SUSTAINABLE AGRICULTURE RESEARCH AND EDUCATION (SARE) PROGRAM AND AGRICULTURE IN CONCERT WITH THE ENVIRONMENT (ACE)

FINAL REPORT -- SECTION II

Project Number: LNE88-01/ANE92.16

Project Title: Development of a Sustainable Apple Production System for the Northeast

1. OBJECTIVES

Develop sustainable apple production systems in the Northeast using scab-resistant apple cultivars and integrated pest management techniques.
Provide economic analyses of sustainable production systems and forecast impact on the Northeast apple industry.
Expedite research and information transfer on sustainable apples production systems for the Northeast.
Compare potential impacts of conventional, agrochemical-intensive pest management with alternative Integrated Pest Management practices upon soil, water, wildlife, and beneficial fauna in the orchard agroecosystem and upon human resources.

2. ABSTRACT

ØProbably the most important accomplishment of the Northeast SARE Apple Production Project was the extensive evaluation of how scab-resistant cultivars (SRCÕs) could contribute to more sustainable production systems. Based on this evaluation of SRCs over an eight-year period, project participants compiled a list of potential benefits and limitations of using SRCs.
A complex environmental question emerged from our project after several years. We had shown that SRCs enabled 50-100% reductions in fungicide usage. But from a broader perspective, what were the off-site and long-term savings involved when the environmental impacts of pesticides in orchard ecosystems or regional food systems were considered? We conducted a thorough review of current methodologies and databases for assessing environmental impacts of different pest-control practices .Major obstacles to meaningful, holistic impact assessment were identifiedÑespecially the lack of comparable or complete databases f îor pesticide effects on key processes, species, and components of agroecosystems.
Research on IPM strategies applicable to scab-susceptible cultivars provided information that was immediately integrated into state apple IPM programs. For example, in Massachusetts, the SARE Apple Project comprised part of an overall apple program

focused on developing and implementing advanced IPM control strategies for sooty blotch and flyspeck, and research on a computer-based predictive model for timing

Ísummer fungicides was initiated and is being continued with other funding sources. In New York, fungicide timing studies showed that flyspeck on apple can usually be controlled by fungicides applied on a three-week interval rather than the 14 day interval that was previously recommended for this disease. And in New Jersey, SARE funds enabled Rutgers Cooperative Extension to expand delivery of IPM scouting and information to an increasing number of growers throughout the life of the grant.

The Management Guide for Low-Input Sustainable Apple Production was authored by SARE-project participants and published in 1990. This production guide, targeted for both large and small apple producers, included comprehensive chapters on economics, horticulture, and disease and insect management, with easy-to-understand information on the best reduced-input approaches for managing orchards. The Northeast SARE Apple Production Newsletter was the only publication in the northe nastern United States devoted to distributing the latest information on alternative apple production methods. In 1993 the Project organized a comprehensive conference/symposium titled Disease-Resistant Apple Cultivars: An Update on Horticulture, Pests, and Marketing. Attended by 60 interested growers, researchers, and extension/industry personnel, the proceedings were subsequently published in Fruit Varieties Journal . SARE project participants authored hundreds of articles in Extension newsletters and peer-reviewed Journals during the duration of the project. In addition, thousands of contacts were made via mass media and through presentations at grower, industry, and professional meetings. In 1994, outreach efforts were extended to the World Wide Web (WWW) via the ÔVirtual OrchardÕ <http://www.orchard.uvm.edu>, a dedicated WWW site for the dissemination via the Int Ïernet of information concerning all aspects of sustainable apple production.

3. SPECIFIC PROJECT RESULTS

3A. Findings and Accomplishments

Because of the breadth and diversity of the Northeast SARE Apple Production Project, it is difficult to succinctly summarize our accomplishments. Some of the project accomplishments are highlighted below. Other results have been published in citations listed at the end of this article under Additional Publications Resulting from the Project. Probably the most important accomplishment of the Northeast SARE Apple Production Project was the extensive evaluation of how scab-resistant cultivars could contribute to more sustainable production systems. By 1992, project participants were working with more than 5,000 trees of SRCs in various commercial and experimental plantings. At least 30 cultivars and numbered selections were evaluated. The greatest disappointment was that most of the cultivars evaluated had serious flaws that ¿ l i mite dtheir usef ul ness for commercial agriculture. Two of the four SRCs included in the reference planting showed a high incidence of fruit defects and have since been removed from consideration as selections that become named cultivars, thereby reducing the usefulness of the reference planting.

Based on extensive evaluation of SRCs over an eight-year period, project participants compiled a list of potential benefits and limitations of using SRCs. Individuals within the project still differ concerning the emphasis they would place on the various benefits and limitations noted below (Rosenberger, 1995), but all agree that the following summary is a fair distillation of what we learned about SRCs.

Benefits of scab-resistant cultivars:

1. SRCs need less fungicide. In northern growing regions where diseases other than apple scab are relatively unimportant, high-quality SRCs can be grown without fungicides in many sites and in most years. However,¬ i n theHuds on Vall eyof New Yo rk and other more southerly regions, SRCs may require three to five fungicide applications annually to prevent cedar apple rust, black rot (Botryosphaeria obtusa), quince rust (Gymnosporangium clavipes), bitter rot (Colletotrichum sp.), flyspeck (Zygophiala jamaicensis), and sooty blotch (a complex involving Peltaster fructicola, Geastrumia polystigmatis, and Leptodontium elatius). Even with three to five fungicide sprays per year, fungicide use on SRCs would be reduced by at least 50% compared to the minimal program required for scab-susceptible cultivars.
2. SRCs have fewer problems with mites. Fungicides have an adverse impact on mite predators. When SRCs were grown either without fungicides or with only a few summer fungicide sprays in our tests, they generally required no miticides other than the delayed-dormant oil spray each year (Bowers et al., 1995), whereas commercial orchards commonly ·receive 1-3 miticide sprays per season.

