

Performance of Ten Apple Orchard Systems: Ten-Year Summary of the 1990 NC-140 Systems Trial

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Abstract

Ten orchard systems, composed of three training systems and several rootstocks, were compared with two cultivars at nine locations for ten years. The training systems were slender spindle (SS) with 2,460 trees/ha, vertical axis (VA) with 1,561 trees/ha, and central leader (CL) with 1,111 trees/ha. Trunk cross-sectional area (TCA) tended to be related to tree density. TCA was greatest for CL trees, smallest for SS trees and intermediate for VA. Cumulative yields per ha varied greatly with location and cultivar, but the relative performance of orchard systems was fairly consistent across locations and cultivars. CL trees on M.26 or Mark rootstock tended to be least productive, whereas SS trees on M.9, Mark, and B.9 rootstocks were the most productive. VA/M.9 was the most productive of the VA systems and at some locations it was as productive as SS. Plantings at Michigan, New York, and Virginia were more productive than plantings at Illinois, North Carolina, Ontario, and Washington. Relative to other systems, VA/M.9 produced higher yields at the high-productivity locations than at the low-productivity locations.

Introduction

An orchard system is the combination of a scion/rootstock unit, a training system, and tree spacing. Orchard management is modified for a given system. Several orchard systems trials have been established in North America for apple (5, 7, 20) and peach (4, 14, 21). Although yields were often positively related to the number of trees per ha (14, 20), profitability may (6, 14) or may not (4) be related to tree density. Training system also may (4, 20) or may not influence yield (5, 14, 20).

No multi-location trials have been established in North America to evaluate the relative performance of different orchard systems at locations with varying soil and environmental conditions. The objective of this study was to evaluate tree growth and productivity of 10 apple orchard systems at nine locations. An

earlier report summarized the first five years of the trial (1).

Materials and Methods

In the spring of 1990, an orchard systems trial coordinated by the NC-140 technical committee was established with several cultivars at nine locations. The cooperators and locations are listed in a companion paper (13). Plantings at Minnesota and Quebec were removed, after six and eight years, respectively. All trees were propagated by TRECO, Inc., in Woodburn, Oregon. The cultivars were 'Empire', 'Nicobel Jonagold', 'Early Red One Delicious', 'Braeburn', and 'Nagafu 1 Fuji'. Cooperators at each location planted two cultivars. The 10 orchard systems are described in Table 1. An orchard system consisted of a combination of training system, tree spacing, and rootstock. Ten-meter-long plots of

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each orchard system treatment were replicated four times at each location. Each plot had 8, 6, and 5 trees per system for the slender spindle (SS), vertical axis (VA), and central leader (CL), respectively. Trees at each end of the plots were considered to be guard trees and were not used for data collection. The 10-meter-long plots were considered the experimental unit, so there was only one observation per orchard system per block.

Slender spindle trees were individually supported by tying to a post up to a height of about 2 m. Vertical axis trees were tied to a height of 3 m to a multi-wire vertical trellis, or to metal conduit or bamboo poles attached to a single wire or to individual posts. Central leader trees had a trunk support to 1 m, but no support above 1 m.

Protocols for pruning and training were those of Wertheim (22) for SS, Lespinasse (10) for VA, and Heinicke (8) for CL. Pruning the CL trees was modified to avoid heading scaffold limbs and to allow excess lower scaffold branches to fruit for a year or two before removal and selection of permanent branches. Protocols were followed as closely as possible; however, inexperience with the systems resulted in site-to-site variation and deviation from the guidelines was necessary due to variation in tree vigor from site to site. Irrigation, fertility, fruit-thinning and crop protection measures followed local recommendations.

Each year data were reported for mean trunk cross-sectional area (TCA), yield, and average fruit weight per surviving tree per plot. These values were used to calculate number of fruit per tree, cumulative crop density (number of fruit per cm^2 TCA, cumulative yield efficiency (kg of fruit per cm^2 TCA) and cumulative yield per ha. For the first five years, the cooperator at Washington summarized the data (1); thereafter the cooperator at Virginia summarized the data. Data for each cultivar at each location were analyzed as a randomized complete block design by analysis of variance (ANOVA) with SAS's Mixed procedure (11) and least squares

means were compared with the probability of the difference (the pdiff option in the Mixed procedure), which is the least significant difference modified for unequal sample size. Because rootstocks and cultivars were not common to all locations, and variances differed with location, ANOVAs were performed for each combination of location and cultivar.

Results and Discussion

Tree survival. Except for Quebec, where 'Jonagold' survival was poor for SS/M.9, SS/Mark, VA/Mark, CL/M.26 and CL/Mark, tree survival was generally good, but some tree death occurred at every location and with every orchard system (Table 2). Other than Quebec, the only orchard system with less than 80% survival was VA/O.3 at Michigan. Over all locations, the most tree death occurred with SS/Mark and VA/O.3. Survival of Mark with VA and CL training was better than with SS. In the companion trial O.3 also had relatively poor survival (13). Tree survival for particular rootstocks has not been consistent in previous rootstock trials, but O.3 has generally survived as well or better than M.26 (2, 12, 13, 17).

Trunk cross-sectional area. TCA was affected by location, cultivar, and orchard system (Table 3). The largest trunks were reported for Illinois, Michigan, and Virginia and the smallest trunks were produced at North Carolina and Ontario (Table 3). The affect of location on TCA is in general agreement with results from other rootstock trials (12, 17). In general, TCA was smaller for 'Empire' than for 'Jonagold', TCA was similar for 'Delicious' and 'Empire', and TCA was larger for 'Fuji' than for 'Braeburn'. TCA generally is positively related to scion vigor (2). It is difficult to determine the individual influence of training system and rootstock on the response variables because Mark is the only rootstock common to all orchard systems, whereas M.9 was used for SS and VA, and M.26 was used for VA and CL. In general, training system influenced TCA, but the response was probably influenced more by rootstock and tree density than by training system.

TCA is usually negatively related to the number of trees per unit area, but it can be affected by training system (16). The overall ranking of TCA for the three training systems was CL > VA > SS. At Illinois, TCA of 'Jonagold' was not influenced by orchard systems. When trees were planted at the same spacing in New York, TCA was 6% higher for VA than for Y-trellis (19). In another trial, where trees were planted at the same spacing, the ranking for TCA was Y-trellis > Vertical Axis > Free spindle (15).

Yield. Cumulative yield per tree was influenced by location, cultivar, and orchard system (Table 4). Yield was lower at Ontario and Illinois than at the other locations. At Illinois, yield was higher for 'Empire' than for 'Jonagold', but at Ontario the opposite was true. 'Empire' out-yielded 'Delicious' at North Carolina, but production of the two cultivars was similar at Virginia. With Mark as the rootstock, yield/tree was highest for CL and lowest for SS for 13 of the 16 cultivar/location combinations. With M.26 as the rootstock, yields were consistently higher for CL than for VA, but at Washington yields were similar for both training systems. Trees at Quebec responded differently, and yield/tree was similar for CL and VA. Regardless of location or cultivar, with M.9 as the rootstock, yield/tree was higher for VA than for SS. In most situations, CL/M.26 had the highest yield/tree and trees trained as SS had the lowest yields. After the first five years of this trial yield per tree tended to follow a similar trend, where yields were highest for VA/M.26 and lowest for the trees trained as SS and for CL/Mark and VA/Mark (1). For trees trained as SS, rootstock did not significantly influence yield/tree at most locations. For trees trained as VA, yield/tree tended to be highest for trees on M.9 and lowest for trees on P.1. For trees trained as CL, trees on M.26 had significantly higher yields than on Mark at five of the 18 combinations of location and scion.

