

# Performance of High-Density Sweet Cherry Training Systems in New York

Terence L. Robinson<sup>1</sup>, Robert L. Andersen<sup>1</sup>, and Stephen A. Hoying<sup>2</sup>

<sup>1</sup>Dept. of Horticultural Sciences, NYSAES, Cornell University, Geneva, NY

<sup>2</sup>Cornell Cooperative Extension, Lake Ontario Fruit Program, Newark, NY

Sweet cherries are a high-value crop of increasing interest in the Northeastern U.S. The introduction of dwarfing cherry rootstocks (Lang, 2000; Perry et al., 1996; Robinson, et al., 2005) and newer varieties (Kappel, 2002) has allowed new possibilities for developing high-density cherry orchards with smaller trees that will be more precocious and productive that can either be covered with rain exclusion shelters or treated with CaCl<sub>2</sub> to prevent rain cracking (Andersen et al., 1999; Balmer, 2001; Lang, 2001; Lang and Ophardt, 2000; Lang and Perry, 2002; Weber, 2001). Several high-density training systems have been developed for sweet cherries (Long, 2001a; Long, 2001b; Perry, 1998) giving fruit growers many options for planting density, rootstock, and training protocol. The objective of this project was to compare high-density production systems on both standard and dwarfing rootstocks for sweet cherries. A second objective was to determine the effect of training system and rootstock on fruit size.

## Materials and Methods

In April of 1999 a replicated field trial was planted at Geneva, New York with Hedelfingen on three rootstocks (Gi.5, Gi.6 and MxM.2), Lapins and Sweetheart on two rootstocks (Gi.5 and Gi.6) and Tehranivee and Regina on one rootstock (Mahaleb). Each variety / rootstock combination was planted into each of six training systems: Central leader, Spanish bush, Slender spindle, V system, Marchant inclined tree system, and

Vertical axis. Tree densities and spacings are given in Table 1. Each training system plot consisted of three 32m long rows and was replicated three times. Each row was planted on a broad 30cm-high berm to control winter damage associated with excessive soil moisture. In addition, a subsurface drainage line was installed in the center of each tractor alley to remove excess moisture in the spring and during heavy rainfalls before harvest.

The Central-leader system was developed by heading the leader at 90cm at planting, removing large diameter feathers, removing buds below the new leader bud along 20cm of the leader and attaching clothespins to lateral branches when 10cm long to improve crotch angle. In the second through fourth year, the leader was headed annually removing one third of last year's growth, large diameter upright shoots were removed and five buds below the new leader bud on the leader were removed at bud swell. Later as the shoots developed in the spring, clothespins were attached to lateral branches when 10cm long to improve crotch angle. In the third year, four primary scaffold branches were tied

The introduction of dwarfing cherry rootstocks has allowed new possibilities for developing high-density cherry orchards with smaller trees that are more precocious and productive. Our results show that high-density cherry orchards with ~ 450 trees/acre can result in substantial yields in the first six years and return four times the gross return of the traditional Central-leader system which has only 130 trees/acre.

down to 15° above horizontal in early June.

The Spanish-bush system was developed by heading the leader at 40cm at planting, attaching clothespins to lateral branches when 10cm long to improve crotch angle, and by reheading each lateral shoots in early July to multiply number of shoots. In the second through fourth years, all shoots on the tree were headed at bud swell removing one half of last year's growth and then reheading by about one half in early July to multiply number of shoots.

The Slender-spindle system was developed by heading the leader at 90cm at planting, removing all feathers, removing buds below the new leader bud along 20cm of the leader and attaching clothespins to lateral branches when

TABLE 1

Tree densities, spacings and initial heading heights of six orchard-planting systems in the NY sweet cherry systems trial.

Planting System	Tree density (trees/ha)	Tree Spacing (m)	Initial heading height (cm)
Modified Central Leader	336	4.9 X 6.1	80
Spanish Bush	673	3.1 X 4.9	40
Slender Spindle	897	2.4 X 4.6	90
V-Slender Spindle	997	1.8 X 5.5	90
Marchant Trellis	1035	2.4 X 4.9	100
Vertical Axis	1196	1.8 X 4.6	120

10cm long to improve crotch angle. As lateral branches grew longer than 25cm, the clothespins were relocated to hang from young developing leaves near the apical end of the shoot to weigh the shoot down to maintain horizontal branch angle. Clothespins were moved further out on the shoot every two weeks to maintain a horizontal branch angle. In the second through the fourth year the leader was headed at bud swell removing one third of last year's growth and the next five buds below the new leader bud were removed. Lateral branching along 'V' scaffold arms was induced in years two - four by removing 67% of lateral buds along the one-year-old section of the scaffold at bud swell (Robinson et al., 2004). New lateral shoots on the leader were weighted with clothespins as in year one.