3. SRCs provide new options for niche markets. Certain SRCs have become established as niche cultivars in commercial apple production. For example, in New England, Liberty is being grown on a limited scale and successfully marketed at roadside farm-stands. Redfree has been widely recognized by progressive growers throughout the east as a viable alternative to more common summer apples such as Paulared. The numbered selection NY 75414-1 has been successfully sold at the University of Vermont Horticultural Research Center. In fact, it has become so popular there, that customers now ask for it by the name ÔSpeckles,Õ referring to the fruitÕs conspicuous lenticels. Scab-resistant cultivars may gain market share if there is significant growth in the current niche market for Ôecologically-grownÕ produce.
4. SRCs provide quality fruit for home gardeners and small-scale farmers, groups that frequently str½u g g l e to cortr ol appl e scab on convent i onal cultivars. SRCs currently available can provide very good quality fruit with only a few insecticide or insecticide/fungicide sprays each year. A pre-bloom oil and insecticide spray, two or three post bloom sprays targeted for plum curculio (Conotrachelus nenuphar) and codling moth (Cydia pomonella) and the use of baited sticky traps for apple maggot (Rhagoletis pomonella) should enable home gardeners and small-scale farmers to harvest quality fruit. By selecting appropriate cultivars, home gardeners could pick fresh apples from late July through October. Several SRCs (Goldrush and Enterprise) will keep up to six months after harvest with common refrigeration.
5. SRCs may have potential for commercial processing. More than half of the apples grown in eastern US are currently destined for processing, so the use of SRCs for

processing could lead to a significant reduction in fungicide use. Until recently, SRCs were evaluated and selected primarily for their potential as fresh-market cultivars. Within the last three years, however, breeders and processors have begun screening advanced selections of SRCs for their potential as processing apples. Processors can clearly define the fruit qualities that they prefer by requesting fruit that fall within certain ranges for size, acidity, soluble solids, firmness, and storage life. Factors such as fruit color, appearance, and minor surface defects are less critical for processing than for fresh-market fruit. Recently, research has been initiated on production systems to produce SRCs for processing (Biggs et al., 1997). A few large processors willing to buy SRCs could provide an immediate outlet for thousands of tons of fruit. By comparison, getting a new cultivar established in fresh market channels requires that thousands of individual produce buyers at both the wholesale and retail levels must be convinced to change cultivars or Ôbrand loyalty,Õ and reluctance to change limits introductions of new cultivars.

Limitations of scab-resistant cultivars

1. SRCs are limited by market economics. Apple marketing and microeconomic studies conducted by project participants in MA (Abrahams, 1992) and NY (Murphy and Willett, 1991) revealed a major barrier to grower acceptance of SRCs. They showed that a net yearly savings of $200 per acre could be achieved if no fungicides were needed to produce SRCs. However, the high market value and productivity of orchards (crop values exceeding $10,000 per acre are readily attainable) means that a mere 2% loss in either production or sales price for SRCs relative to proven conventional cultivars would offset the savings in fungicide costs. Thus, SRCs would be profitable only if they are as productive and as marketable as proven varieties like McIntosh, Delicious, or Granny Smith. The higher prices that were anticipated for eco-labeling and reduced pesticide use in the wake of the Alar scare generally failed to materialize except in a few niche markets.

Planting new varieties is very risky for eastern apple growers wholesaling their fruit through brokers because fresh-market apples are sold and recognized by their varietal names. Shelf space for apples in supermarket produce sections is limited, so any new apple variety must displace better known varieties to gain shelf space. Most of the new apple varieties introduced in supermarkets over the past 20 years had two characteristics that contributed to their successful introduction. First, the new varieties had distinctive qualities (appearance, flavor, texture) that allowed consumers to easily differentiate between the new varieties and previously-available varieties. Second, the new varieties have been strategically promoted by big-budget agencies such as the Washington State or New Zealand apple marketing associations. Under current conditions, it is very unlikely that any new apple cultivars (SRCs or scab-susceptible) can be introduced in supermarkets and achieve a measurable market share unless the introduction is supported and heavily promoted by large apple marketing agencies such as the one in Washington State.

2. SRCs have fruit quality limitations. None of the SRCs that we evaluated have distinctive and desirable fruit quality attributes such as those found in other recent introductions like Gala (unique flavor and appearance) or Ginger Gold (early-maturing, high-quality summer apple). Some of the more fruit quality problems include a short

harvest window and limited long-term storage potential for Liberty (Autio and Costante, 1992); rough appearance and high susceptibility to black rot fruit infections for Freedom; susceptibility to a corky-spot disorder for Enterprise; russetting and small fruit size for Goldrush; susceptibility to ÔsunburnÕ and breakdown of scab resistance for NY 74828-12; severe fruit russet problems with NY 75441-67; undesirable tree growth habit, brittle limb crotches, and conspicuous fruit lenticels for NY 75414-1; uneven ripening and fruit splitting for Priscilla; uneven ripening and short shelf life for Redfree; and objectionably thick and tough skins on many of the SRCs. Several of the SRCs are quite tart at optimum harvest maturity and require several weeks or months in cold storage to attain acceptable sugar/acid balance. Most participants in our SARE project found their personal favorite SRCs, and some SRCs have gained acceptance in local markets, but the perfect fresh-market SRC has yet to be developed.

3. SRCs cannot be grown without fungicides in most locations. Although high quality Liberty apples have been successfully grown without any fungicides near Burlington VT, failur Ée to control flyspeck on Liberty apples grown in the Hudson Valley resulted in an average annual loss of $2,330 per acre, equaling one-third of the potential gross returns for that orchard (Rosenberger et al., 1996). As noted earlier, SRCs need fungicide sprays to prevent cedar apple rust, quince rust, black rot, bitter rot, flyspeck and sooty blotch where these diseases are prevalent. The last three of the diseases mentioned affect fruit during summer and must be controlled with fungicides applied during mid to late summer. As a result, the level of fungicide residues on SRC fruit at harvest will likely remain comparable to fungicide residues found on scab-susceptible cultivars because most residues come for late-summer sprays.

Liberty and other SRCs from the Geneva breeding program, though not susceptible to cedar rust, also developed severe leaf spotting when subjected to high levels of cedar rust inoculum and 40% of leaves on Liberty also developed powdery mildew when grown next to Ginger Gold trees that were severely affected by mildew. At other locations in the same region, SRCs that were isolated from inoculum sources developed little rust or mildew (Rosenberger et al., 1994). Thus, proximity to inoculum will affect the number of fungicides needed to control disease on SRCs.

Liberty trees that were not sprayed with fungicide showed early defoliation in the fall and reduced fruit set the following year (Cooley et al., 1995; Rosenberger et al., 1996). This early defoliation was attributed to weakly parasitic fungi or leaf microflora. The improved yields on Liberty trees treated with fungicides suggests that fungicides may contribute to tree health by eliminating fungi that have not heretofore been viewed as apple pathogens.

4¼. SRCs lose their resistance to apple scab if new scab strains are introduced. Scab-resistance in SRCs has a narrow genetic basis. A race of the scab pathogen discovered in Europe is not controlled by the Vf and Vm genes that confer resistance in SRCs (Parisi et al., 1993). One scab resistant selection with the Vm gene (NY 74828-12) developed scab lesions in two of our Northeast SARE plantings (Brown and Berkett, 1994; Merwin et al, 1994). As of 1996, the incidence of scab on the SRCs remained negligible in the Vermont and Pennsylvania plantings where it was initially observed. However, if the SRCs were widely planted in the Northeast, they might require occasional applications of broad spec ¥trum fungicides to forestall selection of races of Venturia inaequalis able to overcome the Vf and Vm resistance genes.