It is difficult to determine the influence of rootstock, tree spacing, and training system on yield per tree because the three fac-

tors are confounded. In general one might expect that trees grown at close spacing would be small and have lower yield per tree than trees at wider spacing. When data were pooled over two cultivars and four training systems, Robinson (19) found that trees planted at 1,429 trees/ha produced 12% less per tree than trees planted at 1,111 trees/ha. However, training system also affects yield per tree. When data were pooled over two cultivars and two tree densities, yield per tree was about 30% lower for SS than for VA (19). In a Norwegian study, where tree density was held constant, yield per tree was 40% higher for trees trained as Vertical axis than for trees trained as Free spindle (15).

Cumulative yield per ha was influenced by location, cultivar, and training system (Table 5). Cumulative yield per ha was lowest at Ontario and highest at Virginia. After the first five years of this trial, cumulative yield per ha was lowest at NC and IL, and highest at MI and VA (1), so results at year five do not totally agree with results at year 10. At Illinois and Michigan, 'Empire' out yielded 'Jonagold' and at Ontario the opposite occurred. The two cultivars had similar yields at New York. At North Carolina and Virginia 'Empire' out-yielded 'Delicious'. At Washington 'Braeburn' and 'Fuji' had similar yields. With Mark as the rootstock, at most locations SS had the highest yields and CL had the lowest yields. With M.9 as the rootstock, cumulative yields per ha did not significantly differ for SS and VA for 14 of the 17 cultivar/location combinations. With M.26 as the rootstock, cumulative yield per ha was higher for VA than for CL for 5 of the 16 cultivar/location combinations. Previously, where tree densities were held constant, VA out yielded SS by 3% (19) and VA out yielded Free spindle by 40% (15).

Because the numerical values for yield per ha varied considerably from location to location, least squares means within each location were ranked and the sums of the ranks were used to help interpret the data. Sums of ranks is a common approach used by nonparametricians for analyzing data sets that do not meet the assumptions re-

quired for least squares procedures. A major advantage of using sums of ranks is that extreme values do not influence the ranks. Based on the rank sums, yield per ha separated into three groups of orchard systems. The group with the highest yields included SS/B.9 > SS/M.9 = VA/M.9 > SS/Mark > VA/M.26. Orchard systems with intermediate cumulative yield per ha included VA/Mark > CL/M.26 > VA/O3 and orchards systems with the lowest cumulative yields included VA/P.1 > CL/Mark. Although yields differed greatly from one location to another, rankings for yields were fairly consistent. For 'Empire', CL/Mark had the lowest yield per ha at five of the seven locations, and the SS training system ranked among the top three systems at six of the seven locations. Yield efficiency and crop density were influenced by location, cultivar and orchard system (Tables 6 and 7). Illinois, especially for 'Jonagold', and Ontario had the lowest YE and crop density and New York had the highest yield efficiency and crop density. Yield efficiency and crop density were higher for 'Empire' than for 'Jonagold', 'Empire' was slightly higher than 'Delicious', and 'Braeburn' was higher than 'Fuji'. With Mark, yield efficiency and crop density for SS were lowest at 13 of the 16 cultivar/location combinations, and VA and CL were not significantly different at most locations. With M.9, the yield efficiency and crop density for SS was consistently lower than for VA. When M.26 was the rootstock, training system did not consistently influence yield efficiency and crop density. For SS, the rootstock did not consistently influence yield efficiency and crop density. For VA, trees on M.9 and Mark tended to have the highest yield efficiency and crop density and trees on P.1 tended to have the lowest yield efficiency and crop density. For CL, Mark consistently had higher yield efficiency and crop density than did M.26. At most locations VA/Mark and VA/M.9 had the highest yield efficiency and crop density and VA/P.1 had the lowest yield efficiency and crop density. Results for yield efficiency have varied in previous orchard

systems and spacing trials. Costa et al. (3) reported that the influence of tree spacing on yield efficiency varied for different cultivars. When planted at the same tree density, cumulative yield efficiency was 10% higher for Free spindle than for VA (15) and cumulative yield efficiency was 10% higher for VA than for SS (19).

Average fruit weight tended to be lowest at North Carolina and highest at Virginia (Table 8). At most locations 'Jonagold' and 'Delicious' had higher fruit weight than 'Empire'. Average fruit weight was influenced by orchard system for 12 of the 18 cultivar/location combinations (Table 8). The influence of orchard system on average fruit weight was not consistent across locations. Analysis of covariance indicated that average fruit weight was related to crop density or cumulative fruit per tree for only four combinations of cultivar/location (data not presented). Least squares means were not calculated for the other 14 combinations because fruit weight was not significantly related to crop load for 12 cultivar/location combinations. For the other two combinations, the interaction of crop load and system was significant. This indicates that the slope for fruit weight vs. crop load was influenced by the orchard system at some locations. Adjusting means with analysis of covariance requires that the slopes are similar (11, 18), so means could not be adjusted when the interaction was significant. When 'Empire' fruit weight was adjusted for cumulative fruit per tree at Michigan, the VA system with all rootstocks except P.1 had the largest fruit and SS/M.9 had the smallest fruit. When 'Jonagold' fruit weight was adjusted for cumulative number of fruit per tree at Illinois, VA/M.9 and VA/M.26 had the largest fruit and SS/Mark and VA/Mark had the smallest fruit. When 'Empire' fruit weight at North Carolina was adjusted for crop density, CL/Mark had the largest fruit and VA/P.1 had the smallest fruit. When 'Jonagold' fruit weight in Michigan was adjusted for crop density, CL/Mark, VA/Mark, and VA/M.9 produced the largest fruit and SS/M.9 and VA/P.1 pro-

Table 1. Training system, rootstock and tree spacing for the 10 orchard systems.

| Training system | Tree spacing (m) | Trees/ha | Rootstocks |
|----------------------|------------------|----------|------------------------------------|
| Slender spindle (SS) | 1.25 x 3.25 | 2460 | M.9 EMLA, B.9, Mark |
| Vertical axis (VA) | 1.6 x 4.0 | 1561 | P.1, M.26 EMLA, M.9 EMLA, B.9, O.3 |
| Central leader (CL) | 2.0 x 4.5 | 1111 | M.26 EMLA, Mark |

duced the smallest fruit. In previous studies, average fruit weight was also not con-

sistently influenced by orchard system (3, 15, 19).