The 'V' system was developed by heading the leader at 30cm at planting and allowing only two strong buds to develop. Clothespins were attached to the two lateral branches that were oriented toward the tractor alleys when 10cm long to improve crotch angle. At the beginning of the second year, the two primary scaffold branches were tied to training stake at 60° above horizontal at bud swell. In years two - four, the two primary scaffolds were not headed. Lateral branching along the 'V' scaffold arms was induced by annually removing 67% of lateral buds along the one-year-old section of the scaffold at bud swell (Robinson et al., 2004).

The Marchant inclined tree system was developed by planting the trees at 45° angle down the row. The leader was headed at 100cm at planting. All of the feathers were removed and all of the buds on underside of the leader were removed. The remaining buds thinned to a 20cm spacing. The leader was trained to a 60° angle along the row utilizing a four-wire trellis and an inclined bamboo pole at each tree. In the second-fourth year, the vertical lateral branches arising off the inclined leader were tied in the opposite direction down the row by tying to trellis at 45° above horizontal at bud swell. Large-diameter vigorous shoots were removed at bud swell.

The Vertical-axis system was developed by heading the leader at 120cm (Zahn, 1994). Large diameter feathers (larger than two thirds the diameter of the leader) were removed. Lateral branching along leader was induced by removing 67% of buds along branch at bud swell (Robinson et

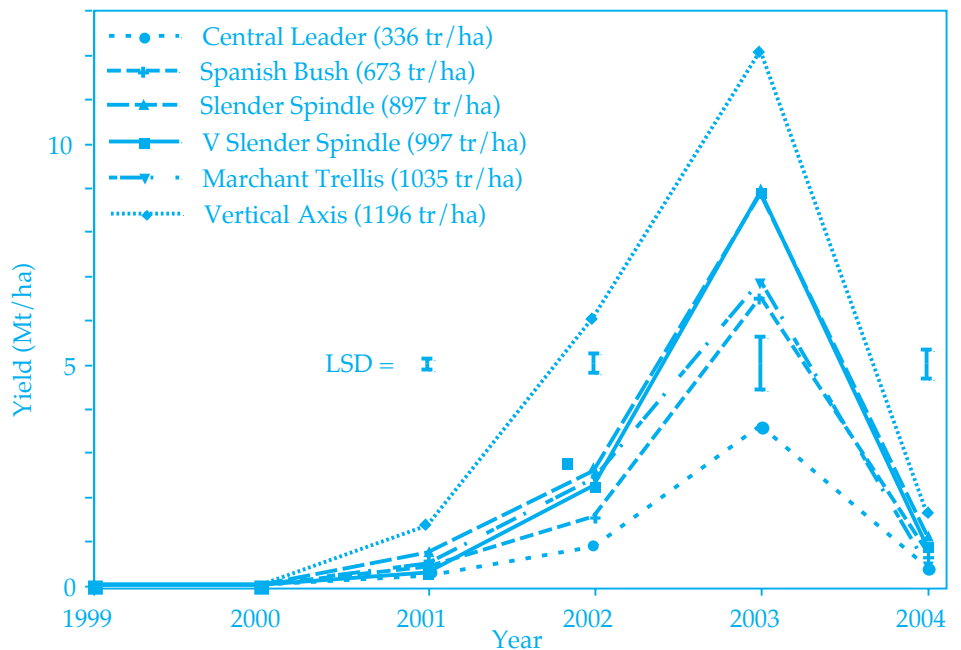
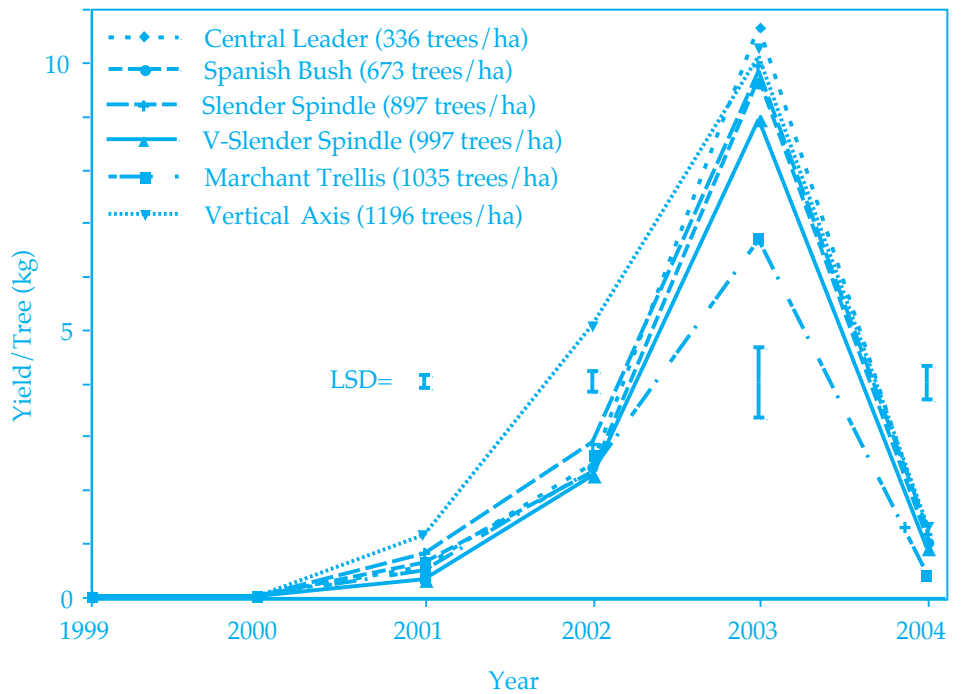