Evaluating reduced environmental impacts of SRC production

A complex environmental question emerged from our project after several years. We had shown that SRCs enabled 50-100% reductions in fungicide usage. Additional reductions in herbicides and insecticides were possible when advanced IPM methods where implemented in SRC orchards. Although an immediate savings of $200 per acre in pesticide costs was possible, this economic assessment did not include the indirect benefits that accrued from reduced environmental impacts of pesticides in orchard ecosystems or improved regional food systems. We wondered if it would be possible to develop an environmental impact assessment for different apple production systems that would include more than just pesticide inputs.

The flexibility of our project manageme ¨nt system made it possible for us discuss, adapt and divert some funds to explore this question in 1992. Starting with the prototype pesticide impact model of Kovach et al. (1992), we conducted a thorough review of current methodologies and databases for assessing environmental impacts of different pest-control practices (Levitan et al, 1995). Major obstacles to meaningful, holistic impact assessment were identified. These included the lack of comparable or complete databases for pesticide effects on key processes, species, and components of agroecosystems. Research linkages were developed with EPA and USDA. Although this work was later continued under separate federal funding, research initiated as part of our apple project is now influencing regional, national and international discussions about pesticide policy, farmer decision tools and eco-labeling systems based on environmental impact criteria (Levitan, 1997). Conclu« sions and recommendations drawn from the work include the following:

1. There is no single definitive set of appropriate environmental and social parameters to consider in evaluating pesticide risk. Pesticide use (by weight or volume) is a is a commonly used but inadequate proxy for pesticide risk. The choice of risk indicators depends upon available data, how system developers and users value different components of the environment, and the scale, objectives, and proposed application of the assessment tool. In part, the choice and weighting of risk indicators reflect value judgments, but such judgments do not necessarily imply bias or illogic. Rather, they will ideally reflect the considered (expert) opinions of stakeholders. The assumptions and structure of assessment systems should be transparent and flexible to enable (a) evaluation of the underlying value judgments, (b) modifications of the system, and (c) sensitivity a °nalysis of the results.

2. Pesticide risk indicators and assessment systems should, as much as possible, incorporate complex ecological realities into tools that are simple-to-use and understand. The validity and utility of pesticide decision tools will improve as the structure and scoring methods of prototype systems are critiqued and improved and as data become more accessible and are generated for a broader array of environmental indicators. Currently, most pest control impact data reflect the toxicity of single doses of single active ingredients to single species of test organisms. Data gaps exist for interactive and

secondary effects, impacts of chemical mixtures, impacts at higher levels of ecological organization, and sub lethal effects on long term health and biodiversity.

3. Assessments of the economic costs of pesticide use (or non-use) should include costs borne by society, such as costs for remediation of environment ³al problems as well as costs borne by the agricultural producer. Production costs should be labeled as such, rather than referring to this subset of costs by the broader term Òeconomic costs.Ó Costs of production should be assessed separately from human health and ecological effects because the magnitude of production costs does not alter the magnitude and importance of environmental effects. However, farm-level decision tools must be able to evaluate both production costs and environmental impacts within an integrated framework so that tradeoffs can be visualized, calculated and considered.

4. Pest control is just one dimension of sustainable agriculture, and pesticidal products are just one type of pest control. Both must be considered within the broader context of sustainability criteria, including the consumption and degradation of energy and natural resources; social stability and vitality of farms and communities; and landscapDe protection for wildlife habitat, ecological processes, and human renewal.

Advances in apple IPM

Research on IPM strategies applicable to scab-susceptible cultivars provided information that was immediately integrated into state apple IPM programs. Control strategies for sooty blotch and flyspeck were evaluated, and research on a computer-based predictive model for timing summer fungicides was initiated and is being continued with other funding sources. A two-year trial in MA where no summer fungicides were applied demonstrated that summer-pruning alone reduced flyspeck by 50%. In commercial orchard blocks using fungicides, summer pruning also significantly reduced disease incidence and improved fruit quality (Cooley et al., 1992, 1997). Pruning was believed to reduce flyspeck by increasing evaporative potential within the trees and by improving spray deposition in the middle and upper portions of the trees when applications were made with an airblast sprayer. Fungicide timing studies in New York showed that flyspeck on apple can usually be controlled by fungicides applied on a three-week interval rather than the 14 day interval that was previously recommended for this disease (Rosenberger, 1994).

In Massachusetts, the SARE Apple Project comprised part of an overall apple program focused on developing and implementing advanced IPM methods. Substantial funding from the state, the federal government, the USDA Northeast IPM program and the Massachusetts Society for the Promotion of Agriculture enabled scientists in MA to make substantial progress towards what has been called second-level IPM (Prokopy et al., 1994; Prokopy et al, 1996; Cooley and Autio, 1997). Because pooled funding sources were used to advance IPM practices within the state, it is difficult to pinpoint impacts specifically attributable to the SARE apple project. Rather, advances in the state IPM program must be considered as a whole with some of the credit devolving to SARE funding.

SARE resources were used in Massachusetts to investigate methods for decreasing fungicides targeted against flyspeck and sooty blotch. Arthropod pests targeted during the summer were apple maggot, codling moth, lesser appleworm (Grapholitha prunivora), leafrollers (Choristoneura rosaceana and Argyrotaenia velutinana), mites (Panonychus ulmi), aphids (Aphis pomi and A. spiraecola), leafminers (Phylonorycter), and leafhoppers (Typhlocyba pomaria and Edwardsiana rosae). Of these, apple maggot and mites were particularly important.

Development and testing of second-level IPM strategies were done over four years, largely in blocks of 2 to 4 ha in commercial orchards in cooperation with` g rœrs . As would be expected, arthropod and disease damage prior to mid-June (about two weeks after petal fall) were similar in both standard and second-level IPM blocks. Total fruit injury from insects active after mid-June was similar in both block types in the first two years of the study (0.5%). However, in the second two years, fruit injury was greater in the second-level blocks (4.8% vs. 1.9%). This difference could be attributed largely to lesser apple worm, leaf rollers, codling moth and maggot fly. Growers used 37% less insecticide against fruit-damaging pests in the second-level blocks, though there was no difference between block types in pesticide use against foliar arthropod pests. Similarly, growers used significantly less fungicide in the second-level blocks (34% less). Results showed that pesticide-use after mid-June may be significan; tly reduced, but at a significant cost in terms of increased management and, over three to four years, increased insect damage.

