

The Evolution Towards More Competitive Apple Orchard Systems in the USA

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The need to improve orchard efficiency, 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 THE USA

There has been a steady increase in tree planting density over the last 50 years from 70 trees/ha to in some cases more than 6,000 trees/ha. The most common tree form in traditional apple orchards in North America until the mid-1900's was a large, globe-shaped tree planted on a seedling rootstock with a height of 6-8m, a density of 70-100 trees/ha 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 300-700 trees/ha and utilized semi-dwarfing rootstocks. The trees had 3-4 tiers of branches spaced along the trunk and a tree height of 4-5m with the widest part of the tree is 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 a significant number of growers in the USA began planting more compact trees on M.9 rootstock at much higher tree densities (1,000-1,500 trees/ha) 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 (2m) 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% of available light (Robinson and Lakso, 1991)

A significant trend in the late 1980's was to increase tree planting density in Slender Spindle orchards to improve light interception and thereby improve both early and mature yields (Oberhofer, 1987). Some growers attempted to increase planting density above 2,000 trees/ha 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 1,000-1,500 trees/ha and were grown to 3-4m high. This system also

introduced renewal pruning of large upper branches to maintain a conic tree shape and improve light exposure of the lower canopy. 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 a Slender Spindle tree. A large portion of the USA 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% light interception and had very high yields. 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. The 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 4,000 and 6,000 trees/ha 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 45-60cm and a tree height of 2.5m. 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 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 50cm above the soil. The low height of the feathers required significant labor to tie the branches up when they began to fruit to prevent fruit from touching the ground. In the late 1990's, the minimum height of feathers on nursery trees was raised to 80-100cm (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 on which system was the most profitable with some growers using densities above 5,000 trees/ha and some growers continuing to use densities below 500 trees/ha with the majority of growers planting densities in-between.

STUDIES ON ORCHARD TREE DENSITIES.

Data from several 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 2-3 years but by year 6 and beyond the relationship is curvilinear (Fig. 1). At the lower end of the density continuum the relationship is almost linear with a slope of 150kg indicating that as tree density is increased an additional cumulative yield of 150kg per hectare was obtained for each additional tree per hectare. This 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 70kg for Jonagold and 20kg 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) produces 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.

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 mid1990's to 5,500-6,000 trees/ha but in the last 10 years there has been a trend towards more moderate planting densities ranging between 2,800 and 3,800 trees/ha. 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 restoring 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 measured. 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 5 common orchard systems: Slender Pyramid, Vertical Axis, Slender Axis, Tall Spindle and Super Spindle. They ranged in density from 840-5,382 trees/ha 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 (Fig. 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 ha, 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 2,500 trees/ha when feathered trees and an individual tree stake plus a single wire trellis were used (Fig. 3A). If a less expensive 4 wire trellis was used, the optimum tree density was increased to 2,600 trees/ha 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 2,700 trees/ha and the profitability of all systems was increased with the greatest effect on the Super Spindle system.

When an alternative method to evaluating profitability (NPV per unit of capital invested rather than per unit of land area) the optimum tree density was lower (around 2,200 trees/ha) regardless of whether a 4 wire trellis or a metal tube tree stake plus single wire trellis were used to support the trees (Fig. 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 \$0.30/kg (excluding packing, storage and marketing expenses). If fruit price was reduced to \$0.25/kg, none of the systems were profitable (Fig. 3C). If fruit prices were very high (\$0.55/kg) such as 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 \$0.30 to \$0.55 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 \$0.25/kg the optimum tree planting density was 2,450 trees/ha while with moderately high fruit prices of \$0.35/kg the optimum planting density was 2,800 trees/ha. At very high fruit prices of \$0.55/kg the optimum tree density was ~5,500 trees/ha.

Effect of establishment cost

Tree price and trellis cost had a large influence on profitability and optimum planting density (Fig. 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 2,400 trees/ha. 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 5,500 trees/ha.