Figure 1. Annual yield/tree and yield/ha of five sweet cherry varieties (Hedelfingen, Lapins, Sweetheart, Regina and Tehranivee) on MXM.2, Gisela 5, Gisela 6 and Mahaleb rootstocks at Geneva NY. Vertical bars represent LSD for significant difference within each year.

al., 2004). Clothespins were attached to lateral branches when 10cm long to improve crotch angle. During the second through the fourth year, the leader was not headed. Large diameter branches were stubbed back to 20cm at bud swell if they were larger than 2/3 diameter of leader. On an annual basis, lateral branching along leader was induced by removing 67% of buds along the branch at bud swell. Cement weights were attached to the ends of

second year lateral branches to maintain horizontal branch angle.

The trees fruited for the first time in the third year, and yield and fruit size data were recorded in the third-fifth years. A 25-cherry sample was collected each year from each tree and analyzed for proportion of cracked fruit and fruit soluble solids. Economic gross returns were calculated as: Gross Return (\$/ha) = [Cumulative yield (kg/ha) - yield of cracked fruit (kg/ha)] \* \$2.20/kg. Data

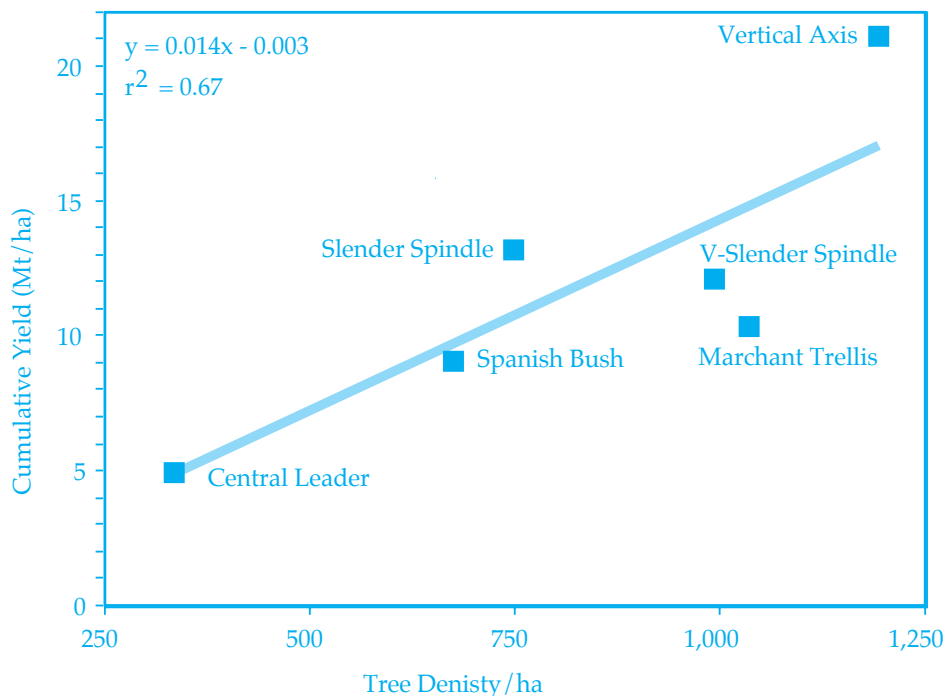


Figure 2. Relationship of tree planting density to cumulative yield/ha of five sweet cherry varieties (Hedelfingen, Lapins, Sweetheart, Regina and Tehranivee) on MXM.2, Gisela 5, Gisela 6 and Mahaleb rootstocks trained to six training systems at Geneva NY.

were analyzed by analysis of variance with each variety analyzed separately since only the Hedelfingen was planted on three rootstocks, while Lapins and Sweetheart were planted on only two rootstocks and Tehranivee and Regina were planted on only on one stock.