In New Jersey, SARE funds enabled Rutgers Cooperative Extension to expand delivery of IPM scouting and information to an increasing number of growers throughout the life of the grant. The NJ program reached 50 growers in 1988, but grew to 61 growers in 1991, and 76 growers by 1996 when over 75% of NJ apple acreage was managed under IPM practices. Some growers managed part of their farms under organic protocols (Polk, 1991). Like MA, SARE funds were pooled with other federal and state support.

Because of information exchange within the project, second-level IPM techniques developed in MA were extended to a limited number of growers in PA and NJ. The techniques introduced including minimizi ªng the use of summer insecticides in order to maximize parasitism of pest populations and replacing some insecticide sprays with red sticky balls used to trap and control apple maggot flies.

3B. Dissemination of Findings

A publication titled Management Guide for Low-Input Sustainable Apple Production was authored by SARE-project participants and published in 1990. This production guide, targeted for both large and small apple producers, included comprehensive chapters on economics, horticulture, and disease and insect management, with easy-to-understand information on the best reduced-input approaches for managing orchards. The guide contained useful descriptions of scab-resistant apple cultivars, including color plates of fruit. More than 3,000 copies of the production guide were distributed, and additional copies are still requested.

During the time it was published, the Northeast SARE Apple Production Newsletter was th œe only publication in northeastern United States committed to distributing the latest information on alternative apple production methods. Alternative was defined as methods which had potential to contribute to more ecologically-stable apple production systems. The newsletter was positioned as a non-refereed outlet for researchers, cooperative extension specialists, and growers. An average of two issues were produced annually, ranging from 8 to 28 pages per issue. The Newsletter had over 1,000 subscribers. While most subscribers were on mailing lists in the states of project participants, there were subscribers in a total of 35 states, five Canadian provinces, and five other countries.

In 1993 the project organized a comprehensive workshop titled Disease-Resistant Apple Cultivars: An Update on Horticulture, Pests, and Marketing. Attended by 60 interested growers, researchers, and extension/industry personnel, t' h e proceedings were subsequently published in Fruit Varieties Journal (Schettini and Berkett, 1994). The workshop provided the first multi-disciplinary forum (including commercial apple growers) for discussing the current status of SRCs, how to grow them, and perspectives on how SRCs would fit into future production systems.

SARE project participants several hundred articles in Extension newsletters and peer-reviewed Journals during the duration of the project (Table 2). In addition, thousands of contacts were made via mass media and through presentations at grower, industry, and professional meetings.

In 1994, outreach efforts were extended to the World Wide Web (WWW) by Cowgill and Clements (VanVranken and Cowgill, 1996). The Virtual Orchard (http://www.orchard.uvm.edu) is a dedicated WWW site êfor the dissemination via the Internet of information concerning all aspects of sustainable apple production. The Virtual Orchard has been visited many thousand times by people as far away as New Zealand and Chile, and has been cited as a valuable Internet resource for apple production in trade magazines (Malone, 1996).

Several special extension education efforts sponsored by project participants are worthy of note. Taste-testing of SRCs was conducted at Terhune Orchards, Princeton, NJ, at their annual Apple Day. This event, which attracts over 13,000 attendees, provided valuable marketing information on New Jersey grown scab-resistant apples. In another cooperative effort, the University of Vermont and Vermont Apple Orchards successfu ölly test marketed 200 boxes of Liberty fruit via a large retail farm-market in Colts Neck, NJ. Consumer acceptance of Liberty was demonstrated via taste-testing and test marketing organized during the Fall of 1992 and 1993 at MartinÕs Grocery, a large retail super-market chain in northern Vermont and New York (Clements et al., 1994.) Taste-testing in NJ also demonstrated consumer acceptance of several SRCs (Durner, et al., 1992).

3C Site Information

Not Applicable

3D. Economic Analysis

Economic studies of the profitability of instituting sustainable practices on apple orchards in the Northeast have focused on micro level analyses and an industry wide analysis. The industry-level analysis centered on using econometric models to evaluate the impa cts of changes in the apple industry and to determine the transmission of prices between the grower, shipping point, wholesale, and retail market levels. A dynamic model of the US apple industry, including relationships for bearing acres, production, utilization, and allocation to the fresh, canned, frozen, juice, dried and other markets, was developed and results from the model were published.

Micro-economic studies showed that growers can significantly reduce pesticide costs without compromising fruit quality by growing SRCs and using size-controlling rootstocks. For SRCs on M. 7 rootstock (mid-size trees), total pesticide use, including fungicides applied for summer diseases, was 40 lb. of product costing $113/Ac. This represents a 50% reduction in pesticide use compared to commercial practices with standard cultivars. On dwarf trees, the total cost was only $55/A.

Growing SRCs with no fungicides, or with inadeq$ uate fungicide protection, can result in costly losses because summer diseases can reduce fruit quality. In a four-year study with Liberty apple trees in southeastern New York, the estimated gross return (in dollars per acre) was 50% greater for fungicide-treated than for untreated plots. The mean value of fruit per tree for 13 tests was $2.93 for trees receiving no fungicides during summer compared to $7.76 for trees receiving summer fungicides. The summer fungicides applied in the sprayed plots failed to provide complete control of sooty blotch and flyspeck. If fungicides had provided complete control of these diseases, the mean value per tree would have been $9.93.

For some cultivars, the increased crop value from mulched trees may justify the greater costs for the mulches. Natural and synt hetic mulches were compared with mechanical tillage and herbicides as orchard ground cover management systems (GMS). Substantial differences in fruit size, color, blemishes, and pre-harvest drop among the eight apple genotypes and 10 GMS treatments resulted in a broad range of fruit packout values, from $3.48 to $7.45 per 42 pound bushel. Cumulative crop market-value estimates based on yields and proportional packouts from 1992 to 1994 also varied greatly, from $3,323 to $7,386/Ac, assuming a planting density of 270 trees/Ac. Some of the most expensive treatments were the least profitable, while trees in several low-cost mulches (white polypropylene, polyester fabric, and hay mulches) produced the most profitable crops.

Voles caused more s erious damage to trees under synthetic and hay mulches, despite the use of mesh trunk guards and rodenticide baits.

Participating growers and retail sales reports confirm that the best immediate market potential for SRCs may exist in the low-volume direct marketing niche that constitutes an important and profitable sales outlet for many fruit growers in the Northeast.

