Should New York Apple Growers Move Up to Higher Tree Densities? (Part 1)

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There is great disparity of opinion on what is the optimum density or optimum tree shape. We have shown through a large field study that increasing tree density significantly limits trees size, which allows a broad range of manageable densities for trees on M.9. After seven years. The cumulative yield of the highest tree density in this study (2X10ft) was three times greater than the lowest density (10X18ft). This could result in substantially greater profitability for the high-density systems with good fruit prices.

Apple growers around the world continue to plant high-tree-density orchards. However, there is great disparity of opinion on what is the optimum density or optimum tree shape. Some growers are using densities above 2,000 trees / acre and some growers at the other extreme, plant densities of 200 trees / acre. There is also considerable debate about which training system is best with some favoring the Slender Spindle system, while others like the Vertical Axis system and others some version of V system. We have previously shown that Y-shaped apple trees at densities of 400-600 trees / acre have higher light interception and are more productive than conic shaped Slender Spindle trees at 800 trees / acre (Robinson and Lakso, 1989; Robinson, 1997). However, as apple growers around the world gain experience with high-density orchards, much higher densities than reported in our previous study are common. In addition, most growers allow trees to grow taller than the original Slender Spindle. At these densities, the value of the V-shaped tree for improved light interception and yield is unclear. The goal of this study was to provide research data on tree growth and production of four common apple varieties at a wide range of densities to assist growers in making proper planting decisions that will provide them the best return on investment. A secondary goal was to compare conic vs. V-shaped trees, each at a range of spacings to determine the independent effects of shape and density. This paper (Part 1) presents the horticultural results of the study while in the next issue (Part 2) will present the economic evaluations of systems.

The Geneva High-Density Trial

In 1997, a four acre replicated field trial was planted at the New York State Agricultural Experiment Station in Geneva, New York with four apple varieties (Gala, McIntosh, Empire and Fuji); eight tree planting densities (range 242-2,178 trees / acre) and two tree shapes (conic and V) were compared (Table 1). At the lowest tree densities, trees were planted on M.7 rootstock (242 trees / acre) and M.26 rootstock (340 trees / acre). At all higher densities, trees were planted on M.9 rootstock. The Slender Pyramid, Vertical Axis, and Slender Axis systems were supported by a single-wire trellis (7.5ft), and a steel conduit pipe (10ft) at each tree (Robinson and Hoying, 1999). The Tall Spindle and the Super Spindle systems were supported by a three-wire trellis (7.5ft). The Y-trellis was supported by a six-wire trellis (7.5ft) with three wires on each side. The V-Slender Axis, the V-Tall Spindle and the V-Super Spindle systems were supported by a steel conduit pipe (9ft) at each tree leaned out 15° from vertical to a two-wire V shaped trellis with one wire on each side.

The Slender Pyramid and Vertical Axis trees were developed by heading the leader at 48" above the graft union at planting and shortening each feather by 1/3 their length. In the second through the sixth year, the leaders were not headed. Beginning in the fifth year, large diameter limbs (>2") were removed back to the trunk with an angled cut to develop replacement limbs. Each year

TABLE 1

Tree densities, spacings and rootstocks of the 16 orchard planting systems compared in the 1997 New York systems trial.

Tree Density (trees/acre)	Spacing (ft)	Rootstock	System Name (Conic Shape)	System Name (V-shape)
242	10 X 18	M.7	Slender Pyramid	Y-trellis
340	8 X 16	M.26	Slender Pyramid	Y-trellis
415	7 X 15	M.9	Vertical Axis	Y-trellis
519	6 X 14	M.9	Vertical Axis	Y-trellis
670	5 X 13	M.9	Vertical Axis	Y-trellis
908	4 X 12	M.9	Slender Axis	V-Slender Axis
1320	3 X 11	M.9	Tall Spindle	V-Tall Spindle
2178	2 X 10	M.9	Super Spindle	V-Super Spindle