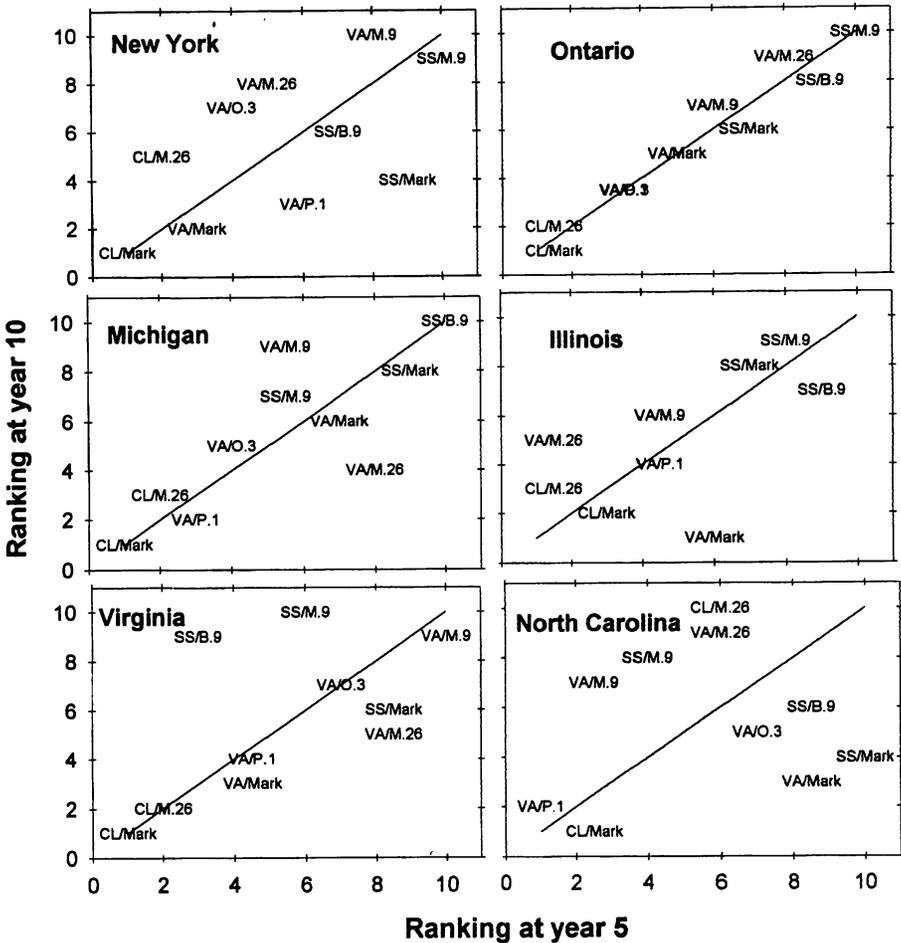


Figure 1. The relationship between cumulative yield per ha after 5 years and after 10 years for 'Empire' trees grown in 10 orchard systems for 10 years at six locations. Cumulative yields were ranked at each location, where 1 = lowest yield and 10 = highest yield. A line of unity, with a slope of 1, is included. If there were perfect agreement between the two rankings, all values would fall on the line.

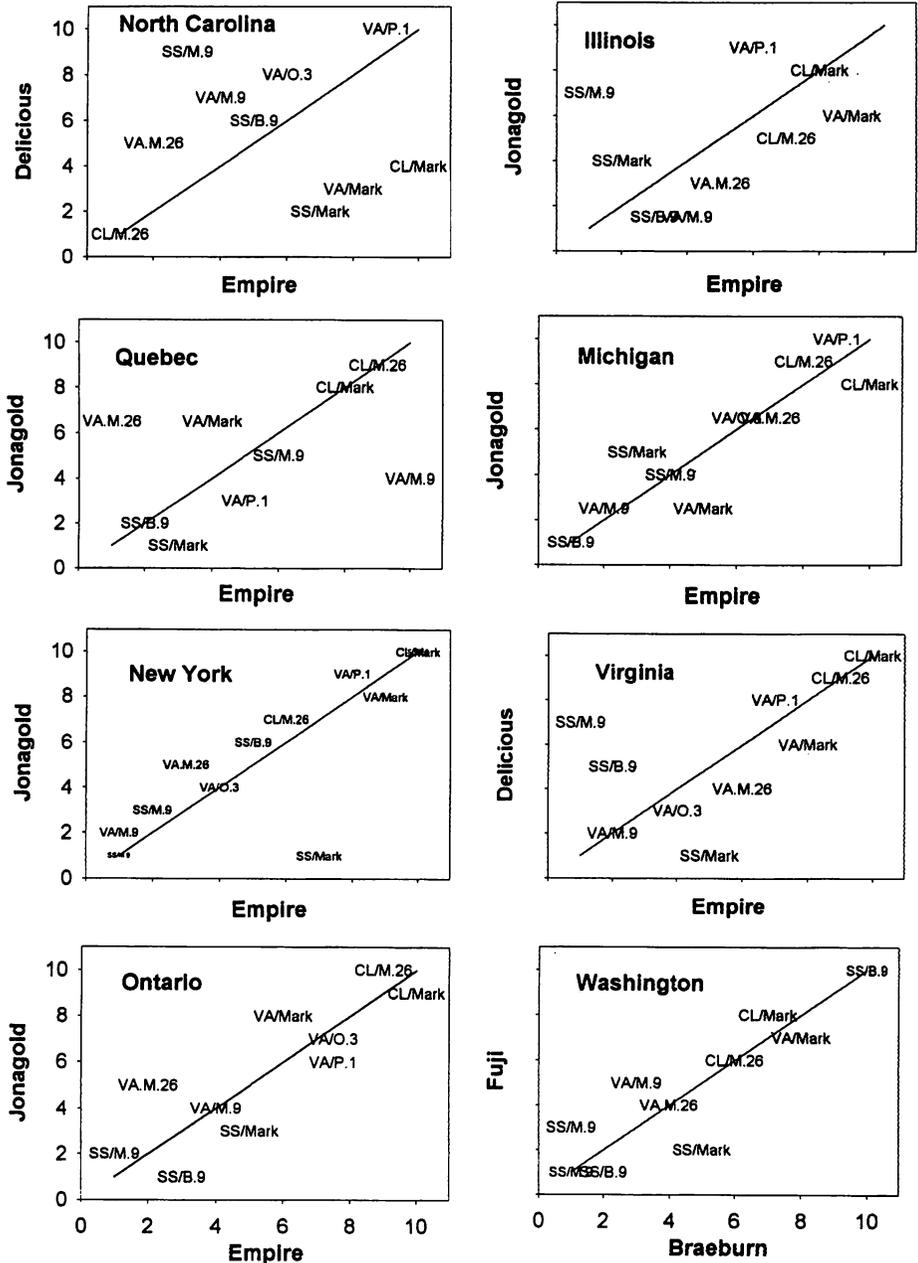


Figure 4. The relationship between two cultivars for cumulative yield per ha after 10 years at seven locations. Cumulative yields for each cultivar were ranked for each location, where 1 = lowest yield and 10 = highest yield. A line of unity, with a slope of 1, is included. If there were perfect agreement between the two rankings, all values would fall on the line.

Table 2. Influence of training system/rootstock combination (system treatment), cultivar and location on tree survival (% alive) after 10 years. Data for Quebec are for 8 years.^Z

