HORTSCIENCE 31(7):1160–1163. 1996.

Performance of 'McIntosh' Apple Trees on Seven Rootstocks and a Comparison of Methods of Productivity Assessment

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Additional index words. yield efficiency, fruit size, fruit color, *Malus domestica*

Abstract. **'Summerland Red McIntosh' apple trees (*Malus domestica* Borkh.) on M.9/A.2, O.3, M.7 EMLA, M.26 EMLA, M.7A, OAR1, and Mark were evaluated over 10 years. Trees on M.7 EMLA and OAR1 were the largest, and trees on Mark were the smallest. Trees on M.7 EMLA produced the highest yields per tree, and those on OAR1 and Mark produced the lowest. The most yield-efficient trees were on O.3 and Mark. The least efficient trees were on OAR1. Fruit from trees on O.3, M.26 EMLA, or M.9/A.2 generally were the largest, and fruit from trees on OAR1 generally were the smallest. Red pigment development was inversely proportional to canopy size, with Mark resulting generally in the most red pigmentation and M.7 EMLA and M.7A generally resulting in the least. Methods of presenting productivity were compared. Presentation of yield per land area occupied or projected yield per planted area were biased in experiments where only some trees naturally would exceed the allotted space and, therefore, were containment pruned and where tree-to-tree competition was directly proportional to tree size. Yield efficiency was a less biased estimate. Further, in single-row planting systems with trees spaced at optimal densities, small trees must be more efficient than large trees to obtain similar yields.**

The New England apple industry depends largely on 'McIntosh', which accounts for more than 50% of the planted acreage (Autio, 1991a). Although New England environmental conditions provide an ideal climate for producing very high-quality 'McIntosh', giving the area a niche cultivar, market competition within New England and in other parts of the country has kept the wholesale returns to 'McIntosh' growers barely above the production costs. Growers, therefore, must pursue all means of reducing input costs, enhancing cost efficiencies, and increasing crop value. Rootstocks, particularly those that produce fully dwarf trees, can affect all of these conditions by reducing some management costs (e.g., Elfving and McKibbon, 1991) and by enhancing productivity (NC-140, 1991), fruit reddening (Autio and Southwick, 1993), and fruit size (Autio, 1991b).

Reports of evaluations of rootstock material use various ways to compare tree productivity. The two most common techniques are yield efficiency (yield per unit trunk cross-sectional area) and projected yield per planted area. These techniques often do not correlate well (e.g., NC-140, 1991). Because of the importance of rootstock evaluation to the future of the apple industry, it is necessary to make accurate comparisons of productivity.

Received for publication 6 Mar. 1996. Accepted for publication 9 July 1996. Massachusetts Agricultural Experiment Station Paper 3153. This work was supported by Massachusetts Agricultural Experiment Station Projects 539 and RRF NC-140. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

The study reported here was initiated to investigate the effects of various rootstocks on the performance of 'McIntosh' apple trees. We also studied the relationships among measures of yield performance and interpretations of these measures.

Materials and Methods

'Summerland Red McIntosh' trees on M.9/A.2, O.3, M.7 EMLA, M.26 EMLA, M.7A, OAR1, or Mark were planted at the Univ. of Massachusetts Horticultural Research Center in Belchertown in Apr. 1985. The in-row spacing was 3.7 m, and the between-row spacing was 6.1 m. The soil was a Scituate fine sandy loam. The design was a randomized complete block with seven replications, each replication including a single tree on each rootstock. All trees were managed as central leaders with minimal pruning. In 1988, a 3-cm-diameter conduit pipe stake was driven beside each tree for leader training and support. Stakes extended 2.5 m from the soil surface. Pest and fertility management were per local recommendations. Trees were not allowed to set fruit until 1988, their fourth growing season.