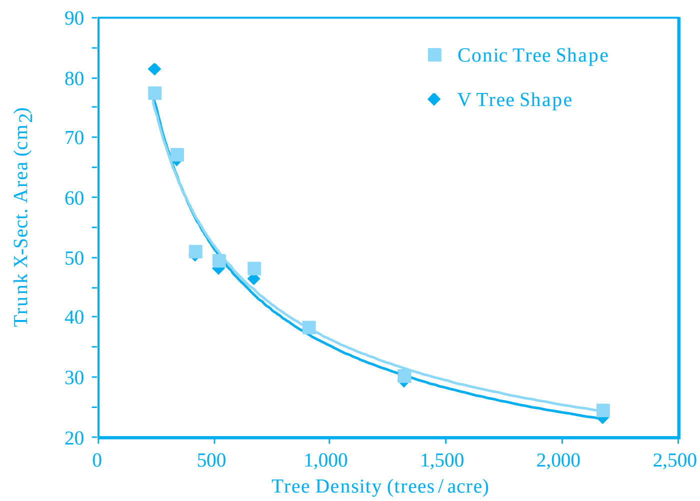

Figure 1. Effect of tree density on trunk cross sectional area after seven years of four apple varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY.

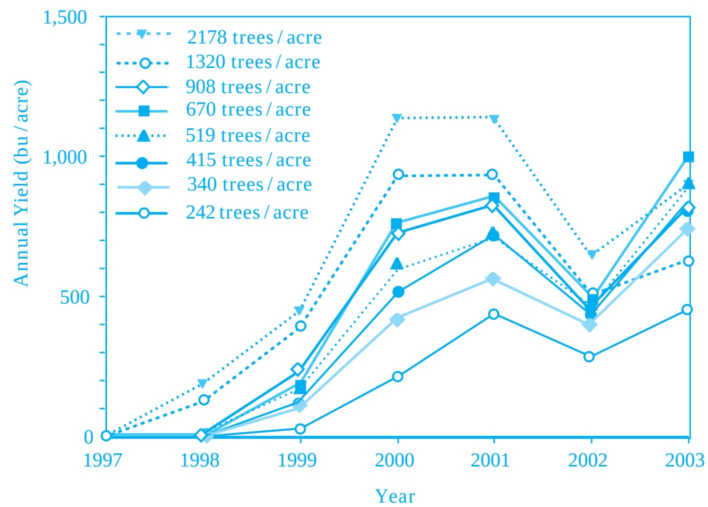

Figure 2. Annual yields of eight planting densities with four varieties (Empire, Gala, McIntosh and Fuji) over the first seven years of the orchards life at Geneva NY.

thereafter, 2-3 large branches were removed. Tree height was limited to 15ft.

The Slender Axis and Tall Spindle trees were developed by heading the leader at 48" above the graft union at planting, removing 1-2 of the largest feathers and leaving the remaining feathers unpruned. In the second through the fourth year, the leaders were not headed. Beginning in the fourth year, large diameter limbs (>1") were removed back to the trunk with an angled cut to develop replacement limbs. Each year thereafter, 2-3 large branches were removed. Tree height was limited to 12ft.

The Super Spindle trees were developed with no pruning of the tree at planting. The leader was not headed until year four when tree height was limited to 10ft. Beginning in the third year, lateral branches whose diameter was larger than 0.75" were removed back to the trunk with an angled cut to develop replacement limbs. Each year thereafter, 2-4 branches were removed. Remaining branches were shortened to no longer than 18" by cutting to a lateral spur.

The Y trellis trees were developed by heading the leader at 24" at planting and allowing 6-8 strong lateral branches to develop. Clothespins were attached to the lateral branches when 4" long to improve crotch angle. In July of the second year, the lateral branches were divided to the two sides of the Y-shaped trellis and attached to the lowest trellis wire at equal spacings along the trellis wire. As the branches grew, they were attached to the higher wires on each side in the third and fourth years. Beginning in the 6th year one branch per year was removed down to the point of origin and a new replacement shoot was tied over to the wire. Tree height was limited to 8ft.

