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FRUIT QUARTERLY

Editorial

The Future of Applied Research and Extension at Geneva

Applied research and extension are key components of the mission of the College of Agriculture and Life Sciences at Cornell. Of the four academic priorities recently identified by the College, faculty at the New York State Agricultural Experiment Station in Geneva are well positioned to contribute to those associated with the land grant mission, environmental sciences and the new life sciences. Land grant mission-related programs are highly visible at Geneva, and often include objectives that positively impact the environment. Faculty are expanding their efforts in the new life sciences as they place more emphasis on plant, insect and microbial genomics and nanobiotechnology, and the application of these technologies to New York food and agriculture.

Declining levels of state and federal funding are influencing our ability to maintain excellence in applied research and extension programs. Budgetary reductions at the State level affect all facets of operations in Geneva and Ithaca, and are contributing to a decline in faculty numbers. In Geneva, there were 68 faculty members in 1978; we now have 48.

It is apparent that we must do a better job of communicating the value of research and extension programs to state and federal government representatives. We must clearly articulate technological benefits to stakeholders, as well as related impacts on business and job creation. Faculty need to actively convey current success stories and participate in the creation of a vision for meeting future challenges.

It will be important to assess how efficiently state and federal funds are used. This effort will require strategic planning between departments in Geneva and Ithaca, clear definition of present and required strengths, and future goals. Cross-disciplinary expertise including those in IPM, the USDA PGRU and the Hudson Valley and Fredonia laboratories should also be recognized. Changes in food and agricultural industries must be taken into consideration, and stakeholder input sought. Results from this process will allow the filling of faculty positions based on a clear vision of future goals.

A key to Geneva's future success is the hiring and retention of the very best faculty. Faculty provide the leadership, initiative and knowledge that is needed to maintain excellence in applied research and extension. Faculty must be opportunistic, embrace new technologies, and lead strong cooperative programs that are visible and able to attract competitive funding.

Excellence in applied research and extension is vital in assuring a prosperous future for New York food and agriculture.

Thomas J. Burr
Director
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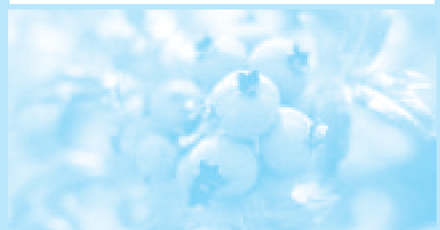

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Recent Advances in Apple Breeding, Genetics and New Cultivars

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This work supported in part by the New York Apple Research and Development Program, and by Motts.

The Cornell apple-breeding program continues its efforts to develop distinct and quality varieties as it explores the expansive genetic diversity of apple. Not only are flavor and appearance important considerations, but nutritional value is also a significant trait.

The genetic diversity that exists within apple is amazing. Diversity in appearance (color, shape, finish), texture (fine, crisp, hard) and flavor (complex, spicy, mild) offer breeders tremendous possibilities for improvements. The existence of several dominant genes for scab and powdery mildew resistance are also advantages.

The Cornell apple-breeding program continues to emphasize the development of new, distinctive cultivars with excellent and consistent quality. Distinctiveness may mean new colors, new striping patterns, different types of fruit finish (extremely glossy or finely russetted), and unusual shapes (uniformly conic, longer).

In trying to improve apples, we take advantage of the diversity that exists and cross parents to create new combinations of characteristics. Sometimes seedlings from a particular cross will be quite diverse, but the combination of characters expressed is not desirable. An example would be a progeny with seedlings bearing fruits of different colors and sizes but an undesirable finish such as russetting or scarfskin. Often we see uniformity of fruit shape in a cross but great diversity in the appearance and finish. Other crosses have a diversity of sizes but are skewed to smaller sized fruits presenting more of a challenge. With respect to fruit quality, we are seeing tremendous diversity for texture, firmness, flavor and other characteristics (Brix, acid, astringency) in our crosses. We are also seeing a range in flavors in crosses, with some seedlings very mild to bland and others strongly flavored and having a high Brix/acid ratio. Research has indicated that there are consumers for both types. The more strongly flavored types sometimes decrease in acidity while in storage, and other times their acidity is maintained.

Use of some of Roger Way's advanced selections as parents has been very successful in producing high quality offspring. One hybrid that has 'Golden Delicious,' 'Monroe' and 'Melrose' in its pedigree imparts wonderful quality when used as a parent. Some seedlings have been selected that have anise flavor, which is a mild licorice-like taste. Ironically, we had greater success in producing non-russetting yellow apples when we used a russet-prone, yellow-fruited cultivar as a parent than when we used a russet-resistant clone. The yellow and green selections we have made have good resistance to russetting.

Quality assessment studies, funded by the Apple Research and Development Program and by Motts, have allowed us to assess initial performance of our advanced selections. The appearance of many of these selections has been documented photographically. With many selections, we are seeing good levels of soluble solids, acids, firmness and crispness that are maintained in storage. We are also finding parental defects in the progeny; for example, we must evaluate 'Gala' offspring for stem end cracking and 'Honeycrisp' offspring for susceptibility to soft scald and fruit rots.

This past November 2004 we held a variety showcase to offer growers an opportunity to see and sample many of our new selections and over 100 cultivars and strains that we also put on display. Many of our selections are registering 15 to 17 pounds firmness when removed from cold storage in January and are free of storage disorders. In 2005, we began collecting a list of growers interested in testing material and will be propagating advanced selections for grower trials under a non-distribution agreement. Any growers interested in test plantings should contact us.

Nutritional Value/Health Benefits

Our program and other apple breeding programs are studying vitamin C (ascorbic acid) and antioxidant content of potential parents and the transmission

A selection with 'Honeycrisp' as a parent. Fruits have wonderful texture and juiciness.

of these nutritional traits to progeny. While many apple cultivars average only 5 to 10 mg of ascorbic acid per 100 g of fresh weight, NY 674, 'Braeburn,' 'Goldrush,' and 'Topaz' have from 15 to 32 mg /100 g of fresh weight, approaching the 40 mg found in oranges. We have made crosses with the objective of increasing vitamin C content in new varieties, coupled with good quality, and have found significant increases in Vitamin C content in seedlings from these crosses.

Studies have demonstrated that vitamin C is just one of the many antioxidants found in apple, and ironically, a variety might have high vitamin C but low total antioxidants. Vitamin C only contributes 12.8% to total antioxidant capacity, with other phenolics such as quercetin are more important (Lee et al., 2003). Certain of our selections have been evaluated for total antioxidants and been found to have very high levels.

As we increase antioxidants we also increase flesh browning. Non-browning cultivars are also desired and can be developed by concentrating on lowering the browning enzymes and raising vitamin C content. Such cultivars are important in value-added products, and low browning cultivars are being developed in our program.

Molecular Markers

Molecular markers for many traits of interest to apple breeders and growers have been discovered by geneticists around the world. At Geneva, we have developed markers for fruit color, columnar and weeping plant form, and several markers for the different scab resistance genes, including V_f, V_m, V_r, V_x, V_a and V_b. Scab genes were found to cluster onto two linkage groups (chromosomes) which is an important finding for breeding and transformation. There are also markers available for several sources of powdery mildew resistance, woolly apple aphid resistance and rosy apple aphid resistance. Self and cross incompatibility genes have also been studied extensively, and markers and knowledge of the genes involved aid pollination plans.

Genes Identified and/or Sequenced in Apple

Genes influencing the time required for a tree to fruit, flowering, fruit development, photosynthesis, stress and fruit maturation have been identified, and many have been sequenced. Genes for dwarfing and disease resistance have also been studied.

Recently, a major grant was funded at the University of Illinois to study expressed sequence tags (ESTs) in apple. Similar research has also been conducted in New Zealand. ESTs reflect genes being expressed at certain stages of development or from different treatments. This research promises to add greatly to our knowledge of genes in apple.

Cultivars Transformed

Many apple cultivars have been transformed by different research groups including (in alphabetic order): 'Delicious,' 'Elstar,' 'Florina' (a scab resistant variety), 'Fuji,' 'Gala' and its sports, 'Golden Delicious,' 'Jonagold,' 'McIntosh' (and its columnar sport 'Wijcik McIntosh'), 'Orin' and 'Pink Lady.'

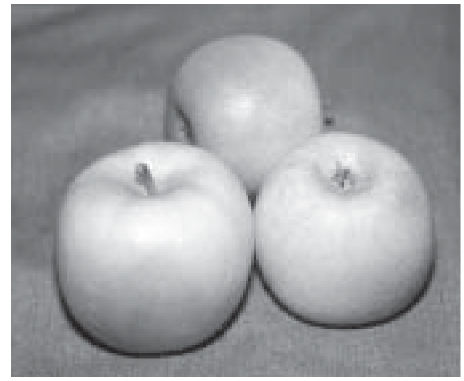
Transgenes Used

Lytic peptides have been used to impart resistance to bacterial diseases such as fire blight (*Erwinia amylovora*), and chitinases have been used for resistance to fungal diseases in rootstocks and scion cultivars (Aldwinckle et al., 2003).

Anti-sense technology, where a gene for a trait of interest is inserted in the wrong direction, is an effective way to turn off or reduce the expression of that gene. The anti-sense approach is being used with the self-incompatibility gene to produce self-fertile cultivars and with reduced polyphenoloxidase (PPO) to reduce flesh browning (Barbier et al., 2003).

With the advances made in apple gene mapping, genes from apple were recently targeted as transgenes. In 2003, 'Gala' was transformed with what was believed to be the V_f scab resistance gene and the transgenic lines produced were resistant to scab.

Studies of transgenic apple trees and their fruits promise to add to our knowledge of transgene expression and transgene interaction with other genes and the environment. An example of this is presented in research that discusses the effect of silencing (turning off) ACS or ACO, enzymes responsible for ethylene production (Dandekar et al., 2004; Hrazdina et al., 2003). In fruits silenced for ethylene, there was no effect on sugar and acid composition but the synthesis of volatile esters (which contribute to flavor) was dramatically suppressed.

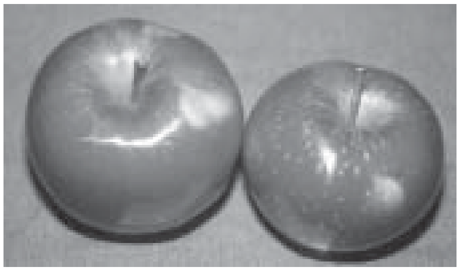


Another 'Honeycrisp' offspring with excellent crispness and long storage life.

