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# Rootstock Effects on Growth and Fruiting of a Spur-Type and a Standard Strain of 'Delicious' Over Eighteen Years

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## Abstract

'Red Prince,' a standard strain and 'Redchief' (Campbell strain), a spur-type strain of 'Delicious' apple were grown on several rootstock/interstock combinations for 18 years. The dwarfs were Malling 9 (M.9), M.26, M.9/Malling Merton 106 (MM.106), and M.9/M M.111. The semi-dwarfs were M.7, MM.106, and MM.111. Five three-tree replications were used. In-row spacing was varied from 1.8 to 5.5 m depending on the scion/interstock/rootstock combination; between-row spacing was 6.1 m throughout the experiment. Tree survival ranged from a high of 100% for five combinations to as low as 13% for both 'Delicious' strains on MM.106. In the dwarf group, trees of both strains on M.26 were the largest, those on M.9/MM.111 were intermediate, and those on M.9 and M.9/MM.106 were the smallest. The greatest numbers of rootsuckers were on trees on M.9/MM.111 and M.7. Crop density tended to be higher with 'Redchief' than 'Red Prince' and higher in the dwarf than semi-dwarf group. With both 'Redchief' and 'Red Prince,' cumulative per-tree yields were greater on M.26 than on M.9 or M.9/MM.111. Trees of 'Redchief' on the three semi-dwarf rootstocks yielded similarly; 'Red Prince' trees on MM.111 out-yielded trees on M.7. With both strains, trees on M.9 and M.9/MM106 tended to have higher cumulative yield efficiencies than those on M.26 or M.9/MM.111. Cumulative yields (T/ha) for both strains were highest for trees on M.26 compared to all other rootstocks. Cumulative yields for the three semi-dwarf rootstocks differed little with either scion.

## Introduction

Most apple growers utilize clonally propagated, size-controlling rootstocks. Genetic dwarfing is the main choice for controlling tree size and productivity because the degree of tree size restriction possible by pruning and training is quite limited, and growth control chemicals are largely unavailable.

Rootstock evaluation studies have been published in many parts of the world. Some of these have been preliminary in nature, often providing data for five years up to a rather common maximum of 10 years. Although these reports are informative, there is also the need for long-term experiments for 15 or more years. Because of the great precocity of the very dwarfing rootstocks, yield data over only a 5-10 year period may tend to bias conclusions in their favor, while in longer term studies, less precocious stocks might

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overcome their lack of precocity with heavy sustained yields in later years. Such studies have been very informative (7, 9, 10, 11, 16, 17, 18, 19). At the conclusion of two 35-year studies in England with rootstocks in a broad vigor range, Preston reported that the ranking of rootstocks based on tree size was unchanged after the 15th year for both cultivars (16, 17). The rankings based on accumulated yields were not established until the 20th year with 'Lane's Prince Albert' (16), and the 32nd year for 'Cox's Orange Pippin' (17). After completion of a later study (19) Preston concluded that seven years of data were adequate for the evaluation of rootstocks more dwarfing than M.7, but more vigorous rootstocks would require an additional eight years of data. In a rootstock trial in central Washington, the cumulative yield trends established by year 16 were generally maintained through year 25 (9, 11).

Our experiment was established to evaluate the long-term performance of a spur and a standard strain of 'Delicious' on several rootstocks and interstock/rootstock combinations in the dwarf and semi-dwarf categories. These data over a period of 18 years also provide the opportunity to explore the potential advantages of long-term rootstock trials.

## Materials and Methods

The experiment was conducted at the Virginia Tech Horticultural Research Farm near Blacksburg, Va. The soil is a clayey, mixed, mesic Typic Hapludult. Prior to clearing in 1974, the site had been in apple trees for at least ten years; the site was covercropped in 1975. No nematode control was used. In the spring of 1976 lime was broadcast at 4.5 T/ha. Three-meter-wide strips were plowed and disced; rows were planted in the middle of each strip. Holes were dug with a 45 cm auger.

Trees of a uniform size were purchased from a commercial nursery in Michigan. The total experiment consisted of standard and spur-type strains of 'Delicious' and 'Golden Delicious.' Results with 'Golden Delicious' were previously reported (3); results with 'Delicious' are presented herein.

The 'Delicious' trees were set in three-tree plots. All trees were planted with the graft union (lower graft union of interstem trees) 3-4 cm above the soil line. Interstem length was 15 cm. Three rows of 'Delicious' alternated with single rows of 'Golden Delicious.' Because of the diversity of anticipated tree sizes, the rootstocks were divided into dwarf (M.9, M.26, M.9/MM.106, and M.9/MM.111) and semi-dwarf (M.7, MM.106, and MM.111) groups, and each group was treated as a separate experiment. Also because of expected differences in tree size, the spur-type and standard growing strains were put in separate experiments. The net result was that we had four 'Delicious' experiments, each of which was analyzed separately as a randomized complete block design with five replications (15 trees per rootstock). Blocks represented different locations in the orchard. All trees on M.9 were supported by a 2.1 m treated wood post; no other trees were supported.