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 charge 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 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 2,500-3,000 trees/ha 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 (~2,500-3,500 trees/ha). 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 3 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 utilized to remove and renew branches as they get too large (>2cm diameter).

Tree density with Tall Spindle orchards can vary from a high of 3,700 trees/ha (0.9m X 3m) to a low of 2,300 trees/ha (1.2m X 3.6m). 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 0.9m (Photo 1) 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 1.2m. Between-row spacing should be 3m on level ground and 3.6m 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 4 or 5, 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 15mm and that they have 10-15 well positioned feathers with a maximum length of 30cm and starting at a minimum height to 80cm on the tree (Photo 1A). 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 (Photo 1B). 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 (Photo 1B). 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 4 year. 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 5-8 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 arising 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 3-5 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 1-2 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 (Table 2). 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) (Photo 2). 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 (Fig. 4). 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 1 year grafts were more profitable at the very high densities. At the optimum planting density from our earlier economic study of 2,600 trees/ha, feathered trees were the most profitable while at densities from 3,000-4000 trees/ha there were no large difference in profitability between tree types. Above 4,000 trees/ha the less expensive sleeping eye or 1 year grafted trees were the most profitable.

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 seen in 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 2 fronts. Motorized platforms to position human workers for greater efficiency and robotic machines.

Motorized platforms are in common use in some parts of Europe but not in the USA. In the last 3 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 (Photo 3). 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 3 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.

TRENDS IN DWARFING ROOTSTOCKS

Although high tree density is the single most important factor affecting yield in the early years of an orchard's life, dwarfing rootstocks are the foundation for any successful high density planting system. The choice of rootstock in combination with the choice of scion variety defines the typical tree vigor and final tree size which dictates its planting density. Rootstock has a dominant effect on tree precocity (flowering and cropping in the early years) and productivity. In many ways the choice of rootstock determines the potential yield of a given variety and ultimate profitability. In addition dwarfing stocks allow high tree densities to be maintained in their allotted space as the orchard matures. The combination of dwarfing rootstocks and higher tree planting densities has dramatically improved the early cropping over the first 10 years of an orchard's life.

Picking the right rootstock depends on the planting density, climate and soil type. Although climate often limits which stocks that will survive, precocity level of a stock is the most important factor from an economic perspective. Dwarfing level of a rootstock becomes the most important factors when considering long term management of high density orchards. Most successful high density plantings are planted with dwarfing rootstocks such M.9, M.26, and B.9. Although more vigorous stocks are sometimes used they become difficult to manage in later years.

M.9 has become the most planted rootstock in the world. It produces trees about 30% the size of seedling. It is highly precocious, productive and produces large fruit size. Although it is quite brittle and is not self supporting growers have learned to support it with great success. It has been successfully used in a wide variety of climates and on a wide variety of soil types. There are about 2 dozen clones of M.9 with different vigor and slightly different similar yield efficiency.

Our recent rootstock trials with different clones of M.9 have shown that the differences in vigor between clones are significant. The weaker clones (M.9NAKBT337 and M.9Flueren56) are significantly less vigorous than the most vigorous clones. (M.9Pajam 2, M.9Nic29, M.9Pajam1 or M.9EMLA) which are almost as vigorous as M.26. All of these clones have shown high yield efficiency and with the range in vigor they express it is possible for a grower to fine tune the choice of M.9 to match his particular soil and the variety he will plant. The weaker clones of M.9 are especially useful with vigorous scion varieties like McIntosh, Mutsu, Jonagold and Fuji or virgin soils. The more vigorous clones useful with weak scion cultivars like Delicious, Empire, Idared, and Jonamac, with weak soils or when orchards are replanted on old orchard sites. For growers to successfully use this strategy will require several years of advance planning before planting the new orchard. A grower must work with his nurseryman far enough in advance so that the nurseryman can purchase the right clone of M.9 for the growers specific situation.

