07) were significant at the 10% level, but MAC.9 (b = 11) was not significantly different from zero. TCSA of M.9, M.27 EMLA, and MAC.9 must be considered very stable across sites, but the mean potential TCSA of these three rootstocks was also very low. As with Yc, stability of TCSA across sites decreased as mean TCSA increased among the rootstocks. MAC.24 had the largest TCSA in all sites, but also had the steepest slope (least stable).

Cumulative yield efficiency. In general, rootstock ranking for YEc was reversed from that for Yc and TCSA (Table 4). All regressions of mean rootstock YEc potential on SI were signifi-

Table 3. Final trunk cross-sectional-area measured in 1989.

Rootstock	Mean TCSA over sites^z (cm^2)	TCSA stability over sites^y (slope)	r^x	Predicted TCSA extremes (cm^2)^w Worst site	Best site
MAC.24	+102	3.14 L	.86°°	74	268
OAR 1	+ 29	1.62 L	.87°°	46	146
M.7 EMLA	+ 27	1.16 L	.79°°	57	129
M.26 EMLA	+ 3	.73 M	.56°°	46	91
O.3	- 19	.61 M	.70°°	27	64
M.9 EMLA	- 23	.58 M	.80°°	24	60
M.9	- 35	.22 M	.41°	22	36
MAC.9	- 36	.11 M	.27ns	24	31
M.27 EMLA	- 54	.07 M	.44°	8	13
Overall mean:	64	1.00			

^zMeans expressed as difference from the overall mean; "+" = better than average, "-" = worse than average.
^yM = more stable than average, L = less stable than average.
^xr is significant at the 5% (°°) or 10% (°) levels, or not significant (ns).
^wWorst site SI = 34 cm^2, best site SI = 96 cm^2.

Table 4. Yield efficiency calculated as cumulative yield per trunk cross-sectional-area.

Rootstock	Mean yield efficiency over sites[z] (kg cm^{-2})	Yield eff. stability over sites[y] (slope)	r[x]	Predicted YEc extremes (kg cm^{-2})[w]	
				Worst site	Best site
M.27 EMLA	+1.4	2.06 L	.78**	.8	9.7
MAC.9	+ .9	1.26 L	.92**	1.6	7.1
M.9	+ .6	1.09 L	.95**	1.6	6.3
O.3	+ .6	1.09 L	.94**	1.6	6.3
M.9 EMLA	+ .6	.75 M	.80**	2.2	5.4
M.26 EMLA	- .2	.85 M	.96**	1.2	4.9
M.7 EMLA	- .6	.80 M	.80**	.9	4.3
OAR 1	-1.3	.79 M	.86**	.3	3.7
MAC.24	-1.6	.52 M	.71**	.4	2.6
Overall mean:	2.8	1.00			

[z]Means expressed as difference from the overall mean; "+" = better than average, "-" = worse than average.
[y]M = more stable than average, L = less stable than average.
[x]r is significant at the 5% (**) level.
[w]Worst site SI = 1.2 kg cm^{-2}, best site SI = 5.5 kg cm^{-2}.

cant at the 5% level or better. M.27 EMLA had the highest mean YEc and lowest stability. Thus, M.27 EMLA had a low predicted YEc at the poorest site (SI = 1.2 kg cm^{-2}) and the highest predicted YEc at the best site (SI = 5.5 kg cm^{-2}). MAC.24 was the opposite extreme, with the lowest mean YEc and highest stability of YEc over sites. Thus MAC.24 was at or near the poorest level of YEc across all sites (stable as a solid D student!).

M.9 EMLA and M.9 differ in that the EMLA designation indicates rootstocks that have been freed of known latent viruses of apple. However, it has been suggested that M.9 EMLA may have been propagated from a subclone with a genetic component of greater vigor potential than the common M.9 (3). M.9 EMLA has been reported to result in a tree 50% larger than M.9 (3). In the present study, mean TCSA and Yc were 41% and 27% greater for M.9 EMLA than M.9, respectively (Table 2, 3). Mean YEc of M.9 and M.9 EMLA did not differ, but YEc of M.9 EMLA was more stable over sites (flatter slope) than M.9. Thus, predicted YEc of M.9 EMLA was greater than M.9 in poor sites, but less than M.9 in good sites (Table 4). These results suggest that at least part of the difference between M.9 and M.9 EMLA may have more to do with differences in response to environment, than with differences in YEc potential at an average site.

Summary. The analysis reported here suggests that rootstock effects on apple tree Yc, TCSA, and YEc do not vary simply in proportion to the population mean over different growing environments, but that rootstock x environment interactions are significant. It must be recognized that rootstocks differ not only in potential at an average site, but also in the effect of growing site on that potential.

Rootstock selection for a particular site might be made in three steps. First, select those rootstocks with acceptable survival rates predicted for the specific site. Second, using the models of predicted average potential and environmental stability developed in this report, narrow the list of rootstocks to those with the best TCSA, Yc, and YEc in sites similar to the specific site. Third, further reduce the list of possible rootstock choices on the basis of desirable horticultural traits (lack of suckering, need for support, etc.) for the specific site and the management system desired. Further results from current and future NC-140 rootstock trials will increase our understanding of these interactions and will improve our ability to use these models as an aid to making rootstock recommendations for specific sites.

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Abnormalities in 'Starkspur Supreme Delicious' on Nine Rootstocks in the 1980-81 NC-140 Cooperative Planting

NC-140[1]

Abstract

'Starkspur Supreme Delicious' on MAC.24, OAR 1, M.7 EMLA, M.26 EMLA, O.3, M.9 EMLA, M.9, Mark, and M.27 EMLA were planted at 27 sites in the United States and Canada in 1980-81. During the 10 years of the trial, biotic and abiotic abnormalities occurred. Some were confined to one location while others were more widespread. An outbreak of fire blight (*Erwinia amylovora* Burr) developed in the Virginia trial. Although there was no significant effect of rootstock on the severity of infection initiated in the scion, tree losses varied with rootstock. Tree losses ranged from 67% and 50% on M.26 EMLA and O.3, respectively, to 0 to 20% for the other rootstocks. In Arkansas, Internal Bark Necrosis occurred; trees on M.27 EMLA and Mark were most severely affected, followed by M.26 EMLA and O.3. The least affected trees were on OAR 1. A growth proliferation occurred on essentially all Mark rootstocks in 7 locations. A swelling was located on the rootstock shank, at the ground line and below, with no apparent relationship to the bud union.

[1]Cooperators shown in Table 1.

Introduction

In addition to tree size control, precocity, and yield, other aspects of rootstock performance are important. This paper summarizes data and observations made by several researchers involved with the 1980/81 NC-140 Cooperative Rootstock Planting (14). The primary emphasis of this paper is on fire blight, internal bark necrosis, and a growth proliferation on the rootstock shank, each of which occurred at one or more of these plantings.

Apple cultivars vary widely in their susceptibility to fire blight [*Erwinia amylovora* (Burr)]. After an extensive literature review, Van der Zwet and Keil (20) reported the 'Delicious' is most often classified as resistant to fire blight. Of the rootstocks used in