Club Marketing

In recent years there have been a greater number of restricted access cultivars since 'Pink Lady' was marketed under a club concept. The New Zealand program's Pacific series and 'Jazz' are examples of restriction and dual location (New Zealand and Washington State) production. Franchise fees and production-based royalties are also new developments. 'Delblush' ('Tentation') is another example of a restricted access variety from the Delbard program in France. In North America, we have seen 'Ambrosia' become restricted to Canada, even after trees had been planted and harvested in the US. 'Sonya,' from the NZ breeding program of John Nelson, is also a club variety in Washington. The most recent restriction is on 'Piñata,' trademarked by Stemilt in cooperation with Pepin Heights orchard in Minnesota. 'Piñata' will be exclusive to that partnership, which is unusual because 'Piñata' was originally introduced as a public variety to the US. This introduction from the Dresden/ Pillnitz breeding program in Germany was available to all growers. Its name was first changed to 'Corail' and later to 'Sonata' for marketing purposes. The trademarked name, 'Piñata,' comes from a combination of the names 'Pinova' (Pin) and 'Sonata' (ata).

'Ariane,' a scab resistant apple from the INRA program in Angers, France, is the newest club release. Its pedigree is complex, involving a hybrid of the scab resistant cultivars 'Florina' and 'Prima,' crossed with a selection derived from



A non-russetting 'Golden Delicious' type seedling with texture similar to its 'Fuji' parent.

'Golden Delicious' open pollinated. This cultivar is the first release by a cooperative program between INRA and French nurseries. Seventeen French nurserymen, with an aim to produce high- quality, disease resistant cultivars, founded the company NOVADI in 1997. This group then partnered with producers and marketers to form POMALIA. The company selects among the best cultivars identified by NOVADI. These groups have already organized the planting of over 95,000 trees of 'Ariane' in France.

New Cultivars Released

Cultivars for which patent applications have been filed in the US include:

'Civni' ('Rubens'®): (USPP#14,177: 9/23/03). This hybrid of 'Gala' x 'Elstar' was developed by the CIV (Consorzio Italiano Vivaisti) in Italy and has been planted fairly extensively in the South Tyrol since 1999. 'Civni-Rubens' may become biennial, like its 'Elstar' parent. Fruits are prone to cracking at the calyx end at harvest, especially on trees with a lighter crop load (Thomann et al., 2004).

'Rebella': (USPP#15,134: 9/7/04). A scab resistant variety released from a German breeding program. This hybrid of 'Golden Delicious' by the scab resistant cultivar 'Remo' is noted to have good fruit quality and good resistance to powdery mildew and fire blight.

'Sundance'™ (Co-op 29): A yellow, scab-resistant variety from the Purdue/Rutgers/Illinois (PRI) cooperative breeding program. It has good quality but is prone to russetting in New York and can also be biennial in production. It was included in the NE183 regional trial evaluating apple cultivars.

'Crimson Crisp' (Co-op 39): Another scab-resistant release from the PRI program that was also tested in the NE183 project. It has good storage characteristics.

'Stella Minnesota': (USPP#13,930: 7/1/03). A chance seedling that ripens in the early season and has good quality fruit with good resistance to flesh browning when cut.

Cultivars and sports with a plant patent application filed but not yet granted include:

'Rosy Glow': A limb sport of 'Cripps Pink' ('Pink Lady') discovered in Australia in 1996. Fruits are more highly colored even in shaded areas of the tree. The red color is said to extend into the calyx.

'Royal Beauty': A sport of 'Royal Gala' discovered in South Africa in 1996 that has intense red color on more of the fruit surface.

New sports of Gala:

'Dalitoga': (USPP#15,465: 1/4/05) A whole tree mutation of 'Imperial Gala' discovered in France.

'Star Gala'™('Weaver'): (USPP #14,752: 5/4/04). A limb sport of 'Fulford Gala' discovered in Pennsylvania that is reported to have larger fruits (~3-3.5" in diameter) with a less vigorous tree than 'Fulford Gala.'

New sports of Fuji':

'Brak' ('Kiku'®): (USPP#15,261: 10/26/04) A branch mutation of 'Fuji' that was discovered in Japan and selected by A. Braun of the South Tyrol along with seven other 'Fuji' sports to be part of the 'Kiku'® brand (www.kiku-apple.com).

'Daybreak Fuji' ('Rankin Red'): (USPP#12,551: 4/16/02). A limb sport of 'Yataka,' 'Daybreak Fuji' ripens five days before 'Yataka' (five weeks before standard' Fuji'). 'Daybreak Fuji' is said to have better and more uniform coloring and a smoother finish.

Summary

New knowledge of apple genes and their interactions will aid apple breeding and transgenic approaches to improvement of existing varieties. Improvements in quality and nutritional content are evident in our seedling populations, and we are creating the needed diversity to produce cultivars that are distinctive in appearance and/or quality and have consistency in these attributes. Access to some new cultivars is being restricted, but our established collaborations with researchers and nursery personnel continue to provide us access to new material from the US and abroad.

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Fungicide Resistance of Apple Scab: Status Quo and Management Options

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Starting with dodine in the early 1960s, five classes of scab fungicides have allowed the post-infection control of apple scab. Unfortunately, resistance has developed or will develop in all five classes. Work on measuring the levels of resistance to all available classes of post-infection fungicides began in 2002. The results of this project will provide an opportunity for growers to practice site-specific management of resistance (SMOR).

Apple scab caused by the fungus *Venturia inaequalis* is an important and recurring disease in all apple-growing regions of New York. In the absence of fungicides, the pathogen can defoliate apple trees prematurely. However, scab lesions on harvested fruits are economically much more important because of the 'zero-tolerance' for scab lesions on apples produced for the fresh market and an increasingly limited market for fruits with defects. Although some management practices, such as leaf litter management in the fall, can assist in the management of apple scab during the following season, fungicides will remain indispensable tools in the commercial production of apples in New York.

Highly effective scab fungicides became available in the early 1950s. Starting with the introduction of dodine in the early 1960s, all new fungicide classes have provided post-infection activities against apple scab. Unfortunately, we have found that the scab fungus has become or will become resistant to all classes of these post-infection fungicides. In this article, we will outline the current problems with resistance to scab fungicides along with management options that might help to avoid crop losses caused by unexpected outbreaks of resistance.

Qualities of Scab Fungicides and History of Resistance

There are two principally different types of scab fungicides on the market today, the protectant fungicides and the post-infection materials. Their inherently different qualities have an immediate impact on the control of apple scab but also on the development and management of resistance.

Protectant fungicides, such as ethylene bisdithiocarbamates (EBDCs) and captan, stop growth of the scab fungus by interfering with numerous steps important to the growth and survival of the scab fungus. Unfortunately, this multiple and nonspecific mode of action also determines the way these fungicides must be used. The scab fungus infects apples via microscopic spores that land on and attach to the surfaces of apple leaves and young fruits. The spores then germinate and penetrate through the surface barrier, after which the fungus will grow underneath the surface until new visible scab lesions appear, approximately two weeks later. Each of these scab lesions can produce 100,000 new infective spores shortly after lesions become visible.

The initial germination and penetration step of spores is rapid and can be completed in less than 24 hours. Any fungicide expected to stop the fungus after it already grows inside the apple host would have to penetrate through the outer surfaces of leaves and fruits in order to reach the fungus. This cannot be accomplished with protectant fungicides. If such nonspecific fungicides were allowed to penetrate into apple tissue, they would cause phytotoxicity. This, for example, is what happens if captan is used in combination with mineral oils. Mineral oils make plant surfaces more penetrable, allowing captan to enter and damage apple tissue.

The only effective way of managing scab with nonspecific protectants is to prevent the germination and penetration of spores. Because most growers find it impractical to apply fungicides within 24 hours after rain began (and because spraying in the rain is generally inadvisable), protectants must already be deposited on the surface before spores are disseminated during rain. The weather conditions conducive to infections are well defined (Mills table and its recent refinements), allowing growers to decide whether an infection took place and whether the application of a post-infection fungicide would be necessary. A sim ilarly precise timing of protectant sprays in advance of an infection period would require the accurate forecasting of such events at the local level, which remains somewhat unreliable. Therefore, routine prophylaxis remains the best option for the effective use of protectants. Strict prophylaxis necessitates the start of scab programs at 'green tip' and the continuation of sprays in weekly (or shorter) intervals up to '1st' or sometimes '2nd cover' in order to replenish fungicide deposits washed off by rain and to protect the new growth of leaves. Applying a purely protective fungicide after infections are established will have minimal effect. The load of secondary spores formed as a result of a missed protectant spray will be very high and much more difficult to control. To correct for a spray missed, subsequent applications of nonspecific protectants must provide excellent coverage, and they must be applied at high rates and / or at shortened intervals.

The EBDCs and captan, currently the most widely used protectants, are ineffective for the control of powdery mildew. However, the EBDCs control rust and some summer diseases in addition to scab, and captan is active on several summer diseases (Table 1).

Stopping the scab fungus after it is established inside leaves or fruits can only be accomplished with fungicides that can reach the pathogen underneath the surface. Such post-infection fungicides must be highly fungal-specific, because they will have to penetrate into the apple tissue without killing or damaging plant cells. Dodine, introduced in the early 1960s, was one of the first scab fungicides with pronounced post-infection activities, in addition to good protectant activity. Small necrotic lesions developed when dodine was applied up to seven days after infection, but they did not form new spores (pre-symptom activity). Although dodine provided no control of other apple diseases (Table 1) and could cause fruit russetting on light-colored cultivars, the fungicide was rapidly accepted as a new and convenient post-infection tool in the management of scab. However, in the early 1970s, control failures were noticed in many New York orchards, where dodine had been used for approximately 10 years on a full-season basis. It was found that the scab fungus had developed resistance. This discovery came as a surprise because resistance had never been observed for the EBDCs or captan. Lack of resistance to nonspecific protectants remains in effect today and is unlikely to become a problem in the future.

TABLE 1

Qualities of commonly used scab fungicides

Class	Common name(s)	Trade name(s)	Post-infection	Additional diseases
EBDCs	mancozeb	Dithane, Manzate, Penncozeb	no	rust, flyspeck, sooty blotch
	maneb, metiram	Manex, Polyram		
Captan	captan	Captan	no	black rot, white rot, flyspeck, sooty blotch
Dodine	dodine	Syllit	yes	none
Benzimidazoles	thiophanate-methyl	Topsin M, T-Methyl	yes	powdery mildew, black rot, white rot, flyspeck, sooty blotch
Sterol inhibitors (SIs)	fenarimol, myclobutanil, triflumizole	Rubigan, Nova, Procure	yes	powdery mildew, rust
Strobilurins	kresoxim-methyl, trifloxystrobin	Sovran Flint	yes	powdery mildew, rust, black rot, white rot, flyspeck, sooty blotch
Anilinopyrimidines (APs)	cyprodinil, pyrimethanil	Vangard, Scala	yes	none

The introduction of the benzimidazoles in the early 1970s, with benomyl (Benlate) as the first representative, offered a solution to the problem of widespread dodine resistance. Benomyl and later thiophanate-methyl provided post-infection control of scab and also controlled powdery mildew and several summer diseases (Table 1). Unfortunately, the scab fungus developed resistance to benzimidazoles even faster than to dodine, with first control failures reported after only four years of season-long use. In addition, the phenomenon of cross-resistance between different fungicides surfaced as a new problem. Individuals of the scab fungus resistant to benomyl were also resistant to thiophanate-methyl and *vice versa*.