Although M.9 is used around the world with great success in high density plantings, it is extreme susceptibility to fire blight and is also susceptible to replant disease woolly apple aphids, In addition it is not well adapted to climates with high soil temperatures.

M.26 is a highly productive dwarfing stock that produces a tree about 35-50% the size of seedling. Its performance is highly variable around the world. In wet climates with good soil tree size can be quite

large. In replant soils or in dry climates it can be almost as small as M.9. It is extremely susceptible to fire blight and replant disease and is also susceptible to Woolly apple aphids. M.26 is very susceptible to *Phytophthora* root rot and will not tolerate wet soils. It is not drought tolerant and requires irrigation on light soils. Yield efficiency of M.26 is less than M.9. Estimates from one of our rootstock trials indicate that if M.9 was planted at its optimum density it would have 74% greater yield M.26 planted at its optimum density. Nevertheless, M.26 remains popular because it is quite productive, cold hardy, produces good fruit size and in some cases can be grown as a free standing tree. In North America its fire blight susceptibility is a huge liability and limits where this stock can be planted.

B.9 is a highly productive dwarfing stock that is similar in size to the weak clones of M.9. In most trials it is slightly smaller than M.9 (20% the size of seedling) but its tree size has been variable around the world. It is as productive as M.9 but is more winter hardy. Although B.9 is susceptible to fire blight our recent work has shown that it has good field tolerance to fire blight. When vigor with this stock is low fruit size is small.

Cornell-Geneva rootstocks.

Although M.9 and M.26 are used around the world with great success in high density plantings, they are both susceptible to fire blight and WAA. In addition M.26 is very susceptible to *Phytophthora* root rot. Although growers have found ways of dealing with most of the shortcomings of the Malling stocks, the susceptibility to fire blight is particularly risky for fruit growers in the United States. Over the last decade, serious tree losses from fire blight infection of M.9 and M.26 rootstock occurred in several regions of the United States. The Geneva rootstocks which are resistant to fire blight are an alternative to the Malling stocks. Since 1998, 5 dwarfing rootstocks have been named and released for commercialization.

Geneva[®] 16 (1981 cross of Ottawa 3 X *Malus floribunda*) G.16 is a fully dwarfing rootstock with tree growth and vigor similar to vigorous clones of M.9 (i.e. Nic29 or Pajam2). Precocity and cumulative yield efficiency have been similar or slightly better than M.9. It is essentially immune to fire blight with no tree death from this disease in field trials. It has excellent performance in the stoolbed and produces a large tree in the nursery. Tree growth in the first 2 years in the orchard is vigorous, but with the onset of cropping tree vigor is moderated similar to M.9. G.16 appears to have wide soil adaptability and good tolerance to replant disease. It is very winter hardiness. Its greatest deficiency is that it is sensitive to one or more latent viruses in scion wood. Infected scion wood results in death of the trees in the nursery or the first year in the orchard. This requires absolute use of virus free scion wood. It is currently one of the best alternatives to M.9 in high fire blight areas. It should be planted at high densities of 2000–6,000 trees/ha.

Geneva[®] 11 (1978 cross of Malling 26 X Robusta 5) G.11 is a dwarfing rootstock that produces a tree similar in size to M.29. G.11 has high yield efficiency (similar to M.9) and produces large fruit size. It has good fire blight tolerance but is not immune. It has good resistance to *Phytophthora* root rot, but it is not resistant to woolly apple aphids. G.11 has good layerbed and nursery characteristics and is not sensitive to latent viruses. Presently G.11 is available only in North America and is available to licensed nurseries worldwide.

Geneva[®] 41 (1975 cross of Malling 27 X Robusta 5) G.41 is a fully dwarfing stock with vigor similar to M.9. It is highly resistant to fire blight and *Phytophthora* but is not resistant to woolly apple aphids. Its precocity and productivity have been exceptional surpassing M.9. It also has excellent fruit

size and induces wide crotch angles. It appears to be very winter hardy. It produces a smaller tree than G.16 in the nursery and similar to M.9. It also does not have the virus sensitivity of G.16. Its graft union with Gala and Honeycrisp is brittle like M.9 and M.26. It has shown good resistance to replant disease. At the moment, it appears that G.41 will be a possible replacement for M.9.