The V-Slender Axis, the V-Tall Spindle and the V-Super Spindle were developed by alternately angling the entire trees 15° to one side of the V and tying the tree to an angled training stake. The training stake was angled 15° from vertical and was supported on each side of the V by a single wire at 7ft high. After leaning the newly planted tree, it was trained in a manner similar to its conic shaped counterpart. However, starting in year two, branches that grew into the center of the V were removed each year during the dormant season.

Results for the First 7 Years

At the end of seven years, there was a strong negative effect of tree planting density on trunk cross-sectional area (Figure 1). As expected, the trees on M.7 were the largest, followed by those on M.26 while those on M.9 were the smallest. Among M.9 planting densities, the highest planting density produced trees about one third the size of the lowest planting density. There was no effect of tree shape on tree size as estimated by trunk x-sectional area at any of the planting densities or on any of the rootstocks (Figure 1).

The strong effect of increasing tree density on limiting tree growth indicates that with M.9 there is a large range of tree densities that are manageable. At the wider plant spacings, a larger tree developed than at the closer spacings. This was likely due to three effects: 1) The higher tree densities began cropping earlier (second year) and had greater crops over the first five years than the lower tree densities. This likely reduced availability of carbohydrates for use in structural parts of the tree. 2) At the higher densities, the canopy of the tree was limited by pruning beginning in the third year, which likely reduced total carbohydrate supply and thus tree size. 3) Root competition could also have contributed to reduced tree size. With the Super Spindle and the Tall Spindle systems, the main pruning strategy was to remove large diameter limbs each year. When this was repeated over several years, the size of the canopy remained small and presumably root system size was also limited.

The Super Spindle and the Tall Spindle systems (two highest densities) began production in the second year with a commercially significant yield (Figure 2).The Super Spindle system continued with the highest yield through year six and achieved a maximum yield of 1,000 bu / acre by year four. The lowest density system (Slender Pyramid) developed much more slowly and had only a 470 bu / acre yield in the seventh year. In year seven, the moderate density systems of Tall Axis and Vertical Axis had similar yields to that of the very high density Super Spindle system.

Tree density had a highly significant negative effect on cumulative yield per tree, but when considered on a per acre basis there was a highly significant positive effect of increasing tree density on yield. Cumulative yield / acre by the end of year seven was highest for the Super Spindle system and was related to tree density in a curvilinear manner (Figure 3). The cumulative yield of the Super Spindle system (>4,600 bu / acre over seven years) was three times greater than the lowest density system (1,500 bu / acre

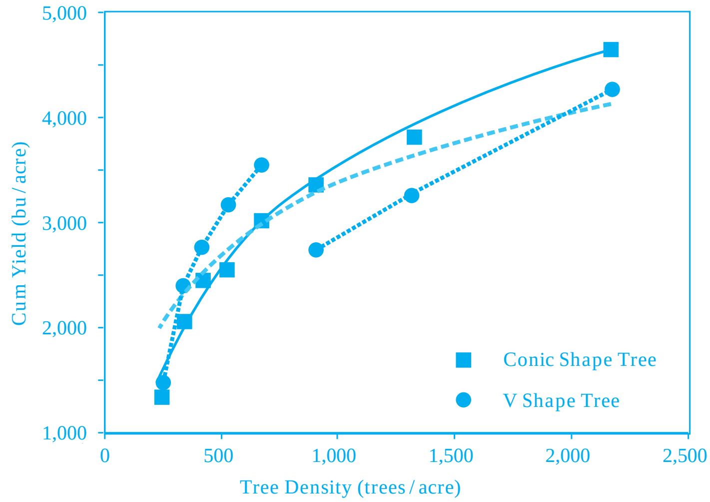

Figure 3. Relationship of tree density and cumulative yield over seven years with two tree shapes and four varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY. Solid line and dashed line are the regression relationships for the conic and V shapes, respectively. The dash/dot line shows the two distinct relationships within the V-shaped systems.