| System treatment | Empire | | | | | | | Jonagold | | | | | Delicious | | Braeburn | Fuji |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | NC | NY | ONT | QUE | VA | IL | MI | NY | ONT | QUE | NC | VA | WA | WA |
| SS/M.9 | 100 | 100 | 100 | 100 | 100 | 75 b | 100 | 96 | 100 | 100 | 95 | 7 bc | 100 | 96 | 97 | 100 |
| SS/B.9 | 100 | 100 | 100 | 96 | 100 | 96 ab | 100 | 100 | 97 | 100 | 100 | 79 a | 100 | 96 | 91 | 97 |
| SS/Mark | 85 | 97 | 96 | 96 | 95 | 100 a | 100 | 100 | 94 | 96 | 96 | 29 bc | 96 | 100 | 100 | 100 |
| VA/P.1 | 100 | 100 | 100 | 100 | 100 | 80 b | 100 | 100 | 96 | 88 | 94 | 75-a | 100 | 100 | — | — |
| VA/M.26 | 100 | 96 | 94 | 100 | 100 | 100 a | 100 | 100 | 83 | 100 | 100 | 55 ab | 94 | 100 | 100 | 100 |
| VA/O.3 | — | 67 | 94 | 94 | 100 | 75 b | 94 | — | 96 | 100 | 94 | — | 94 | 100 | 100 | — |
| VA/M.9 | 100 | 100 | 100 | 100 | 100 | 90 ab | 100 | 100 | 92 | 100 | 88 | 70 ab | 100 | 100 | 100 | 100 |
| VA/Mark | 100 | 100 | 100 | 100 | 100 | 90 ab | 94 | 94 | 100 | 100 | 100 | 25 bc | 100 | 100 | 100 | 96 |
| CL/M.26 | 100 | 100 | 100 | 92 | 100 | 100 a | 100 | 92 | 100 | 92 | 100 | 25 bc | 100 | 100 | 100 | 95 |
| CL/Mark | 100 | 100 | 100 | 100 | 100 | 88 ab | 93 | 100 | 100 | 100 | 100 | 38 b | 100 | 100 | 95 | 95 |
| <i>P-value</i> | 0.353 | 0.092 | 0.595 | 0.735 | 0.462 | 0.031 | 0.611 | 0.494 | 0.620 | 0.235 | 0.791 | 0.001 | 0.595 | 0.573 | 0.615 | 0.763 |

^ZLeast squares means followed by common letters do not differ at the 5% level, by probability of the difference.

The influence of orchard systems on cumulative yield per ha reported in this study is probably related to canopy volume and light interception per ha. Apple yield per ha increases nearly linearly with increasing light interception, especially the amount of light intercepted by spur leaves early in the season (9). Robinson (19) found that increasing the tree density by 29% (1,111 to 1,429 trees/ha), light interception was increased by 18%. When data were pooled over two cultivars and two tree spacings, light interception was similar for SS and VA (19). In our trial, yields within a location were probably also related to light interception. The rel-

atively low yields for CL-trained trees probably occurred because it took longer to fill the space between the trees than for other systems. At most locations trees on Mark rootstock had lower yields than trees trained similarly but on different rootstocks. The low yields produced by Mark probably resulted from relatively small canopies produced by Mark.

Orchard systems trials are expensive to establish and to maintain. Therefore, it would be advantageous to terminate systems trials earlier than the 10-year period used in this trial. One way to determine if early termination would be possible is to correlate cumulative yields per ha for the

first five years with cumulative yields after 10 years. When regression models were fit for each location, the linear relationship was significant for all locations except IL, but the coefficients of determination were fairly low (0.32 to 0.75) and the slopes varied greatly with location (slopes varied from -0.75 at IL to 12.4 at North Carolina). Comparison of these models was further complicated by the fact that the range of cumulative yield after 10 years differed depending on location (90 to 144 T/ha for Ontario and 251 to 471 T/ha for Virginia). To simplify comparisons, cumulative yield/ha for the 10 systems was ranked from 1 to 10 for

each location for the first five years and for the ten years, where 1=lowest yield and 10=highest yield. The two ratings were then plotted against each other for each location (Fig. 1). A line of unity, with a slope of 1.0 was included in each plot. If the

rankings for the 10 systems were exactly the same after 5 and 10 years, all points would fall on the line. Systems falling below the line had a higher ranking for the first 5 years than at the end of the study. Systems falling above the line had lower

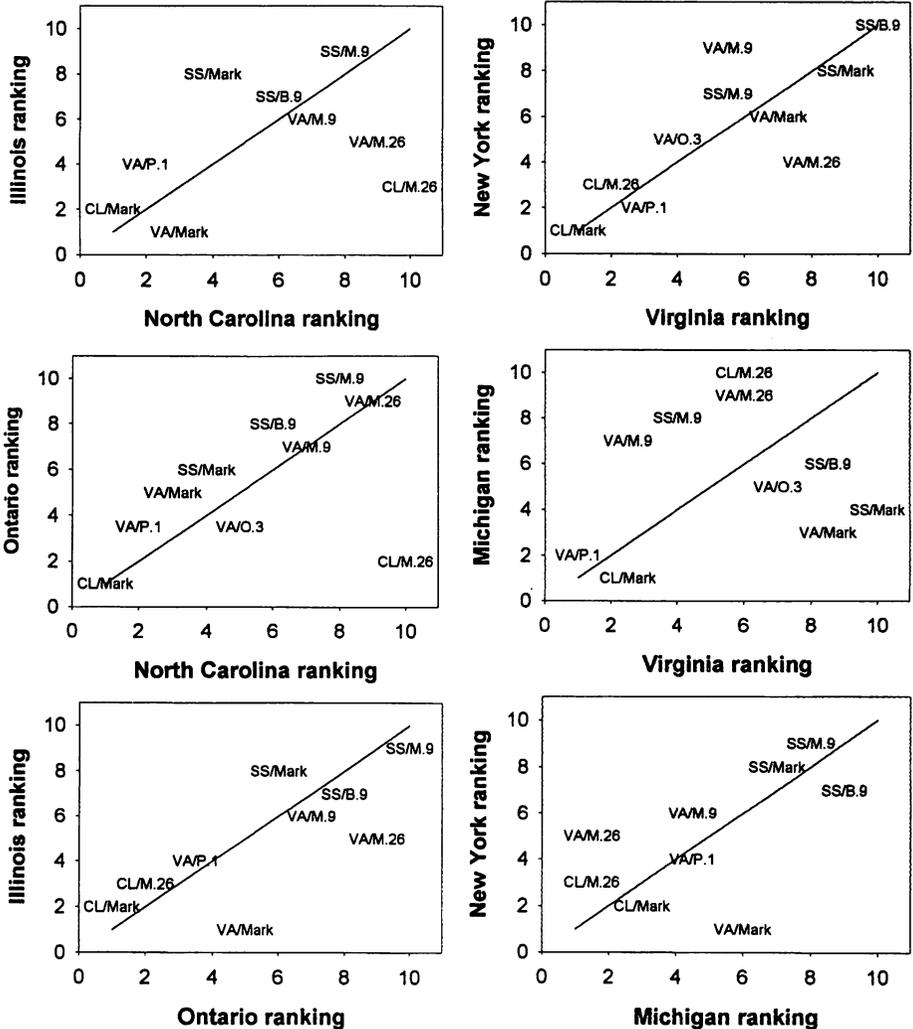


Figure 2. The relationship between cumulative yield per ha after 10 years for 'Empire' trees grown in 10 orchard systems for 10 years at six locations. Plots are presented for all possible two-way comparisons of three low-yielding locations (Illinois, North Carolina and Ontario) and three high-yielding location (Michigan, New York and Virginia). Cumulative yields were ranked at each location, where 1 = lowest yield and 10 = highest yield. A line of unity, with a slope of 1, is included. If there were perfect agreement between the two rankings, all values would fall on the line.