In the entire experiment the between-row spacing was 6.1 m. Tree spacings within rows were varied according to expected tree vigor (Table 1). Where plots with different spacing met, the mean of the two spacings was used between those trees.

Throughout the study, fertilizer (N only) was broadcast uniformly, regardless of tree spacing or cultivar. Additional lime was applied as indicated by soil tests. Weeds were controlled in the row by application of herbicides in a 1 m strip. Trees were not irrigated. Row middles were mowed periodically to minimize competition with the trees. Pruning, pest control, fruit thinning, and pre-harvest drop control were done according to local recommendations. All trees were trained to a central leader utilizing the head and spread system (8). Tree height was restricted to a maximum of approximately 5 m, and trees were pruned as necessary to maintain drive rows of approximately 2.4 m.

At harvest the fruit from each 'Delicious' tree were counted and their total weight determined. In the early years, tree height and tree spread were measured annually; in later years these variables were measured less frequently. Due to the constant row spacing, the trees on vigorous rootstocks required more severe pruning than did trees on the dwarfing rootstocks to keep the drive middles open. Therefore tree spread measurements in the later years were made in the row only. Trunk circumferences were measured annually at 40 cm above the soil line. Root suckers were counted annually early in the study and occasionally thereafter. When a tree broke off or died, it was dropped from the experiment; data for each year are based on the surviving trees.

***Statistical analyses.*** For statistical analysis of the yield data, means for each three-tree plot were used; for tree growth measurement data, individual trees were treated as sub-samples within blocks. Yield, fruit weight, crop density, and yield efficiency data were tested with analysis of variance using the Mixed Procedure of SAS, and LSMEANS were compared with Tukey's test (21). Rootstock was a fixed effect and blocks were designated as a random effect. Tree height, tree spread, trunk circumference, and total yield were measured annually, except as indicated above. These types of measurements, taken on the same tree over time, were evaluated with the Repeated Measures analysis of variance with the Mixed Procedure of SAS. In most cases, the year by rootstock interaction was significant ($P < 0.05$), so data were analyzed by year and LSMEANS were compared by Tukey's test. Further details on the statistical procedures used were described in our earlier paper (3).

**Table 1. In-row spacing of 'Delicious' apple tree on seven rootstocks (planted 1976).[z]**

| Rootstock/ interstock | 'Redchief' Tree spacing (m)[y] | 'Redchief' Trees/ha | 'Red Prince' Tree spacing (m)[y] | 'Red Prince' Trees/ha |
|---|---|---|---|---|
| **Dwarf** | | | | |
| M.9 | 1.8 | 896 | 2.4 | 672 |
| M.26 | 2.4 | 672 | 3.0 | 538 |
| M.9/MM.106 | 3.0 | 538 | 3.7 | 448 |
| M.9/MM.111 | 3.0 | 538 | 3.7 | 448 |
| **Semi-dwarf** | | | | |
| M.7 | 3.7 | 448 | 4.3 | 384 |
| MM.106 | 4.3 | 384 | 4.9 | 336 |
| MM.111 | 4.9 | 336 | 5.5 | 298 |

[z]Between-rows spacing was 6.1 m throughout the experiment.
[y]When trees at different spacings were adjacent, the mean of the two spacings was used.

## Results and Discussion

***Tree survival.*** For the first 10 years, tree survival was 87% or more for both 'Redchief' and 'Red Prince' on all dwarf rootstocks (Table 2). By the end of the experiment, considerable tree loss had occurred with 'Red Prince'/M.9/MM.106