Geneva® 202 (1975 cross of Malling 27 X Robusta 5) G.202 produces a tree similar in size to M.26. In addition to fire blight, resistance like other Geneva stocks, it also has good resistance to woolly apple aphid. It performs very well in the stoolbed and produces good quality nursery trees. It has good tolerance to replant disease. G.202 has been tested mostly in New York state and New Zealand. In New Zealand, it has been found to be much more productive than M.26 and is one of the best stocks available. It appears that G.202 will be a useful alternative to M.9 and M.26 in climates that have problems with woolly apple aphid.

Geneva® 935 (1976 cross of Ottawa 3 X Robusta 5) G.935 is a semidwarfing stock that produces a tree similar in size to M.26. G.935 is the most precocious and productive semidwarf Geneva rootstock. It has had similar efficiency to M.9 along with excellent fruit size and wide crotch angles. It is very winter damage and is highly resistant to fire blight and *Phytophthora*, but it is not resistant to woolly apple aphid. It has good propagability in the stoolbed and produces a large tree in the nursery. It appears that G.935 will be a possible replacement for M.26.

Choosing the right rootstock Often the success of a high-density orchard depends on the ability of the grower to choose the right rootstock for his particular soil, climate and tree spacing. If the combination of rootstock, spacing, soil and climate results in excessive vigor, the trees will quickly outgrow their assigned space and will require excessive pruning to manage the planting. If on the other hand, the trees do not fill their allotted space as soon as expected, then yields will be less than expected. The use of dwarfing stocks and high tree densities has been the key to greater profitability in many plantings but where the choice of rootstocks or spacing has been wrong, the uses of dwarfing apple rootstocks has resulted in financial losses for growers. Because of the difficulty in predicting rootstock performance before planting due to site, climate and management variability, the decision of which rootstock and spacing to plant is a challenge for even the most progressive apple grower.

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 production. Our most recent economic analysis shows the optimum economic density for New York State is 2,500-3,000 trees/ha. 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 3 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.

Table 1. Simplified pruning and training plan for the Tall Spindle system.

First Leaf

At Planting	Plant highly feathered trees (10-15 feathers) at a spacing of 3-4' X 11-12' (90cm-1.2m X 3.3m-3.6m). Adjust graft union to 6" (15 cm) above soil level. Remove all feathers below 24" (60 cm) using a flush cut. Do not head leader or feathers. Remove any feathers that are larger than 2/3 the diameter of the leader
3-4" Growth	Rub off 2nd and 3rd buds below the new leader bud to eliminate competitors to the leader shoot.
May	Install a 3-4 wire tree support system that will allow tree to be supported to 3m. Attach trees to support system with a permanent tree tie above 1st tier of scaffolds leaving a 2 inch diameter loop to allow for trunk grow.
Early June	Tie down each feather that is longer than 10" (25 cm) to a pendant position below horizontal.

Second Leaf

Dormant	Do not head leader or prune trees.
10-15 cm growth	Pinch lateral shoots in top 1/4 of last years leader growth removing about 5 cm of growth (the terminal bud and 4-5 young leaves).
Early June	Hand thin crop to single fruit four inches apart. (Target 15-20 fruits/tree)
Mid June	Re-pinch all lateral shoots in top 1/4 of last years growth. Tie developing leader to support system with permanent tie.

Third Leaf

Dormant	Do not head leader. Remove overly vigorous limbs that are more than 2/3 the diameter of the leader using a bevel cut.
Late May	Chemically thin according to crop load, tree strength, and weather conditions, then follow up with hand thinning to appropriate levels to ensure regular annual cropping and adequate fruit size. (Target 50-60 fruits/tree)
June	Tie developing leader to support system with a permanent tie.
August	Lightly summer prune to encourage good light penetration and fruit color.