## Results

**Yield Performance.** In the third year (2001) the Vertical-axis system had the highest yield per tree, followed by the Slender-spindle system, the Spanish bush, Central leader, Marchant inclined tree and the V system, respectively (Figure 1). On a hectare basis the Vertical-axis system had the highest yield per tree followed by the Slender-spindle system, the Marchant system, the Spanish bush system, the V system and the Central-leader system (Figure 1). By the fifth year, yield ranged from 6-11 kg/tree and from 3-11 Mt/ha. The cumulative yield per tree over 6 years was highest for the Vertical-axis system (17.6 kg) followed by the Central-leader system (14.9 kg), the Slender-spindle system (14.7 kg), the Spanish bush system (13.5 kg), the V system (12.2 kg) and the Marchant inclined tree system (9.9 kg). On a hectare basis the highest cumulative yield was with the Vertical-axis system (21.1 Mt), followed by the Slender-spindle system (13.2 Mt), the V system (12.1 Mt), the Marchant inclined tree system (10.2 Mt),

the Spanish bush system (9.1 Mt) and the Central-leader system (5.0 Mt).

The differences in yield between systems were largely a function of tree density. There was a linear relationship of tree planting density and yield that explained 67% of the variation in cumulative yield per hectare (Figure 2). The Marchant system, and to some extent the V system, had significantly lower cumulative yield than expected from their tree density. The Vertical-axis system, and to a lesser extent the Slender-spindle system, had a higher cumulative yield than expected from their tree density. With the Vertical-axis system, this resulted from the highest yield per tree and the highest tree density.

With Hedelfingen, Gi.5 had the greatest yield each year while Gi.6 was intermediate and MXM.2 had the lowest yield (Figure 3). In the winter preceding 2004, severe winter temperatures killed most of the flower buds in this trial. The drop in yield from 2003 to 2004 shows that Gi.6 was the most sensitive to winter cold while MXM2 was the least sensitive. Gi.5 was intermediate. Cumulative yield of MxM.2 was extremely low compared to the Gisela rootstocks (Figure 3). Cumulative yield over 6 years of Gi.5 was 19.3kg while Gi.6 was 12.9 and MXM.2 was 3.8. With Lapins and Sweetheart there was no large difference in cumulative yield between Gi.5 and G.6 (data not shown).

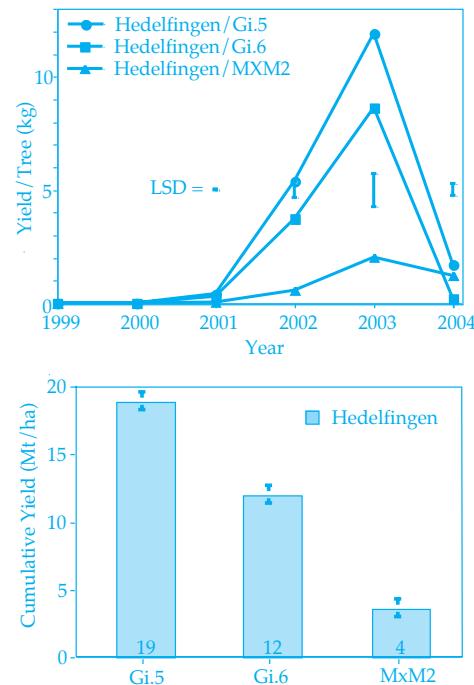


Figure 3. Annual yield/tree and six-year cumulative yield/ha of Hedelfingen sweet cherry on MXM.2, Gisela 5, and Gisela 6 rootstocks at Geneva NY. Vertical bars represent LSD for significant differences between stocks.

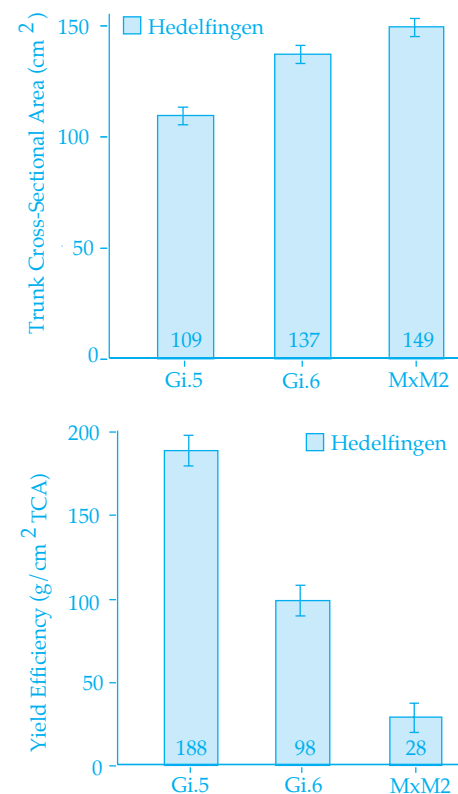


Figure 4. Effect of rootstock on final trunk cross-sectional area and cumulative yield efficiency of Hedelfingen sweet cherry trees on MXM.2, Gisela 5, and Gisela 6 rootstocks at Geneva NY. Vertical bars represent LSD for significant differences between stocks.

Among varieties, Sweetheart was the most productive followed by Tehranivee, Lapins, Hedelfingen and lastly Regina (data not shown). Regina had significantly lower production than any of the other varieties. However, following the winter of 2004, which killed most flower buds on Sweetheart and Lapins and many flower buds on Hedelfingen, Regina had the highest flower bud survival. Thus it appears to be slightly more winter hardy than the others.

