Tree Density or Training System—What is Important in Apple Orchard Design?

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During photosynthesis, plants convert carbon dioxide gas into sugar. This process is powered by solar energy in the form of certain wavelengths of light ("photosynthetically active radiation," in this article simply called "light"). In other words, as we all know, plants require light. Within certain limits, the more light is intercepted, the greater is total plant production (both fruit and vegetative parts like leaves).

The importance of light interception to plant productivity has been well established in the past few decades. For instance, apple yield is directly proportional to the amount of light intercepted, up to about 50% interception (Wünsche and Lakso, 2000). When light interception is very high (over 70%), the base and interior of the leaf canopy is often poorly illuminated. Poor light penetration into these regions of the canopy adversely affects fruit quality (size, color, soluble solids) and flower bud formation. Several researchers have suggested that apple orchard managers should aim for about 60 to 70% interception (Wertheim et al., 2000; Wünsche and Lakso, 2000).

The total amount of sunlight received by the orchard is determined by factors like latitude and cloudiness of the climate, which are beyond our control. But previous research has demonstrated that many elements of orchard design affect total light interception and the distribution of light within the leaf canopy. These factors include the proportion of the orchard's surface area occupied by leaf area, which is affected by tree density and age of the orchard, width of tractor alleys, tree height and tree arrangement. North-south rows tend to have more even illumination on both sides of the tree row than do east-west rows. Tree training system determines canopy shape, which in turn affects both total interception and penetration of sunlight. Pruning affects both interception and distribution of light.

In this article, we describe a two-part study examining only two of these factors, training system and tree density. Part one is a comparison of four different training systems with identical rootstock and tree spacing. Part two is a comparison of one training system (V trellis) at two different tree densities.

Y-shaped canopies had greater cumulative yield after 8 years than slender spindles or V trellis trees at the same spacing.

DESCRIPTION OF TRAINING SYSTEMS AND ORCHARD PLOTS

The orchard performance of four training systems was compared over 8 years. The goal was to see whether angled canopies could improve orchard performance relative to spindle trees, which had been in greater use locally at the time the study was initiated. All systems used virus-free Royal Gala on M.9 rootstocks, and tree spacing was 1.2 m (4 ft) within the row and 2.8 m (9.1 ft) between rows in all cases. This works out to 2976 trees/ha (1204 trees/acre). In this part of the study, we made a point of using the same rootstock and tree spacing for all the systems in order to keep training system effects separate from confounding factors like rectangularity, rootstock efficiency and tree density that exert their own influence on tree growth and productivity. *(Note: rectangularity is the ratio of alley width to in-row spacing.)*

The training systems were slender spindle, Geneva Y-trellis, V trellis and a system we called the "Solen Y." The slender spindle was trained classically (Wertheim, 1978) to a target height of 2.5 m (8.1 ft). The Geneva Y-trellis (Fig 1A) was trained as described by Robinson et al. (1989) wiith a trellis height of 2.0 m (6.5 ft) and an angle of 60° between the arms of the Y. There were 3 support wires. Trees for the Solen Y (Fig. 1B) were pruned after planting, and two branches were selected as cordons during the following growing season. Each cordon was curved back over the trunk and placed along the bottom wire of the trellis. Secondary branches were trained upward in a Y shape, with 60° between the arms of the Y. This is quite different from the original Solen training, which is a downward-hanging canopy. The Solen Y trellis had 7 support wires, including the bottom one where the cordons lay, and was 2.3 m (7.5 ft) high. An important advantage of the Solen Y was that the Y junction was higher than for the Geneva Y (0.85 m or 2.8 ft, compared to 0.6 m or 2 ft), making picking and branch training easier. The V trellis (Fig. 1C) was 2.0 m (6.5 ft) high, with trees planted to lean alternately to one side or the other of the trellis. There were 5 support wires.

The goal of the second part of the study was to determine the effect of increasing tree density to approach that of local super spindle plantings on the performance of the V trellis. The "low density" V (LDV) was the system described above. Trees for the high density V (HDV) were trained the same way, but in-row spacing was 0.5 m (1.6 ft), for a tree density of 7143 trees/ha (2891 trees/acre).

The trees were drip irrigated, with supplemental overhead irrigation in July and August. Fertilization and pest control were in accordance with commercial orchard practices in the region. The trees were planted in spring of 1993 and were first cropped in 1994. The alleys were seeded to ryegrass, with a weed-free strip 1.5 m (4.9 ft) wide maintained under the tree rows with herbicides. The experiment was terminated in autumn 2000, after 8 years.