Fourth Leaf

Dormant	Do not head leader. Remove overly vigorous limbs that are more than 2/3 the diameter of the leader using a bevel cut.
Late May	Chemically thin then follow up with hand thinning to appropriate levels to ensure regular annual cropping and adequate fruit size.(Target 100 fruits/tree)
June	Tie developing leader to support system with a permanent tie at the top of the pole.
August	Lightly summer prune to encourage light penetration and fruit color.

Mature Tree Pruning (Fifth- Twentieth Leaf)

Dormant	Limit tree height to 10' (3m) by cutting leader back to a fruitful side branch. Annually, remove at least 2 limbs including lower tier scaffolds that are more than 2/3 the diameter of the leader using a bevel cut. Shorten bottom tier scaffolds where needed back to side branch to facilitate movement of equipment and preserve fruit quality on lower limbs. Remove any limbs larger than 1" diameter in the upper 2ft (60cm) of the tree
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Late May	Chemically thin then follow up with hand thinning to appropriate levels to ensure regular annual cropping and adequate fruit size. (Target 100-120 fruits/tree)
August	Lightly summer prune to encourage light penetration and maintain pyramidal tree shape.

Table 2. Establishment Costs for 0.9m X 3.3m Tall Spindle Orchard Systems (10 rows X 120m long)

Item	Number/ha	Material Costs (\$/ha)	Labor Costs (\$/ha)	Total Cost (\$/ha)
Trees	3,370	\$21,200	\$250	\$21,450
Anchor poles (2m long)	20	\$300	\$250	\$550
Inline poles (3.5m long)	110	\$2,700	\$1,360	\$4,060
High-tensile wire	3,700m	\$700	\$250	\$950
Staples, tightners and crimps		\$120	\$250	\$370
Total		\$25,020	\$2,360	\$27,380