There was an interaction of rootstock and training system with Hedelfingen, but not with Lapins and Sweetheart. The combination of Vertical axis training and Gi.5 rootstock resulted in very high six-year cumulative yields per hectare of 31.8, 19.7 and 26.5 tons/ha for Hedelfingen, Lapins and Sweetheart, respectively. In contrast, the Vertical-axis system with the full vigor MXM.2 rootstock had a cumulative yield of only 8.3 tons/ha with Hedelfingen.

**Tree Size.** There was a clear rootstock effect on tree size, as measured by trunk cross-sectional area, with trees on Gi.5 being significantly smaller (30%) than trees on Gi.6 which in turn were about 20% smaller than trees on MXM.2 (Figure 4). Planting system also had a significant effect on final trunk cross-sectional area. The central-leader trees were the largest and the Marchant-trellis trees were the smallest. There was a significant negative curvilinear relationship between tree planting density and tree size with the highest density Vertical Axis trees being only 60% as large as the lowest density central leader trees (Figure 5).

**Yield Efficiency.** There was a significant effect of rootstock on yield efficiency. Trees on Gi.5 were four times as efficient as trees on MXM.2 (Figure 4). Trees on Gi.6 were intermediate. Among training systems, the Vertical-axis system was substantially more efficient than any other system and almost twice as efficient as the traditional Central-leader system. There was a significant positive curvilinear relationship between tree density and yield efficiency (Figure 5). However, the Marchant trellis and the V-Slender Spindle were significantly less efficient than predicted by the regression equation.

**Fruit Quality.** With Hedelfingen, the largest average fruit size over the three cropping seasons was with Gi.6, while MXM.2 was intermediate and Gi.5 had