COMPARISON OF FOUR TRAINING SYSTEMS

Most of the trees in all systems filled their space by the third leaf and reached their final height by the third or fourth leaf. Thereafter height and spread fluctuated a little from year to year due to pruning. Table 1 shows tree height and maximum canopy spread in the last year of the trial. The upper branches in the low density V (LDV) trellis never completely filled their allotted space, but the bottom of the trellis was filled. Because of the alternate-leaning layout, these trees had a larger spread at the base of the canopy (Table 1) than any of the other systems.

Light interception was measured at the base of the canopy for three consecutive years in August, after all shoot extension had ceased. The results for 2000 are shown in Table 1. Although the interception of the two Y-shaped systems tended to be a little higher than the slender spindle and LDV trellis, the difference was not statistically significant. All systems intercepted close to the 60 to 70% interception considered to be optimal for balancing yield and fruit quality.

In the first two cropping years, the Solen Y yielded less than the other systems (Table 2), which we attribute to the severe pruning required to establish the cordons. Later on, this system caught up to the others. By the end of the experiment, the cumulative yields of the two Y shaped canopies were 11 to 14% greater than the LDV trellis and slender spindle (Table 1), in accord with their slightly higher light interception (about 10% more). *Note: one metric tonne per hectare is about the same as one bin per acre, assuming a bin weighs 900 lb.* This experiment was terminated after the seventh crop. However, in an adjacent experimental block, the Geneva Y trellis consistently intercepted more light and yielded slightly more than the slender spindle beginning in year 6 (data not shown). Robinson (1997) found that the Geneva Y slightly outyielded slender spindle and vertical axis systems in New York.

In many regions of North America, growers are paid largely on the basis of fruit size and fruit color. Unfortunately we were not able to produce a packout detailing the box sizes and grades produced by each training system because we have no grading line. Such information would have been very valuable in determining economic returns. We did collect some data on fruit size and color. After adjusting for crop load, the average fruit weight was about the same for all four training systems in all but two of the seven cropping years (data not shown). In those two years, the average fruit weight was significantly less on the Y shaped systems than on the slender spindles, even after adjusting for crop load. Gala is a multiple-pick apple, and in most years we did three picks. The percentage (by weight) of fruit left for the last pick can be used as an estimate of delayed and/or poor color development. Differences were not consistent every year, but there was a tendency for the Y shapes to have a greater proportion of the crop left for the last pick (Table 3).

There are several possible explanations for the fruit color effects seen here. One is that these systems tended to have slightly higher crop loads, as mentioned. Secondly, Robinson et al. (1989) recommended a clear space of 1.5 m between adjacent rows at the top of the Y trellis for optimal color development, and in our study there was only about 1.3 m. Third, we did no summer pruning on any of the systems. Fruit color probably could have been improved on all systems by judicious summer pruning. Lastly, the Geneva Y trellis was developed in a climate that experiences many uniformly overcast days. Light penetration is better in such conditions than when the sun is direct because incoming light is diffuse and there are fewer harsh shadows. In our study, many apples on the Y systems hung below the canopy and were shaded by leaves.

To summarize, the Y-shaped systems tended to yield more than the slender spindle and LDV. Balanced against the 10 to 15% yield gains are the disadvantages of Y-shaped canopies. These include higher trellis costs, periodic tightening of wires, tree training time in years 2 to 4, difficulty of hand-thinning inside the Y and possibly poorer color in some years. Color problems might be eliminated by summer pruning and/or increasing the alley widths. Summer pruning would add to labor costs. Theoretically, if the alley width had been increased by 0.2 m to leave 1.5 m between adjacent rows at the top of the Geneva Y trellis for color development, the cumulative yield per unit area would have been about the same as for LDV or slender spindle, unless yield per tree increased. The Solen Y was easier to pick than the Geneva Y (no squatting was required), but its low yield in the first two cropping years makes it economically unattractive. The LDV resembled the slender spindle in all aspects of performance measured in this study.

TABLE 1

Tree height, maximum canopy spread, light interception and cumulative yields after 8 years of Royal Gala apple trees grown under five different training systems and densities.