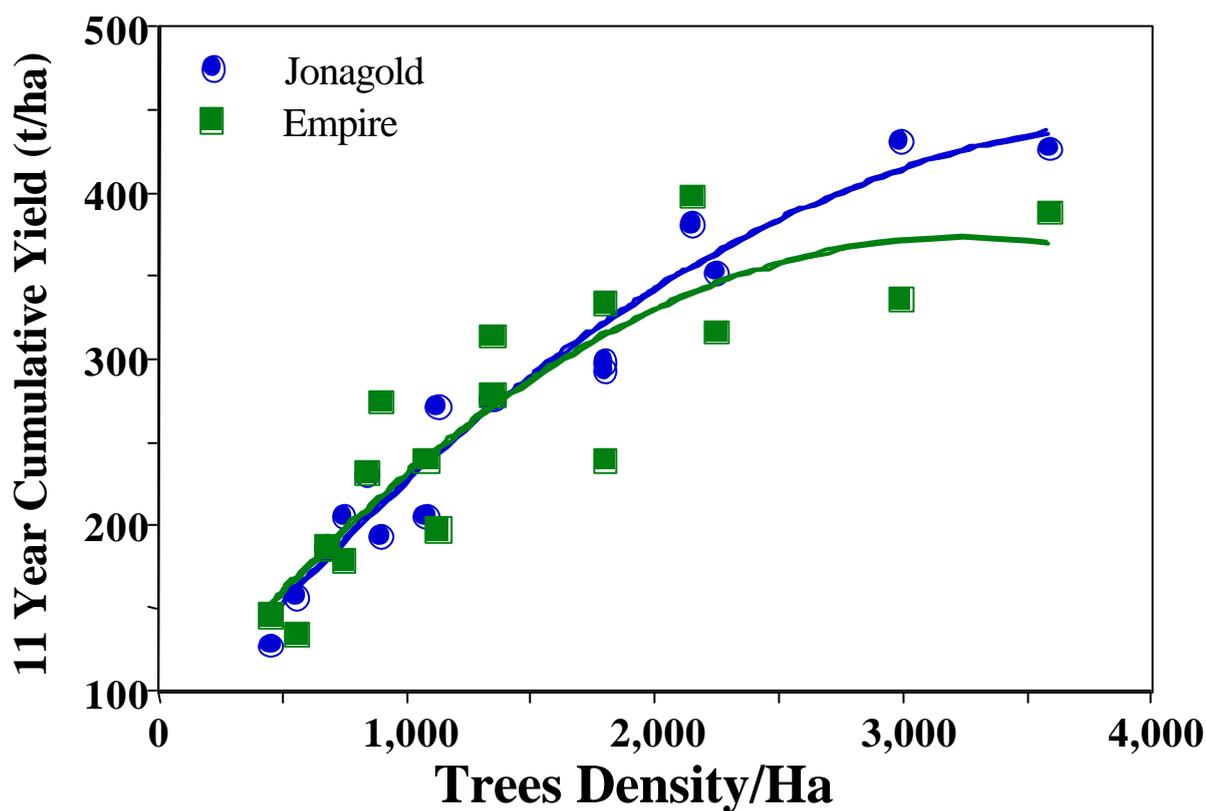


Figure 1. Relationship of tree density and cumulative yield over the first 11 years of an apple orchard on M.26 trained to Y-trellis system in New York state, USA. (Jonagold $r^2=0.95$; Empire $r^2=0.79$)

