The Evolution Towards More Competitive Apple Orchard Systems in New York

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To become more competitive' NY apple growers should increase tree planting density to the optimum economic density for New York State which is 1,000-1,200 trees/acre. The Tall Spindle system, which utilizes these densities, achieves improved yield and quality that can result in significant gains in lowering the cost per unit of production. Further gains may come from partial or complete mechanization of pruning, harvesting and tree training.

The need to improve orchard effi ciency, change varieties or improve fruit quality is causing growers to seek more competitive orchard systems that have higher yields, improved fruit quality and lower production costs per unit of production.

Evolution of Orchard Systems in NY State

There has been a steady increase in tree planting density over the last 50 years from 35 trees / acre to in some cases more than 2,500 trees / acre. The most common tree form in traditional apple orchards in NY until the mid-1900's was a large, globe-shaped tree planted on a seedling rootstock with a height of 20-25ft, a density of 35-40 trees / acre and with enough room under the canopy for cattle to graze. In the early 1960's, researchers (Cain, 1972; Heinicke, 1963; Looney, 1968) studied the light distribution within the canopies of large globe-shaped apple canopies and concluded that much of the canopy received too little light for good fruit quality and was unproductive. They proposed a conic or pyramidal canopy shape as an improved tree form. Heinicke (1975) developed the Central Leader system in North America and this tree training system was widely adopted. This system was planted at densities from 120-250 trees / acre and utilized semi-dwarfing rootstocks. The trees had three to four tiers of branches spaced along the trunk and a tree height of 14-16ft with the widest part of the tree at the bottom tier. The trees were usually not supported with a trellis or individual tree stakes. In many cases, as central leader trees aged, the upper limbs outgrew the bottom of the tree resulting in excessive shade in the bottom of the trees, which reduced flowering and fruiting in the center of the tree

During the late 1970's and early 1980's led by Dick Norton, a significant number of growers in NY State began planting more compact trees on M.9 rootstock at much higher tree densities (400-600 trees / acre) to achieve higher early yields. They used the Slender Spindle training system developed by Bob Wertheim, (1968) in Holland. The Slender Spindle orchards had significantly higher early yields and management efficiency was improved by limiting tree height to allow all management to be done from the ground (pedestrian orchards). However, the short stature of the Slender Spindle tree (6ft) and moderate density often resulted in moderate mature yields and dense canopies. Studies on light interception illustrated that these pedestrian orchards with regular tractor alleys did not intercept more than 55% or available light (Robinson and Lakso, 1991)

A significant trend in the late 1980's was to increase tree planting density in Slender Spindle orchards in order to improve light interception and thereby improve both early and mature yields (Oberhofer, 1987). Some growers attempted to increase planting density above 800 trees / acre by planting double and triple rows. However, the multiple row systems developed dense canopies, which were difficult to manage, and vigor usually became a problem as the orchards matured.

Another more successful approach to improving yield in the late 1980's was to again grow taller trees by using the Vertical Axis system developed by Jean Marie Lespinasse, (1980). Typical vertical axis trees were planted at 400-600 trees / acre and were grown to a height of 10-13. This system also introduced renewal pruning of large upper branches to maintain a conic tree shape and improved exposure of the lower canopy to light. Although this advance meant that tree height was again too high to manage the canopy from the ground, yields were improved significantly and often fruit quality was also improved since there was more space between the branches of a Vertical Axis tree than with a Slender Spindle tree. A large portion of the NY apple growers adopted a version of this system.

An alternative method of improving light interception was the adoption of V-shaped canopies (Robinson, 2000). This tree shape, positions a portion of the canopy over the tractor alleys thus capturing some of the light that normally falls on the alleyways. Our work in New York State (Robinson and Lakso, 1991) showed the Geneva Y-trellis captured greater than 70% of available light and had very high yields. Only a few growers in NY State adopted this system, but a significant number of growers in Washington state adopted the V-system in the 1990's and have utilized this tree form at a variety of densities. Their systems were called the V-trellis (Auvil trellis) and the V-Super Spindle (Robinson, 2000).