Table 3. Influence of training system/rootstock combination (system treatment), cultivar and location on trunk cross-sectional area (TCA) (cm²) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years.²

| System treatment | Empire | | | | | | | Delicious | | | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | MN | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 52.4 | 46.3 e | 18.5 d | 18.6 b | 36.4 e | 30.0 cd | 13.1 c | 53.6 de | 22.5 b | 24.5 c | 57.3 bc |
| SS/B.9 | 37.8 | 41.7 e | 26.2 c | 29.2 b | 33.8 e | 29.9 cd | 13.2 c | 39.2 e | 29.0 b | 26.1 c | 45.8 c |
| SS/Mark | 34.1 | 32.9 f | 22.30 cd | 33.8 b | 24.9 f | 25.5 d | 13.9 c | 41.7 e | 26.2 b | 26.6 c | 37.2 c |
| VA/P.1 | 77.4 | 115.3 a | 48.9 a | 69.1 a | 88.2 a | 71.5 a | 29.4 a | 121.5 a | 45.7 a | 59.3 a | 111.7 a |
| VA/M.26 | 62.0 | 79.2 c | 28.0 b | 60.4 a | 61.2 c | 52.7 b | 20.3 b | 86.3 b | 30.0 b | 56.2 a | 96.4 a |
| VA/O.3 | — | 62.6 d | 28.7 bc | 51.9 a | 45.1 d | 37.1 c | 13.1 c | 72.0 c | — | 47.8 b | 70.6 b |
| VA/M.9 | 50.0 | 56.2 d | 20.7 cd | 38.1 b | 43.8 d | 30.5 cd | 13.3 c | 57.8 d | — | 30.9 c | 61.6 bc |
| VA/Mark | 54.6 | 35.8 f | 22.4 cd | 28.4 b | 24.3 e | 28.6 cd | 15.4 bc | 50.2 de | 23.0 b | 24.0 c | 44.2 c |
| CL/M.26 | 83.8 | 99.9 b | — | 49.2 a | 76.9 b | 55.6 b | 16.5 bc | 94.0 b | — | 49.5 ab | 104.0 a |
| CL/Mark | 47.4 | 39.8 ef | — | 26.9 ef | 29.6 ef | 34.1 cd | 14.1 c | 51.3 de | — | 28.9 c | 52.0 c |
| P-value | 0.084 | 0.001 | 0.008 | 0.001 | 0.001 |

| System treatment | Jonagold | | | | Braeburn | Fuji | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | NY | ONT | QUE | WA | WA |
| SS/M.9 | 71.9 ab | 68.2 d | 52.7 d | 52.6 bcd | 21.4 b | 21.8 b | 49.5 b |
| SS/B.9 | 69.7 b | 59.2 ef | 50.0 d | 45.9 cd | 20.0 b | 20.0 bc | 40.7 bc |
| SS/Mark | 47.8 b | 51.5 f | 40.0 e | 40.6 d | 20.6 b | 20.0 bc | 31.0 c |
| VA/P.1 | 107.4 a | 114.2 ab | 102.0 a | 76.4 a | 43.3 a | — | — |
| VA/M.26 | 94.6 ab | 104.4 b | 79.8 b | 62.1 abc | 23.6 b | 34.6 a | 73.2 a |
| VA/O.3 | — | 85.8 c | 60.0 c | 56.6 bc | — | 13.6 c | — |
| VA/M.9 | 58.3 b | 81.6 cd | 66.2 c | 62.6 abc | 24.2 b | 22.7 b | 50.1 b |
| VA/Mark | 47.5 b | 57.9 ef | 41.4 e | 39.5 d | 22.3 b | 17.7 bc | 26.4 c |
| CL/M.26 | 106.3 a | 124.0 a | 80.8 b | 65.9 abc | 21.8 b | 36.5 a | 81.2 a |
| CL/Mark | 54.0 b | 68.0 de | 48.4 d | 55.2 c | 23.2 b | 21.9 b | 32.9 c |
| P-value | 0.001 | 0.001 | 0.001 | 0.001 | 0.016 | 0.001 | 0.001 |

²Least squares means followed by common letters do not differ at the 5% level, by probability of the difference.

rankings for the first 5 years than after 10 years. The rankings put all systems and locations on the same scale to facilitate comparisons.

Several types of information can be obtained from these plots. Lack of deviation from the line indicates good agreement for rankings after 5 and 10 years. There was good agreement between the rankings at only Ontario, indicating that these types of trials should not be terminated after only 5 years. At North Carolina cumulative yield after 5 years was poorly related to yield after 10 years. This poor relationship may be due to management modifications after year 5 (M. Parker, personal communication). There were some similarities between locations. Considering only cumulative yield, the most desirable orchard systems would be those that occurred in

the upper right-hand corner of the plot because these systems were precocious, but also had high cumulative yields for the duration of the study. SS/B.9 and SS/M.9 were in the upper right-hand corner of the plots for 3 of the six locations. Other systems with desirable cumulative yield characteristics included SS/Mark and VA/M.9. At most locations CL/Mark and CL/M.26 tended to occur at the lower left-hand corner indicating that those orchard systems ranked low for cumulative yield per ha after 5 and 10 years.

Plotting rankings after 10 years for two locations allows one to evaluate the agreement between those locations. Plots in Figure 2 show the agreement between locations with similar cumulative yields per ha after 10 years. The three plots on the left side of Figure 2 are all possible combina-

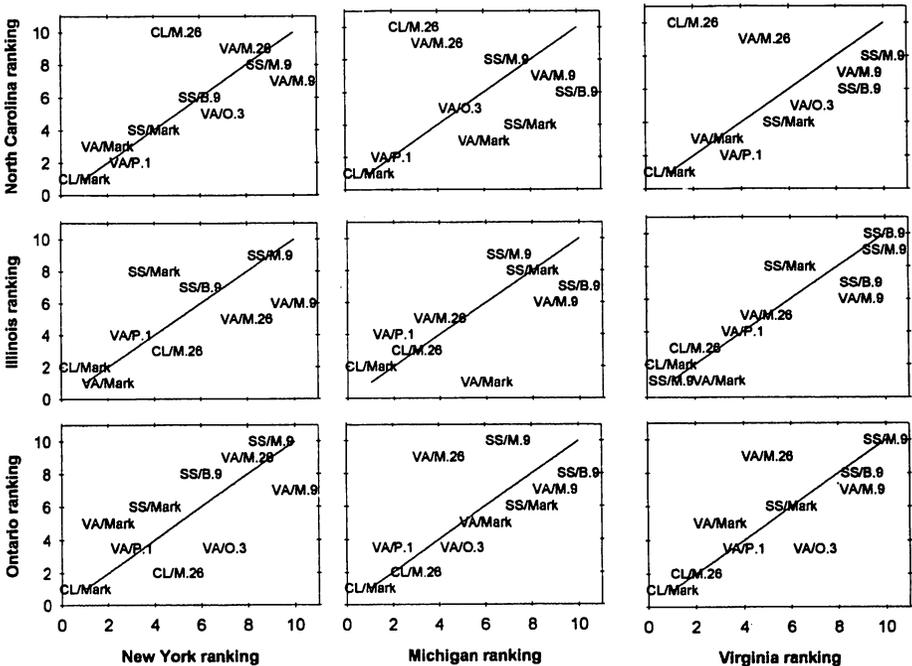


Figure 3. The relationship between rankings for cumulative yield per ha after 10 years for 'Empire' trees grown in 10 orchard systems for 10 years at six locations. Plots are presented for all possible three-way comparisons of the low-yielding locations (Illinois, North Carolina and Ontario) and three high-yielding locations (Michigan, New York and Virginia). Cumulative yields were ranked at each location, where 1 = lowest yield and 10 = highest yield. A line of unity, with a slope of 1, is included. If there were perfect agreement between the two rankings, all values would fall on the line.