**Table 2. Tree survival (%) of 'Delicious' as influenced by strain and rootstock (planted 1976).**

| Rootstock/interstock | 'Redchief' 1980 | 1985 | 1990 | 1993 | 'Red Prince' 1980 | 1985 | 1990 | 1993 |
|---|---|---|---|---|---|---|---|---|
| **Dwarf** | | | | | | | | |
| M.9 | 93 | 93 | 93 | 93 | 100 | 93 | 80 | 71 |
| M.26 | 100 | 100 | 100 | 100 | 100 | 93 | 93 | 93 |
| M.9/MM.106 | 100 | 87 | 80 | 80 | 88 | 88 | — | 43 |
| M.9/MM.111 | 100 | 100 | 100 | 100 | 100 | 93 | 87 | 87 |
| **Semi-dwarf** | | | | | | | | |
| M.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 83 |
| MM.106 | 80 | 13 | 13 | 13 | 53 | 47 | 13 | 13 |
| MM.111 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**Table 3. Trunk cross sectional area ($cm^2$) of 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| | 'Redchief' | | | | 'Red Prince' | | | |
|---|---|---|---|---|---|---|---|---|
| Rootstock/interstock | 1980 | 1985 | 1989 | 1993 | 1980 | 1985 | 1989 | 1993 |
| **Dwarf** | | | | | | | | |
| M.9 | 6c[z] | 18c | 31c | 48c | 11b | 44c | 89c | 120c |
| M.26 | 14a | 52a | 94a | 144a | 21a | 108a | 190a | 252a |
| M.9/MM.106 | 9b | 25c | 41c | 57c | 11b | 38c | 54c | 71d |
| M.9/MM.111 | 9b | 35b | 67b | 94b | 12b | 63b | 130b | 175b |
| Significance ($P \leq F$) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| **Semi-dwarf** | | | | | | | | |
| M.7 | 15ab | 74a | 146a | 211a | 16ab | 104a | 206b | 238b |
| MM.106 | 14b | 44b | 111b | 156b | 15b | 62b | 168b | 229b |
| MM.111 | 16a | 77a | 152a | 227a | 18a | 124a | 255a | 354a |
| Significance ($P \leq F$) | 0.022 | 0.001 | 0.043 | 0.031 | 0.049 | 0.001 | 0.001 | 0.001 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance by Tukey-Kramer test.

with smaller losses of 'Red Prince'/M.9 (Table 2). Tree survival of both strains was excellent on M.7 and MM.111, but tree losses were heavy for both strains on MM.106; only 13% of which survived through 1990. The decline and death of both strains on MM.106 were due primarily, if not completely, to apple union necrosis and decline (20).

Although tree survival data were published in the recent NC-140 reports (14, 15), many earlier reports of rootstock evaluation offered no tree survival data (5, 9, 11, 22). Mean tree survival across all sites in the 10-year NC-140 trials ranged from 61 to 97% for the 1980 trial (14) and 66 to 100% for the 1984 trial (15). At the end of the tenth year in our trial (1985), tree survival ranged from 87 to 100%, except for the drastic tree losses on MM.106. The majority of tree losses in our study were the result of apple union necrosis and decline (AUND), indicating the great susceptibility of 'Delicious'/MM.106 to this disorder. Combined with its well known susceptibility to collar rot, MM.106 is not widely recommended, especially as a rootstock for 'Delicious.'

***Tree size.*** On the dwarf rootstocks, TCA was largest for both strains on M.26 followed by M.9/MM.111 (Table 3). 'Red Prince' trees had larger TCA on M.9 than on M.9/MM.106, whereas 'Redchief' trees on M.9 and M.9/MM.106 had similar TCA's. 'Red Prince' tended to have TCAs considerably larger than 'Redchief' on both dwarf and semi-dwarf rootstocks. With 'Redchief,' TCA's of trees on M.7 and MM.111 did not differ while those on MM.106 were smaller. The smaller TCA's of trees on MM.106 likely reflected the prevalence of AUND. It should be remembered that only 13% of trees of either strain on MM.106 survived through 1990. In the later years of the experiment 'Red Prince' trees on MM.111 had larger TCA's than those on M.7 and MM.106.

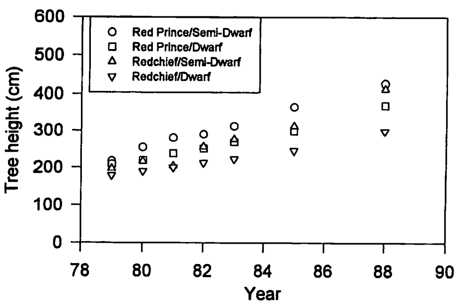


**Figure 1. Tree height (cm) of 'Delicious' apple trees as influenced by strain and rootstock; dwarf: mean for M.9, M.26, M.9/MM.106, and M.9/MM.111; semi-dwarf: mean for M.7, MM.106, and MM.111. Trees planted in 1976.**