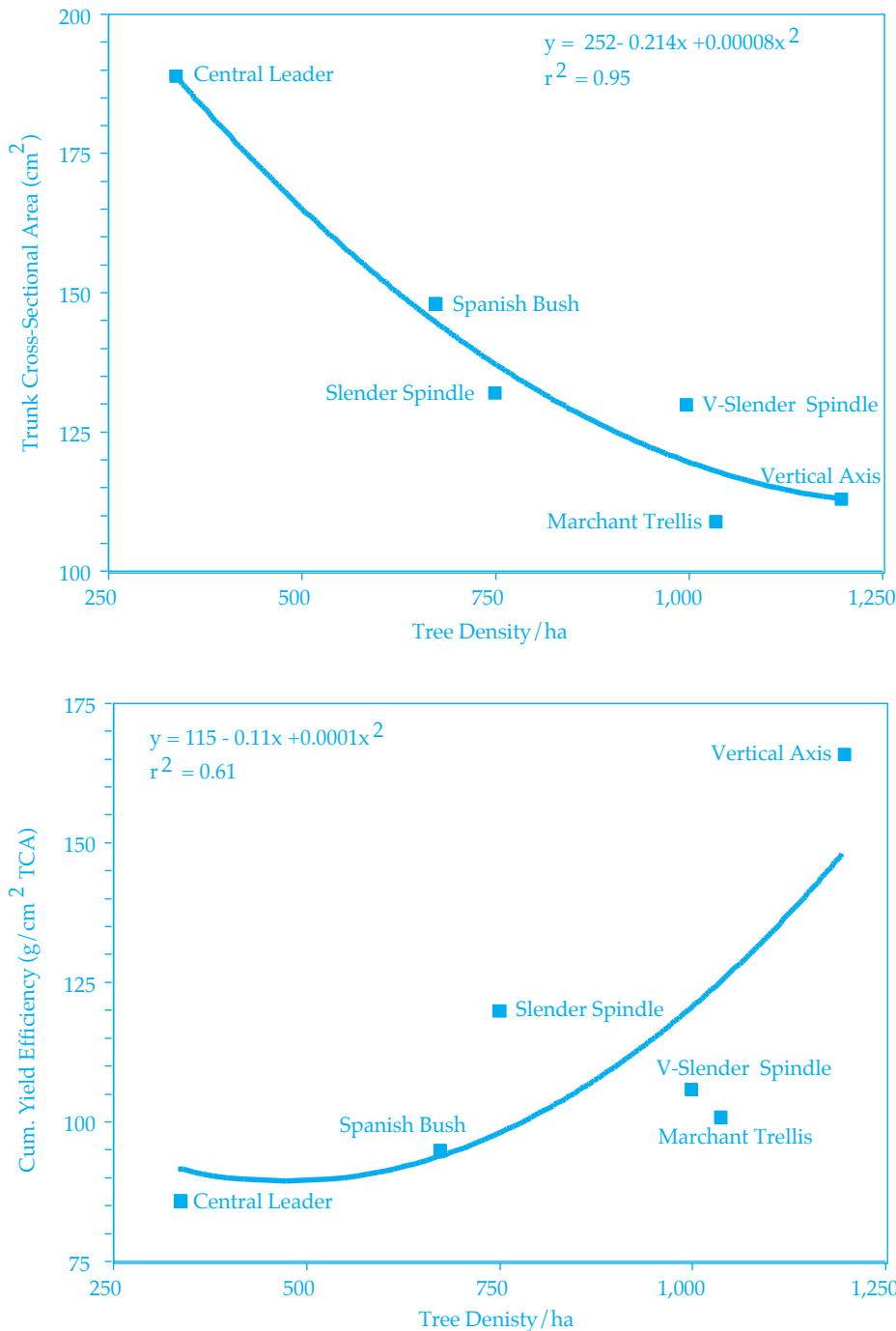


Figure 5. Relationship of tree planting density to final trunk cross-sectional area or yield efficiency of five sweet cherry varieties (Hedelfingen, Lapins, Sweetheart, Regina and Tehranivee) on MXM.2, Gisela 5, Gisela 6 and Mahaleb rootstocks trained to six training systems at Geneva NY.

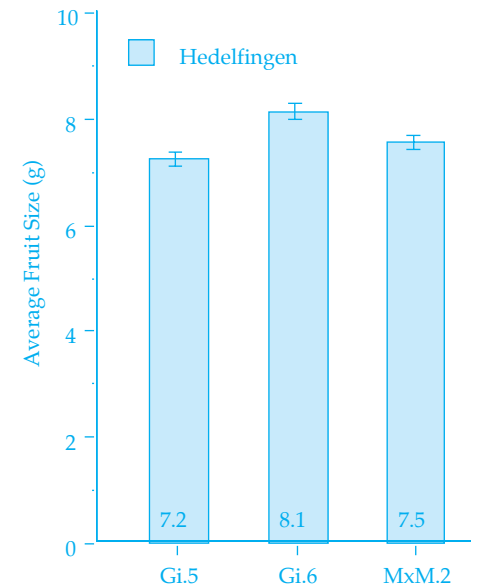


Figure 6. Effect of rootstock on average fruit size of Hedelfingen sweet cherry trees on MXM.2, Gisela 5, and Gisela 6 rootstocks at Geneva NY. Vertical bars represent LSD for significant differences between stocks.

the smallest fruit size (Figure 6). However, there was an interaction with variety. With Lapins and Sweetheart there was no difference in fruit size between Gi.5 and Gi.6 (data not shown). Among training systems, average fruit size was greatest for the Slender-spindle system followed by the Central leader, V system, Spanish bush, Marchant and Vertical-axis systems, respectively. Although the

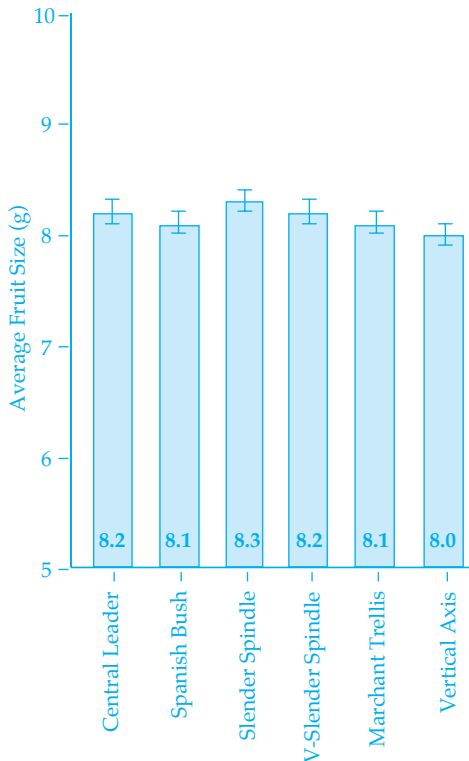


Figure 7. Effect of training system on average fruit size of five sweet cherry varieties (Hedelfingen, Lapins, Sweetheart, Regina and Tehranivee), on MXM.2, Gisela 5, Gisela 6 and Mahaleb rootstocks at Geneva NY. Vertical bars represent LSD for significant differences between systems.

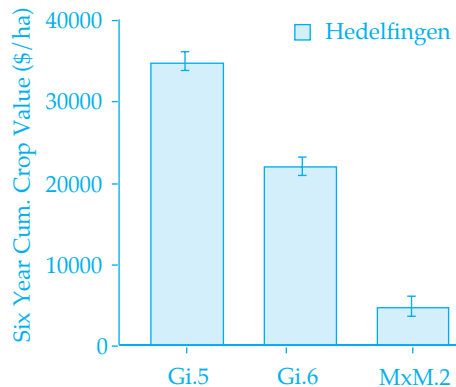


Figure 8 Effect of rootstock on six-year cumulative crop value per hectare of Hedelfingen sweet cherry trees on Gi.5, Gi.6 and MXM.2 rootstocks at Geneva NY. Vertical bars represent LSD for significant difference between rootstocks.

difference between the top two systems and the bottom two systems was significant, these differences were not great (Figure 7).