Trunk circumference, 50 cm above the soil line, was measured at planting and each October and transformed to trunk cross-sectional area (TCA). Total yield per tree was recorded each year from 1988 through 1994. Tree height and canopy spread were measured in Oct. 1994. Spread data were used to calculate projected planting density for each tree by assuming that trees could be spaced within rows at 90% of the spread and between rows at the in-row spacing plus 2 m. This assumption of optimal spacing may be incorrect for all tree-vigor levels because dwarf trees may be closer to mature size at 10 years than semidwarf trees; however, a consistent value must be used to prevent interjecting subjective bias. Yield per square centimeter TCA (yield efficiency), yield per square meter land area occupied (derived from the average diameter of the canopy at its base, i.e., canopy spread), and yield per hectare (based on yield per tree and projected density) were calculated.

About 40 fruit were sampled randomly from each tree and weighed on 6 Oct. 1989, 12 Sept. 1990, 16 Sept. 1991, 14 Sept. 1992, 24 Sept., 1993, and 14 Sept. 1994. Average fruit mass was calculated from these data. On 16 Sept. 1991, 24 Sept. 1993, and 14 Sept. 1994, 10 of the fruit sampled for mass were assessed visually for percentage of red surface.

Data were subjected to analysis of variance using the GLM procedure of SAS 6.10 for Windows (SAS Institute, Cary, N.C.).

Results

At the end of 10 growing seasons, trees on M.7 EMLA and those on OAR1 were the largest in the planting, based on TCA, height, and spread (Table 1). Trees on M.7A were similar in height and spread to those on M.7 EMLA, but had significantly smaller TCA. Trees on M.26 EMLA and M.9/A.2 were similar in size. Trees on O.3 were similar in TCA and spread to those on M.26 EMLA and those on M.9/A.2 but were significantly shorter than those on M.26 EMLA. The smallest trees in the planting were on Mark. Projecting planting density based on canopy spread gave a range of densities from 460 to 1196 trees/ha (Table 1).

Trees on M.7 EMLA yielded the most per tree (Table 2). Trees on M.9/A.2, O.3, M.26 EMLA, and M.7A yielded similarly, and trees on OAR1 and Mark yielded the least per tree.

Yield efficiency (Table 2) was highest for trees on O.3 and Mark. Trees on M.9/A.2 and M.26 EMLA were the next most efficient, followed by trees on M.7 EMLA and M.7A. The least efficient trees were on OAR1.

Mark, M.7 EMLA, O.3, and M.26 EMLA resulted in the highest and similar yields per land area occupied by the canopy (Table 2). OAR1 resulted in the lowest yields, and M.7A and M.9/A.2 resulted in intermediate yields.

M.7 EMLA, O.3, Mark, and M.26 EMLA resulted in the highest and similar projected yields per hectare (Table 2). Trees on OAR1 yielded the least, and those on M.7A and M.9/A.2 were intermediate in yield.

Year and rootstock interacted to affect size of 'McIntosh' apples (Table 3). O.3, M.26 EMLA, and M.9/A.2 consistently resulted in fruit in the highest statistical category. OAR1, in contrast, consistently resulted in fruit in the lowest statistical category. M.7 EMLA, M.7A, and Mark were not consistent in their effect on fruit size.

Year and rootstock also interacted to affect red pigment development (Table 4). Mark consistently led to red pigmentation in the highest statistical category. M.7A and M.7 EMLA consistently put fruit in the lowest statistical category for redness. Reddening of fruit from trees on OAR1, M.9/A.2, M.26 EMLA, or O.3 was inconsistent or intermediate.

Discussion

The results presented here conform roughly to the results of other studies with similar rootstocks (e.g., Ferree et al., 1994; Ferree and Schmid, 1987; Granger et al., 1993; Meheriuk et al., 1994; NC-140, 1991; Schupp, 1992). Specifically, Mark and O.3 produced small, productive trees, and M.7 EMLA, OAR1, and M.7 produced large, less productive trees. However, there was an inconsistency among the measures of productivity (Table 2). Specifically, M.7 EMLA produced trees that were among the least yield efficient but with among the highest projected yields per planted area. Because of this type of inconsistency, also reported by NC-140 (1991), the accuracy of various methods of reporting productivity must be questioned. Further, the interpretation of differences using these methods must be questioned.