**Table 4. Tree height (cm) of 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| | 'Redchief' | | | 'Red Prince' | | |
|---|---|---|---|---|---|---|
| Rootstock/interstock | 1980 | 1985 | 1988 | 1980 | 1985 | 1988 |
| **Dwarf** | | | | | | |
| M.9 | 171c[z] | 219b | 275b | 205b | 282b | 338bc |
| M.26 | 212a | 286a | 350a | 263a | 350a | 450a |
| M.9/MM.106 | 188bc | 215b | 256b | 193b | 258b | 314c |
| M.9/MM.111 | 189b | 265a | 313a | 217ab | 306b | 381b |
| Significance (P ≤ F) | 0.001 | 0.001 | 0.001 | 0.014 | 0.001 | 0.001 |
| **Semi-dwarf** | | | | | | |
| M.7 | 223 | 344a | 421 | 262 | 356ab | 428ab |
| MM.106 | 212 | 248b | 398 | 241 | 321b | 375b |
| MM.111 | 216 | 343a | 421 | 260 | 421a | 479a |
| Significance(P ≤ F) | 0.232 | 0.006 | 0.707 | 0.201 | 0.005 | 0.008 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance by Tukey-Kramer test.

The results for tree height (Table 4) were generally similar to those for TCA (Table 3), but relative differences among rootstocks were smaller than with TCA. In the dwarf group, trees of both strains were tallest on M.26, followed by trees on M.9/MM.111. Among the more vigorous stocks, there were no significant differences after twelve years with 'Redchief'; with 'Red Prince,' trees on MM.106 were shorter than those on MM.111. The trends in mean tree height for the four groups show a widening of differences, especially between the 'Redchief'/dwarf and 'Red Prince'/vigorous in 1985 and 1989 (Fig. 1). Tree height data were not collected in the later years of the experiment because of the strong effect of pruning on tree height of the larger trees.

Tree spread results (Table 5) were much like the tree height data (Table 4). In comparing the data in Tables 1 and 5, it is apparent that trees of 'Redchief on both M.9 and M.26 exceeded their allotted in-

**Table 5. Tree spread (cm) of 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| | 'Redchief' | | | 'Red Prince' | | |
|---|---|---|---|---|---|---|
| Rootstock/interstock | 1980 | 1985 | 1988 | 1980 | 1985 | 1988 |
| **Dwarf** | | | | | | |
| M.9 | 71c[z] | 169b | 214c | 127 | 344bc | 335b |
| M.26 | 123a | 278a | 322a | 165 | 445a | 431a |
| M.9/MM.106 | 92b | 184b | 222c | 120 | 308c | 296c |
| M.9/MM.111 | 96b | 215b | 261b | 137 | 394ab | 410ab |
| Significance (P ≤ F) | .001 | .001 | .001 | .094 | .018 | .001 |
| **Semi-dwarf** | | | | | | |
| M.7 | 123 | 297 | 371 | 170a | 446 | 449b |
| MM.106 | 113 | 235 | 349 | 149b | 364 | 458ab |
| MM.111 | 117 | 292 | 368 | 161ab | 481 | 555a |
| Significance(P ≤ F) | 0.069 | 0.122 | 0.795 | 0.003 | 0.060 | 0.002 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance by Tukey-Kramer test.

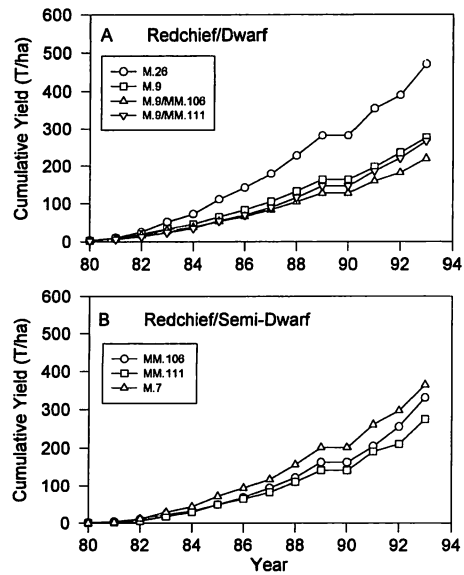


**Figure 2. Cumulative yields (T/ha) of 'Redchief Delicious' on (A) dwarf and (B) semi-dwarf rootstocks. Trees planted in 1976.**

row space. 'Redchief' trees on the two interstem combinations did not fill their allotted space. 'Red Prince' trees on all dwarf rootstocks exceeded their allocated space except for those on M.9/MM.106. Except for 'Redchief'/MM.106 and 'Redchief'/MM.111, the trees on the semi-dwarf rootstocks approximately matched their spacing.