During the early 1990's, much higher tree densities between 1,600 and 2,500 trees / acre were tested in single rows in either a vertical tree shape or a V-shape. A more narrow tree form was developed which was named the Super Spindle system (Nuberlin, 1993). These trees had a canopy diameter of only 18-24" and a tree height of 7 ft. This system had extremely high early yield and excellent fruit quality. However, the establishment cost of the Super Spindle system was prohibitive for all except those who grew their own trees. The management of the tree canopy was based on never allowing permanent scaffold branches to develop which kept the trunk, root system and tree canopy small and manageable for many years.

Another trend was to minimize pruning of young trees. In the 1990's, many Slender Spindle growers began to avoid pruning after planting or during the first few years. If the central leader was cut, as was typical with Slender Spindle trees of the 1980's, a vigorous frame developed which needed a lot of summer pruning labor to maintain good light distribution in the tree for good fruit quality. Without pruning of the leader and with feathers starting at 30 inches above the soil, the tree could be allowed to crop in the second year which gave natural bending of lateral branches that kept the canopy narrow.

Another significant trend during the late 1980's and 1990's was greater emphasis on the use of highly feathered trees to obtain significant yield in the second year after planting. However, many of the trees used in the 1980's and 1990's had feathers that started at 18" above the soil. The low height of the feathers required significant labor to tie the branches up when they began to fruit in order to prevent fruit from touching the ground. In the late 1990's, the minimum height of feathers on nursery trees was raised to 30" (Balkhoven-Baart et al., 2000). This allowed branches to hang in a pendant position with a crop load and still not touch the ground, thus eliminating the need to tie up branches.

At the turn of the century there was a great disparity of opinion among growers as to which system was the most profitable with some growers using densities above 2,200 trees / acre and some growers continuing to use densities below 200 trees / acre with the majority of growers planting densities in between.

Studies on Orchard Tree Densities

Data from several of our studies show that during the early years, yields are related to tree density with the highest tree density producing the highest cumulative yield. The relationship of tree density and cumulative yield is linear in the first two to three years but by year six and beyond the relationship is curvilinear (Figure 1). At the lower end of the density continuum the relationship is almost linear with a slope of 330 lbs indicating that as tree density is increased an additional cumulative yield of 8.25 bushels per acre was obtained for each additional tree per acre. The value of this additional fruit would be about 8 times the cost of the additional tree. At the higher tree densities the gain in cumulative yield was very small with a slope of 150 lbs for Jonagold and 44 lbs for Empire. This would be about 3.5 and 1 times the cost of the additional tree for Jonagold and Empire, respectively. The relationship of planting density and cumulative yield over the life of an orchard is typical of the law of diminishing returns which states that additional increases in an input factor (tree density) produce a smaller and smaller increase in an output factor (yield). At the high end of this curvilinear relationship additional increases in trees density will not produce enough extra yield to pay for the additional costs incurred to purchase and plant the extra trees.

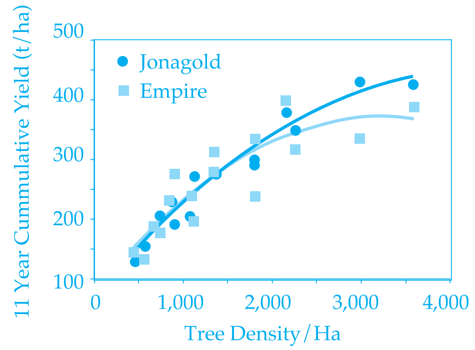

Figure 1. Relationship of tree density and cumulative yield over the first 11 years of an apple orchard on M.26 trained to Y-trellis system in New York state, USA. (Jonagold r^2=0.95; Empire r^2=0.79)

The optimum tree density in any apple producing area is an economic question. The laws of economics dictate that the optimum density will be less than the density with the highest yield. In Europe, average planting densities increased until the mid-1990's to 2500 trees / acre but in the last 10 years there has been a trend toward more moderate planting densities ranging between 1,200 and 1,500 trees / acre. The reason why more moderate planting densities are favored may be explained by the law of diminishing returns. Another reason for more moderate plant densities is the difficulty of managing excessive vigor especially of virus-free plant material. Many growers have not been successful balancing vegetative and reproductive growth of a Super Spindle orchard. A third reason may be the increased economic risk associated with very high density orchards.