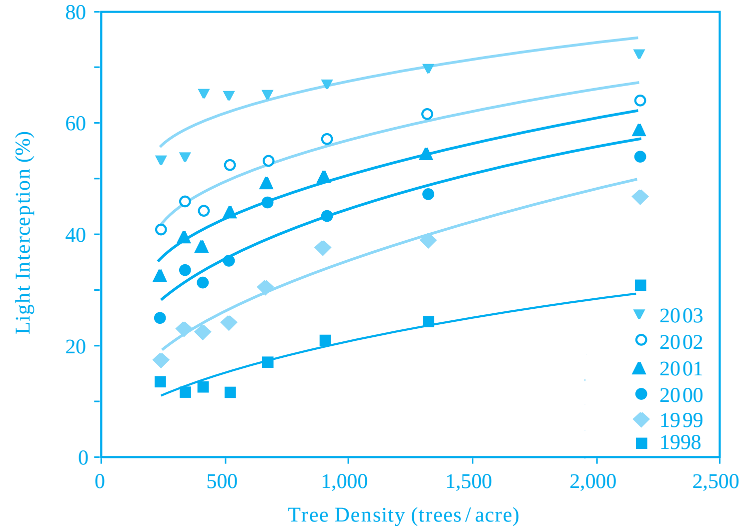

Figure 4. Relationship of tree density and light interception of Empire apple trees on Sept. 1 for each of six years at Geneva NY.

over seven years). There was a significant interaction of tree shape and tree density on cumulative yield / acre. At the higher tree densities, the V shape had a lower yield than the conic shape while at lower tree densities the V shape was superior to the conic shape.

The strong curvilinear relationship between tree density and cumulative yield at the end of year seven indicates that although the Super Spindle system produced the highest yield, the medium density systems produced almost the same cumulative yield. It is likely that as the orchard ages, the relationship will be even more strongly asymptotic (DeMarree et al., 2003; Robinson, 2003). The changing relationship from a linear one during the early years to a curvilinear one at year seven indicates that the highest density systems provide a greater advantage in the early years, but that in the later years the advantage disappears. The optimum density from an economic perspective is probably somewhat less than the highest density due to the law of diminishing returns (Robinson, 2003). The very high density systems would have the greatest potential when orchard lifespan is short or when fruit prices are very high during the early years of an orchard's life.

Tree density had a strong effect on canopy light interception from year two through seven (Figure 4). In each year, there was a positive relationship between tree density and canopy light interception. In year two, the highest tree density achieved 25% light interception while the lowest density had only 12% interception. The highest tree density achieved 60% light interception by year five and 70% light interception by year seven. The lowest density systems did not surpass 50% light interception until year seven. There was no effect of tree shape on canopy light interception until year four, after which, the V shape surpassed the conic shape at similar densities (Figure 5). The V shape continued to intercept more light in later years, which confirms our earlier studies (Robinson and Lakso, 1989; Robinson, 1997).

Cumulative yield was a linear function of light intercepted by the canopy (Figure 6). Differences in light interception accounted for most of the differences in yield across all of the densities and with both tree shapes. However, the three highest density V systems had significantly lower yield than predicted from the relationship of the conic shaped systems. Thus, despite