***Rootsuckers.*** In the dwarf rootstock group, both strains produced the most rootsuckers on M.9/MM.111 at 10 (1985) and 15 (1990) years (Table 6). Somewhat surprising was the relatively large number of rootsuckers on trees on M.9. With 'Redchief' in the semi-dwarf rootstock group, the most rootsuckers were on trees on M.7 at 10 and 15 years. With 'Red Prince,' trees on M.7 produced the most rootsuckers. As we reported for 'Golden Delicious' (3), the severity of the rootsucker problem continued to increase up through the 15th year. M.7 has long been known to be very prone to form rootsuckers (6). Using two strains of 'McIntosh,' Autio and Southwick (2) reported that suckering was much higher with M.7 and M.9/MM.111 than with M.9 or M.26. Noteworthy is that trees of both strains of 'Delicious' on M.9/MM.111 suckered considerably worse than did trees on M.9/MM.106 (Table 6), perhaps due to the greater vigor of the former combination.

***Crop Density.*** Throughout this experiment, crop densities (CD's) within the scion/rootstock groups were generally similar; data are presented as means for 3 to 14 year periods (Table 7). With both

**Table 6. Number of rootsuckers on 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| Rootstock/interstock | 'Redchief' 1980 | 1985 | 1990 | 'Red Prince' 1980 | 1985 | 1990 |
|---|---|---|---|---|---|---|
| **Dwarf** | | | | | | |
| M.9 | 0 | 0b | 25b | 1 | 2b | 16b |
| M.26 | 0 | 0b | 1c | 2 | 1b | 1b |
| M.9/MM.106 | 1 | 2b | 9bc | 2 | 1b | 0b |
| M.9/MM.111 | 0 | 29a | 70a | 2 | 47a | 86a |
| Significance (P ≤ F) | 0.303 | 0.001 | 0.001 | 0.395 | 0.001 | 0.001 |
| **Semi-dwarf** | | | | | | |
| M.7 | 1 | 58a | 115a | 0 | 34 | 60a |
| MM.106 | 0 | 1b | 6b | 0 | 2 | 8b |
| MM.111 | 1 | 2b | 5b | 0 | 7 | 23b |
| Significance (P ≤ F) | 0.632 | 0.001 | 0.001 | 0.596 | 0.154 | 0.026 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance by Tukey-Kramer test.

**Table 7. Crop density[z] (fruit/cm2 TCA) of 'Delicious' as influenced by strain and rootstock (planted 1976).[z]**

| Rootstock/Interstock | 'Redchief' 1980-'84 | 1985-'89 | 1991-'93 | 1980-'93 | 'Red Prince' 1980-'85 | 1986-'90 | 1991-'93 | 1980-'93 |
|---|---|---|---|---|---|---|---|---|
| **Dwarf** | | | | | | | | |
| M.9 | 4.5 | 6.0 | 7.8 | 5.8 | 3.6 | 5.4 | 6.0 | 4.9 |
| M.26 | 3.6 | 4.7 | 5.8 | 4.5 | 1.8 | 3.7 | 6.0 | 3.5 |
| M.9/MM.106 | 4.6 | 5.5 | 8.6 | 5.9 | 2.9 | 6.1 | 8.8 | 5.5 |
| M.9/MM.111 | 3.5 | 4.9 | 7.2 | 4.9 | 1.8 | 4.4 | 6.6 | 3.9 |
| Mean | 4.0 | 5.3 | 7.4 | 5.3 | 2.5 | 4.9 | 6.9 | 4.4 |
| **Semi-dwarf** | | | | | | | | |
| M.7 | 2.4 | 3.9 | 5.2 | 3.6 | 1.6 | 2.6 | 5.0 | 2.9 |
| MM.106 | 3.8 | 4.3 | 8.7 | 5.1 | 2.9 | 4.4 | 6.1 | 4.3 |
| MM.111 | 1.9 | 3.2 | 5.7 | 3.3 | 1.3 | 2.9 | 5.4 | 3.0 |
| Mean | 2.7 | 3.8 | 6.5 | 4.0 | 0.5 | 2.9 | 5.2 | 3.1 |

[z]Means within column and rootstock/interstem group do not differ (5% level).

strains, CD's of trees on M.9 tended to be higher than on trees on M.26, but for no period was the difference significant. During the first five cropping years, CD's tended to be higher for 'Redchief' than for 'Red Prince.' This would be a typical difference between a spur-type and standard strain for most cultivars (1). In both strains, CD's tended to be higher on the dwarfing than on the semi-dwarf rootstocks, especially in the early years of the trial.

***Cropping.*** With the dwarfing rootstocks, final per-tree yields of 'Redchief were greatest on M.26, intermediate on M.9/MM.111 and M.9/MM.106, and lowest on M.9 (Table 8). With 'Red Prince,' final yields per tree were higher on M.26 than on either M.9 or M.9/MM.111. Among the semi-dwarf rootstocks, per-tree yields of 'Redchief' did not differ, whereas with 'Red Prince,' final yields on M.7 were less than on MM.111.