From 1998-2003 an economic crisis hit the USA apple industry with several years of low prices and losses for growers. The New York apple industry responded with a strategic plan that outlined several steps to restore profitability which included improved marketing structures to give growers more market power, new varieties with higher prices, improved fruit quality and reduced unit cost of production. The later objective had two components: 1) Develop improved orchard systems that resulted in improved yield and fruit quality, and 2) Improve labor efficiency (fruit output per labor hour). To address the first objective we began an economic study of orchard system profitability based on our research data from field trials (Robinson et al., 2007). Our objective was to evaluate the economic profitability and costs of the most promising orchard planting systems over a wide range of densities where yield, quality and labor requirements were mea-

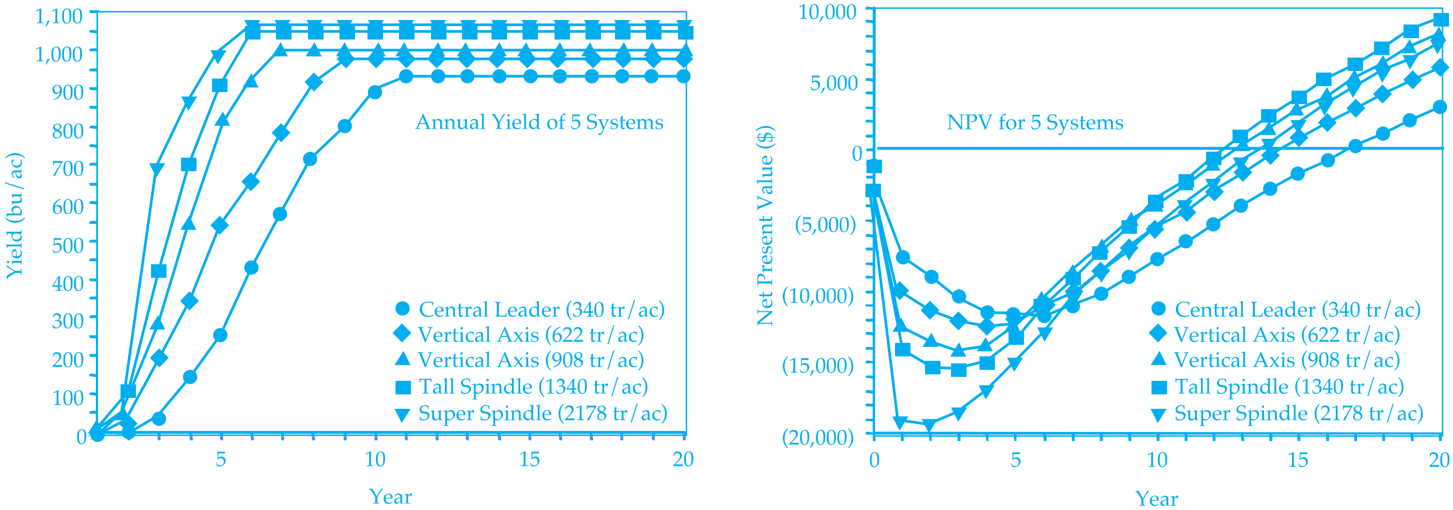

Figure 2. Idealized annual yields and cumulative profitability of 5 high density orchard systems over 20 years. (Curves based on data from research plots in New York State.)

sured. We also evaluated the effect of various economic factors on the profitability of each planting system.

Economic Analysis of Orchard Systems

We conducted an economic evaluation of five common orchard systems: Slender Pyramid, Vertical Axis, Slender Axis, Tall Spindle and Super Spindle. They ranged in density from 340-2,180 trees / acre, which represents the range of tree densities growers are currently using in New York State. Yields of each system were estimated from research plot data in New York (Figure 2A). The analysis estimated Net Present Value (NPV) for each system over 20 years (Fig 2B). The methods and results were reported previously (Robinson, et al., 2007).

In general our results showed that the greater the planting density, the greater the investment cost to establish the orchard. However, due to higher early yield and higher cumulative yield, profitability was generally increased with increased tree density. Nevertheless, the law of diminishing returns which results in less gain in cumulative yield as more trees are planted per acre, meant that very high tree densities were not more profitable than more moderate densities. In addition, economists suggest that risk increases with increasing level of investment, thus making the very high-density systems riskier.

Effect of tree density.

When NPV of the accumulated profit over 20 years was calculated per unit land area the greatest profitability was at a tree density of 1,000 trees / acre when feathered trees and an individual tree stake plus a single wire trellis were used (Figure 3A). If a less expensive 4 wire trellis was used, the optimum tree density was increased to 1,050 trees / acre and profitability of each system was increased with the greatest effect on the highest density Super Spindle system. If inexpensive feathered trees were used, the optimum tree density was increased to 1,100 trees / acre and the profitability of all systems was increased with the greatest effect on the Super Spindle system.