Training system	Tree density (/ha)	Tree Height (m)	Tree Spread (m)	Light interception (% of full sun)	Cumulative yield (kg/tree)	Cumulative yield (M/ha)
Slender spindle	2976	2.73	1.82 b	56.2 b[Z]	89.5 bc[Z]	266.3 bc[Z]
Geneva Y	2976	2.66	1.81 b	68.8 ab	99.3 ab	295.5 b
Solen Y	2976	2.73	1.67 b	71.9 ab	101.7 a	302.7 b
Low density V (LDV)	2976	2.90	2.87 a	60.6 ab	86.0 c	255.7 c
High density V (HDV)	7143	2.96	1.76 b	76.2 a	59.2 d	422.6 a

[Z]Means followed by the same letter are not significantly different at the 5% level.

TABLE 2

Yield per tree of Royal Gala under four different training systems in the second and third leaf.

Training system	Yield in second leaf (kg/tree)	Yield in third leaf (kg/tree)
Slender spindle	1.52 a[Z]	5.00 ab
Geneva Y	1.39 a	5.34 a
Solen Y	0.56 b	3.02 c
Low density V	1.26 a	4.37 ab

[Z]Means followed by the same letter are not significantly different at the 5% level.

TABLE 3

Proportion of crop (% by weight) left for the last pick on Royal Gala under different training systems and densities in different cropping years.

		Crop left for last picking (%)				
Training system	Tree density (/ha)	Fourth leaf	Fifth leaf	Sixth leaf	Seventh leaf	Eighth leaf
Slender spindle	2976	24.9 b[Z]	26.3	14.8 b	4.1	10.5 c[Z]
Geneva Y	2976	35.7 b	11.4	27.4 a	3.6	26.9 ab
Solen Y	2976	60.5 a	23.1	30.7 a	3.6	35.0 a
Low density V	2976	22.8 b	24.8	14.0 b	5.1	9.1 c
High density V	7143	36.7 b	31.2	27.1 a	6.2	18.5 bc

[Z]Means followed by the same letter are not significantly different at the 5% level.

COMPARISON OF V TRELLIS AT TWO DENSITIES

Trees in the low density V (LDV) had greater canopy spread than in the high density V (HDV) as expected due to the greater allotted space per tree (Table 1). The trees were about the same height. The HDV trees were too vigorous for their spacing, however, and in later years became self-shading.

Light interception was not measured in early years in this plot, but it is well known that interception is directly proportional to tree density at that time, so the HDV would have intercepted more light. It is also well documented that lower density plantings start to catch up in terms of interception as time passes. On average over the last 3 years of this trial, light interception was only about 10% higher in the HDV, although its tree density was 2.4-fold that of the LDV. The HDV intercepted more than 70% of incoming light at maturity (Table 1). As in other studies of density, the yield per tree was less and the yield per unit area was much higher for the HDV than the LDV (Table 1). After 8 years, the cumulative yield per hectare was 65% greater on HDV than LDV (Table 1). Trees planted at high density were no more yield efficient, i.e., the proportion of fruit to wood was the same.

On average, the HDV tended to have a greater percentage of fruit left for the last pick than the LDV (Table 3), but the difference was only statistically significant one year of seven. After adjusting for crop load, the average fruit weight was similar in four years and significantly smaller on the HDV in three years (Table 4). Although adverse effects on fruit size and color did not occur every year, they are consistent with the light interception being a little too high for optimal light penetration in the inner and lower parts of the canopy. Summer pruning could have improved fruit color. Summer pruning occurs too late in the season to have much effect on fruit size or flower bud formation, but it may have been helpful for keeping the HDV trees contained in their space. We did not have problems with return bloom in