It had been noticed that benzimidazoles continued to control scab in regions where they had been mixed with an EBDC in order to control apple rust. The concept of mixing benzimidazoles with a protectant was quickly adapted as a general anti-resistance strategy. Unfortunately, resistance to the benzimidazoles continued to develop even where they were used in mixture. By the early 1980s, the benzimidazoles failed to contribute to scab management in many orchards, and the protectant in the mixtures became solely responsible for the level of scab control achieved.

The third class of specific scab fungicides, the sterol inhibitors (SIs), was introduced in the late 1980s (Table 1). The SIs were highly effective in both after-infection and pre-symptom applications. For up to 96 hours after an infection period had started, they stopped the development of the pathogen inside the apple tissue without allowing visible symptoms to emerge (after-infection activity). Even when applied seven days after infection, only small necrotic lesions developed, but their conversion to sporulating lesions was prevented (pre-symptom activity). These excellent post-infection properties allowed the development and implementation of a 'delayed spray' program in orchards with very good scab control in the previous season. In such low-inoculum orchards, scab was effectively controlled with only four SI applications made at 'tight cluster', 'pink', 'petal fall' and '1st cover', a scheme that allowed growers to merge scab control with routine insect control in pre- and post-bloom applications. In addition to providing excellent scab control, the SIs also controlled powdery mildew and rust, thereby combining control of all major 'early season' apple diseases.

From the time the SIs were permitted in the US to be used in apple production, it was recommended that they should be applied in a mixture with protectants at half of their full 'stand-alone' rates. The rationale for this recommendation was to complement the protection of fruits – where the SIs had shown some weaknesses when used alone – and to add an anti-resistance component.

The first control failure in a commercial orchard caused by SI resistance was reported in 1995. In this Michigan orchard, the delayed spray program had provided good scab control for eight years. The same speed of resistance development was identified in an IPM test orchard at the Geneva Experiment Station where the same delayed program was used in scab management. The development of SI resistance has been slower in other orchards, but as described below, SI resistance is now established in many orchards in New York. Orchards resistant to one SI will be equally resistant to all other SIs available.

Two new classes of scab fungicides with post-infection activities became available in 2000: the strobilurins and the anilinopyrimidines (APs) (Table 1). For both classes, cases of control failures caused by resistance have not been documented in New York orchards. However, our assessments of resistance risks and the monitoring of orchard sensitivities leave no doubt that both classes are prone to resistance development, with cross-resistance apparent for all members of each class.

The Pathways of Resistance Development

Over the past two decades, we have been able to answer the question of how resistance to post-infection fungicides develops. Although the apple scab pathogen causes typical and apparently uniform scab lesions, the fungus exists in each orchard as a community of different individuals with different and distinct characteristics. The characteristics with importance to fungicide resistance are the different sensitivities individuals have to a new class of fungicides. Most of the individuals will be sensitive at the time the new fungicide is introduced, and their reproduction will be prevented. A few individuals of the scab fungus, however, will be able to survive treatments and will continue to multiply. In sprayed orchards, these individuals will have a clear reproductive advantage over their sensitive counterparts, and their preponderance in treated orchards will increase. This increase will first lead to an erosion of the initial efficacies in scab control and then to the stage of full resistance where economically acceptable scab control is no longer provided. Unfortunately, the transition from a noticeable erosion of performances to control failures is most often too short to be recognized by growers.

The speed of resistance development depends on the intensity of the fungicide used in individual orchards but also on the dose resistant individuals of the scab fungus will survive. For some fungicides, resistant individuals are entirely immune. They are not slowed down at any feasible application rate of the fungicide, and resistance will build up rapidly. The benzimidazoles are the classical example for this 'immunity' type of resistance. For other fungicides, resistant individuals continue to be inhibited at high doses, with the SI fungicides as an example. In such cases, emergence of resistance will be slower and more gradual, especially when application rates are kept at the high end of respective label rates.

Over the past 15 years, we also have learned how to measure the development of resistance in individual orchards. This task required both a quantitative sensitivity test and the development of data describing the two sensitivity extremes: baseline sensitivities prior to the first use of a new fungicide class and threshold sensitivities at which control failures will become a reality. We started to measure sensitivities and to monitor the development of resistance for the SIs from the time they were introduced, and we gradually added tests and data sets for all classes of post-infection fungicides currently available. We found that the status of resistance to the five classes of post-infection fungicides available was different from orchard to orchard, and that control failures were usually caused by outbreaks of resistance rather than by flawed practices of scab management.

Our findings opened an opportunity to manage resistance more effectively. Precise knowledge of the levels of resistance to all fungicide options in individual orchards would allow growers to design their own orchard-specific scab management program, with sufficient warning before control failures caused by resistance would become imminent. Although the sensitivity tests we had developed in the past have helped to better understand how resistance develops and how it can be managed, our tests were too costly and too complicated to be used in measuring the sensitivity of individual orchards on a broad scale.

Since 2002, we have simplified and unified our test procedures. The reproducibility and precision of the new test, as evaluated over two seasons, is sufficient to rank individual orchard sensitivities into four functional categories and, at the same time, to predict the expected performances of post-infection fungicide options:

Sensitive	good performance is expected
Slight shift	good performance is expected at high label rates
Strong shift	performance must be supplemented with another fungicide
Resistant	insufficient contribution to scab control to warrant further use

Our new test measures orchard sensitivities to dodine, the SIs, the strobilurins and the APs. A test for the benzimidazoles was omitted for reasons given below, but this test segment could be added easily if a need should exist.

Status Quo of Fungicide Resistance in New York Orchards

With the new sensitivity test in hand and the sets of crucial data established, we have measured the fungicide sensitivities of 13 commercial orchards across all major apple-growing regions in New York during 2003 and 2004 (Table 2). Although the number of orchard sites we tested is small, our results illustrate the current problems but also the opportunities for managing fungicide resistance. We will describe the status of resistance in New York orchards according to the history of fungicide introductions.

Dodine. Widespread resistance to dodine was first documented in the 1970s. During the past decade we verified that dodine-resistant individuals in scab populations were not immune to dodine. At the application rates recommended, however, full resistance to dodine was reached after a total of approximately 60 applications had been made in any given orchard. These 60 applications could be spread over 10 years with six applications per season or over 30 years with only two applications made per season. We found in surveys conducted in the mid 1990s that once dodine resistance had been established in an orchard, the proportion of dodine-resistant individuals did not decline to baseline levels even after dodine use had been discontinued for 20 years. We also found that some orchards expected by growers to be dodine-resistant were sensitive; whereas, some orchards expected to be sensitive to dodine contained large numbers of resistant individuals.

Our most recent survey of orchard sensitivities (Table 2) confirmed our previous results. Only four of the 13 commercial orchards we tested in New York were diagnosed as dodine-resistant, while nine orchards were sensitive or only slightly shifted. We also confirmed the longevity of dodine resistance once it was established in an orchard. Resistance was found even in young orchards after old orchards

TABLE 2

Sensitivities of the apple scab fungus in New York orchards. Orchards 1-13 are commercial orchards. 'McIntosh' and 'Empire' are experimental test orchards at the Geneva Experiment Station.

Orchard	Dodine	SIs	Strobilurins	APs
1	sensitive	strong shift	slight shift	sensitive
2	**resistant**	**resistant**	slight shift	strong shift
3	slight shift	**resistant**	sensitive	strong shift
4	sensitive	**resistant**	slight shift	strong shift
5	**resistant**	**resistant**	strong shift	**resistant**
6	sensitive	slight shift	slight shift	strong shift
7	slight shift	strong shift	slight shift	strong shift
8	**resistant**	**resistant**	slight shift	strong shift
9	sensitive	**resistant**	sensitive	slight shift
10	sensitive	slight shift	slight shift	strong shift
11	slight shift	strong shift	slight shift	strong shift
12	slight shift	**resistant**	slight shift	slight shift
13	**resistant**	**resistant**	strong shift	strong shift
'McIntosh'	strong shift	**resistant**	slight shift	strong shift
'Empire'	slight shift	**resistant**	sensitive	slight shift

with resistance problems in the 1970s had been replanted. In summary, the reintegration of dodine into scab management appears feasible and potentially advantageous in many orchards, but only if the dodine sensitivity of a particular orchard has been determined before dodine is applied.

Benzimidazoles. For several reasons, the benzimidazoles were not included in our recent orchard survey. The US registration for benomyl (Benlate) was voluntarily withdrawn by the manufacturer, leaving thiophanate-methyl as the single benzimidazole product available for scab control. Also, our surveys in the 1990s had indicated that benzimidazole resistance, once established in an orchard, remains stable. More recent test results indicated that the number of benzimidazole-resistant orchards could even have increased above the levels observed in our initial surveys. A reason for this increase might be that a mixture of thiophanate-methyl with captan has been widely used for the management of summer diseases. Because the end of the scab season and the start of the summer disease program often overlap, the scab fungus has remained under continuous selection pressure toward increasingly higher levels of benzimidazole resistance. As a result, thiophanate-methyl will not be an option for scab control in the majority of New York's apple orchards. In many orchards, powdery mildew has also developed resistance to the benzimidazoles, and the future role of thiophanate-methyl appears to be largely restricted to the management of summer diseases.

SIs. With their initially excellent after-infection and pre-symptom activities, and their activity against powdery mildew and rust, the SIs became the post-infection materials of choice during the 1990s. We found that mixing EBDCs at half of their full rates provided the additional control of fruit scab needed, but we also found that the selection of SI-resistant individuals of the scab fungus was not slowed by EBDCs in the mixtures. However, the speed of their selection could be slowed down with high rates of the SIs, because resistant individuals were not immune to the SIs.

When SI programs were started at 'tight cluster' with application rates at the low end of their label rates, 30-40 SI applications in total were sufficient to render an orchard SI-resistant. Our recent survey of orchards (Table 2) showed that SI resistance has now become widespread in New York. Only two of the 13 orchards we tested (15%) were rated 'slightly shifted', while eight orchards (62%) were diagnosed as SI-resistant. Control failures following SI applications had been experienced in three of the orchards, but SIs had not been applied in the other five SI-resistant orchards. Taking our sampling bias into account, the results suggest that approximately 40-50% of New York's orchards have reached the stage of SI resistance. Many other orchards showed strong sensitivity shifts. If SI resistance in these 'strongly shifted' orchards is not managed prudently (high protectant rates in mixtures with SIs and applied at shortened spray intervals), respective growers will experience unexpected control failures in the near future.

In fully SI-resistant orchards, the SIs in mixture with an EBDC can no longer be expected to contribute to scab management. Rather, the EBDC in the mixture will have to bear the full burden of scab control. The current EBDC labels allow either one of two use options: At a high rate (6 lb / acre) they can be applied up to four times and no later than bloom. At half of the rates (3 lb / acre) they can be used up to seven times and to within 77 days of harvest. The effectiveness of EBDCs at these low mixture rates was tested in the two SI-resistant experimental orchards 'McIntosh' and 'Empire' at the Geneva Experiment Station (Table 2). The high inoculum levels in these test orchards would be similar to those expected in commercial orchards where fungicide resistance has contributed to control failures. Our trial results are described in Tables 3 and 4.