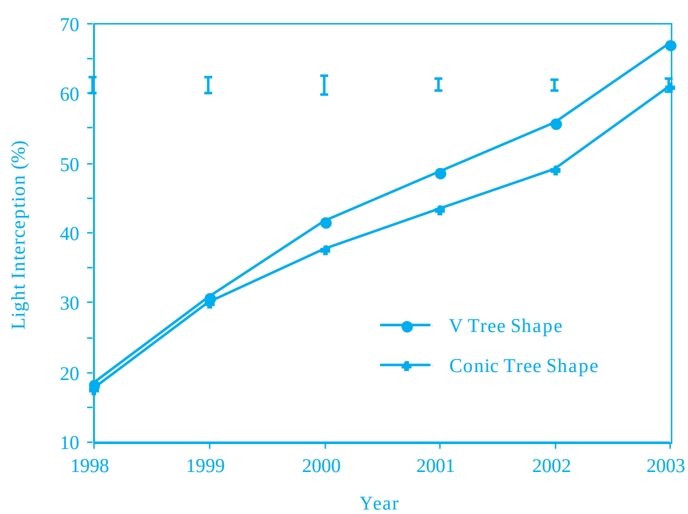

Figure 5. Annual light interception of conic and V shaped Empire apple trees averaged over eight planting densities (598-5,382 trees/ha) for the first seven years of the orchard's life at Geneva NY.

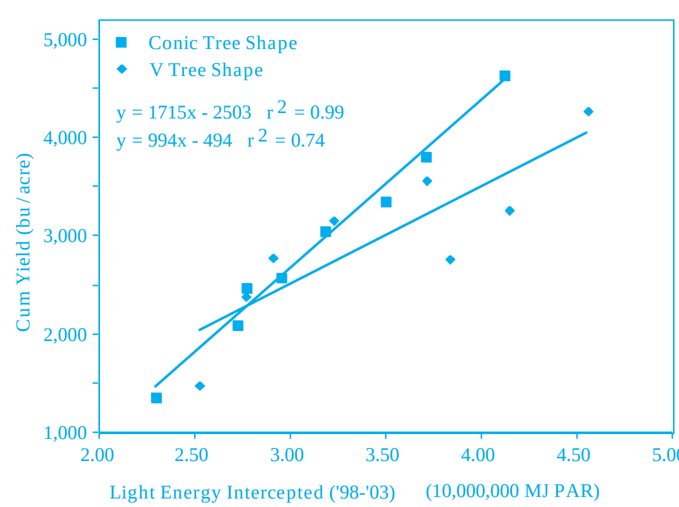

Figure 6. Relationship of 6-year (1998-2003) cumulative light interception and cumulative yield of Empire apple trees with two tree shapes at Geneva NY.

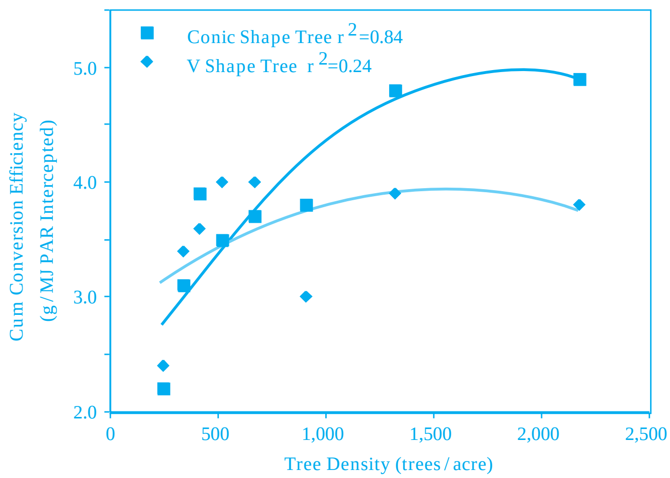

Figure 7. Relationship of tree density and cumulative light conversion efficiency of Empire apple trees over seven years with two tree shapes at Geneva NY.