When an alternative method for evaluating profitability (NPV per unit of capital invested rather than per unit of land area) was used, the optimum tree density was lower (around 890 trees / acre) regardless of whether a four-wire trellis or a metal tube tree stake plus single wire trellis were used to support the trees (Figure 3B).

Effect of fruit price.

Fruit price had the greatest effect on the potential profit of each planting system. All systems were profitable at a fruit price of $5.50 / bu (excluding packing, storage and marketing expenses). If fruit price was reduced to $4.50 / bu, none of the systems were profitable (Figure 3C). If fruit prices were very high ($10.00 / bu) like with a new club variety, the shape of the curve was asymptotic with the highest density system having the greatest profitability. A doubling of the fruit price from $5.50 to $10.00 resulted in a 9-fold increase in profitability. The high-density systems were more sensitive to price than the low-density systems. This means that under low prices they drop the most, but also under high prices they benefit the most. With low prices of $4.50 / bu the optimum tree planting density was 990 trees / acre, while with moderately high fruit prices of $6.50 the optimum planting density was 1,130 trees / acre. At very high fruit prices of $10.00 / bu the optimum tree density was ~2,200 trees / acre.

Effect of establishment cost .

Tree price and trellis cost had a large influence on profitability and optimum planting density (Figures 3A and 3D). At low tree planting densities, tree price had only a small effect on profitability while at high-planting densities, tree price had a very large impact on profitability. With high tree prices, profitability of all systems was low and the optimum tree density was 1,000 trees / acre. As tree price was reduced, profitability of each system was increased and the optimum planting density increased. With an extremely low tree price of $2.00 / tree, the optimum density was above 2,200 trees / acre.

Risk.

The greater the level of initial investment, the greater the risk in meeting projected profits. It is difficult to quantify risk associated with the different systems; however, if two systems produce about the same NPV but one has much lower investment requirements, then it is the preferred investment. Alternatively, the more expensive systems could be charged a 1% higher interest rate to account for risk. The Super Spindle orchards depends to a large extent on very early, high yields of a high priced new variety, low priced trees from the nursery, higher picking output and less management hours to maintain the system. Fixed costs for the establishment of a Super Spindle orchard are higher than other systems and must