In 1999, the scab program in the 'McIntosh' orchard was started at '1/2 inch green' and ended with '2nd cover', with a total of seven applications made (Table 3). Dithane alone at the low mixture rate provided poor control of leaf scab and commercially unacceptable control of fruit scab. Mixing Dithane with Rubigan had little effect on the level of scab control because the orchard was SI-resistant.

At the 'Empire' orchard examined in 2003, the program was initiated at 'green tip' with a protective spray five days in advance of the first scab infection period, and the program continued with six additional applications (Table 4). Dithane at the low rate provided a marginally acceptable level of scab control. Mixing Dithane with Nova at the four stages emphasized in the original 'delayed spray program' did not significantly improve scab control above the level achieved with Dithane alone, as expected from the status of SI resistance.

The trial results confirmed our previous predictions. Mixing SIs with an EBDC will not prevent the development of SI resistance. As the level of SI resistance rises over time, the EBDC will carry an increasingly greater burden of scab control provided by the mixture. When full SI resistance is reached, the SI will no longer contribute to the management of scab.

If the results of our most recent sensitivity orchard survey (Table 2) are representative of New York orchards, sole reliance on the low EBDC rate in mixture with SIs will be risky because the post-infection activity formerly provided by the SIs will be lost in SI-resistant orchards. In such orchards, only the Dithane com ponent in the mixtures can be expected to control scab. The risk a grower unaware of the situation will take is apparent from the result of a trial where the protective spray with Dithane at 'green tip' was omitted (Table 4). Scab lesions on cluster leaves developed freely, and the extreme load of secondary spores in the immediate vicinity of developing fruits caused a failure of fruit scab control.

In summary, the original security and convenience of the 'delayed four-spray SI program' will no longer be applicable in the majority of New York orchards. However, the SI fungicides remain effective in controlling powdery mildew and rust. In SI-resistant orchards, the timing of mildew and rust applications must be adjusted to these diseases. Sufficient scab control must be provided by another scab fungicide.

It must be noted that the status of SI resistance has by now surpassed the status of dodine resistance (Table 2). Unfortunately, four of the SI-resistant orchards were also resistant to dodine. In these orchards, reintegration of dodine into scab management programs will not be an option. The potential for double-resistance constitutes a problem. Although dodine could be reintroduced as a post-infection fungicide in early parts of the season, the longevity of dodine resistance might contribute to the false assumptions that an orchard is sensitive to dodine. Reliance on dodine in such cases will lead to severe control failures.

Strobilurins. In New York, the strobilurins became available in 2000. Our early risk assessment studies had suggested that resistance could develop as a gradual shift of orchard sensitivities (similar to dodine and the SIs), and/or as a mutation conferring the benzimidazole-type of immunity. Both predictions were confirmed for the apple scab fungus. Following an initially gradual sensitivity shift in Germany, immune mutants emerged after a total of 20-30 applications had been made. Cases of such orchard immunities are spreading slowly through Europe and, most recently, were detected in Chile. Fortunately, we have not yet found strobiluin-immune mutants in New York orchards. However, the initially gradual shifts of orchard sensitivities are clearly apparent in many orchards (Table 2).

We have tested the performance of the strobilurins in both of our SI-resistant test orchards. In trials at both orchards, the strobilurins provided the best control of scab (Tables 3 and 4), and good performance of strobilurins can be expected in SI-resistant orchards throughout New York State. However, several concerns relating to the future use of strobilurins have surfaced. Our experience suggests that the slight sensitivity shifts typical for New York orchards will diminish the after-infection activity strobilurins will provide. In comparison with the SIs, the strobilurins are excellent protectants but less potent in after-infection applications. When strobilurins are used 96 hours after infection in 'slightly shifted' orchards, as allowed by the product labels, their activity might not be sufficient to provide complete control of scab. In such orchards, strobilurins should be restricted to 48 hours post-infection action, and they should be applied at their highest label rates.

Strong shifts of strobilurin sensitivities were found in two of the commercial New York orchards we tested recently (Table 2). Incidentally, both orchards were also resistant to dodine and the SIs. In such orchards, strobilurins might have to be used on a strictly protective schedule, because post-infection action is no longer assured. Trials are under way to fully explore this additional restriction.

Another concern is the speed by which the initially gradual sensitivity shifts toward strobilurin resistance can turn into the stage of full immunity. Once this immunity stage is reached, the strobilurins will no longer contribute to scab control, and they will have to be used in

TABLE 3

Performance of fungicides in an SI-resistant experimental orchard (McIntosh) in 1999. Timing of applications (dilute) was 1, April 12 (1/2-inch green); 2, April 23 (tight cluster); 3, May 5 (pink); 4, May 13 (bloom), 5, May 20 (petal fall); 6, May 27 (1st cover), 7, June 7 (2nd cover).

			Scab incidence (%)		
Fungicides	**Timing**	**Rate/100 gal**	**Cluster leaves (June 26)**	**Terminal leaves (August 1)**	**Fruits (August 17)**
Untreated check			42.8	81.4	68.5
Dithane 75DF	1-7	1 lb	33.4	43.0	12.3
Rubigan 1E + Dithane 75DF	1-7	3 floz + 1 lb	26.0	46.8	8.5
Flint 50WG	1-7	0.67 oz	4.6	7.4	1.3
Vangard 75WG	1,2	1.67 oz			
Vangard 75WG + Dithane 75DF	3-7	1 oz + 1 lb	13.5	46.2	5.5
Vangard 75WG	1,2	1.67 oz			
Vangard 75WG	3-7	1 oz + 1 lb	22.8	49.7	30.3

TABLE 4

Performance of fungicides in an SI-resistant experimental orchard (Empire) in 2003. Timing of applications (dilute) was 1, April 16 (green tip); 2, April 24 (1/2-inch green); 3, April 30 (tight cluster); 4, May 7 (pink); 5, May 15 (bloom); 6, May 22 (petal fall); 7, May 29 (1st cover). The first infection period was on April 21.

			Scab incidence (%)		
Fungicides	**Timing**	**Rate/100 gal**	**Cluster leaves (June 14)**	**Terminal leaves (August 20)**	**Fruits (August 20)**
Untreated check			8.8	64.3	77.5
Dithane 75DF	1-7	1 lb	2.5	7.0	6.0
Dithane 75DF	1,2,5	1 lb			
Dithane 75DF + Nova 40W	3,4,6,7	1 lb + 1.5 oz	1.5	9.8	12.5
Dithane 75DF	2-7	1 lb	9.8	8.0	32.0
Dithane 75DF	1,2,5	1 lb			
Sovran 50WG	3,4,6,7	2 oz	0.0	1.5	0.5
Scala 60SC	2,3 4-7	3 fl oz 1 lb	1.8	11.0	12.0

mixture with another scab fungicide. The current anti-resistance strategy recommended by the strobilurin manufacturers and enforced in product labels is to limit the number of strobilurin applications to a maximum of four per season. This number might be too high to sustain the potency of strobilurins over many more seasons. At present, we recommend to use strobilurins when conditions demand after-infection activity in addition to a strong forward protection of leaves and fruits, and to restrict the number of strobilurin scab sprays per season to less than the four currently allowed applications. We also have good evidence that the transition from gradual sensitivity shifts to full immunity will be slowed when strobilurins are used at their highest label rates.

Anilinopyrimidins. The AP cyprodinil (Vangard) was introduced in 1999, and the AP pyrimethanil (Scala) will become available in 2005. Both APs provide up to 48 hours after-infection control of scab, but they lack activity on apple diseases other than scab. Both of these features are reflected in their product labels. APs used alone are only recommended for pre-bloom applications. Mixtures at lower rates with unrelated fungicides are allowed in later than pre-bloom applications.

In our testing of orchard sensitivities, we noticed that the AP sensitivities varied widely in commercial orchards where APs had never been used. We found that some of this variation was dependent on the status of SI resistance. Many SI-resistant individuals of the scab fungus were also less sensitive to the APs, suggesting that SI-resistant orchards can be less sensitive to the APs even before these fungicides were used for the first time.

Our 'McIntosh' and 'Empire' test orchards at the Geneva Station provided an opportunity to test the efficacy of APs in SI-resistant orchards. The recommended Vangard program was tested in our 'McIntosh' orchard (Table 3). Vangard was used alone up to 'tight cluster', followed by the recommended mixture of Vangard plus Dithane. The Vangard program improved the control of scab on cluster leaves and fruits slightly above the level achieved with Dithane alone. The relative contribution of Vangard for control of scab was tested by omitting Dithane from the mixture segment of the program. The results suggested that Vangard alone provided a very low and unacceptable level of scab control. Similar results were obtained during several other seasons. The results prompted us to designate the test orchard as 'strongly shifted' to the APs (scab control must be supplemented).

Our second SI-resistant 'Empire' orchard had remained more sensitive to the APs and was designated 'slightly shifted'. Here, the first of two Scala applications was applied 72 hours after-infection, after omission of the first application at 'green tip'. The levels of cluster leaf and fruit scab control achieved were higher than for the comparatively delayed 'Dithane alone' program, indicating a benefit from the after-infection action of the AP. However, the level of control achieved was not higher than for the Dithane program initiated with a spray at 'green tip' (Table 4).

Although APs had never been used in any of the 13 commercial orchards we tested (Table 2), only four were 'sensitive' or 'slightly shifted'. All other orchards were already 'strongly shifted' or even beyond the 'strong shift' designation derived from our 'McIntosh' test orchard where Vangard was largely ineffective. This new phenomenon of 'shifted sensitivities' prior to the use of a new class of fungicides might pose a future problem. Orchards where scab has developed resistance to several classes of fungicides may not be fully sensitive to a new class of fungicides before it is used. The variable performances of APs might be an example for this future challenge.

In New York, AP fungicides could find their best fit in the management of scab when after-infection activity is required in the early pre-bloom period. Unfortunately, respective AP activities are not expected to be sufficient in many orchards, and mixtures of APs with other fungicide will become important in order to supplement their performance, even in pre-bloom applications.

Management of Fungicide Resistance

Multiple resistance of the scab fungus to several post-infection fungicides has become a reality in New York. Although we have learned to cope with resistance in the past, our management strategies have only responded to control failures after they became evident. Unfortunately, the growers affected first had to shoulder the economic impact of control failures they could not foresee. This purely reactive practice of managing resistance to fungicides is both unsatisfactory and unsustainable.

To avoid the risk of crop losses caused by resistance, we need to develop tools that will allow the continued use of post-infection fungicides and, at the same time, protect apple growers from crop losses caused by unexpected outbreaks of resistance. The periodic measurement of orchard sensitivities to all fungicide options can provide reliable predictions. As noticed previously and confirmed in our recent survey, both the pattern and magnitude of resistance to scab fungicides is different from orchard to orchard. Therefore, resistance management must become a site-specific rather than a regional endeavor.