4. POTENTIAL CONTRIBUTIONS AND PRACTICAL APPLICATIONS

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Using SRCs is simply one kind of pest management tactic (genetic resistance), and therefore might be expected to have limited value if used exclusively as a disease management strategy. Used in conjunction with other IPM tactics, SRCs have the potential for reducing, but not eliminating, the need for fungicides. Several impediments to fungicide reduction exist in SRC-based systems, including potential for damage from important diseases other than scab, marginal cost savings relative to increased costs for important diseases other than scab, marginal cost savings relative to increased costs for alternative management methods, and increased risks for some alternative methods (Penrose, 199 5) .

Project participants have also shown that the current production methods are largely defined by the free-market system that forces growers to compete on a world market to supply consumers with a blemish-free product. SRCs that are currently available should be promoted for home garden use and for niche-market sales. Fruit quality and storage life of named SRCs are not yet good enough to warrant large commercial plantings for fresh market sales. Like any other new cultivar of apples, SRCs face formidable barriers in gaining recognition and market acceptance in fresh-market channels. SRCs may gain more rapid acceptance in the processing market if acceptable selections can be identified.

5. FARMER ADOPTION AND DIRECT IMPACT

Apple production systems are very complex and ch Æange slowly. Because of the complexity of the cropping system, the value of the crop, and the high pesticide use rates, apple growers in the Northeast have traditionally benefited from a close working relationship with academic scientists and cooperative extension agents. Those familiar with the apple industry recognize that apple growers are very quick to adopt new practices that are profitable. Virtually no gap exists between advances in knowledge and technology and application of that knowledge and technology except when economic constraints limit the application.

Since the introduction of IPM in the early 1970's apple growers have significantly reduced their use of pesticides both in terms of poun ùds and dosage equivalents applied per acre (Kovach and Tette, 1988; Prokopy et al, 1996; Cooley and Autio, 1997). This has occurred in spite of the observation that the benefits of pesticide reduction are presumably public, while the risks of loss are private (Penrose, 1995). Nevertheless, because of their continued reliance on pesticides, apple growers are sometimes considered regressive by those who believe pesticide use could be further reduced or eliminated if growers were only better educated.

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6. PRODUCER INVOLVEMENT

See Table

7. AREAS NEEDING ADDITIONAL STUDY

Several areas of further research were identified in the ProjectÕs Annual Reports. These include:

Breeding new scab-resistant cultivars

Screening for arthropod resistance to new cultivars

Building a predictive model for summer disease management that includes measurements of ambient temperature and accumulated hours of surface (apple) wetness
Effects of pesticides on non-target pests
Fruit thinning recommendation for new cultivars
Mechanisms of soil conservation and sustainable fertility enhancement in perennial crop systems such as orchards
Determine why Ziram-sulfur combination sprays provide such exceptional control of sooty blotch and flyspeck, and determine if Ziram-sulfur will also control bitter rot and black rot
Effects of specific horticultural management practices (i.e. nutrition, pruning, rootstock selection, and thinning) on comm© ercial fruit quality of SRCÕs.

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Scab-Resistant Apples for the Northeastern United States: New Prospects and Old Problems

Fruit growers and the produce industry have been under intense public scrutiny during the past decade. Apples (*Malus* × *domestica*) have been especially controversial, cited by some as the epitome of healthy eating and by others as a prime example of pesticide-contaminated food. Commercial orchards in most fruit-growing regions require frequent treatments with a costly array of insecticides, miticides, herbicides, and fungicides. Pesticides compose about 13% of the costs of apple production, or $750/ha in the northeastern United States (7). Seasonal applications of pesticides in apple orchards can include more than 20 different chemicals, in 12–18 separate treatments, in quantities approaching 80 kg/ha annually (8). Apple scab, caused by *Venturia inaequalis* (Cooke) G. Wint., is the most widespread disease and accounts for much of the pesticide usage on apples. Uncontrolled apple scab can have catastrophic consequences—total crop loss, defoliated trees, increased susceptibility to winter cold injury, and decreased bloom or crop in subsequent years (2).

Management programs for apple scab have evolved rapidly in recent years in response to technological, regulatory, and economic developments, and pesticide usage has been substantially reduced where integrated pest management (IPM) tactics have been implemented. In this article, we review the various options and IPM strategies for scab control, describe recent progress in the breeding and evaluation of scab-resistant apple cultivars (SRCs), and evaluate the potential of SRCs to reduce the need for fungicides in apple production. Determining the commercial potential of selected SRCs is the focus of a comprehensive, multidisciplinary project involving researchers and extension specialists at Cornell University, the Rodale Institute Research Center at Kutztown, Pennsylvania, the University of Massachusetts, and the University of Vermont. More than 3,500 scab-resistant apple trees are being evaluated at 50 orchards across five states in this ongoing project, which was initiated in 1988 and is supported in part by the USDA Sustainable Agriculture Research and Education (SARE, formerly LISA) program. The major objectives of the project are to: 1) develop more sustainable apple production systems for the northeastern United States by use of SRCs and IPM techniques, 2) provide economic and environmental impact analyses comparing conventional and alternative apple production systems, and 3) expedite transfer of research information and adoption of more sustainable systems by commercial fruit growers.

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Historical Background

Scab has plagued apple growers for many centuries; symptoms of the disease are evident on fruit in still-life paintings dating back to the 14th century. The depiction of scab by artists of past eras implies that its fruit symptoms were once considered acceptable and that consumers of the past must have been less squeamish about eating blemished fruit. Also, most of the apples produced in past centuries were destined for cider or preserves, and fruit with lesions and cracks were still usable. Until the late 1800s, there were no effective chemical controls for apple scab. A few "antique" cultivars—russet types such as Roxbury Russet and Golden Russet, the Russian cultivar Antonovka, and others—were somewhat less susceptible to the disease but were also less productive or marketable than the more susceptible cultivars such as McIntosh and Delicious, which became dominant following the advent of fungicides.

Apple Scab Fungicides

The copper or sulfur-based fungicides of the early 1900s provided only preinfection protection and caused substantial injury to tree foliage. The development of effective, nonphytotoxic chemical protectants and eradicants for scab and other fruit diseases has been considered one of the success stories in modern agriculture (19). By the late 1970s there were at least 17 different fungicides in some 30 brand-name formulations available for controlling apple scab. With the recent availability of sterol biosynthesis inhibiting (SI) fungicides (fenarimol, myclobutanil, and flusilazol), growers are afforded unprecedented postinfection control of apple scab, cedar apple and quince rusts caused by *Gymnosporangium* spp., and powdery mildew caused by *Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon with fewer applications of fungicides (12,27). The narrow-spectrum SI fungicides are usually combined with broad-spectrum protectant fungicides to increase efficacy and minimize the selection of resistant scab biotypes. However, registrations for most of the key broad-spectrum protectant fungicides—the ethylene-bis-dithiocarbamates (EBDCs), captan, and the benzimidazoles—are now jeopardized because of the zero-risk standard imposed by the Delaney Amendment (22). Further prohibition of the use of broad-spectrum fungicides may severely limit chemical options for scab control and cause the apple industry to resort increasingly to cultivars resistant to scab.