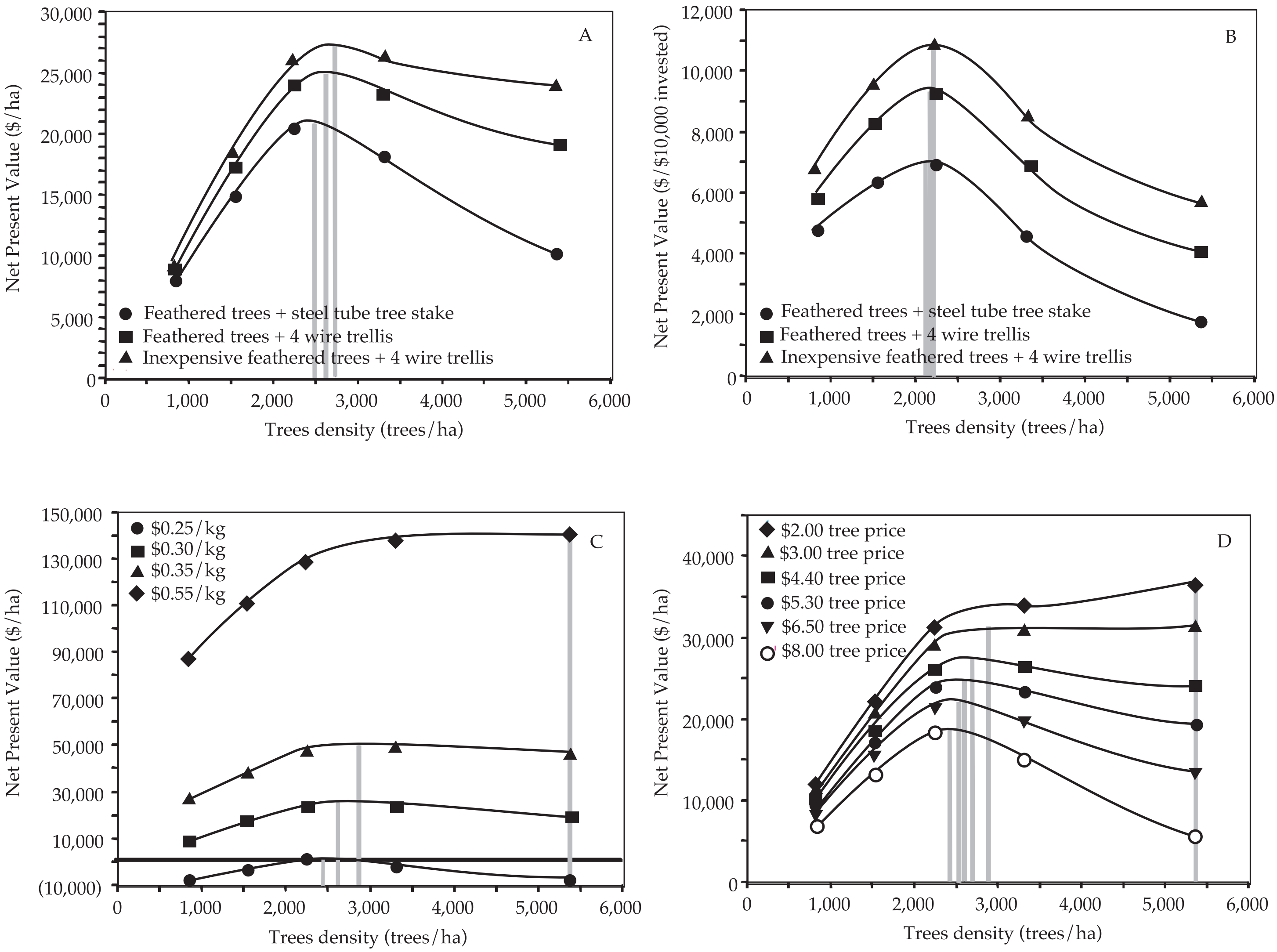

Figure 3. Effect of tree density on 20 year profitability calculated as either Net Present Value per hectare (A) or NPV per $10,000 invested (B) of 5 high density orchard systems. Effect of fruit farm gate fruit price (C), and tree cost (D) on profitability after 20 years of 5 high density orchard systems.

be justified by the market returns of the variety and the early yields. The high cost of the system makes it a riskier system than more moderate density systems. However, if there is an economic friendly market situation with a new high priced variety that has good fruit size and a non-biennial bearing habit coupled with inexpensive plant material, profitability for a new Super Spindle orchard can be achieved in a short time period. This permits a short orchard lifetime, which gives growers flexibility to respond to new varieties and changes in market demand of existing varieties. Under the best scenario, orchard life of Super Spindle orchards can be as short as 10 years but under poor price conditions, orchard life would have to be 20+ years. It is generally believed that the very high density systems will be difficult to maintain for longer than 12-15 years due to tree containment difficulties. Other ways to reduce risk with new orchards is to purchase crop insurance with hail protection, use irrigation, control diseases and other pests carefully, develop and maintain human resources and use new technologies where appropriate and cost effective.

In general our economic study indicated an optimum tree density of 1,000-1,200 trees/acre unless fruit price was very high. This tree density led to the development of a training system we call the Tall Spindle.

The Tall Spindle System

By the late 1990's we began working on an amalgamation of the Slender Spindle, the Vertical Axis and the Super Spindle systems, which we began calling the Tall Spindle system (Robinson et al., 2006). This system utilized the concept of high tree densities from the Slender Spindle system but utilized lower planting densities than the Super Spindle (~1,000-1,200 trees/acre). The system used tall trees similar to the Vertical Axis but very narrow canopies like the Super Spindle. It also used highly feathered trees (10-15 feathers) and pendant limb angles to induce cropping and reduce branch growth and vigor. The system also utilized minimal pruning at planting and during the first three years. With the Slender Spindle trees when the central leader was cut a vigorous frame developed which needed a lot of summer pruning to maintain good light distribution in the tree for good fruit quality. Without pruning of the leader and with feathers starting at 80 cm above the soil, the Tall Spindle tree can be allowed to crop in the second year, which gives natural bending of lateral branches, which keeps them weak. At maturity the Tall Spindle canopy has a dominant central trunk and no permanent scaffold branches. Limb renewal pruning is uti-

Figure 4. A young Tall Spindle orchard (A) with highly feathered trees (15+ feathers) planted at 3' x 11'. A newly planted Tall Spindle tree with feathers tied below horizontal (B).

lized to remove and renew branches when they get too large (>3/4" diameter).