Table 4. Influence of training system/rootstock combination (system treatment), cultivar and location on cumulative Yield (kg/tree) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years. ²

| System treatment | Empire | | | | | | | Delicious | | | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|--------------|--------------|
| | IL | MI | MN | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 116 | 132 e | 25 | 88 c | 132 d | 59 bc | 22 b | 191 bc | 16 | 49 c | 123 c |
| SS/B.9 | 102 | 152 de | 26 | 82 c | 118 d | 52 c | 27 b | 166 c | 19 | 62 c | 133 c |
| SS/Mark | 103 | 138 e | 30 | 78 c | 120 d | 48 c | 26 b | 164 c | 23 | 76 bc | 156 bc |
| VA/P.1 | 141 | 143 e | 24 | 107 bc | 172 c | 74 ab | 37 a | 252 ab | 21 | 63 c | 187 b |
| VA/M.26 | 144 | 190 c | 31 | 173 b | 214 b | 88 a | 46 a | 263 ab | 19 | 107 bc | 222 ab |
| VA/O.3 | — | 195 c | 33 | 130 bc | 200 bc | 74 ab | 33 ab | 269 ab | — | 90 bc | 225 ab |
| VA/M.9 | 147 | 231 ab | 27 | 137 b | 218 ab | 83 a | 28 ab | 281 ab | — | 99 bc | 234 ab |
| VA/Mark | 112 | 201 bc | 28 | 115 bc | 133 d | 76 ab | 39 a | 239 b | 22 | 112 b | 218 ab |
| CL/M.26 | 168 | 244 a | — | 248 a | 247 a | 89 a | 40 a | 308 a | — | 168 a | 247 a |
| CL/Mark | 163 | 177 cd | — | 143 b | 141 cd | 81 a | 40 a | 226 b | — | 146 ab | 230 ab |
| P-value | 0.118 | 0.001 | 0.642 | 0.001 | 0.001 | 0.001 | 0.006 | 0.001 | 0.123- | 0.001 | 0.001 |

| System treatment | Jonagold | | | Braeburn | | Fuji |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | NY | ONT | QUE | WA |
| SS/M.9 | 46 c | 110 e | 128 c | 83 cd | 21 | 93 bc |
| SS/B.9 | 59 c | 136 cde | 114 c | 84 cd | 30 | 91 bc |
| SS/Mark | 57 c | 149 cd | 138 c | 78 d | 33 | 76 bc |
| VA/P.1 | 51 c | 125 de | 166 bc | 107 bc | 48 | — |
| VA/M.26 | 101 ab | 162 c | 195 b | 114 abc | 32 | 122 a |
| VA/O.3 | — | 162 c | 201 ab | 105 bc | — | 42 d |
| VA/M.9 | 96 ab | 229 ab | 221 ab | 123 ab | 38 | 130 a |
| VA/Mark | 83 b | 228 ab | 183 b | 99 c | 33 | 73 c |
| CL/M.26 | 116 a | 212 b | 249 a | 118 ab | 16 | 125 a |
| CL/Mark | 102 ab | 255 a | 197 ab | 126 a | 34 | 95 b |
| P-value | 0.001 | 0.001 | 0.001 | 0.001 | 0.256 | 0.001 |

²Least squares means followed by common letters do not differ at the 5% level, by probability of the difference.

Table 5. Influence of training system/rootstock combination (system treatment), cultivar and location on cumulative yield ($T \cdot ha^2$) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years.²

| System treatment | Empire | | | | | | | | Delicious | | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | MN | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 285 | 325 ab | 61 ab | 216 ab | 324 ab | 144 a | 55 abc | 471 a | 38 bc | 121 bc | 303 |
| SS/B.9 | 251 | 373 a | 63 ab | 202 ab | 290 ab | 127 ab | 66 ab | 409 a | 49 ab | 154 ab | 327 |
| SS/Mark | 252 | 338 a | 75 a | 191 bc | 271 b | 118 ab | 64 ab | 403 a | 56 a | 186 ab | 385 |
| VA/P.1 | 212 | 214 c | 38 c | 161 c | 259 b | 111 bc | 56 abc | 378 b | 33 c | 94 c | 281 |
| VA/M.26 | 217 | 285 b | 48 bc | 260 abc | 322 ab | 133 ab | 68 a | 395 a | 29 c | 161 ab | 333 |
| VA/O.3 | — | 293 b | 51 bc | 195 b | 300 ab | 111 bc | 49 bc | 404 a | — | 136 bc | 337 |
| VA/M.9 | 220 | 347 a | 42 c | 206 abc | 327 a | 125 ab | 42 c | 423 a | — | 148 ab | 351 |
| VA/Mark | 169 | 302 ab | 44 bc | 173 bc | 200 c | 114 bc | 58 abc | 360 b | 35 c | 168 ab | 326 |
| CL/M.26 | 186 | 271 b | — | 275 a | 275 b | 99 bc | 44 bc | 342 b | — | 187 a | 274 |
| CL/Mark | 181 | 196 c | — | 159 bc | 157 c | 90 bc | 45 bc | 251 c | — | 163 ab | 256 |
| P-value | 0.323 | 0.001 | 0.006 | 0.030 | 0.001 | 0.021 | 0.033 | 0.002 | 0.004 | 0.023 | 0.069 |

| System treatment | Jonagold | | | | Braeburn | Fuji |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | NY | ONT | QUE | WA |
| SS/M.9 | 114 bc | 269 b | 315 a | 205 a | 51 | 205 a |
| SS/B.9 | 145 ab | 335 a | 281 b | 207 a | 73 | 188 a |
| SS/Mark | 140 ab | 268 a | 339 a | 191 ab | 82 | 161 b |
| VA/P.1 | 77 c | 187 c | 250 bc | 160 bc | 72 | — |
| VA/M.26 | 152 a | 244 b | 293 ab | 171 b | 49 | 163 b |
| VA/O.3 | — | 244 b | 302 ab | 158 bc | — | 56 d |
| VA/M.9 | 145 ab | 343 a | 332 a | 184 ab | 57 | 162 b |
| VA/Mark | 124 ab | 343 a | 275 b | 149 c | 49 | 91 c |
| CL/M.26 | 129 ab | 235 bc | 276 b | 131 c | 18 | 116 c |
| CL/Mark | 113 b | 283 b | 219 c | 140 c | 38 | 93 c |
| P-value | 0.010 | 0.001 | 0.001 | 0.001 | 0.052 | 0.001 |

²Least squares means followed by common letters do not differ at the 5% level, by probability of the difference.

Table 6. Influence of training system/rootstock combination (system treatment), cultivar and location on cumulative yield efficiency (kg·cm²) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years.²