With Hedelfingen, Gi.6 had significantly higher soluble solids than MXM.2, which had greater soluble solids than Gi.5 (data not shown). Among rootstocks, there was an interaction with variety. With Lapins and Sweetheart, there were no significant differences in soluble solids content between Gi.5 and Gi.6. Among systems, fruit-soluble-solids was highest with the V system followed by the Central leader, Slender spindle, Vertical axis, Spanish bush and the Marchant system (data not shown). Although the maximum difference in soluble solids was only 0.5%, the bottom two systems had significantly lower soluble solids than the top four systems. This likely reflects the thick canopies resulting in excessive shade within the Spanish bush and the Marchant canopies.

**Economics.** Cumulative crop value was greatest for trees on Gi.5 followed by Gi.6 and then MXM.2 (Figure 8). Among rootstocks there was an interaction with variety. With Hedelfingen and Lapins, the largest cumulative crop value was with Gi.5, intermediate with Gi.6 and smallest with MXM.2. With Sweetheart, there was no difference in cumulative crop value between Gi.5 and Gi.6. Among systems, cumulative crop value over the first

six years of the orchard's life was greatest for the Vertical-axis system (\$37,500/ha), followed by the V system (\$22,100/ha), the Slender-spindle system (\$20,900/ha), the Marchant inclined tree system (\$17,100/ha), the Spanish bush system (\$16,400/ha) and the Central-leader system (\$9,000/ha). The difference between the top system and the bottom system was more than four fold. There was a significant positive curvilinear relationship between tree density and crop value (Figure 9). The Marchant trellis had significantly lower cumulative crop value than predicted by the regression relationship.

## Discussion

Our results after six years show the strong correlation of tree densities and level of early yields that can be achieved. This is similar to the results of studies of planting density with apple (Robinson, 2003). With our cherry data the relationship appears to be linear over the densities we considered, whereas with apple, the relationship is curvilinear. It is likely, that over a broader range, the relationship would be curvilinear with cherry.

A second result is that the systems, which utilized the least pruning, had the highest yield in the first six years. An important component of the high yields

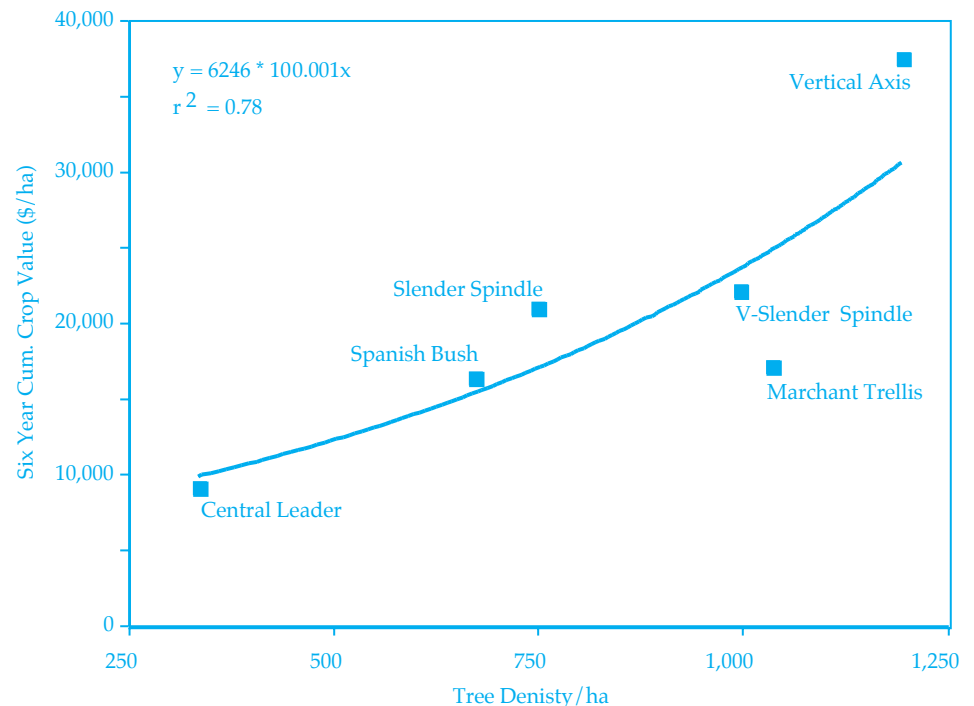


Figure 9. Relationship of tree density and six-year cumulative crop value per hectare of 5 sweet cherry varieties (Hedelfingen, Lapins, Sweetheart, Regina and Tehranivee), on MXM.2, Gisela 5, Gisela 6 and Mahaleb rootstocks trained to six planting systems at Geneva NY.