Orchard-specific measurements of resistance levels will have to be combined with reliable management alternatives. Unfortunately, all past strategies of resistance management – replacing one fungicide class with a new class, mixing post-infection fungicides with a protectant fungicide, or applying certain fungicide classes at high doses – have not accomplished the goal of protecting apple growers from sudden and unexpected crop losses.

Where do we go from here? At present, there are two solutions to the problem of fungicide resistance in the control of apple scab. Growers can revert to exclusive use of protectants (mostly EBDCs and captan), or they can implement site-specific management of resistance in order to adjust scab management programs before control failures become imminent.

The option of abandoning reliance on any of the post-infection fungicides would not be without consequences. As described above, sole reliance on nonspecific protectants will be 'unforgiving' when protective applications in advance of infection periods are missed. In addition, both captan and the EBDCs have been under continuous toxicological scrutiny as 'B2 carcinogens' (probable human carcinogens). They may be further restricted in order to protect pesticide applicators, orchard workers and consumers. Some apple buyers may be unwilling to accept fruit treated with these fungicides.

Under the 1996 FQPA mandate, captan was granted a Re-registration Eligibility Decision (RED) by EPA in 1999 and remains available for the management of apple scab. EPA is currently in the process of amending the RED for captan, which might downgrade (but not eliminate) the cancer risk associated with captan. For the EBDCs, the metabolite ETU, which is common to all EBDC products, has been affiliated with carcinogenic risks. The RED for EBDCs should be issued in 2005. Although EBDCs will probably remain available for use in apple production, some label changes might be imposed as a result of this most recent label review.

The critical scab management question for the immediate future is this: when and under what circumstances can apple growers rely on post-infection fungicides to stop scab when a protective spray was missed or its expected efficacy eroded during extensive rain? As apparent from our recent orchard survey, in two of the 13 orchards we tested (orchards 5 and 13), current post-infection choices are few, but in 11 orchards, some post-infection fungicides remain as viable alternatives to protectants. The question of which post-infection fungicides are expected to provide good scab control can only be resolved by measuring the level of resistance to all options available. Based upon this knowledge, management programs can be designed to use all active fungicides to their best advantage. Utilization of several viable classes of fungicides over a single season will prolong the useful lifetime of each class used because the speed of resistance development will be slower when such fungicides are used less frequently.

Our new sensitivity test was designed to accomplish the goal of measuring fungicide sensitivities in individual orchards. Once the sensitivities are known, the information can be used to predict the site-specific risk of control failures before they happen. Our limited experience with this site-specific management of resistance (SMOR) has been positive. Several growers managing the orchards described in Table 2 had experienced poor scab control or control failures after they had applied fungicides to which the scab fungus had become resistant. In those orchards, management changes based on the knowledge of orchard sensitivities to all fungicide options has restored effective scab control.

We plan to further develop SMOR as a service available to apple growers in New York. The costs for this service will have to be defrayed by the growers requesting the service, but the potential savings by avoiding unexpected crop losses caused by sudden and unexpected outbreaks of resistance would outweigh these costs. Major hurdles such as current uncertainties regarding the laboratory and organizational infrastructure required for conducting the sensitivity tests will need to be overcome before the service can be fully implemented.

Conclusions

Fungicides that allow post-infection management of apple scab have become valuable tools in the commercial production of apples. Unfortunately, the progress made has coincided with the emergence of resistance and the risk of sudden, unexpected and costly crop losses. We found that fungicide-resistant orchards remained resistant over several decades. This robustness of resistant individuals of the scab fungus makes it difficult to predict all levels of resistance in an individual orchard. Equally disturbing is the fact that multiple rounds of resistance development might have resulted in some orchard populations of the scab fungus that are now 'trained' to evade new fungicide challenges more quickly than in the past.

The current status quo might sound discouraging. Although apple growers in New York have the choice among nine scab fungicides with post-infection activities, only a fraction of these choices will provide reliable scab control because durable resistance to one or more of these options exists in many orchards. The options for managing scab without risking control failures are either the complete reliance on protectants or the site-specific management of resistance (SMOR) based upon measurements of sensitivities to all post-infection options available. Utilizing all available scab fungicides in full awareness of their limitations and their benefits will be the key to reliable control of apple scab in the future.

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Growing Blueberries in Cold Climates

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Growing blueberries in cold climates presents growers with many challenges due to low temperatures, fluctuating temperatures, and low moisture. Timing and severity of injury varies, but there are ways for growers to reduce crop damage in cold climates.

It is tempting to assume that the presence of wild blueberry plants in a locality is a good indicator of success for their commercial cousins (Figure 1). However, just because wild plants grow in an area does not imply that cultivated plants will thrive. The large amount of genetic diversity in wild plants allows particular types to survive in some unbelievably harsh habitats, from windswept rocky roosts to boggy bottoms. Commercial varieties, though very stress tolerant, usually do not have the resiliency to tolerate exceptional conditions. Breeding advances have increased tolerance to some extent, but special considerations must be made to produce fruit superior to wild berries using currently available cultivars in cold climates.

Low temperatures present a significant challenge, not only because of the direct effect of cold on the plant, but due to the indirect effect of the reduction of moisture availability. Extremely cold temperatures, coupled with high winds, can desiccate buds and kill plant tissue. Few woody plants of any species can tolerate temperatures below -40°F. The hardiest blueberries will be damaged below -20°F, unless they are covered with snow. Growers living in climates where the mid-winter low temperature consistently approaches -20°F should plant only on sites that have good air drainage, and use only hardy varieties such as Patriot, Jersey and Northland. Low-statured half-high varieties (e.g. Northblue) can also be successful in cold climates because plants are frequently covered with snow that protects against desiccation in mid-winter. In Quebec, varieties that tend to produce fruit on lower branches, such as Duke and Reka, are often successful, even though they are not particularly hardy, because lower branches are usually protected by snow during extremely cold weather.

In addition to low temperature extremes, fluctuating temperatures can be damaging as well. Once the chilling requirement has been met, buds are able to grow when the weather warms. The first step in the growth process is for free water to move into the cells and vascular system at the base of the buds. If the temperature drops suddenly and the water freezes, the bud will expand and the ice may rupture cell walls and disrupt vascular connections. The result can be permanent damage to the bud even though visible damage may not show up until late spring when rapid growth begins. Avoid planting on a steep southern exposure as this location can exacerbate temperature fluctuations. Researchers in Michigan have been recording the hardiness of blueberries after exceptionally cold winters, and after severely cold springs. The ranking of varieties differs considerably between years, indicating that varieties tolerant of severe cold in winter are not necessarily tolerant of fluctuating temperatures in spring. Late-fruiting varieties are more tolerant of spring frosts than the typically winter-hardy varieties.

Woody plants growing in cold climates often have many of the same adaptations as desert plants (thick leaves, narrow vessels, small stomata, ability to store salt in leaves), because the fundamental problem in both climates is the lack of water. In the desert it does not rain; in cold climates during winter, the soil water is in the form of ice and the air is exceptionally dry. Blueberries have several adaptations that allow them to tolerate a relatively large amount of water stress and desiccation. Despite these adaptations, adequate soil moisture is necessary during the growing season in order to realize a reasonable yield. It is also important to make sure that plants are well irrigated going into the winter to compensate for inevitable water loss that occurs when temperatures and humidity fall. Preventing desiccation by using windbreaks can also help minimize winter damage. Some growers use a floating

Figure 1. This blueberry plant appears to be a natural hybrid between lowbush (*Vaccinium angustifolium*) and highbush (*V. corymbosum*) blueberry and is growing in the Adirondack Mountains in a very cold region of New York State.

Figure 2. Overwintering half-high blueberries under a floating row cover in Minnesota.

Figure 3. Raised beds help prevent stunting and disease development in wet sites.

Figure 4 (left). Phomopsis canker often infects plants through winter-injured wood.

Figure 5 (center). Vascular collapse of an entire cane on a young plant infected with Phomopsis canker.

Figure 6 (above). Cold temperatures during winter have killed the floral buds.

row cover over half-high blueberries to increase survival in cold climates (Figure 2). Excessive nitrogen fertilizer or late applications can make plants susceptible to cold temperatures too. Balanced nutrition, determined with a foliar analysis, will help ensure that plants have the capacity to harden properly as winter approaches.

Mulches help conserve moisture and protect roots when snow cover is absent. Mulch is particularly important for young plantings that have not yet established a strong root system, as it prevents extreme temperature fluctuations in the soil. Repeated soil freezing and thawing can heave out new blueberry plants, causing a significant economic loss. This will most likely occur with fall planting.

Excessive soil water can be problematic as well, particularly when roots are growing. Root growth involves respiration, which in turn, requires oxygen from the surrounding air pockets in the soil. If air spaces are filled with water, then no oxygen is available and roots accumulate toxic metabolic waste. Flooded or saturated soil brings a risk of oxygen starvation. Although 60°F is optimal for root growth, roots grow at temperatures as low as 43° F. So, even if the plant appears to be dormant, some root growth may be occurring. If the soil is flooded in fall when the plant is attempting to move starch and nitrogen compounds in to the roots for winter storage, then plant growth the following spring may be compromised. Installing drainage or planting on raised beds can be good practices for blueberries, even though they are less prone to soil diseases as some other fruit crops (Figure 3).

It is unusual for a mature blueberry plant to die suddenly from cold temperature injury; the decline is most often gradual. First, shoot growth is reduced and, as a result, a low number of floral buds are produced on the shoots. Since the floral buds are formed at the tips of shoots, and winter injury always starts at the tips and works down, the first buds to die are flower buds. Vegetative buds are hardier than floral buds. Blueberries growing in cold climates may exhibit reasonable vegetative growth, but little fruiting. Winter-injured blueberry plants are susceptible to cane diseases, particularly Phomopsis canker (Figure 4). This fungus can invade canes through dead buds and further weaken the plants. But even without canker, repeated winter injury will result in poor shoot growth and low yields.

A second level of winter injury occurs when plants appear to be healthy in spring, but shoots suddenly collapse and die when the weather warms significantly. Although Phomopsis canker can cause these symptoms (Figure 5), they also may be due to vascular collapse as previously injured vascular tissue is unable to support the rapidly growing shoot. Active connections are too few, so the shoot wilts, despite what may be abundant water in the soil.

A third level of injury occurs when the temperature drops low enough at the wrong time of the year so that both floral (Figure 6) and vegetative buds are killed. Although new canes will usually develop from buds below the ground, injury of this degree will set back the planting by several years.

Growers with established plantings can minimize winter injury with windbreaks, and ensure that nutrients and water are managed properly. Planting low-statured varieties on good sites may enable growers to produce blueberries in regions once considered too cold for commercial production, particularly if row covers and windbreaks are used.