| System treatment | Empire | | | | | | | Delicious | | | |
|------------------|--------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MN | MI | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 2.4 | 1.3 a | 2.9 d | 3.1 c | 3.6 c | 2.0 bc | 1.7 c | 3.6 b | 0.7 ab | 2.0 c | 2.2 cd |
| SS/B.9 | 2.8 | 1.0 abc | 3.7 c | 2.8 c | 3.5 c | 1.7 c | 2.0 bc | 4.3 ab | 0.7 ab | 2.4 c | 3.0 bc |
| SS/Mark | 3.6 | 1.4 a | 4.2 bc | 2.3 cd | 4.4 b | 1.9 bc | 1.9 bc | 4.1 ab | 0.9 a | 2.8 bc | 4.2 a |
| VA/P.1 | 2.1 | 0.5 c | 1.2 e | 1.6 d | 2.0 d | 1.1 d | 1.3 c | 2.1 c | 0.5 b | 1.1 d | 1.7 d |
| VA/M.26 | 2.4 | 0.8 bc | 2.4 d | 2.9 c | 3.5 c | 1.7 c | 2.3 b | 3.1 bc | 0.6 b | 2.0 c | 2.3 cd |
| VA/O.3 | — | 1.1 abc | 3.1 cd | 2.7 cd | 4.4 b | 2.1 bc | 2.5 ab | 3.7 b | — | 1.9 c | 3.2 bc |
| VA/M.9 | 3.3 | 1.3 a | 4.1 b | 3.6 bc | 5.0 ab | 2.7 a | 2.2 b | 4.9 a | — | 3.2 b | 3.8 b |
| VA/Mark | 2.2 | 1.2 ab | 5.7 a | 4.2 b | 5.5 a | 2.7 a | 2.6 ab | 4.8 ab | 0.9 a | 4.7 a | 5.0 a |
| CL/M.26 | 2.1 | — | 2.4 d | 5.0 ab | 3.2 c | 1.7 c | 2.4 ab | 3.2 b | — | 3.3 b | 2.4 cd |
| CL/Mark | 4.3 | — | 4.6 b | 5.4 a | 4.7 b | 2.4 abc | 2.9 a | 4.6 ab | — | 5.1 a | 4.6 ab |
| P-value | | 0.179 | 0.004 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.046 | 0.001 | 0.001 |

| System treatment | Jonagold | | | | Braeburn | Fuji | |
|------------------|--------------|---------------|--------------|---------------|--------------|-----------------|-----------------|
| | IL | MI | NY | ONT | QUE | WA ^x | WA ^x |
| SS/M.9 | 0.8 c | 1.6 e | 2.4 c | 1.6 c | 1.3 | 3.8 ab | 1.5 bc |
| SS/B.9 | 0.9 c | 2.3 d | 2.3 c | 1.8 bc | 1.5 | 3.8 ab | 2.1 ab |
| SS/Mark | 1.2 bc | 2.9 c | 3.5 b | 1.9 bc | 1.6 | 3.3 b | 2.5 ab |
| VA/P.1 | 0.5 c | 1.1 e | 1.6 d | 1.5 c | 1.2 | — | — |
| VA/M.26 | 1.1 bc | 1.6 e | 2.4 c | 1.8 bc | 1.5 | 3.4 b | 1.6 bc |
| VA/O.3 | — | 1.9 de | 3.4 b | 1.9 bc | — | 2.8 c | — |
| VA/M.9 | 1.8 ab | 2.8 cd | 3.3 b | 2.0 b | 1.5 | 4.8 a | 2.3 ab |
| VA/Mark | 1.9 ab | 4.0 a | 4.5 a | 2.6 a | 1.6 | 3.4 b | 2.7 a |
| CL/M.26 | 1.1 bc | 1.7 e | 3.1 bc | 1.8 bc | 0.8 | 2.9 c | 1.4 c |
| CL/Mark | 2.0 a | 3.8 a | 4.1 a | 2.3 ab | 1.6 | 3.9 ab | 2.9 a |
| P-value | 0.001 | 0.001 | 0.001 | 0.007 | 0.548 | 0.001 | 0.001 |

²Least squares means followed by common letters do not differ at the 5% level, by probability of the difference.

^xTCA was not measured in Washington in 1999, so data are for 1998.

Table 7. Influence of training system/rootstock combination (system treatment), cultivar and location on cumulative crop density (number of fruit·cm²) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years.²

| System treatment | Empire | | | | | | | Delicious | | | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | MN | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 17.2 | 23.9 bc | 7.6 ab | 26.6 bc | 24.0 c | 16.1 ab | 14.6 c | 22.9 b | 4.6 b | 1.5 c | 13.5 cd |
| SS/B.9 | 18.8 | 28.0 b | 9.5 ab | 23.4 bc | 23.2 c | 13.9 b | 16.5 bc | 26.8 ab | 4.3 b | 15.6 bc | 17.4 cd |
| SS/Mark | 25.3 | 33.6 a | 10.2 a | 19.2 c | 30.2 b | 15.1 b | 15.6 bc | 24.2 b | 5.5 ab | 17.8 bc | 25.4 b |
| VA/P.1 | 15.2 | 11.2 e | 4.0 c | 14.3 bc | 13.7 d | 8.7 c | 10.4 d | 13.6 c | 2.9 b | 7.3 d | 10.8 d |
| VA/M.26 | 17.0 | 16.2 cd | 6.8 bc | 24.9 bc | 25.4 c | 12.8 bc | 18.8 d | 19.9 bc | 4.4 b | 12.8 cd | 14.7 cd |
| VA/O.3 | — | 20.0 cd | 9.1 a | 23.4 bc | 30.8 b | 16.4 a | 22.9 a | 25.1 a | — | 12.1 cd | 20.1 bc |
| VA/M.9 | 22.3 | 25.4 bc | 10.1 a | 30.7 b | 34.8 ab | 20.3 a | 17.8 bc | 31.8 a | — | 20.3 b | 24.9 b |
| VA/Mark | 14.8 | 36.4 a | 9.2 ab | 35.5 ab | 39.0 a | 21.4 a | 20.6 ab | 30.1 a | 8.4 a | 31.6 a | 31.8 a |
| CL/M.26 | 15.2 | 18.0 d | — | 42.6 a | 23.1 c | 12.4 bc | 20.1 ab | 21.0 b | — | 20.4 b | 14.9 cd |
| CL/Mark | 30.0 | 33.4 a | — | 43.1 a | 33.1 ab | 18.8 ab | 22.9 a | 28.3 ab | — | 33.9 a | 27.9 ab |
| P-value | 0.164 | 0.001 | 0.015 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.043 | 0.001 | 0.001 |

| System treatment | Jonagold | | | | | Braeburn | Fuji |
|------------------|--------------|--------------|--------------|--------------|--------------|-----------------|-----------------|
| | IL | MI | NY | ONT | QUE | WA ^Y | WA ^Y |
| SS/M.9 | 3.7 bc | 17.1 b | 10.2 c | 9.5 c | 8.2 | 16.2 bc | 5.7 d |
| SS/B.9 | 4.3 bc | 19.9 ab | 10.0 c | 11.1 bc | 8.9 | 16.9 b | 8.6 c |
| SS/Mark | 6.3 b | 27.1 a | 16.1 b | 12.2 b | 10.1 | 14.6 cd | 11.6 b |
| VA/P.1 | 2.5 c | 10.1 c | 7.4 c | 9.1 c | 6.9 | — | — |
| VA/M.26 | 5.2 bc | 10.3 c | 11.3 c | 10.9 bc | 8.7 | 13.4 cd | 6.1 cd |
| VA/O.3 | — | 11.9 c | 15.5 b | 11.7 bc | — | 13.2 cd | — |
| VA/M.9 | 8.5 ab | 17.3 b | 14.8 b | 11.5 bc | 8.3 | 19.9 a | 9.7 c |
| VA/Mark | 10.4 a | 23.3 a | 21.7 a | 16.6 a | 9.6 | 15.3 bc | 14.2 a |
| CL/M.26 | 5.3 bc | 10.5 c | 13.8 b | 11.1 bc | 4.6 | 12.0 d | 5.7 d |
| CL/Mark | 11.6 a | 22.4 a | 21.0 a | 13.7 ab | 9.6 | 17.5 ab | 14.9 a |
| P-value | 0.001 | 0.001 | 0.001 | 0.002 | 0.474 | 0.003 | 0.001 |

²Least squares means followed by common letters do not differ at the 5% level, by probability of the difference.