The data most useful to the orchardist are those that relate yield to actual planting area, i.e., the yields measured per tree (Table 2) multiplied by the projected density per hectare (Table 1). Alternatively, yields presented per actual land area occupied by the canopy (Table 2) can be similarly useful. Both of these techniques of presentation assume that tree-to-tree root competition is similar for all treatments and that pruning has been conducted to a similar degree for all treatments. Further, it is assumed that trees have reached maturity by the end of the experiment and will continue to extend to a constant percentage of their diameter. In very few research studies are these conditions met. In our study, trees with a range of potential vigors were planted at the same spacing throughout the experiment. The most vigorous trees required some containment pruning to maintain them in their allotted space, while the least vigorous trees did not. Also, the most vigorous trees may not have reached maturity and may be expected to require more space than 90% of their uncontained spread at 10 years. Therefore, use of the actual land area occupied by the canopy to either estimate optimal tree density or to express yield is biased toward the large tree, i.e., a large tree will have a smaller canopy and higher projected tree density relative to its inherent vigor than a small tree.

TCA is one way to assess inherent vigor. Granted, it is also biased to some degree in the situation described above, but probably is a more accurate measure of inherent vigor than the land area occupied. The problems related to containment pruning are shown in Fig. 1, where TCA is plotted against land area occupied. The relationship when trees were not contained was very good; however, it was much poorer when trees were contained. Most of the variation in land area occupied among trees receiving containment pruning resulted from vegetative growth only during the season before canopy measurement, because they were pruned to the allotted space before the beginning of the season. Part of the difference, noted as a difference between trees that were contained and ones that were not contained, possibly reflects a change in the relationship between TCA and land area occupied for vigorous trees compared to dwarf trees.

These problems suggest that only in studies where tree spacing was adjusted to account for vigor differences and pruning was consistent across all treatments, would yield estimates related to tree size or density be accurate. Unfortunately, the procedure is not as directly useful to the orchardist.

This discussion brings out another important relationship, i.e., the one between productivity per land area occupied and the actual percentage of the planted area occupied by tree canopy in single-row systems. Cain (1969) described this relationship while comparing standard seedling-rooted and semidwarf M.7-rooted apple trees. He found that the canopies of seedling-rooted trees occupied 80% of the planted area, whereas canopies of M.7-rooted trees occupied only 50% of the planted area. Therefore, to produce similarly at maturity, the M.7-rooted trees must yield 60% more fruit per square meter than the seedling-rooted tree. Figure 2 details this relationship theoretically for trees of up to 800 cm canopy spread.

Table 1. Tree size at the end of the tenth growing season (1994) and projected density of 'Summerland Red McIntosh' trees on seven rootstocks.[z]

	Tree size criteron				
Rootstock	Trunk cross-sectional area (cm^2)	Tree ht (cm)	Canopy spread (cm)	Land area occupied (m^2)[y]	Projected density (trees/ha)[x]
M.9/A.2	59 c	268 cd	371 a–c	11.0 bc	581 bc
O.3	44 cd	229 d	334 c	8.9 c	682 b
M.7 EMLA	117 a	364 a	423 a	14.1 a	460 c
M.26 EMLA	66 c	288 bc	361 bc	10.4 bc	602 bc
M.7A	91 b	330 ab	393 ab	12.1 ab	513 bc
OAR1	104 ab	339 ab	379 a–c	11.5 a–c	565 bc
Mark	30 d	225 d	238 d	4.6 d	1196 a

[z]Within columns, mean separation by Duncan's new multiple range test, $P \leq 0.05$.
[y]Land area occupied = Π(canopy spread/200)^2. Values were calculated for each tree before statistical analysis.
[x]Projected density = 10,000/{0.9(canopy spread/100)*[0.9(canopy spread/100) + 2]}. Projected densities were calculated for each tree before statistical analysis.