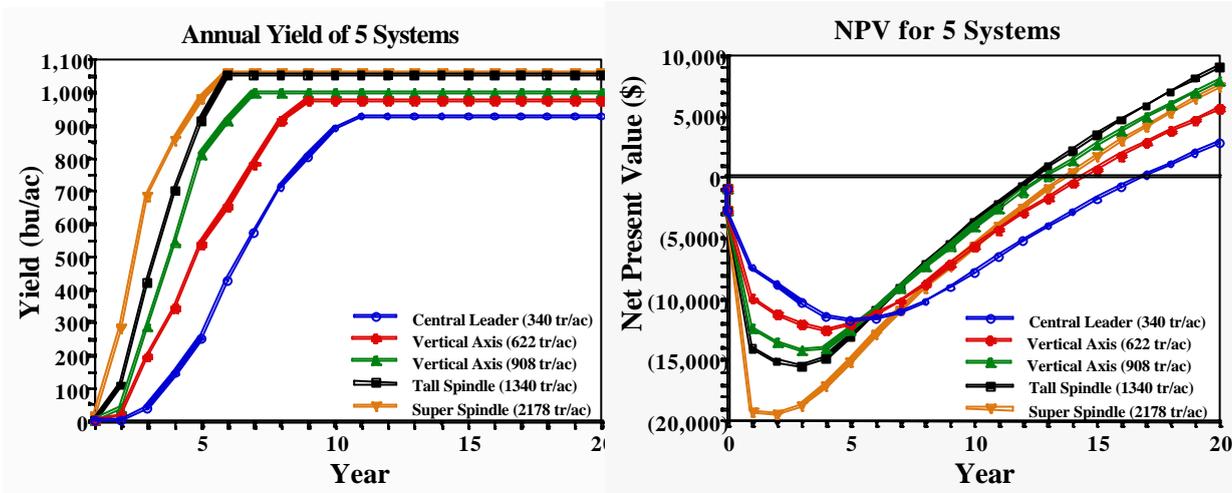
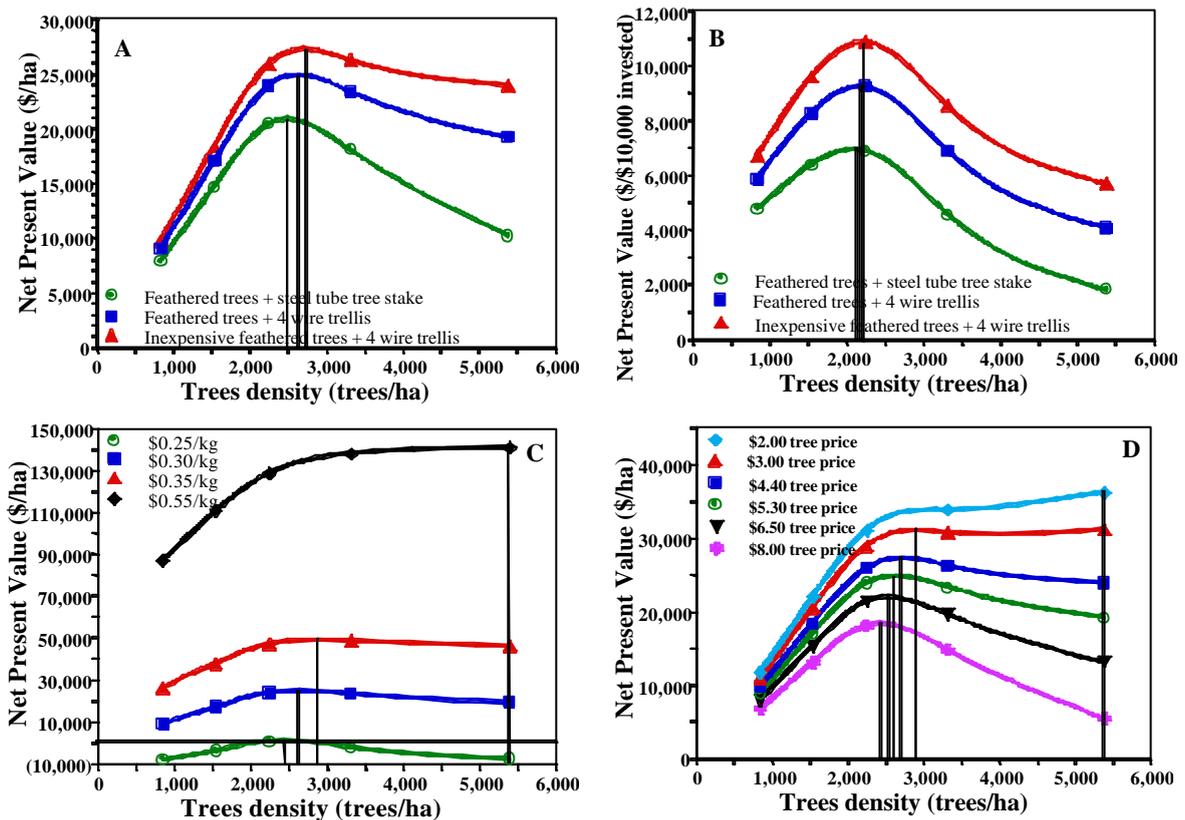


Figure 2. Idealized annual yields and cumulative profitability of 5 high density orchard systems over



20 years. (Curves based on data from research plots in New York State.)

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.