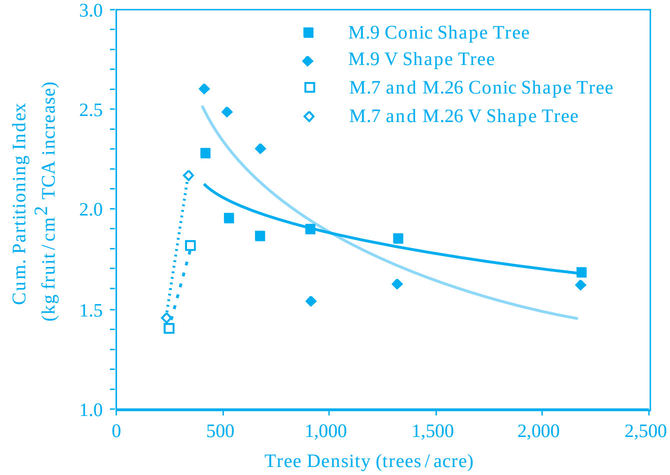

Figure 8. Relationship of tree density and cumulative partitioning index over seven years with two tree shapes and four varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY. Trees on M.7 and M.26 were not included in the regression analysis.

having higher light interception than their conic counterparts, these three systems had lower yields. This gives the appearance of two distinct relationships of light interception and yield in Figure 6. This may be due to the two different training styles of the V systems.

Our results once again confirm that cumulative yield is largely a function of light interception (Robinson and Lakso, 1989). All of the systems exceeded 50% light interception by the end of year seven. However, only the systems on M.9 at densities greater than 400 trees / acre exceeded 60% and only the Super Spindle and Tall Spindle systems with >1,200 trees / acre exceeded 70% light interception. It is likely that the moderate density systems will achieve 70% light interception in later years; however, it is unlikely that the low density systems will ever achieve that level. We have suggested in the past that 70% light interception should be the goal of all orchard systems to optimize light interception (Robinson et al., 1991). This suggests that fruit growers should plant high tree densities (>1,200 trees / acre).

Estimates were made of the physiological efficiency of each tree shape and density by calculating the efficiency of converting intercepted light energy into fruit. With conic-shaped trees, there was a positive effect of increasing tree density on the tree's efficiency of converting light energy into fruit (Figure 7). With the V-shaped trees at low and moderate tree densities, there was little difference in the conversion efficiency of the two tree shapes. However, at the higher densities the conic shape was much more efficient than the V shape. During the early years of the orchard's life there was a strong positive relationship between light conversion efficiency and yield, but in the sixth and seventh years the relationship was flat or negative. This was likely due to the increased pruning of the super high-density systems in the last two years. There was a significant interaction of tree density and tree shape with conversion efficiency which showed that at the lower densities, the V systems were no different than the conic systems in physiological efficiency. However, at the higher tree densities the V systems had significantly lower physiological efficiency than the conic systems. This may be due to the two different training styles of the V systems.

Estimates of tree partitioning between vegetative growth (trunk cross-sectional area increase) and fruiting (cumulative yield) using only M.9 rootstock, showed an interaction with tree shape and tree density (Figure 8). With both tree shapes, there was a negative effect of increasing tree density on cumulative partitioning index. At the highest tree density, the partitioning index of M.9 was reduced to a level similar to M.7. This was likely due to the increased pruning associated with the higher tree densities. Among tree shapes, the decrease in partitioning index was steeper for the V systems than for the conic systems. This was due to the fact that with the Y trellis trees, the lower densities required almost no pruning until year seven while the higher density V systems required significant pruning beginning in year three.

The largest average fruit size was achieved with the lowest density systems. This was likely due to the lower croploads of the low-density systems. With conic-shaped trees there was no significant relationship of tree density and fruit size, but with the V-shaped trees there was a small negative effect of increasing tree density on fruit size.

Fruit red color was greatest at the lowest densities. During the first few cropping years, there was no effect of tree density or tree shape on fruit color. In the sixth and seventh years however, the highest densities had slightly lower fruit color. The reduction in fruit color associated with high tree densities was not great but is a common result with very high tree densities as light interception approaches 70%.