Tree density with Tall Spindle orchards can vary from a high of 1,450 trees / acre (3 ft X 10 ft) to a low of 908 trees / acre (4 ft X 12 ft). The proper density considers the vigor of the variety, vigor of the rootstock, and soil strength. For weak and moderate growing cultivars such as Honeycrisp, Delicious, Braeburn, Empire, Jonamac, Macoun, Idared, Gala, NY674, and Golden Delicious we suggest an in-row spacing of 3ft (Figure 4). For vigorous varieties such as McIntosh, Spartan, Fuji, Jonagold, Mutsu, etc, and tip bearing varieties such as, Cortland, Rome Beauty, Granny Smith and Gingergold we suggest an in-row spacing of 4ft. Between-row spacing should be 10ft on level ground and 12ft on slopes.

Dwarfing rootstocks such M.9, B.9 or the fire blight-resistant dwarf rootstocks from Geneva® (G.16, G.11 and G.41) have been used successfully in Tall Spindle plantings. The weaker clones (M.9NAKBT337, M.9Flueren56, B.9 G.11 and G.41) are especially useful with vigorous scion varieties on virgin soil. The more vigorous clones (M.9Pajam 2, M.9Nic29, M.9EMLA, and G.16) are much better when orchards are planted on replanted soil or when weak scion cultivars are used.

An essential component of the Tall Spindle system is a high-branched (feathered) nursery trees. The Tall Spindle system depends on significant 2nd and 3rd year yield, for the economic success of the system. If growers use whips or small-caliper trees which do not produce significant quantities of fruit until year four or five, often the carrying costs from the extremely high investment of the Tall Spindle orchard overwhelms the potential returns and negates the benefit of the high tree density on profitability. We recommend that the caliper of trees used in Tall Spindle plantings be a minimum of 5/8" and that they have 10-15 well positioned feathers with a maximum length of 12" and starting at a minimum height to 30" on the tree (Figure 4A). Generally nursery trees in North America have not had this number of feathers until recently. Many nursery trees have 3-5 long feathers instead of 10 short feathers (Figure 4B). The tree with fewer long feathers requires more branch management than the tree with more short feathers.

One of the most significant differences between the Tall Spindle and the more traditional Vertical Axis and Slender Spindle systems is that the Tall Spindle tree typically has no permanent lower tier of branches. With the Tall Spindle all of the feathers are tied or weighted below the horizontal at planting to induce cropping and to prevent them from developing into substantial lower scaffolds (Figure 4B). The pendant position results in a weak fruiting branch instead of a scaffold branch. With the Vertical Axis and Slender Spindle systems the feathers are tied down a little above horizontal, which allows them to grow into scaffolds over the first four years. Growers who attempt to plant feathered trees at the Tall Spindle spacing but do not tie the feathers down often end up with limbs in the lower part of the tree that are too strong which requires severe limb removal pruning at an early age which invigorates the tree and makes long term canopy containment problematic. This simple change in feather management allows for long-term cropping of many feathers and little invasive pruning for the first five to eight years at the very close spacing of the Tall Spindle system.

After the initial tying down of feathers at planting, new lateral branches that arise along the leader do not need to be tied down. In most climates, moderate tree vigor results and lateral shoots that rise along the leader often bend below horizontal with cropload in the third year. This creates a natural balance between vigor and cropping without additional limb positioning. However, in vigorous climates or where winter chilling is insufficient, often limbs become too large before they set sufficient crop loads to bend the branches down. In these climates, tying down of all vigorous limbs must be done annually for the first three to five years until the tree settles down and begins to crop heavily. However, in most traditional apple growing areas, growers often invest too much money in limb tying which should be limited to only the feathers at planting. Thereafter, the precocity of the rootstock induces heavy cropping and a natural balance is established.