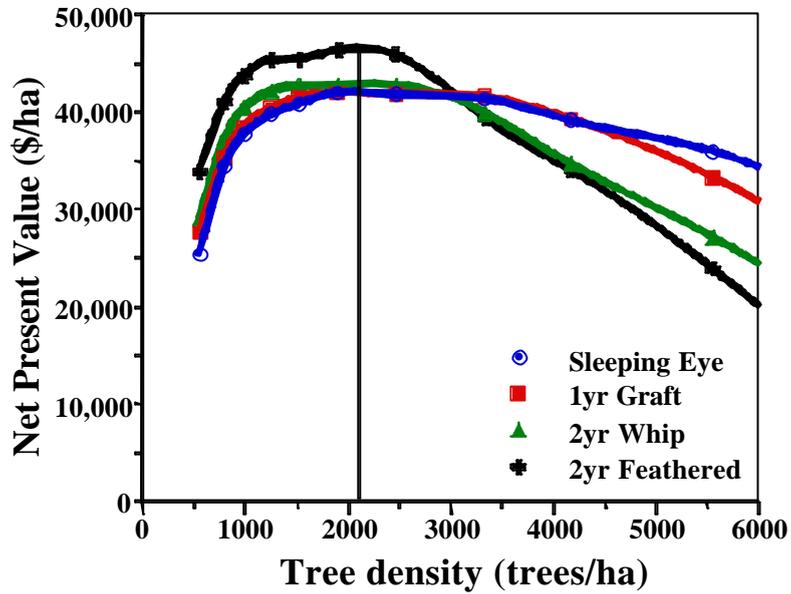


Figure 4. Effect of tree quality on orchard profitability after 20 years (Net Present Value/acre)



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Photo 1. A young Tall Spindle orchard (A) with highly feathered trees (15+ feathers) planted at 90cm X 3.3m. A newly planted Tall Spindle tree with feathers tied below horizontal (B).

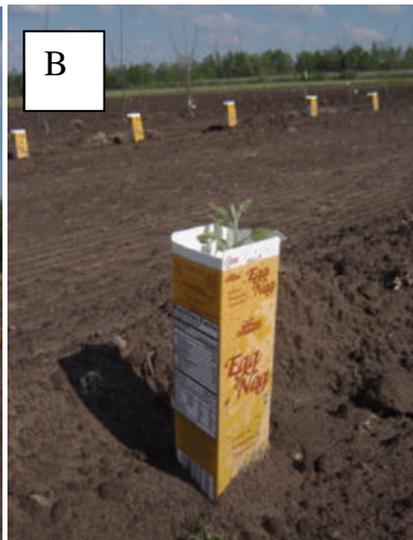


Photo 2. A Tall Spindle orchard using either feathered trees(A) spring bench grafted trees (B)



Photo 3. Self steering motorized platforms to improve dormant pruning efficiency.



Terence L. Robinson

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B.S. 1978 Brigham Young University
M.S. 1982 Washington State University
Ph.D. 1984 Washington State University

Areas of Expertise:

Tree Fruit Crop Management and Applied Physiology of apple, pear, cherry, peach, plum, and apricot.

I am an applied fruit crop physiologist. My goal is to do practical research and extension on tree fruit production problems that will increase the profitability and strength of the NY fruit industry and fruit growers around the world. My research and extension efforts are in 5 areas:

1. Orchard Systems: My goal is to understand the fundamental principles of orchard system performance in both biological and economic terms. I do in-depth studies at Geneva and applied trials on grower's farms around the state in cooperation with extension field staff (Steve Hoying, Mike Fargione and Kevin Iungerman). Our field trials are evaluated from an economic perspective in cooperation with Gerald White, and Alison DeMarree.
2. Rootstocks: My goal is to evaluate apple rootstocks for adaptability and performance under New York conditions. We are testing rootstocks from around the world including new Cornell-Geneva series of rootstock. This work is done in cooperation with Genarro Fazio of the USDA, Herb Aldwinckle of Plant Pathology and the national rootstock testing project- NC-140.
3. Crop Load and Canopy Management: My goal is to develop improved thinning and canopy management practices that improve fruit size and fruit quality while managing orchard tree canopies at a variety of tree densities. This work is in cooperation with and Alan Lakso, Lailiang Cheng, Duane Greene of U. of Mass and Greg Lang of Michigan State University.
4. Irrigation/Fertigation: My goal is to develop fertilization and irrigation strategies and scheduling programs that will enhance fruit size, quality and yield of both young and older orchards. This work is in cooperation with Lailiang Cheng.

5. Extension Leadership: I serve as chair of the fruit program research and extension team at Cornell and on the advisory committees of the tree fruit extension specialists. We provide high quality in-service training meetings for extension educators through the regional Great Lakes Fruit Workers Conference with Michigan and Ontario Canada. I serve as editor,(along with Steve Hoying) of the NY Fruit Quarterly which is the primary research reporting magazine that provides the fruit industry with regular communication on the progress of research programs at Cornell.