^YTCA was not measured in Washington in 1999, so data are for 1998.

Table 8. Influence of training system/rootstock combination (system treatment), cultivar and location on average fruit weight (g/fruit) of surviving trees after 10 years. All values are least squares means adjusted for missing values. Data for Minnesota are for 6 years and data for Quebec are for 8 years. ^Z

| System treatment | Empire | | | | | | | Delicious | | | |
|------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | IL | MI | MN | NC | NY | ONT | QUE | VA | MN | NC | VA |
| SS/M.9 | 143 | 120 e | 139 a | 116 | 152 a | 122 b | 116 b | 159 bc | 153 ab | 149 | 161 b |
| SS/B.9 | 146 | 132 cd | 136 a | 120 | 151 ab | 124 b | 124 a | 162 b | 156 ab | 155 | 169 a |
| SS/Mark | 142 | 124 de | 139 a | 124 | 145 ab | 126 b | 121 ab | 168 a | 159 a | 159 | 167 ab |
| VA/P.1 | 141 | 111 e | 128 b | 114 | 142 b | 122 b | 124 a | 152 c | 153 ab | 148 | 155 bc |
| VA/M.26 | 138 | 149 b | 123 b | 117 | 138 b | 131 a | 121 ab | 154 c | 140 ab | 154 | 158 bc |
| VA/O.3 | — | 155 ab | 125 b | 115 | 144 b | 126 b | 109 c | 149 c | — | 157 | 161 b |
| VA/M.9 | 146 | 163 ab | 131 ab | 117 | 143 b | 135 a | 124 a | 154 c | — | 157 | 153 c |
| VA/Mark | 149 | 155 ab | 133 ab | 120 | 142 b | 127 b | 124 a | 160 b | 124 b | 150 | 157 bc |
| CL/M.26 | 139 | 135 cd | — | 117 | 141 b | 134 a | 122 a | 155 c | — | 161 | 163 ab |
| CL/Mark | 142 | 136 cd | — | 125 | 141 b | 130 ab | 126 a | 162 b | — | 151 | 167 ab |
| P-value | 0.361 | 0.001 | 0.005 | 0.252 | 0.029 | 0.032 | 0.001 | 0.001 | 0.033 | 0.464 | 0.002 |

| System treatment | Jonagold | | | | Braeburn | Fuji |
|------------------|--------------|--------------|--------------|--------------|--------------|-----------------|
| | IL | MI | NY | ONT | QUE | WA ^Y |
| SS/M.9 | 214 a | 95 b | 239 a | 170 | 171 | 234 ab |
| SS/B.9 | 197 b | 117 b | 233 ab | 165 | 170 | 224 b |
| SS/Mark | 193 b | 111 b | 217 c | 157 | 159 | 223 b |
| VA/P.1 | 214 a | 110 b | 222 bc | 163 | 177 | — |
| VA/M.26 | 208 ab | 155 a | 217 c | 169 | 176 | 247 a |
| VA/O.3 | — | 160 a | 217 c | 160 | — | 211 b |
| VA/M.9 | 217 a | 169 a | 226 bc | 173 | 184 | 234 ab |
| VA/Mark | 184 bc | 171 a | 207 cd | 155 | 170 | 215 b |
| CL/M.26 | 207 ab | 162 a | 223 bc | 166 | 183 | 240 a |
| CL/Mark | 174 c | 168 a | 196 d | 169 | 179 | 219 b |
| P-value | 0.006 | 0.001 | 0.001 | 0.166 | 0.621 | 0.001 |

^ZLeast squares means followed by common letters do not differ at the 5% level, by probability of the difference.

^YTCA was not measured in WAshington in 1999, so data are for 1998.

tions of the three locations with low cumulative yields and the three plots on the right side are for the three locations with high yield. Rankings at Ontario, North Carolina, and Illinois agree fairly well except that VA/Mark performed better at Ontario than at Illinois, and CL/M.26 performed better at North Carolina than at Ontario and Illinois. Rankings for New York agreed fairly well with rankings for Michigan and Virginia, but rankings for Michigan did not agree very well with rankings for Virginia. Rankings for VA/Mark, SS/Mark, and SS/B.9 were higher for Virginia than for Michigan and the ranking for VA/M.26 was higher for New York than for Michigan (Fig. 2). Rankings for each of the high yielding locations were also plotted against rankings for each of the low-yielding locations (Fig. 3). Interestingly, VA/M.9 ranked 7th at the low-yielding locations and 9th or 10th at the high-yielding locations, respectively (Fig. 3). The ranking for VA/O.3 was higher at the high-yielding locations than at the low-yielding locations. VA/Mark ranked higher at all the high-yielding locations than at Illinois. CL/M.26 and VA/M.26 ranked higher at North Carolina than at all the high-yielding locations.

To determine if more than one cultivar should be included in a systems trial, rankings for cumulative yield per ha for one cultivar was plotted against similar values for the other cultivar for each location (Fig. 4). Locations where agreement for the two cultivars was good included Michigan, Washington and New York, except for SS/Mark at New York where the relative ranking was higher for 'Empire' than for 'Jonagold'. At North Carolina, SS/M.9 was more productive with 'Delicious' than with 'Empire' and the opposite was true for SS/Mark, VA/Mark and CL/Mark. At Illinois, SS/M.9 performed better with 'Jonagold' than with 'Empire'. At Virginia SS/Mark performed better with 'Empire' than with 'Delicious'. At Ontario VA/M.26 performed better with 'Jonagold' than with 'Empire'. This graphical display of the results indicates that the relative performance of an orchard system

may differ with cultivar, so more than one cultivar should be included in systems trials.

Conclusions.

It is difficult to draw general conclusions from this study because cultivars and rootstocks were not common to all locations. In future trials an effort should be made to plant the same rootstocks and cultivars at each location to facilitate analysis and interpretation of the data. Cumulative yields per ha varied greatly from one location to another, but the relative performance of the 10 orchard systems was fairly consistent across locations. At most locations relatively low yields per ha were obtained for CL/Mark and CL/M.26, whereas the three orchard systems with SS-training tended to have high yields. For VA-trained trees, M.9 was the most productive rootstock, whereas Mark and P.1 were the least productive. Because the interaction between location and orchard system did not appear to be great, the number of locations for future systems plantings should be reduced. Four to six well-chosen locations would probably provide results that would apply to most apple-growing regions of North America. More than one cultivar, and preferably the same cultivars at all locations, should be included in future trials.

Results from this trial should be interpreted cautiously because yield and average fruit weight are the only economically important variables presented. Fruit size distribution, fruit color and quality, and costs for orchard establishment and maintenance also influence orchard profitability. In this trial SS was the most productive training system, but costs for trees would also be the highest. At some locations SS produced fruit with poor red color because there was too much within-tree shading. At locations with high tree vigor, SS required additional pruning time to hold trees within their allotted space. Therefore, cumulative yield may not be a good indicator of profitability.

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Peach Rootstocks - Fruit Phenolics

In all cultivars fruit from trees grafted on Nanking cherry contained more total phenolic compounds than did those on 'Tuseito' or 'Nagano-Yaseito'. There was wide variation in phenolic contents among cultivars; being low in 'Soctome', 'Yahata-hakuho' and 'Chikuma' but high in 'Sanyo-suimitsu', 'Setouchi-hakuto' and 'Golden Peach.' From Kubota et al 2001. *J.Japan.Soc.Hort.Sci.* 70(2)151-156.