When expressed as T/ha for the actual tree spacings, yields of 'Redchief'/M.26 were markedly greater than any of the other three dwarf rootstocks which were similar (Fig. 2A). With 'Red Prince' on the dwarf rootstocks, yields were greatest for trees on M.26, intermediate for trees on M.9 and least for the interstem trees (Fig. 3A). Over the 18 years of the study, average cumulative yields (T/ha.) of 'Red Prince' on the dwarf rootstocks were approximately 1/3 higher than average cumulative yields of 'Redchief on the dwarf rootstocks (Fig. 2A and 3A). Cumulative yields per ha for 'Redchief' on M.7 were

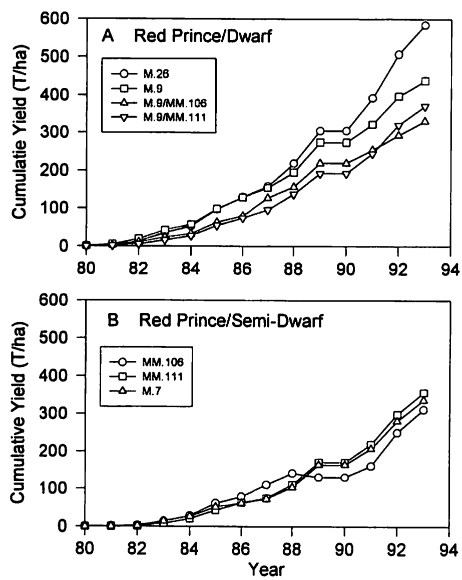


**Figure 3. Cumulative yields (T/ha) for 'Red Prince Delicious' on (A) dwarf and (B) semi-dwarf rootstocks. Trees planted in 1976.**

**Table 8. Cumulative yield (kg/tree) of 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| | 'Redchief' | | | | 'Red Prince' | | | |
|---|---|---|---|---|---|---|---|---|
| Rootstock/interstock | 1980 | 1984 | 1989 | 1993 | 1980 | 1984 | 1989 | 1993 |
| **Dwarf** | | | | | | | | |
| M.9 | 3b[z] | 51b | 183c | 316c | 2a | 84 | 407 | 630b |
| M.26 | 4b | 108a | 419a | 700a | 1b | 97 | 566 | 1097a |
| M.9/MM.106 | 6a | 71b | 237bc | 423bc | 2a | 71 | 485 | 764ab |
| M.9/MM.111 | 4b | 65b | 273b | 555b | 1b | 61 | 430 | 747b |
| Significance ($P \leq F$) | 0.001 | 0.001 | — | 0.001 | 0.014 | 0.122 | 0.054 | 0.003 |
| **Semi-dwarf** | | | | | | | | |
| M.7 | 1b | 99 | 450 | 825 | 0 | 69 | 427ab | 837b |
| MM.106 | 5a | 82 | 438 | 1005 | 1 | 87 | 387b | 925ab |
| MM.111 | 2b | 85 | 421 | 839 | 0 | 67 | 572a | 1196a |
| Significance ($P \leq F$) | 0.001 | 0.131 | 0.542 | 0.158 | 0.997 | 0.065 | 0.047 | 0.039 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance by Tukey-Kramer test.

higher than those on MM.111 (Fig. 3A). Cumulative yields for trees of 'Red Prince' on all of the semi-dwarf rootstocks were remarkably similar (Fig. 3B). Overall yields of trees of both strains were considerably lower on the semi-dwarf than the dwarf rootstocks.

In comparing the standard in-row spacing of 6.1 m with the tree spread in 1988 (Table 5), it is apparent that the 6.1 m spacing was much more appropriate for some combinations than others. Assuming that the between-row tree spread was the same as in-row spread (Table 5), the average drive middles would have been 3.6 and 2.4 m for the 'Redchief'/dwarf and 'Red Prince'/dwarf, respectively. The open drive middles for the 'Redchief'/semi-dwarf and 'Red Prince'/semi-dwarf would have averaged 2.5 and 1.2 m, respectively. From these estimates it is obvious that the between-row spacing was appropriate for standard orchard equipment in the 'Redchief'/semi-dwarf and 'Red Prince'/dwarf. However, the 3.6 m drive middle for the 'Redchief'/dwarf was somewhat excessive and the 1.2 m in the 'Red Prince'/semi-dwarf was completely inadequate. Little could be done to fill the extra space between the rows of 'Redchief'/dwarf, but rather severe containment pruning was required with 'Red