Table 2. Cumulative yield of 'Summerland Red McIntosh' trees on seven rootstocks.[z]

	Cumulative yield (1988–94)			
Rootstock	Per tree (kg)	Per trunk cross-sectional area (efficiency) ($kg \cdot cm^{-2}$)	Per land area occupied ($kg \cdot m^{-2}$)	Per planted area (projected) ($t \cdot ha^{-1}$)
M.9/A.2	235 b	4.18 b	21.7 c	130 b
O.3	239 b	5.42 a	27.4 a–c	159 ab
M.7 EMLA	391 a	3.36 cd	28.3 ab	179 a
M.26 EMLA	254 b	3.98 bc	25.0 a–c	149 ab
M.7A	278 b	3.05 d	22.8 bc	141 b
OAR1	132 c	1.26 e	11.4 d	70 c
Mark	143 c	5.04 a	31.5 a	156 ab

[z]Within columns, mean separation by Duncan's new multiple range test, $P \leq 0.05$.

Table 3. Average fruit mass from 'Summerland Red McIntosh' trees on seven rootstocks. All means are least-squares means adjusted for the effects of crop load by analysis of covariance.[z]

	Fruit mass (g)					
	Year of harvest					
Rootstock	1989	1990	1991	1992	1993	1994
M.9/A.2	194 a	---	155 a	164 a	172 ab	156 ab
O.3	187 ab	152 a	150 a	164 a	171 ab	164 a
M.7 EMLA	181 b	137 b	156 a	165 a	180 a	159 ab
M.26 EMLA	183 ab	152 a	158 a	160 a	179 a	157 ab
M.7A	182 ab	135 b	154 a	162 a	175 ab	161 ab
OAR1	---	121 c	115 b	146 b	154 c	150 b
Mark	156 c	149 ab	152 a	144 b	164 bc	151 ab

[z]Within columns, mean separation by Duncan's new multiple range test, $P \leq 0.05$.

Table 4. Percentage of red surface of fruit from 'Summerland Red McIntosh' trees on seven rootstocks.[z]

	Red surface (%)		
	Year of harvest		
Rootstock	1991	1993	1994
M.9/A.2	81 b	68 b	76 ab
O.3	82 ab	66 b	70 bc
M.7 EMLA	79 b	58 c	66 c
M.26 EMLA	82 ab	68 b	75 ab
M.7A	83 ab	63 bc	69 bc
OAR1	89 a	68 b	81 a
Mark	83 ab	79 a	79 a

[z]Within columns, mean separation by Duncan's new multiple range test, $P \leq 0.05$.

The percentage of the land area occupied by tree canopy declines dramatically as tree spread declines, even when the trees are spaced much more closely. For example, trees with a natural canopy spread of 800 cm may be planted at a spacing of 720 cm in the row and at an overall density of 151 trees/ha. These trees would occupy 70% of the planted area. Trees with a natural spread of 200 cm may be planted at a spacing of 180 cm in the row and at an overall density of 1462 trees/ha. These trees would occupy only 40% of the planted area. The larger trees and the smaller trees would need to produce ≈7 and 10 $kg \cdot m^{-2}$, respectively, to obtain a yield of 47.5 $t \cdot ha^{-1}$.

It is reasonable to assume that yield efficiency is well-correlated with yield (per unit land area) of trees with little tree-to-tree competition and no containment pruning. Therefore, when comparing the yield efficiencies of trees on various rootstocks, it is important to realize that smaller trees must be more efficient than larger trees to produce the same amount of fruit. This higher efficiency may come from a tree providing more fruit per volume of canopy or by having more volume of canopy that is productive, either with less nonproductive, shaded canopy or with a taller canopy. Further, many growers use narrower equipment for dwarf plantings and, therefore, could use narrower row spacings, thus increasing the percentage of the planted area covered by tree canopy.

Yield performance alone does not determine the success of a particular rootstock in a commercial planting. Fruit value must also be considered. The primary determinants of value of 'McIntosh' fruit are size and color. In this study, O.3, M.26 EMLA, and M.9/A.2 consistently resulted in large fruit, and OAR1 consistently resulted in small fruit. Autio (1991b), studying the effects of rootstock on 'Delicious' fruit, found a similar relationship among M.26 EMLA, O.3, and OAR1. Likewise, Fallahi (1985) found that M.26 generally produced large fruit and OAR1 had small fruit.