With precocious dwarfing rootstocks, young apple trees can often overset in the 2nd or 3rd year resulting in biennial bearing as early as the 4th year. This then results in increased vigor in the 4th year just when the trees have filled their allotted space and when reduced vigor is needed. Varieties differ in their biennial bearing tendency and this must be incorporated into the croploads allowed on young trees. For annual cropping varieties like Gala, we recommend croploads of 15-20 apples/tree in the second year, 50-60 apples/tree in the third year, and 100 apples/tree in the fourth year. For slow growing and biennial bearing varieties like Honeycrisp, croploads should be half that used with Gala.

Good light distribution and good fruit quality can be maintained as trees age if the top of the Tall Spindle tree is kept more narrow than the bottom of the tree, and if there is a good balance between vegetative growth and cropping. For the Tall Spindle system, maintaining a conic shape as the trees age is critical to maintaining good light exposure, in the bottom of the tree. In our experience the best way to maintain good light distribution within the canopy as the tree ages, is to remove whole limbs in the top of the tree once they grow too long rather than shortening back permanent scaffold branches in the tops of trees. A successful approach to managing the tops of trees has been to annually remove one to two upper branches completely. To assure the development of a replacement branch, the large branch should be removed with an angled or beveled cut so that a small stub of the lower portion of the branch remains. From this stub a flat weak replacement branch often grows. If these are left unheaded they will naturally bend down with crop.

Efforts To Reduce Costs Per Unit of Production

Less Expensive Planting Systems.

High-density systems such as the Tall Spindle seem to offer the greatest potential profitability but they are very expensive to establish. The greatest initial cost is for the trees. If the cost of trees could be reduced without reducing early yield then profitability could be increased. Several recent efforts have attempted to examine the impact of utilizing less expensive trees. Some growers have begun growing their own trees to reduce tree costs. This usually results in medium size unbranched trees instead of large caliper highly feathered trees. A few growers have experimented with planting fall budded rootstocks (sleeping eye trees) and others have planted spring-grafted rootstocks (bench grafts) (Figure 5). The initial cost of such orchards is substantially less than using feathered trees; however, early yields are also delayed by one year. The economic value of such a strategy has been studied in only one replicated experiment (Robinson and Hoying, 2005). In our study tree quality at planting had a significant impact on profitability (Figure 6). Although large caliper feathered trees produced more fruit in the first few years, the yield benefit was somewhat offset by higher initial tree price. The more expensive large-caliper, feathered trees were more profitable when planted at low to medium-high densities while sleeping eye or one year grafts were more profitable at the very high densities. At the optimum planting density from our earlier economic study of 1,500 trees / acre, feathered trees were the most profitable while at densities from 1,200-1,600 trees / acre, there were no large difference in profitability between tree types. Above 1,600 trees / acre the less expensive sleeping eye or one-year-grafted trees were the most profitable.

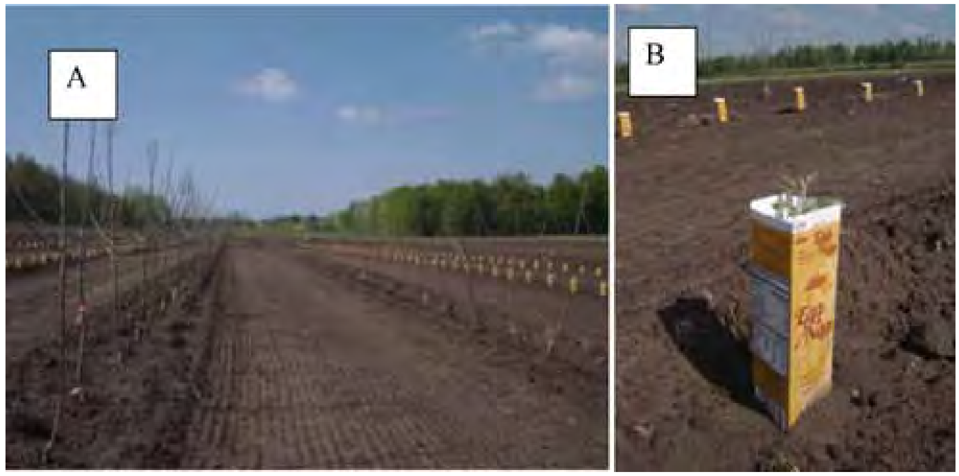

Figure 5. A Tall Spindle orchard using either feathered trees(A) spring bench grafted trees (B)

Mechanization

In addition to improving yield and reducing production costs per unit of production through improved orchard systems, the USA apple growers have begun an effort to reduce costs through partial mechanization of orchard tasks. This effort is based on the phenomenal advances in computer technology over the last 10 years. It is now possible with machine vision for computers to identify fruits, branches, trunks and trellis posts and wire. This has stimulated a national effort (technology roadmap) by the USA apple industry to spur research on using technology in the orchard to reduce the costs of production. The effort is proceeding along two fronts: 1) motorized platforms to position human workers for greater efficiency and 2)robotic machines.