**Table 9. Cumulative yield efficiency (kg/cm² TCA) of 'Delicious' trees as influenced by strain and rootstock (planted 1976).**

| | 'Redchief' | | | 'Red Prince' | | |
|---|---|---|---|---|---|---|
| Rootstock/interstock | 1984 | 1989 | 1993 | 1984 | 1989 | 1993 |
| **Dwarf** | | | | | | |
| M.9 | 3.3a[z] | 5.8a | 6.4ab | 2.4a | 4.7a | 5.6a |
| M.26 | 2.5b | 4.6b | 5.0c | 1.2b | 3.0b | 4.3b |
| M.9/MM.106 | 3.4a | 5.8a | 7.1a | 2.0a | 5.7a | 7.2a |
| M.9/MM.111 | 2.4b | 4.2b | 5.3bc | 1.2b | 3.3b | 4.7b |
| **Semi-dwarf** | | | | | | |
| M.7 | 1.7b | 3.1b | 3.9b | 0.8b | 2.0b | 4.1 |
| MM.106 | 2.7a | 4.0a | 5.8a | 1.6a | 3.2a | 4.0 |
| MM.111 | 1.4b | 2.8b | 3.6b | 0.7b | 1.8b | 3.4 |

[z]LS means within column and rootstock/interstock group followed by the same letter do not differ at the 5% level of significance, by Tukey-Kramer test.

**Table 10. Average fruit weight (g) of 'Delicious' as influenced by strain and rootstock (planted 1976).[z]**

| | 'Redchief' | | | | 'Red Prince' | | | |
|---|---|---|---|---|---|---|---|---|
| Rootstock/interstock | 1980-'85 | 1986-'90 | 1991-'93 | 1980-'93 | 1980-'85 | 1986-'90 | 1991-'93 | 1980-'93 |
| **Dwarf** | | | | | | | | |
| M.9 | 217 | 178 | 133 | 186 | 193 | 195 | 130 | 179 |
| M.26 | 204 | 190 | 150 | 188 | 188 | 180 | 120 | 170 |
| M.9/MM.106 | 200 | 184 | 134 | 180 | 200 | 175 | 117 | 173 |
| M.9/MM.111 | 200 | 173 | 134 | 177 | 183 | 170 | 127 | 166 |
| **Semi-dwarf** | | | | | | | | |
| M.7 | 190 | 178 | 130 | 172 | 180 | 184 | 130 | 169 |
| MM.106 | 187 | 180 | 137 | 173 | 184 | 175 | 120 | 165 |
| MM.111 | 200 | 182 | 130 | 178 | 190 | 168 | 123 | 166 |

[z]Means within column and rootstock/interstem group do not differ at the 5% level.

Prince'/semi-dwarf. These considerations should be kept in mind as the accumulated per-hectare yields are considered (Figs. 2 and 3).

***Yield Efficiency.*** For 'Redchief on the dwarf rootstocks, yield efficiency (YE) was greatest for M.9 and M.9/MM.106, intermediate for M.9/MM.111, and lowest for M.26 (Table 9). With 'Red Prince,' YE's were also higher for M.9 and M.9/MM.106 than for trees on M.9/MM.111 and M.26 which did not differ. With 'Redchief' on the semi-dwarf rootstocks, YE's were higher for MM.106 than M.7 or MM.111. With 'Red Prince' YE's did not differ among the semi-dwarf rootstocks.

***Fruit Size.*** Over the course of this study, average fruit weight varied from about 120 to about 215 g, but there were no consistent effects of strain or interstem/rootstock (Table 10). Fruit weights were particularly low in the 1991-1993 period due to inadequate thinning. Trees carried excessive fruit loads but not enough to preclude adequate flower bud formation. There are reports of rootstock effects on fruit size (4, 14), but most are with certain rootstocks such as M.27 and OAR 1 which tend to produce small fruit and which were not included in this study.

The cumulative yield (T/ha) data in this paper (Figs. 2 and 3) provide the opportunity to estimate the number of years required to assess the relative productivity of different rootstocks. In evaluating our data it should be kept in mind that these trees did not receive the intensive treatments in the early years typically given to high density orchards today. It is therefore likely that production was delayed by a year or two. From the data herein, it is apparent that cumulative yields up through year 5 (1980) were minimal and grossly insufficient to draw conclusions (Table 8). By year 9 (1984), the long-term trends on a per-tree yield basis were somewhat better established. With 'Red Prince' on the dwarf rootstocks, however, it took until about the 14th year (1989) for the differences in cumulative yields per tree to be significant at the 5% level (Table 8). Likewise the final rankings of 'Redchief/dwarf rootstocks were not reached until the 14th year (1989). In Figs. 2 and 3, the separation of treatments became clearer as the experiment continued. With 'Redchief on dwarf rootstocks (Fig. 2A), trees on M.26 were obviously most productive by the 10th year (1985), and the difference widened through the rest of the trial. With 'Redchief on the semi-dwarf rootstocks (Fig. 2B), there was a trend toward greater productivity of trees on M.7, and the separation from MM.111 expanded in the later years. With 'Red Prince' on dwarf rootstocks (Fig. 3A), there appeared to be two groups after 10 years (1985). In subsequent years there was additional separation which was relatively clear at 15 years (1990). (Excessive losses of trees on M.9/MM.106 caused a shift between 1990 and 1993). With 'Red Prince' on the semi-dwarf rootstocks there were only small differences at any time. On the basis of these data, 10 years appears to be a reasonable compromise; in some cases less may be adequate but in others, 15 years can be preferable. Barritt et al. (4) recently concluded that it takes about seven years (including five cropping seasons) to assess yield efficiency. Our data indicate that yield efficiency could be assessed in most cases by the tenth year (Table 9).