Other factors are also changing management strategies for the apple disease complex. Fewer than one-half of the fungicides available a decade ago are still registered and effective against scab (Table 1). Dodine and the benzimidazoles benomyl and thiophanate-methyl are still available but are no longer effective in many orchards because of resistant strains of *V. inaequalis* and *P. leucotricha*. Resistance to the SI fungicides has also been reported in several loca-

tions (11,16), but this problem is not yet widespread. As more rigorous testing requirements have been imposed for registering new fungicides and reregistering older ones, corporate and government funds that could have been directed toward developing novel fungicide chemistries have instead been diverted into registration expenses. The future availability of fungicides for managing scab and other tree-fruit diseases has become increasingly uncertain, and there is renewed interest in other disease management strategies.

IPM Tactics for Scab Control

Contemporary IPM strategies for scab control are based primarily on precise timing and application of fungicides to reduce disease inoculum or eradicate incipient infections. Various models have been proposed for predicting key developments in the epidemiological cycle of scab, but most growers continue to rely on refined versions of the venerable Mills system (20) to determine the occurrence of infection periods and the optimal timing of fungicide applications. Plant pathologists in the northeastern United States monitor weather and crop data with electronic devices and sample pseudothecia in overwintering leaves to predict the release of primary ascosporic inoculum (13). Simulation models such as the one described by James and Sutton (17) have been proposed for predicting ascospore maturity, but none is currently used by commercial growers because the predictive confidence intervals are too wide to provide a sufficient margin of crop safety. Also, the recent report (4) that viable conidia of *V. inaequalis* can overwinter within apple buds indicates that suppression of ascosporic inoculum may not adequately control scab in orchards with high carryover disease pressure.

The risk of scab epidemics can be greatly reduced by cultural practices that minimize inoculum from the previous year. Removing or destroying infested leaves on the orchard floor can substantially reduce overwintering inoculum. Natural degradation of leaves has been enhanced by applying urea sprays in the fall, by tilling leaves into the orchard soil, and by chopping leaves with flail mowers. Establishing fungal saprophytes such as *Athelia bombacina* Pers. on apple leaves and applying such compounds as dinitro-*o*-cresol (Elgetol), benzimidazoles, and some SI fungicides after harvest have also been shown to reduce development of pseudothecia in overwintering scabby leaves (12).

Several novel tactics for inoculum reduction are being evaluated by growers and researchers in the Northeast. One strategy is to induce noninfective spore release by applying water to orchards with a sprayer when ascopores are ready for release but the weather is not conducive to germination and infection. Another strategy, being evaluated by Burr et al (6) in New York, involves isolating hyperparasitic bacteria and fungi from orchard soils, scab lesions, and pseudothecia on fallen leaves. They report (6) finding several promising antagonistic microorganisms, including one strain of *Pseudomonas syringae* van Hall that appeared to control scab as effectively as captan under greenhouse conditions. At present, these inoculum reduction methods are not widely used in commercial orchards because they are perceived as unproven or uneconomical. Growers find it inconvenient to reactivate sprayers after harvest to apply fungicides, urea, or biocontrol agents. Also, overwintering inoculum is never completely suppressed within an orchard, and commercial orchards in the Northeast are usually close to abandoned orchards, wild apple trees, and other sources of scab inoculum.

The integration of improved models for predicting scab infection periods, cultural practices and biological control agents that reduce scab inoculum, and narrow-spectrum fungicides with greatly improved postinfection activity into coherent disease management programs has enabled apple growers to effectively reduce crop losses to scab in most years. However, even the most advanced IPM strategies are based on the continuing availability and affordability of effective fungicides. Given the possibility of drastically reduced fungicide options in the future, there is much interest in apple cultivars with field resistance to scab and other major fungal diseases.

Disease-Resistance Breeding Programs in North America

There are currently three major programs to develop disease-resistant apples in the United States and Canada (Table 2). A cooperative breeding program involving Purdue, Rutgers, and Illinois universities (PRI) was initiated in 1948 to develop scab-resistant apples. By 1992, the PRI program had named and released 11 cultivars (9). The program is now in transition, formulating plans concerning future collaborations and continuing to stress disease resistance, using both traditional and molecular plant breeding techniques. Cornell University's disease-resistant apple breeding program was initiated at the New York State Agricultural Experiment Station in Geneva in the late 1940s. From the outset it has emphasized disease resistance to apple scab, cedar apple rust, powdery mildew, and fire blight. Two cultivars have been named, and many advanced selections are available for testing. The Cornell/Geneva program emphasizes integration of traditional and molecular methods to genetically improve apples. Many researchers are involved cooperatively in projects on developing regeneration, transformation, and genetic mapping systems; on targeting resistance to virus, fungal, and bacterial diseases; on enhanc-

Table 1. Fungicides available for controlling apple scab over the past two decades

1973	1983	1993
Benomyl	Benomyl	Benomyl[a,b]
Captafol	Captafol	
Captan	Captan	Captan[b]
Dichlone	Dichlone	
Dodine	Dodine	Dodine[a]
Ferbam	Ferbam	Ferbam
Folpet	Folpet	
Glyodin	Glyodin	
Maneb + zinc	Maneb + zinc	
Metiram	Metiram	Metiram[b]
Sulfur	Sulfur	Sulfur
Thiram	Thiram	Thiram
Zineb	Zineb	
Ziram	Ziram	Ziram
	Thiophanate-methyl	Thiophante-methyl[a,b]
	Triforine	Triforine
		Fenarimol
		Myclobutanil

[a] Of limited usefulness because resistant strains have developed in many orchards.
[b] Future registration status uncertain because currently listed by EPA as potential Class B or Class C human carcinogen.

Table 2. North American disease-resistant apple breeding programs, selected cultivars introduced (with year of formal release), and advanced selections undergoing final evaluations

Purdue/Rutgers/Illinois	Cornell/Geneva	Nova Scotia	Ontario/Quebec
Prima (1970)	Liberty (1979)	Nova Easygro (1971)	Macfree (1974)
Priscilla (1972)	Freedom (1985)	Nova Mac (1978)	Moira (1978)
Priam (1974)	NY74828-12	Nova Spy (1986)	Trent (1978)
Sir Prize (1975)	NY75414-1		Britegold (1978)
Jonafree (1979)	NY7541330		Murray (1978)
Redfree (1981)	NY73334-35		Richelieu (1983)
Dayton (1988)			Rouville (1983)
McShay (1988)			
William's Pride (1988)			
Enterprise (1992)			
Goldrush (1992)			
Co-op 27-29 and 31			

ing quality; and on genetically regulating tree form.