TABLE 4

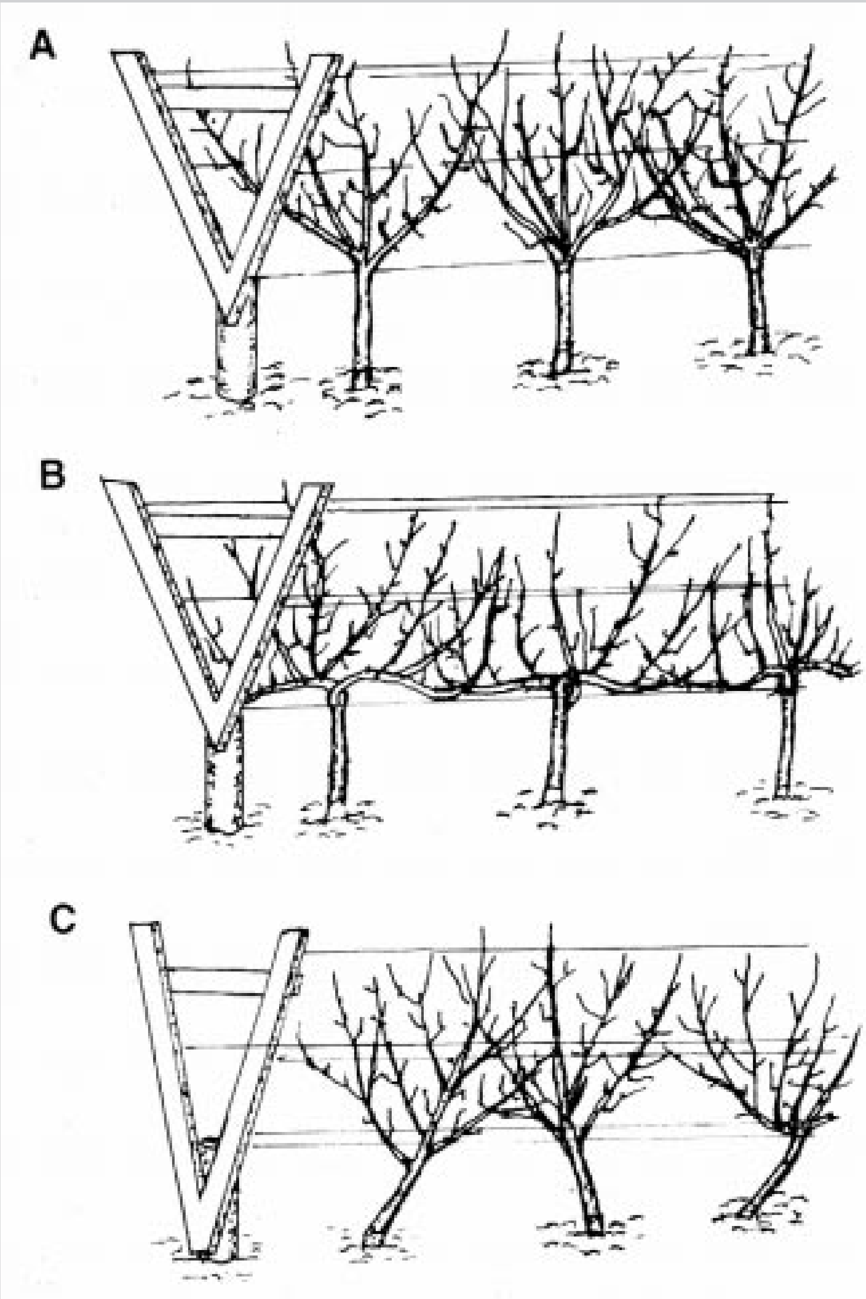
Average fruit weight (g) adjusted for crop load of Royal Gala trained to a V trellis at two different densities in different cropping years.

Training system	Tree density (/ha)	Second leaf	Third leaf	Fourth leaf	Fifth leaf	Sixth leaf	Seventh leaf	Eighth leaf
Low density V trellis (LDV)	2976	238	184 a[Z]	181	199 a[Z]	208	182	179 a[Z]
High density V trellis (HDV)	7143	232	168 b	168	172 b	206	178	163 b

[Z]Means that are significantly different at the 5% level are indicated by different letters following the value for average fruit weight.

FIGURE 1

Diagrammatic representations of (a) Geneva Y trellis, (b) Solen Y trellis, (c) V trellis.



this study.

In summary, a much greater cumulative yield per unit area was the chief advantage of the HDV over the LDV. In later years, the trees in the HDV became too top dominant and difficult to contain. While summer pruning may have helped to devigorate these trees and improve color, it represents an additional labor cost. Alternate tree removal is easier when the trees are not leaning alternately.

CONCLUSIONS

Y-shaped canopies had 11 to 14% greater cumulative yield after 8 years than slender spindles or V trellis trees at the same spacing. No major differences were found in tree growth or fruit size. Balanced against the yield advantage of Y-shaped systems are disadvantages such as higher trellis costs, tree training time in years 2 to 4, difficulty of access during hand thinning and possibly poorer color in some years. The slender spindle and low density V were similar in most aspects of performance, but the V requires a more elaborate trellis.

High density drives early productivity by increasing light interception in young orchards so that early yields per unit of land area are much higher than at lower density. At full canopy, the interception of light is similar and density effects decline.

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