Red pigmentation largely is determined by light penetration to the fruit. The differences among trees on the various rootstocks is likely related to differences in canopy size and shape. Trees on Mark had the smallest canopy and likely the easiest for light to penetrate and therefore produced the reddest fruit. M.7A and M.7 EMLA had among the largest canopies and consistently resulted in the poorest coloring. Other rootstocks, with the exception of OAR1, resulted in intermediate canopy sizes and intermediate or less consistent red pigment. OAR1, however, colored better than may be expected from its canopy size. Fallahi et al. (1985) noted better yellow color development with 'Golden Delicious' on OAR1 than with other rootstocks. The better red pigmentation may be a manifestation of the same phenomenon.

Overall, this study confirmed relationships among trees on various rootstocks, in terms of productivity, fruit size, and fruit color. It also pointed out important considerations regarding the reporting of results from similar studies. Specifically, the use of land-based yield presentations must be done very carefully and limited to those situations where the canopy dimensions of small trees are not affected differently by the management of the trees than those of large trees. Further, we suggest that yield efficiency likely is the least biased estimate of relative productivity; however, it is important to note that it cannot be used to compare productivity of trees of different sizes directly. Small trees must be more efficient than large trees to produce the same yield because they occupy less land area, at least in a single-row system.

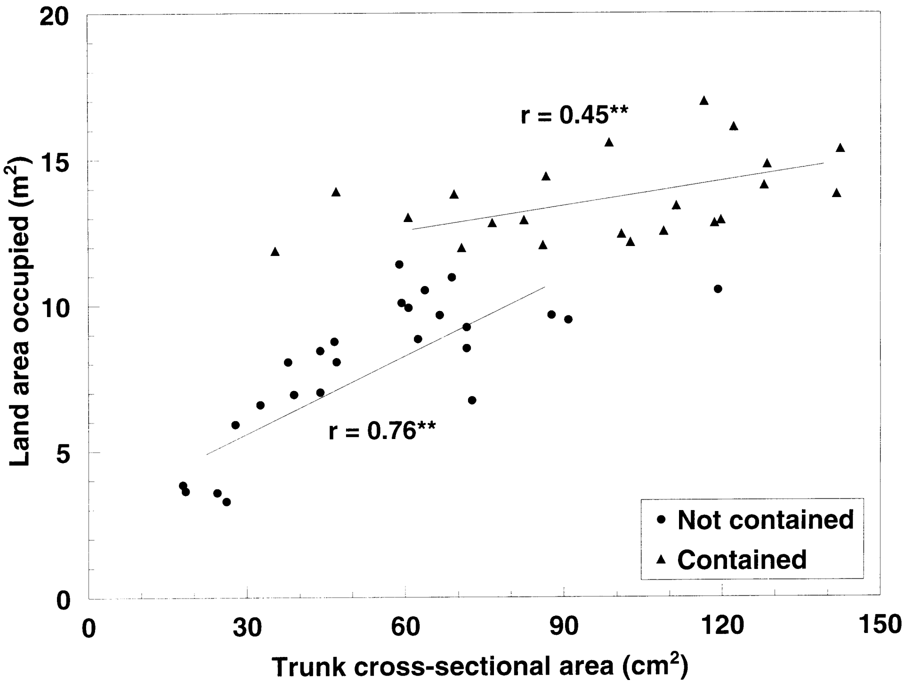

Fig. 1. Relationship of trunk cross-sectional area and land area occupied at the end of 10 growing seasons, comparing 'Summerland Red McIntosh' trees that required containment pruning and those that did not.