Another factor in estimating the number of years needed to evaluate a rootstock trial is how the trees are spaced. When a constant spacing is used for rootstocks representing a relatively wide range in vigor (4), the necessary pruning will eventually affect the results. Barritt et al. (4) indicated that this was not a major problem in the 8 years of their study. This concern, however, prevents the continuation of such a study long enough to fully evaluate the potential long-term differences among the rootstock candidates. To obtain information on potential tree spread for spacing recommendations, 10 years seems reasonable for the dwarf rootstocks, but 15 years may be required for vigorous rootstocks (Table 5). A variable spacing as used in our trial obviously requires more information on rootstock vigor than is typically available for relatively new rootstock candidates. Perhaps the most logical solution is the approach taken in the 1994 NC-140 trials in which the different vigor categories are put in different trials with constant but appropriate spacings in each.

With high early yields in today's intensive orchards, there is increasing interest in more frequent orchard replacement to grow new cultivars and strains of older cultivars. If a grower may want to replace an orchard after 15 years, there may well be limited interest in rootstocks that do not reach their potential until 15 years or more. On this basis, the logical end point for comparison may well be in the range of ten years, even though the "ultimate" trends may not yet be clear.

As discussed by Autio and Southwick (2), the use of YE by itself to characterize rootstock productivity needs to be reevaluated. In Table 9, the cumulative YE for both 'Redchief' and 'Red Prince' on M.26 were lower than on M.9, and much lower than on M.9/MM.106. However, for cumulative yield per tree and per ha, the reverse is true. In spite of very high YE's, trees which are particularly weak, may have limited yield potential. In our data, trees on M.9/MM.106 were in this category; in other trials, it is often M.27.

Results in these experiments with 'Delicious' as well as the earlier report on 'Golden Delicious' indicate little or no difference in cumulative yields and only moderate differences in size of trees on the three semi-dwarf rootstocks. Since MM.106 has serious problems with AUND as well as collar rot *(Phytophthora cactorum)* and M.7 not only suckers badly but is also rather poorly anchored, MM.111 should be considered if a relatively large tree size is acceptable. Both survival and anchorage of MM.111 have been outstanding with 'Delicious' (Table 7) and 'Golden Delicious' (3). Throughout this trial MM.111 has been at least as productive as M.7 for both 'Delicious' (Table 8) and 'Golden Delicious' (3). The excellent yield performance of trees on MM.111 in our study are in rather sharp contrast with those reported by Autio and Southwick (1) who found MM.111 to have much lower yields and YE than M.7, but their data were only through the fifth growing season.

In overview of our entire experiment, the outstanding performance of M.26 is noteworthy. Cumulative yields (T/ha) for both strains of 'Delicious' on M.26 far exceeded any other rootstock/interstock. Similar results were previously reported for a spur-type and standard growing strain of 'Golden Delicious' (3). In 1987 fireblight, *Erwinia amylovora,* killed several trees of 'Starkspur Supreme Delicious'/M.26 in an orchard about 100 m away from this experiment, but at no time during the 18 years of this trial was there an outbreak of fireblight in this block. Neither 'Golden Delicious' nor 'Delicious' is particularly susceptible to fireblight, but several of the rootstocks, particularly M.9 and M.26, are classified as very susceptible (12). A recent report from New York (13) offers evidence that *Erwinia amylovora* can be transmitted from an infection in the scion through healthy tissue to the rootstock. Assuming that the bacteria reaching the roots can induce an infection, these fireblight susceptible rootstocks and interstocks hold the potential for a disaster, particularly with scion cultivars which are highly susceptible to fireblight, such as 'Gala' and 'York.' With such combinations, it is imperative that every effort be made to prevent, rather than to try to cut out or cure the initial infection.

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