Discussion

Increasing tree density to the extreme spacing of 2 X 10ft resulted in two interesting results. First the size of the tree was dramatically smaller than at wider spacings. This is important since it shows that growers can manage M.9 at a range of densities. Often growers look at M.9 trees planted at wider spacings, and wonder how they would fit at tighter spacings. This experiment shows that at closer spacings the more intense pruning and cropping utilized with the Super Spindle and Tall Spindle systems keeps tree size much smaller, thus allowing successful management even at the extremely close spacings.

The second interesting result is the high level of yield possible with the extremely close spacings in year three and four. From an economic perspective, yield in the first five years is extremely valuable in repaying the investment to establish the orchard. If a high-priced variety is planted, it is quite feasible that the total initial investment could be paid off by the end of year four. With more moderate-priced varieties the initial investment could be paid off by year six or seven. Over the first seven years, average yield for the very high-density systems was 650 bushels per acre, which is higher than many existing mature blocks in NY State. It is clear that extreme densities can be managed successfully and are very productive. However, whether or not growers should plant these densities is an economic question. In the next issue of the *Fruit Quarterly* we will present an economic analysis of tree density to answer that question. Nevertheless, it is clear from this experiment that much higher densities than those common in NY are possible and more than likely much more profitable.

The shape a tree had been trained had no effect on tree size, but there was an interaction of tree shape and tree planting density on cumulative yield. The V-shaped trees had higher yield at the low and moderate densities than the conic-shaped trees, but at the highest density they had poorer yield than their conic-shaped counterparts. This is in contrast to our earlier work, which showed the Geneva Y-trellis had higher yield than conic-shaped trees (Robinson and Lakso, 1989; Robinson, 1997). This anomaly may be due to the two distinct styles of tree training for the V-shaped trees. The three highest densities of the V shape were all trained by alternately leaning entire trees in each row to one side or the other of the V trellis, whereas at the lower densities the V-shaped trees were trained by dividing the canopy to both sides of the trellis. In hindsight, this may have resulted in a smaller V canopy per tree at the very high densities than would have been the case had each tree been trained to both sides of the trellis. This effect is most clear in Figure 3 where the five lower density V systems appear to fall on a similar line that is distinctly different than the line for the three higher density V systems.

Summary

The results of this study show that increasing tree planting density results in significantly greater cumulative yield. This study shows that a whole new level of yield is possible in NY. Growers' expectations over the first five years of an orchard should be raised considerably. We have also shown in this study that increasing tree density limits trees size significantly, which allows a broad range of manageable densities for trees on M.9. The curvilinear relationship of yield and tree density indicates that the optimum planting density depends on the influence of economic factors and the law of diminishing returns. We will present an economic analysis in the next issue of the *Fruit Quarterly*. The V tree shape appears to be slightly better than conic shapes at low and moderate tree densities, but at the very high tree densities the alternating V tree systems are inferior to the conic systems. This was likely due to excessive pruning of the highest tree density V systems.

References

DeMarree, A., T.L. Robinson. and S.A. Hoying. 2003. Economics and the orchard system decision. *Compact Fruit Tree* 36:(special issue) 42-49.

Robinson, T.L. 1997. Interaction of tree form and rootstock on light interception, yield and yield efficiency of 'Empire' and 'Jonagold' trained to 4 systems. *Acta Hort.* 415:427-436.

Robinson, T.L. 2003. Apple orchard systems. In: D.C. Ferree and I.J. Warrington (eds.). *Apples: Physiology, production and uses.* CABI Publishing. Wallingford, Oxon, United Kingdom.

Robinson, T. L and Hoying, S. A. 1999. What we learned about tree support from the 1998 Labor-Day storm. *New York Fruit Quarterly* 7(2):17-24.

Robinson, T. L. and Lakso, A. N. 1989. Light interception, yield and fruit quality of 'Empire' and 'Delicious' apple trees grown in four orchard systems. *Acta Hort.* 243:175-184.

Robinson, T. L., A. N. Lakso and Z. Ren. 1991. Modifying apple tree canopies for improved production efficiency. *HortScience* 26:1005-1012.

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