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

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

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

The Geneva High-Density Trial

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

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

TABLE 1

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

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

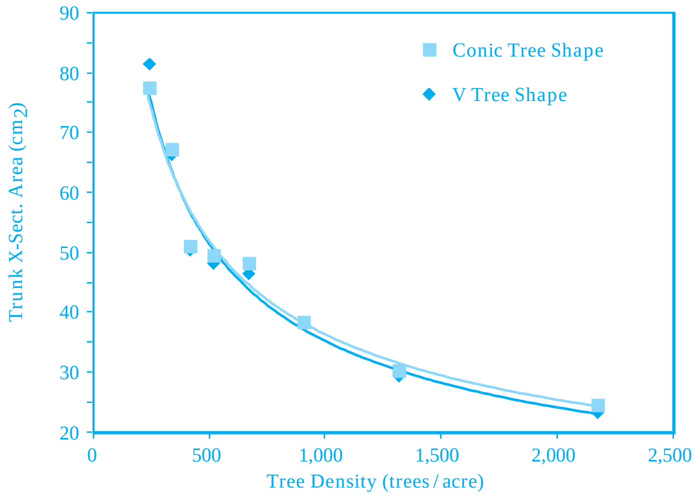

Figure 1. Effect of tree density on trunk cross sectional area after seven years of four apple varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY.

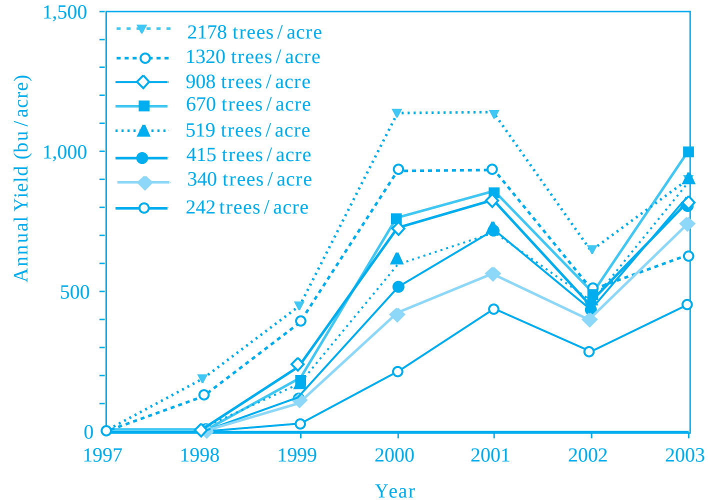

Figure 2. Annual yields of eight planting densities with four varieties (Empire, Gala, McIntosh and Fuji) over the first seven years of the orchards life at Geneva NY.

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

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

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

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

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

Results for the First 7 Years

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

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

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

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

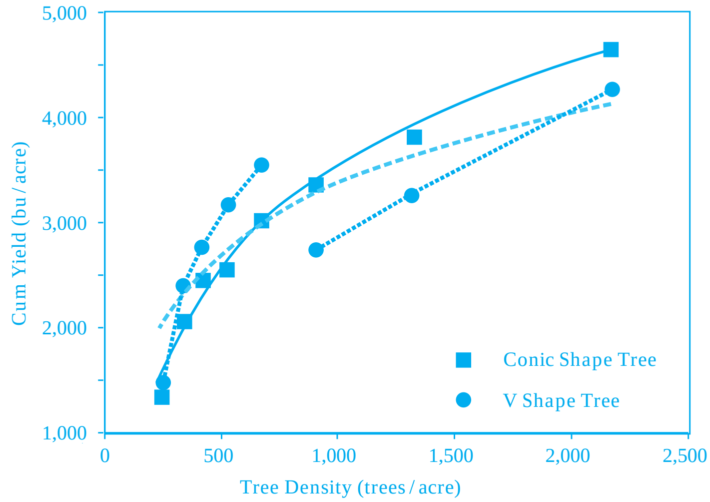

Figure 3. Relationship of tree density and cumulative yield over seven years with two tree shapes and four varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY. Solid line and dashed line are the regression relationships for the conic and V shapes, respectively. The dash/dot line shows the two distinct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

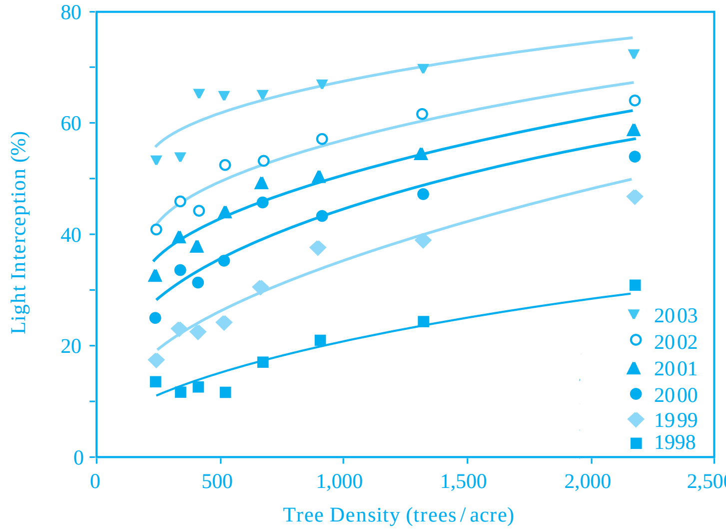

Figure 4. Relationship of tree density and light interception of Empire apple trees on Sept. 1 for each of six years at Geneva NY.

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

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

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

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

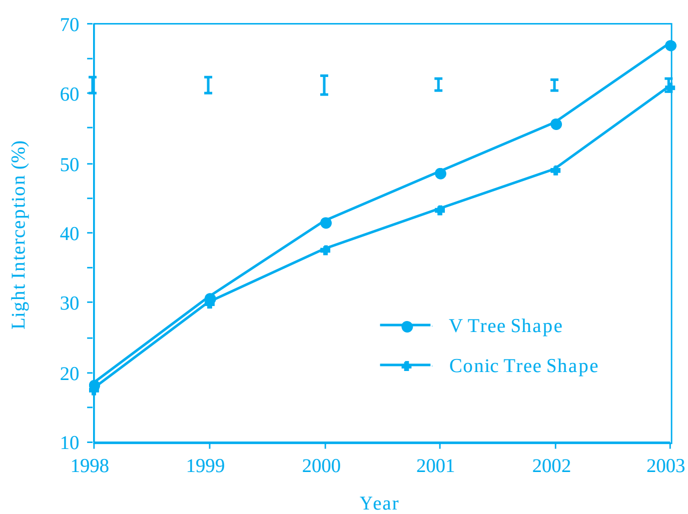

Figure 5. Annual light interception of conic and V shaped Empire apple trees averaged over eight planting densities (598-5,382 trees/ha) for the first seven years of the orchard's life at Geneva NY.

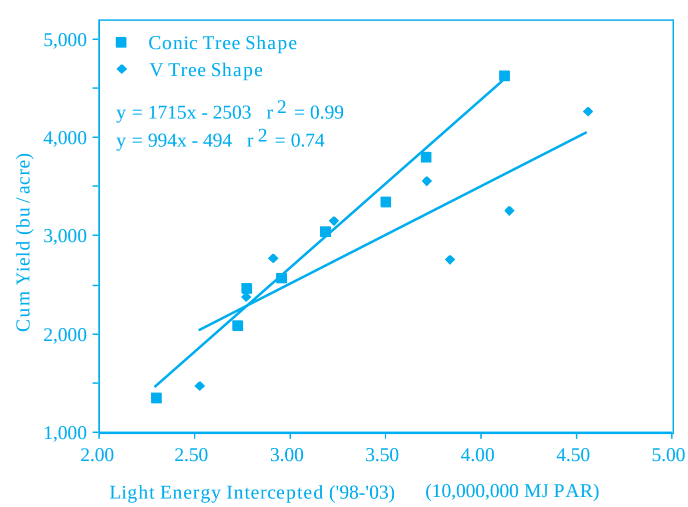

Figure 6. Relationship of 6-year (1998-2003) cumulative light interception and cumulative yield of Empire apple trees with two tree shapes at Geneva NY.

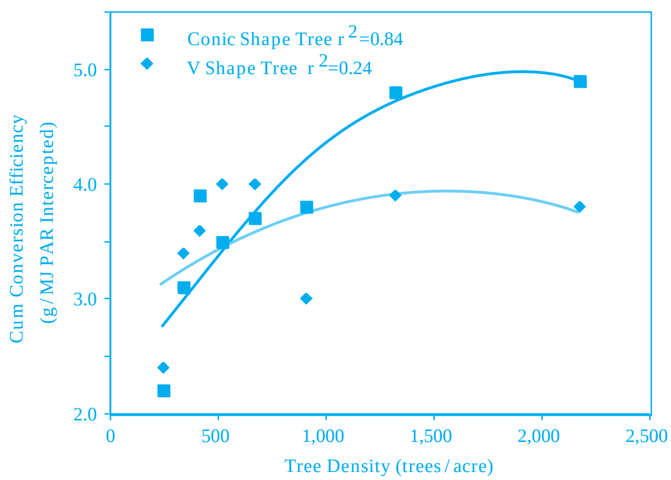

Figure 7. Relationship of tree density and cumulative light conversion efficiency of Empire apple trees over seven years with two tree shapes at Geneva NY.

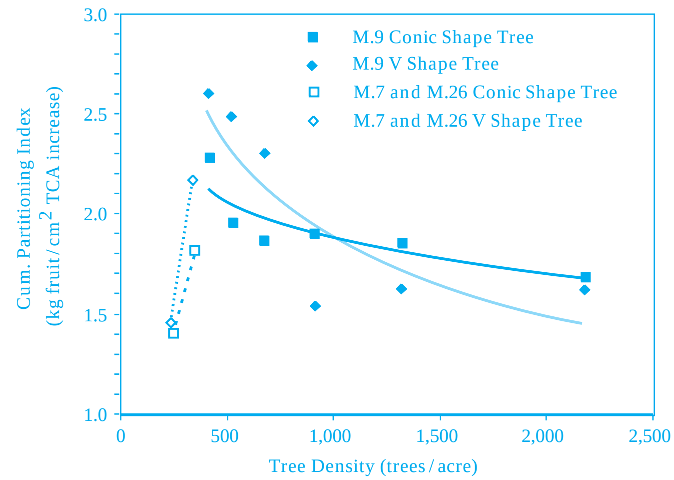

Figure 8. Relationship of tree density and cumulative partitioning index over seven years with two tree shapes and four varieties (Empire, Gala, McIntosh and Fuji) at Geneva NY. Trees on M.7 and M.26 were not included in the regression analysis.

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

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

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

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

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

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

Discussion

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

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

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

Summary

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

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Field Performance of Grafted and Seedling Chestnuts in New York

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Chestnuts may be a crop worth investigating for NY growers looking to diversify. Several considerations must be examined before embarking in this new direction. This report discusses various cultural practices of interest.