of the Vertical axis and the Slender-spindle systems, was the minimal pruning during the first two years. In contrast, the Spanish Bush system had very severe pruning during the first two years. The Perpendicular V system had severe pruning at planting, but minimal pruning after that. The severe pruning was related to lower yields of these systems in the 3<sup>rd</sup> and 4<sup>th</sup> years. To successfully incorporate minimal pruning with sweet cherry, branching techniques are needed due to the strong apical dominance resulting in a suppression of lateral bud development with most varieties. Our previous work showed bud removal early in the spring was very successful at stimulating lateral bud development without heading the leader (Hoying et al., 2001, Robinson et al., 2004). This technique allows minimal pruning resulting in more rapid development of the canopy and earlier production, yet proper limb placement along the leader. In humid climates like the Northeast of the United States, bacterial canker infection is a high risk with this procedure and the application of copper sprays immediately before and/or after the buds are removed is essential.

A third important result is the reduction in tree size (as measured by trunk cross-sectional area) with increasing tree density. This is important since it means that at higher tree densities trees will be manageable in the smaller allotted space for a greater period of time. It was of interest to note that in the Vertical-axis system with renewal pruning (Zahn, 1994), all of the lateral limbs on each tree were less than 10cm in diameter since when they exceeded that diameter, we removed them back to 10cm stub and developed replacement branches. In contrast, the central leader trees on the same stocks had lower scaffold branches that exceeded 25cm in diameter by the end of the 6<sup>th</sup> year. The larger branch structure of the Central Leader trees led to larger trunks and probably much larger root systems giving difficulty in managing the tree into a small area.

The Vertical-axis system, because of its high yield per tree due to minimal pruning and the highest tree density, produced 1.5 times the yield per ha of the next best system. As expected, the traditional system (low density Central-leader system) had a very low yield. Among the other four high-density

systems, the Slender-spindle and the V system had very similar yield and were significantly higher than the Spanish bush which had reduced early yield due to excessive pruning and relatively low tree density. The Marchant system had unusually low yield. We judge the Marchant system to be inferior since yields were low and labor for tree training was much higher than with any other system.

Considering yield, fruit size, soluble solids and gross economic returns, the Vertical axis, Slender-spindle and the V system were the three best systems in this trial. The Slender-spindle and the V system combined relatively high yields with good fruit size and quality. The Vertical-axis system was extremely productive, but had slightly smaller fruit size and soluble solids content. The large fruit size and the high soluble solids content with the Slender-spindle and the V system indicates that these systems were not over-cropped, whereas, the smaller fruit size and lower sugar content of the Vertical-axis system indicates this system was slightly over-cropped. To make the Vertical-axis system perform better will require modified pruning strategies such as annual heading of one-year-old lateral shoots to reduce the cropping potential of the system.

Our results show the value of the precocious Gisela rootstocks for early production (Balmer, 2001; Lang, 2000; Perry et al, 1996; Weber, 2001). The Gisela 5 trees had a significant crop in the third year and 10 times the yield as the vigorous MxM.2 trees in the fourth year and six times the yield in the fifth year. The Gisela 6 trees had about seven times the yield of the MxM.2 trees in the fourth year and four times the yield in the fifth year. In addition, the Gisela trees have remained smaller than the MxM.2 trees and have a more "calm" appearance than do the MxM.2 trees, which makes them more suited to high planting densities. The Gi.6 trees have had larger fruit size and higher fruit soluble solids than the standard sized MxM.2 trees indicating that they have not over-cropped. In contrast, the Gi.5 trees had such large crops that fruit size and soluble solids were both lower than the Gi.6 trees. This indicates that the Gi.5 trees were over-cropped and that resources were limiting for fruit development. The successful commercialization of Gi.5 will require modified prun-

ing strategies such as heading of all one-year-old shoots. It is also possible that the large crops on Gi.5 may be limiting tree carbohydrate or nitrogen reserve accumulation, thus increasing vulnerability to winter damage (Andersen, et al, 1999; Lang and Ophardt, 2000; Lang and Perry, 2002). Our results after the winter of 2004 indicate that both Gi.6 and Gi.5 may be more vulnerable to severe winter temperatures than the full vigor MXM.2.

The results of this study show that planting systems which use much higher tree densities than the common Central-leader system combined with new precocious rootstocks and minimal pruning, can give substantial yields in the first five years and return significant gross returns. With a high value crop like sweet cherries, this should help rapidly recoup the investment associated with planting a new cherry orchard (Seavert, 1997; Weber, 1998).

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Terence Robinson is a research and extension professor at Cornell's Geneva Experiment Station who leads Cornell's research and extension program in high density orchard systems. Robert Andersen is a recently retired emeritus professor of Horticulture at Cornell's Geneva Experiment Station who specializes in the breeding and culture of stone fruits. Steve Hoying is a regional extension specialist in orchard management in the Lake Ontario Region of NY State.