Several apple breeding programs in Canada have concentrated on disease resistance. The breeding and evaluation of cultivars resistant to apple scab began at two Department of Agriculture facilities in Ontario in 1949. Five SRCs were released from 1974 to 1980 by breeding programs in Ottawa and Trenton, Ontario (15). The Ontario programs have since been discontinued, and the remaining advanced selections are being evaluated and released at the Agriculture Canada Research Station in Saint-Jean-sur-Richelieu in Quebec. The breeding program at the research station in Kentville, Nova Scotia, has released three SRCs, and plans are under way to license this material for distribution in the United States. The Nova Scotia program is emphasizing resistance to scab and other major diseases, with an interest in pyramiding sources of resistance from diverse apple types. SRC apple breeding programs are also under way in France, England, Russia, the Netherlands, Poland, Romania, and Brazil (9).

Genetic Sources of Resistance

Quantitative and qualitative sources of resistance to scab are available, with the latter behaving as single dominant genes or a block of closely linked genes (29). Both types of resistance may confer field immunity to scab with either no macroscopic evidence of infection or fewer and smaller sporulating lesions. Resistance to scab was first noted in progenies of *Malus floribunda* 821 (25). A program was initiated in 1955 to study sources of resistance and to determine the relationship of the scab resistance genes, and symbols were designated to identify the different gene loci. Ten of the qualitative genes were identified as being located at the V_f (*M. floribunda* 821) locus and two at the V_m (*M. micromalus* pit) locus. The later discovery of pathogen race 5 and the finding that both *M. micromalus* and *M. atrosanguinea* 804 were susceptible to this race provided evidence that both loci have the same gene (28). Three other loci—V_b (Hansen's baccata No. 2), V_{bj} (*M. baccata jackii*), and V_r (*M. pumila* R12740-7A)—were identified, with a single gene pair at each.

Controlled inoculations under greenhouse conditions established definite reaction classes for each source of resistance (25): class 1 = pinpoint pits and no sporulation; class 2 = irregular chlorotic or necrotic lesions and no sporulation; class 3 = few restricted sporulating lesions; class M = mixture of necrotic, nonsporulating, and sparsely sporulating lesions; and class 4 = extensive, abundantly sporulating lesions. The class 1 (pinpoint) reaction is considered a hypersensitive response in which host epidermal cells below the infection peg collapse within 40–72 hours and the fungus is killed soon after. The other classes of host reactions are not expressed until 3–12 days after inoculation, and the fungus remains viable for as long as 21 days. Breeding programs vary in classification of scab-resistant plants. The PRI program considers classes 2, 3, and M as resistant and only class 4 as susceptible, which has resulted in nearly 1:1 ratios of resistant to susceptible progeny in their crosses. The Cornell/Geneva program defines resistance more stringently, with any sporulation classified as a susceptible host response. This conservative rating system has produced a much lower proportion of resistant progeny, but the justification is that any sporulation in the greenhouse might indicate susceptibility under field conditions.

There has always been a concern that new races of the pathogen might arise and overcome existing sources of scab resistance. For this reason, most breeding programs inoculate young seedlings with a mixture of the known scab races and provide optimum conditions for disease development. Because of a close correlation between leaf and fruit infection, progeny can be rated and eliminated at the seedling stage, greatly reducing expense and time involved. Five different virulent races were initially identified on apple, four of which can overcome certain genes for resistance (28). The recent report of a new sixth race of *V. inaequalis* capable of overcoming the resistance of some SRCs with V_f resistance, but not the resistance of *M. floribunda* 821 itself, is of great concern (23). At two of our Northeast SARE apple plantings, variants of scab have appeared in the advanced selection NY74828-12, which relies solely on the V_m resistance gene. These observations emphasize the need to diversify sources of resistance, to combine at least two independent genes in new cultivars, and to develop new breeding strategies. The situation also illustrates the importance of developing integrated strategies for deploying disease-resistant fruit cultivars in commercial production. For example, it may be that one or two applications of a broad-spectrum fungicide in SRC orchards early each summer—as is often recommended for SI fungicide programs—would be beneficial in delaying or averting the selection of pathogen biotypes resistant to the V_f genes.

The possible vulnerability of our apple scab-resistant material needs to be stressed. Of the approximately 50 scab-resistant cultivars that have been released worldwide, 39 are reported to carry the V_f gene from *M. floribunda* 821. Freedom carries additional polygenic resistance from Antonovka, Rouville has the V_m gene from *M. atrosanguinea* 804, Nova Easygro and Nova Spy have the V_r gene from a Russian seedling, and Murray has the V_m or V_f gene from *M. micromalus* (9). The extensive reliance on V_f as a source of resistance needs to be curtailed, and pyramiding of genes should be a high priority in breeding programs. Breeders also need to ensure that minor genes for resistance are not ignored. Rousselle et al (24) suggested that the expression of V_f may be modified by minor genes, transmitted by resistant or susceptible parents, with additive effect. A loss in quantitative factors fortifying the resistance may also be occurring within some breeding protocols. The work on finding molecular markers for sources of scab resistance will greatly increase the efficiency by which multiple sources of resistance may be pyramided.

Fig. 1. Taste panels conducted by participants in the USDA Sustainable Agriculture Research and Education (SARE) project in the northeastern United States indicate consumers may prefer several of the scab-resistant apple cultivars to conventional cultivars.

Breeding Strategies

The original *M. floribunda* 821 that provided the V_f resistance gene has very small fruit (<2 cm in diameter) and unpalatable crabapple fruit characteristics. An examination of the pedigrees of most scab-resistant material reveals identical first- and second-generation crosses. In the first generation, *M. floribunda* 821 was crossed with Rome Beauty. Two sister seedlings selected from this cross for their scab resistance and fruit characteristics were intercrossed to produce an F_2 seedling designated 26829-2-2. These two generations from the original crosses are the common progenitors of many of today's named cultivars, with subsequent generations reflecting the particular priorities of each breeding program (9). To improve size and quality in these early generations, and still maintain scab resistance, a modified backcrossing procedure was necessary. Apple suffers from inbreeding depression, so repeated backcrossing to the same parent is not desirable. In a modified backcrossing strategy, the seedling with the best size and commercial quality that possesses resistance to scab is selected in each generation and crossed to a different high-quality recurrent parent. This process is continued for as many generations as are required to produce the qualities desired. Most scab-resistant cultivars currently being tested represent four or five generations from the original *M. floribunda* × Rome Beauty cross.