American chestnut (*Castanea dentata*) was once a dominant tree in forests of the Eastern US, where its small but flavorful nuts were an important food staple for wildlife, Native Americans and subsistence farmers. A devastating blight caused by the fungus *Cryphonectria parasitica* was introduced accidentally from Asia into North America around 1900 on trees imported by plant breeders seeking to improve nut quality of the American chestnut through hybridization with its Asian cousins. Chestnut blight decimated our native trees in just 50 years because they had never been exposed to the pathogen and had no genetic resistance to it. Fortunately, the Asian chestnut species (*Castanea mollissima* and *C. crenata*) are resistant to this disease. With European chestnut *(C. sativa*) stands now slowly succumbing to chestnut blight, the Asian chestnut species will continue to provide an important nut crop worldwide.

As fruit growers in the Northeast look for alternative crops for profitable niche markets, there has been renewed interest in chestnuts. Domestic production in the US is small, and most of our $20 million annual market demand is met by chestnuts imported from China, Korea, and Europe. Growers are planting chestnuts from the Southeast to the Pacific Northwest, and there are several chestnut orchards in the Finger Lakes and Hudson Valley regions of NY. Besides a potential cash crop to market, chestnut growers can expect other less tangible benefits as well. Nut trees require fewer inputs than most other fruits, and can be grown in pastures or woodlots that might otherwise not produce a marketable crop. Chestnut wood is highly resistant to decay and can be used instead of pressure treated pine for fence posts and similar purposes. Other benefits are enjoyed by those who plant a small grove of chestnuts for the sake of their pungent flowers, interesting foliage, and wildlife observation or hunting opportunities during autumn.

Because chestnuts are strictly a minor crop in the US, little horticultural information is available to assist growers in successful nut production. Those currently growing or interested in planting chestnuts often have trouble finding answers to basic horticultural questions because little research has been done on this crop in North America. This report describes our attempts to answer some of these basic preliminary questions about the feasibility of chestnut production in the Northeast.

Experimental Procedures

What varieties are best for our growing conditions? After a thorough review of the published information and available sources for chestnuts by Cornell graduate student Miranda Kahn, we selected six cultivars that appeared to be well suited to our climate in Upstate NY, and were available both as grafted and seedling trees. The six commercially available chestnut cultivars, included 'Mossbarger' (*Castanea mollissima*), 'Douglas 1A' (*C. mollissima* X *dentata*), 'Eaton' (*C. mollissima* X (*crenata* X *dentata*)), 'Skioka' (*C. mollissima* X *sativa*), 'Layeroka' (an open pollinated seedling of 'Skioka'), and 'Grimo 142Q' (an open pollinated seedling of 'Layeroka'). These cultivars and their seedling progeny were chosen because they represented a sample of commercially available cultivars thought to have enough cold tolerance and blight resistance to survive in our region. They were also available in adequate numbers of both grafted and seedling trees, a requirement for meeting our other objectives of comparing grafted and seedling tree performance, and estimating heritability in these chestnuts. We planted 25 grafted and 25 seedling trees of each variety in five randomized replicate plots each containing five trees, for a total of 300 trees. Within each plot of five trees, two were pruned and trained to an open-center form and two as central leader trees, while one tree was left unpruned and untrained.

Is it better to plant grafted or seedling chestnuts? With most fruit crops, commercial growers plant trees that are propagated by grafting mature budwood onto rootstocks, because grafted trees will be "true-to-type" and begin to bear fruit sooner than seedlings. Grafted trees are "clones" or genetically uniform populations, their performance is usually more predictable and consistent than that of seedlings. However, with chestnuts the situation is more complicated than with other fruit and nut species. One of these complications is that grafted chestnut trees cost much more than seedlings (about $20 vs. $3 per tree). Also, in the US there have been problems with delayed graft incompatibility in chestnuts that causes stunting or death of grafted trees during their early years in the orchard. This problem may be caused by genetic incompatibilities between seedling rootstocks and some chestnut cultivars. It could also result from improper grafting techniques that are complicated by the vascular anatomy of chestnut twigs, which develop cambium in discrete arched units rather than a simple circle around the stem. There are also unanswered questions about the relative vigor of grafted vs. seedling chestnuts that need to be answered in order to determine the optimum tree spacing that will allow enough row space for each tree in the mature planting.

To evaluate the trade-offs between planting costs and tree performance of grafted vs. seedling chestnuts in our experiment, we obtained trees of six cultivars that were grafted onto their own seedling rootstocks (to avoid genetic incompatibility). At the same time, we obtained seedling trees grown from these six cultivars. By comparing the performance of grafted cultivars with that of seedling trees grown from nuts of each grafted clone, we hoped to learn which of these six cultivars performed best in NY, which of them had problems with graft incompatibility, and whether some of the cultivars could produce seedling trees of comparable horticultural quality to their parents.

Another objective of our study was to estimate the extent to which important horticultural traits in chestnut are passed on from parent cultivars to their seedling progeny. Geneticists call this characteristic "heritability." Cultivars with high heritability can impart many of their desirable horticultural traits to their offspring, and are excellent candidates for selective breeding. They are also "good parents" that are likely to produce seedling trees with the desirable traits of their parents—such as yield precocity and efficiency, good nut size and quality, disease and cold resistance. Knowledge about the heritability of chestnut cultivar traits thus has practical implications for nut growers trying to decide whether it is worth making the extra investment in grafted trees. If some chestnut varieties reliably produce open-pollinated seedlings that closely resemble their mother tree, then growers could save money and avoid graft incompatibility problems by planting inexpensive seedling trees from parent varieties that have demonstrated high levels of heritability for essential horticultural traits.

Where can chestnuts be grown in the Northeast? We located the study at a Cornell research farm near Lansing NY that provided favorable conditions for chestnuts—a somewhat acid soil, good soil and air drainage, a moderating Cayuga Lake effect, and southwest facing slopes. Previous research by Miranda Kahn with seedlings in controlled environment growth chambers had shown that chestnuts would grow and produce best in sites with about 3000 Growing Degree Days (GDD base 50°F); so good exposure to afternoon sun and heat are important for this crop in our region. Chestnuts bear on flowers that bloom in early July upon current year shoots. Considering how late in the season they begin to develop with our short growing season in the Northeast, chestnut varieties that mature too late in autumn may be damaged by frost before their nuts mature. A lake-moderated site that extends the frost-free season will be beneficial for chestnuts, as for wine grapes or late ripening apples like 'GoldRush,' 'Cameo' and 'Fuji.'

How should chestnut trees be managed? Another important management question for chestnuts, pruning and training system, is also one of the least studied. Chestnuts bear on flowering laterals that develop in axillary buds on vigorous shoot growth from the previous year; so mature trees usually fruit mostly in the outer canopy margins. Hence the most productive part of mature chestnut trees is usually an outer layer of the canopy, surrounding an unproductive inner tree volume. Pruning and training systems that increase light penetration into the canopy might increase the proportion of productive wood in chestnut trees. By forming a smaller more open-center tree, such a training system could also improve pest control efficacy. In this study, we evaluated two pruning/training tree-forms—open center, and central leader—for five years during establishment of the planting. We also monitored insect pests and diseases to determine whether they could be adequately controlled.

Our experiment enabled us to make comparisons between grafted and seedling trees, among grafted varieties, among seedling varieties, and among pruning/training systems across varieties. We collected data on the following traits: 1) dates of bud break, bloom, fruit set, and nut ripening for each variety; 2) tree age at first flowering and fruiting; 3) productivity (number and size of nuts); 4) consistency of bearing from year to year; 5) tree mortality and damage from winter cold, insects and pathogens; and 6) tree vigor and form. Nutritional status and fertilizer responses were assessed by leaf analysis. The trees were obtained from commercial nurseries and planted by hand in mid-April 1995, in north-south rows on a west-facing slope close to Cayuga Lake. Tree spacing was eight meters (26.2 ft) between rows and three meters (9.8 ft) within rows. Deer protection was provided by a high fence around the orchard, and trees had plastic mesh trunk guards to protect them from meadow voles and rabbits. Weed and insect control consisted of glyphosate herbicide applications in the tree row during May and July, and carbaryl insecticide applications during June and July. Trees were drip-irrigated as needed.

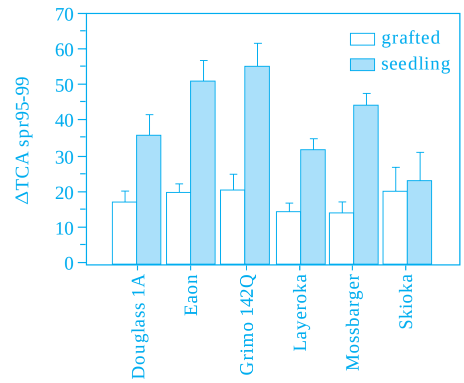

Figure 1. Cumulative increase in trunk cross-sectional area (cm^2) of six chestnut varieties as grafted or seedling trees, during five years of growth after planting in 1995. Values are means of five replications ± SE of means.

Results

Cumulative tree growth and mortality. During five years of observations, tree growth was not significantly different among the grafted cultivars, but among the seedling lineages, trees of 'Douglas1A,' 'Layeroka' and 'Skioka' were smaller than the others (Figure 1). Average trunk cross-sectional area was about twice as great for seedling trees compared with their grafted parents, and this trend was consistent for all lineages except 'Skioka.' There were also major differences in cumulative tree mortality among the cultivars and their seedlings (Figure 2). The lowest mortality rates after five years were for seedlings of 'Eaton' and 'Grimo 142Q' (both 4%), while the most tree losses occurred for grafted 'Skioka' (71%) and its seedlings (40%). For 'Douglas 1A,' 'Eaton,' 'Grimo 142Q,' Mossbarger,' and 'Skioka,' the mortality rates were two to three times greater for grafted cultivars compared with their seedling progeny.

Nut yields and quality. The grafted trees all produced some nuts in the second and third years after planting (1996-97), while seedling lineages produced only a few nuts in those early years. From the fourth year onward, both grafted and seedling trees have produced a marketable crop of nuts annually. Surprisingly, seedlings of 'Grimo 142Q' produced more nuts per tree than their grafted parent cultivar. In general, the cultivars that were more productive as grafted trees—such as 'Mossbarger,'

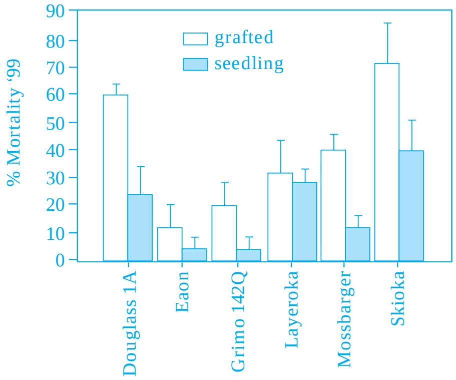

Figure 2. Cumulative mortality (percent) of grafted and seedling chestnut trees of six varieties, after five years growth. Values are means of five replications ± SE of mean.