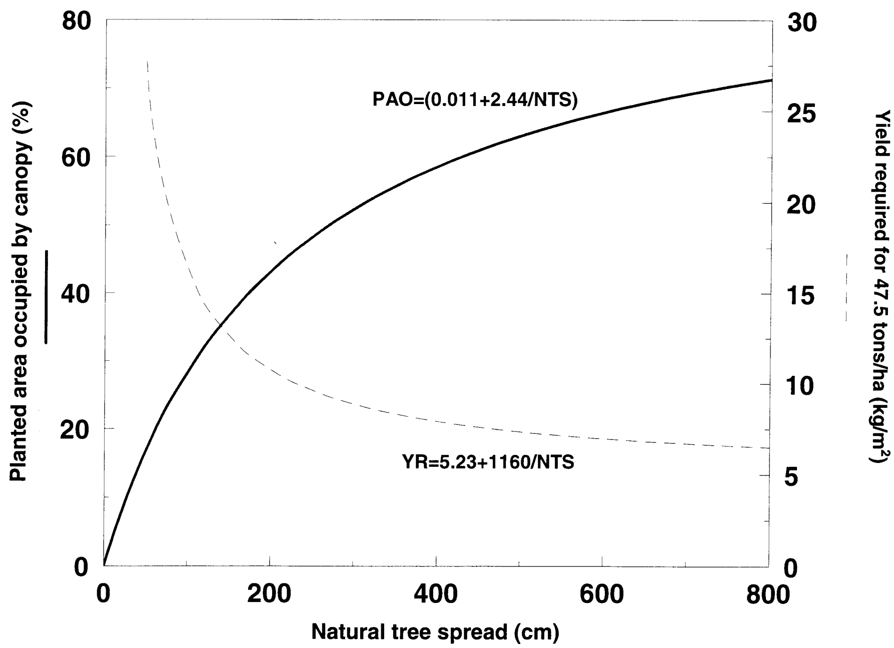

Fig. 2. Relationship of natural tree spread (NTS) to the percentage of the planted land area occupied by tree canopy (PAO) and to the yield per square meter required to obtain 47.5 t 'Summerland Red McIntosh' apples/ha (YR). PAO was calculated from area occupied by a theoretical tree and the appropriate planting density, assuming the cross section of the base of each tree canopy to be a circle with a 10% overlap with adjoining trees (i.e., tree spacing = 90% NTS) and row spacing to be 2 m plus the tree spacing. The equation presented is the arithmetic derivation of a progression of NTS values. The equation for YR was derived by using PAO to calculate the square meter occupied by tree canopy per hectare and dividing that number into 47,500 kg.

Literature Cited

Autio, W.R. 1991a. Contemporary evolution of the New England apple industry: Cultivar and rootstock trends. Fruit Var. J. 45:98–100.

Autio, W.R. 1991b. Rootstocks affect ripening and other qualities of 'Delicious' apples. J. Amer. Soc. Hort. Sci. 116:378–382.

Autio, W.R. and F.W. Southwick. 1993. Evaluation of a spur and standard strain of 'McIntosh' on three rootstocks and one dwarfing interstem over ten years. Fruit Var. J. 47:95–102.

Cain, J.C. 1969. Tree spacing in relation to orchard production efficiency. N.Y. State Agr. Expt. Sta. Res. Circular No. 15.

Elfving, D.C. and E.D. McKibbon. 1991. Effects of rootstock on productivity and pruning requirements of 'Starkspur Supreme Delicious' apple trees in the NC-140 Cooperative Planting. Fruit Var. J. 45:242–246.

Fallahi, E., D.G. Richardson, and M.N. Westwood. 1985. Quality of apple fruit from a high density orchard as influenced by rootstock, fertilizers, maturity, and storage. J. Amer. Soc. Hort. Sci. 110:71–74.

Ferree, D.C., D.D. Miller, and M. Lynd. 1994. Performance of AL.800 as an apple rootstock and interstem in Ohio. Fruit Var. J. 48:186–191.

Ferree, D.C. and J.C. Schmid. 1987. Performance of 'McIntosh' on 14 rootstocks. Fruit Var. J. 41:150–152.

Granger, R.L., M. Meheriuk, S. Khanizadeh, and Y. Groleau. 1993. Performance of 'Starkspur Supreme Delicious' grown on twenty-five rootstocks in Quebec. Fruit Var. J. 47:226–229.

Meheriuk, M., H.A. Quamme, and R.T. Brownlee. 1994. Influence of rootstock on fruit and tree characteristics on 'Macspur McIntosh'. Fruit Var. J. 48:93–97.

NC-140. 1991. Performance of 'Starkspur Supreme Delicious' apple on 9 rootstocks over 10 years in the NC-140 Cooperative Planting. Fruit Var. J. 45:192–199.

Schupp, J.R. 1992. Early performance of four apple cultivars on Mark and other rootstocks in Maine. Fruit Var. J. 46:67–71.