Motorized platforms are in common use in some parts of Europe but not in the USA. In the last three years, research and extension projects have been conducted to adapt motorized platforms to existing high-density orchard for the operations of harvest, hand thinning, pruning and tree training. Platform assisted harvest has not been very successful due to greater bruising with the mechanized bin fillers than with the current bucket and ladder hand harvest system. The gains in efficiency have also been modest. Greater success has been achieved with the use of platforms to position workers for pruning, hand thinning and tree training (Figure 7). Significant acreage is currently managed with self-steering motorized platforms for dormant pruning, hand thinning and tree training.

Greater possibilities for mechanization exist with robotic machines. Inexpensive powerful computers and advances in robotics now make possible such field robots. In the last three years significant research has been conducted on machine vision to locate fruits and branches for possible mechanical harvest. This effort will require many years due to the extreme complexity of identifying the fruit location, detaching the fruit without bruising, and transporting the fruit to the bin without bruising. A more near-term possibility is the use of robots to prune apple trees. This will require simple, single dimensional trees with no permanent branches such as the Tall Spindle or the super spindle. It will also require machine vision to locate branches and map a pruning path and simple pruning rules. The Tall Spindle could be adapted to such a system since the pruning could be simplified to the single rule of removing any branch that is larger than 2cm in diameter. Lastly the robot will need a robotic arm(s) with pruning shears to remove unwanted branches. The machine will need to have redundant safety features to ensure human safety.

Conclusions

Apple growers in the USA are seeking improved orchard systems that have improved yield, improved fruit quality and reduced production costs per unit of

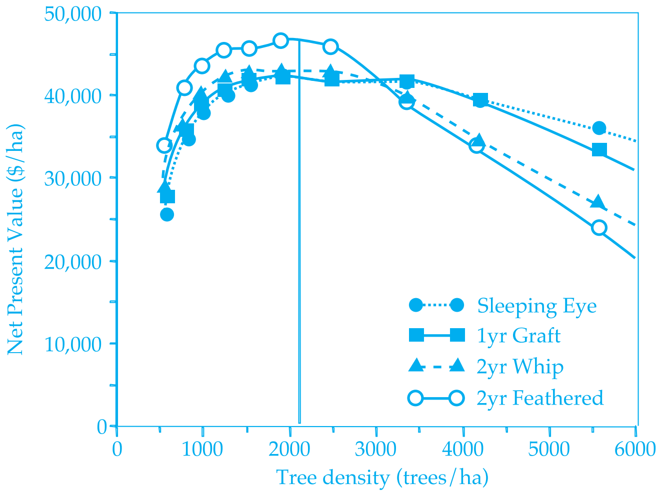

Figure 6. Effect of tree quality on orchard profitability after 20 years.

Figure 7. Self steering motorized platforms to improve dormant pruning efficiency.

production. Our most recent economic analysis shows the optimum economic density for New York State is 1,000-1,200 trees/acre. Our analysis also shows that profitability (competitiveness) can be improved more by planting high priced varieties than by reducing costs. Profits can also be improved more by improving fruit quality and producing desired fruit sizes than by reducing costs. The Tall Spindle system is designed to accomplish these objectives by combining high tree planting densities, highly feathered trees that have many small branches instead of a few large branches, minimal pruning at planting or during the first three years, branch angle management by tying down all of the feathers at planting to induce cropping and prevent the development of strong scaffold branches that cause difficulty in tree management in later years, and branch caliper management by the systematic removal of large branches to keep the tree manageable. New rootstocks, which are fire blight-resistant and very productive will improve long-term productivity and profitability. The improved yield and quality of the Tall Spindle system can result in significant gains toward reducing costs per unit of production. In addition, current efforts on partial or complete mechanization of pruning, harvesting and tree training may further reduce costs of production to improve the competitiveness of USA apple growers.

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