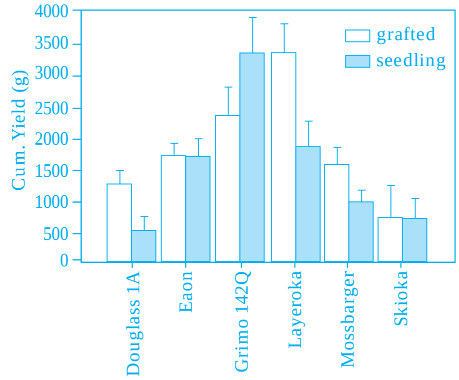

Figure 3. Cumulative yields (average grams of nuts per tree, dried to 15% moisture content) of six grafted and seedling chestnut varieties during the first five years of growth. Values are means of five replications ± SE or mean.

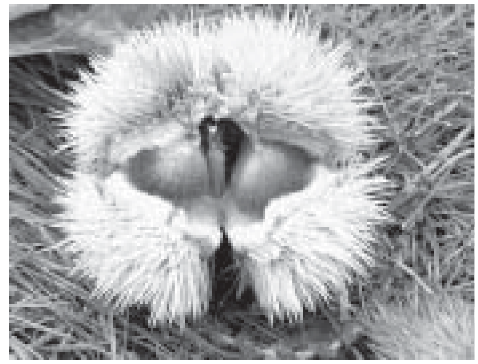

Figure 4. As chestnuts ripen, they expand rapidly and burst open the protective burr that surrounds them during summer as they develop. Each burr usually contains three nuts, but only one or two of them develop to maturity. These chestnuts are ready to harvest.

'Layeroka,' Grimo 142Q' and 'Eaton'—were also relatively productive as seedling trees. Heritability of the early yielding trait in these cultivars appeared to be quite high. Considering the cumulative yields of grafted and seedling trees for each cultivar, dry-weight nut production was greatest for seedlings of 'Grimo 142Q' and grafted trees of 'Layeroka' (Figure 3). Yields were equivalent for seedlings vs. grafted trees of 'Eaton' and 'Skioka,' and relatively low but greater for grafted trees of 'Douglas 1A' and 'Mossbarger.' Yield efficiency (nut yields per unit of trunk cross-sectional area) was several times greater for all of the grafted cultivars compared with their more vigorous seedlings (data not shown), even though total yields per tree were actually less for some grafted cultivars (Figure 3). Average size and dry weight per nut were slightly greater (4 vs. 6 g dry weight per nut) on grafted vs. seedling trees in the early bearing years. However, by the fourth and fifth years average nut weights were statistically similar for grafted and seedling trees, ranging from 8 to 12 g dry weight per nut. Nut size was somewhat greater on the lower yielding cultivars (e.g. 'Douglas 1A') and reduced on the heavier yielding trees. The values recorded for nut yields were for nuts dried to about 15% moisture content, to correct for differences in fresh weight values caused by rainfall during harvest time. Fresh weight values for nuts were about four times greater than dry weights, so the values in Figure 3 can be multiplied by a factor or four to estimate marketable fresh weight nut production per tree.

Discussion

Grafted cultivars generally did not provide more uniformity or consistency of yield and nut quality than their seedlings for the variables that we measured. Considering the higher costs and greater mortality of grafted trees during establishment years, there appears to be little financial reward that would justify the greater costs and risks of planting grafted chestnuts—if growers can obtain seedling trees of varieties such as 'Eaton,' 'Layeroka' or 'Grimo 142Q' that performed reliably as seedling trees. Some of the differences within these chestnut lineages were surprising. For example, 'Skioka' was the worst performing variety, while its daughter 'Layeroka' was among the most productive. We were also surprised at the yield precocity of all these cultivars and seedling trees, most of which produced nuts in the second or third year after planting.

For grafted trees, planting density could probably be increased by closer spacing than our 3 by 8 meter grid for the trees in this experiment. Most of the grafted trees have barely filled their allotted space in the tree rows at the time of this report, ten years after they were planted. A problem with higher planting densities for grafted chestnuts would be that rootstock sprouts almost always replaced grafted trees that died, and those seedlings would soon overshadow the surrounding grafted trees. For seedling orchards, a planting distance of 6 by 10 meters would be appropriate, as these trees became too crowded at the 3 by 8 meter spacing in this experiment.

Responses to pruning and training systems also differed for grafted vs. seedling trees. The less vigorous grafted trees responded quite well to open-center training, developing multiple scaffolds with relatively wide branch angles and adequate light maintained in the tree center. In contrast, open-center pruning and training of the more vigorous seedling trees produced an overly dense and shaded central area, while seedling trees developed a reasonably good pyramid form that benefited from apical dominance after five years of central-leader pruning and branch spreading.

A few general comments about chestnuts may be useful in concluding this report. With respect to marketing, the demand for chestnuts is mostly among immigrants from Asia and Europe, who live in major metropolitan areas of the US. Growers should develop a marketing plan to reach these customers before investing in a chestnut orchard. We were able to sell all of the chestnuts from our experiment for $3 per pound at a Cornell Horticulture Department's retail produce market that serves a diverse consumer base, but many of our local customers needed instruction in how to prepare chestnuts for cooking.

As our planting matured, a resident population of the chestnut-oak curculio weevil developed. This pest is native in oak acorns and fed on the American chestnut before it was decimated by blight. The chestnut weevil has a long snout and ovipositor that enable it to puncture the thick spiny integument or "burr" that protects developing chestnuts. It deposits eggs in the interior nutmeat, where they hatch in August and partially consume the nutmeat before over-wintering as inactive larvae. It is difficult to detect curculio egg-laying damage in harvested chestnuts, and some of our customers were not pleased when they spent a considerable time peeling and preparing chestnuts, only to discover weevils inside some of them! Several well-timed insecticide sprays during July and early August may be required to control this pest in established chestnut orchards. Other than occasional European red mite flare-ups and gypsy moth infestations during some years, there were no serious insect or disease problems with our planting during this experiment.

Perhaps the greatest challenge in growing chestnuts is harvesting your nuts before the squirrels, woodchucks, raccoons, foxes, coyotes, deer, feral hogs, or bears get them! Squirrels are the most difficult wildlife pest to control, as they climb trees and sever the stems of almost mature chestnut burrs, returning later to extract the nuts when the fallen burrs have opened on the ground. The other pests can be managed if you harvest nuts every few days over the one to two week period between late September and mid October when most chestnut varieties reach harvestable maturity in NY. Chestnuts increase rapidly in size and change color from creamy white to light brown as harvest time approaches, carbohydrates convert to soluble solids and the nuts absorb water and fill out (Figure 4). During this maturation phase the nuts burst open their protective spiny covering, and within a week or so the mature nuts will drop to the ground. There is a brief window of opportunity at this time, when a picker with sturdy gloves can pull off or shake down the opening chestnut burrs and extract the one to three nuts that each contains. Once those nuts pop out of the open burrs and fall on the ground, they are difficult to find. They may also become soiled, water soaked and more prone to mold in storage, and are soon devoured by appreciative local wildlife.

Researchers in Michigan have tested pre-harvest Ethephon treatments and cherry-tree shakers as mechanical methods for harvesting chestnuts, with encouraging results. For tart cherry growers with the necessary equipment, growing chestnuts could be an option for niche markets. Otherwise, harvest labor could be a prohibitive part of production costs—especially if northeastern growers are competing with chestnut growers in China to serve the relatively limited US market for this crop.

For long-term storage, chestnuts can be disinfested with a dilute Clorox solution, and stored in airtight containers under refrigeration. Alternatively, they can be dried down to about 15% moisture content in a dehydrator or spread out in trays on a greenhouse bench. Dried chestnuts can be stored for months in airtight bags under refrigeration, but they must be boiled and rehydrated before they can be consumed or used in most recipes.

There are many economic and horticultural challenges to growing chestnuts in the US, Growers interested in a niche market fruit crop with a long history in our region, a high market value, and many delicious uses ranging from traditional turkey stuffing, to bread, cookies or elaborate French pastries, or just those nostalgic "chestnuts roasting on an open fire," might consider chestnuts. There are some good chestnut varieties available from commercial nurseries. They establish quickly and produce well in a good orchard site, grown either as grafted trees or seedlings of several varieties.

Further Reading

The Northern Nutgrowers Association meets annually in the region and publishes an informative newsletter and proceedings of their meetings. Dr. Sandra Anagrostakis **(Sandra.Anagnostakis @po.state.ct.us)** is a chestnut expert and breeder at the Connecticut Agricultural Experiment Station, and has many useful scientific and general-interest publications about chestnuts available by request. Greg Miller is a chestnut breeder and owner of the Empire Chestnut Company and nursery in Carrollton, OH. His webpage **(www.empirechestnut.com)** has excellent information and other links to relevant sites and sources for chestnut growers. The standard textbook for chestnuts and other nut trees (the Handbook of North American Nut Trees, published by R. Jaynes in 1969) is out of print but still available in many libraries. Several dozen commercial nurseries sell grafted or seedling chestnut trees, and a quick Google search will yield their contact information and catalogs.

Summary

In this project we investigated some practical questions about edible chestnut production in New York. Specifically, we wanted to know which chestnut varieties or lineages would perform best under NY growing conditions, and whether it was more economical to grow inexpensive seedling trees or more expensive grafted trees of known chestnut cultivars. We began the experiment in 1995, planting six clonal (grafted) cultivars, and six groups of seedling trees grown from nuts of each grafted cultivar. We compared a number of different traits among the six varieties and their seedlings, including: 1) tree age at first bearing, 2) nut production and quality, 3) cold hardiness and tree survival, 4) pest problems, and 5) tree vigor and form. The grafted trees began fruiting in the second year and produced more nuts per unit of trunk cross-sectional area (higher yield efficiencies). They suffered greater mortality during the first five years, however, up to 70% losses for one cultivar ('Skioka'), compared with less than 10% mortality rates for most of the seedling lineages. Cumulative yields per tree were best for 'Eaton,' seedlings of 'Grimo 142Q,' and grafted trees of 'Layeroka.' Nut size and quality were similar for grafted cultivars and their seedling progeny, and the seedlings came into production a year later than their grafted parent trees. Chestnut curculio weevil was the main pest problem, although wildlife such as squirrels, woodchucks and deer could also be a problem unless the nuts are harvested before they fall to the ground. Grafted trees responded well to open-center pruning and training, while the seedling trees were easier to manage as central leader trees. Grafted trees were about 40% smaller than their seedling progeny after 10 years. We concluded that growers could successfully produce chestnuts in upstate NY regions with lake-moderated climates. Inexpensive and hardy seedlings of chestnut cultivars such as 'Grimo 142Q,' 'Eaton,' 'Layeroka,' or 'Mossbarger' may be more economical than, and equally productive as grafted trees under our growing conditions. Harvesting chestnuts is very labor intensive, and marketing them will require careful development of a niche customer base in major metropolitan areas of the Northeast.

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