Genetic engineering techniques hold promise for future possibilities of cloning resistance genes for apple. Molecular markers are being found for scab resistance and are also being sought for other disease resistance genes. Closer linkage between the markers and genes for resistance is needed before gene cloning becomes a possibility. The polyploid nature of apple may make this approach difficult, because genes for scab resistance may behave like single genes but actually be much more complex. Recently determined markers and those now being sought should facilitate the pyramiding of resistance genes and avoid the need for extensive progeny testing. Genes outside of *Malus* with broad-spectrum activity against fungal pathogens are also being examined. Recent advances in developing transformation and regeneration systems in apple make future prospects for improvement excellent. In fact, some growers are hesitant to plant SRCs at this time because they anticipate that scab-resistance traits may soon be available in transgenic lines of familiar cultivars such as Delicious and McIntosh.

Availability and Acceptance of Scab-Resistant Cultivars

Scab-resistant cultivars introduced by Cornell, Nova Scotia, and the PRI program are now available from several commercial nurseries in the United States. Advanced selections undergoing final evaluations are available from Cornell's program under a nondistribution agreement, and selections from the other programs may also be available for field testing with certain restrictions. Although SRCs have been available for several decades, almost all of the major commercial cultivars today are older, scab-susceptible types that originated as chance seedlings in the late 1800s. This situation contrasts sharply with agronomic crops, where producers quickly adopt the latest disease-resistant cultivars of maize, rice, wheat, and soybeans as these become available. Unique consumer attitudes about apples are partly responsible for this anomaly. Few market patrons inquire or care about particular cultivars of wheat or maize, but most have definite favorites when it comes to apples for fresh consumption. Buyer loyalty to old-time favorites has made growers and commercial outlets reluctant to commit precious retail shelf space to the new scab-resistant apples.

Despite these limitations, there is increasing interest in SRCs from growers and processors. For example, although Liberty accounted for only 0.6% of the apple acreage planted in New England during 1985–1989, an increase to 5% of new plantings has been projected for 1990–1994 (3). Mounting concerns about pesticide applications may be fueling some of this interest, but the higher quality of recent disease-resistant releases is also a factor. Taste panel evaluations conducted by SARE project participants around the Northeast indicate excellent consumer acceptance of several SRCs (Fig. 1). Two new introductions from the

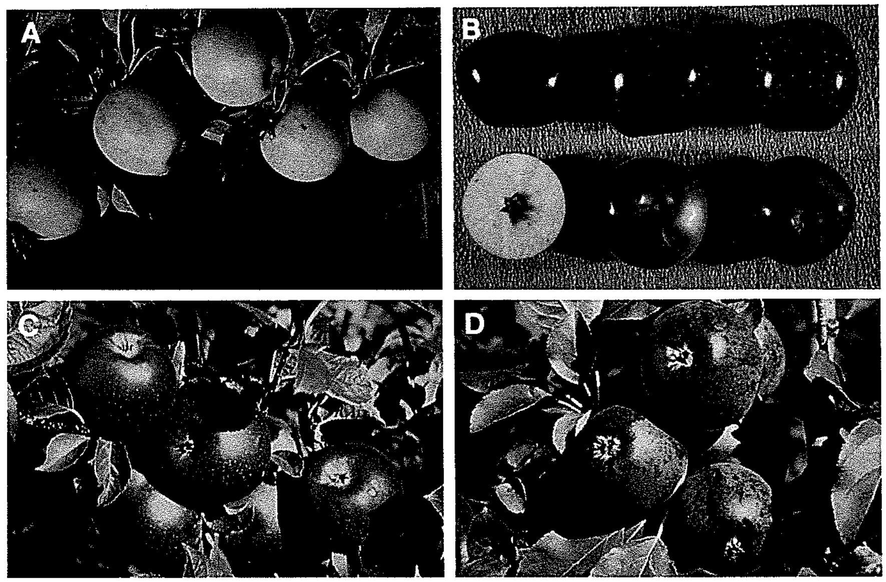


Fig. 2. Selected new scab-resistant apple cultivars from the Cornell/Geneva and Purdue/Rutgers/Illinois breeding programs: (A) Goldrush, (B) Enterprise, (C) Freedom, and (D) Liberty.

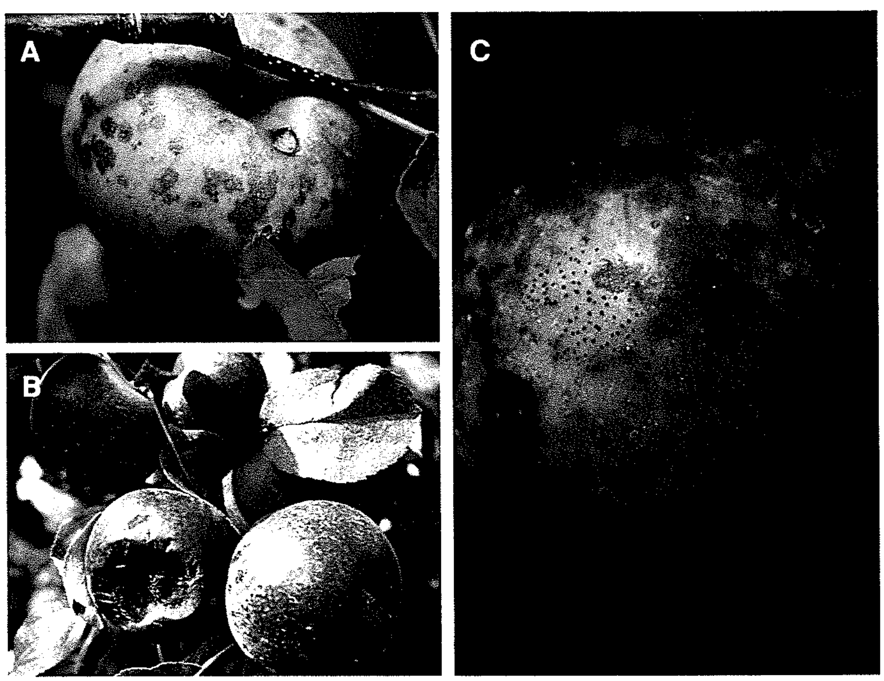


Fig. 3. So-called summer diseases on scab-resistant apple cultivars not receiving any fungicides: (A) Sooty blotch on Sir Prize, (B) black rot on Liberty, and (C) sooty blotch and flyspeck on Freedom.

PRI program, Goldrush (Fig. 2A) and Enterprise (Fig. 2B), were recently rated better than standard cultivars and other SRCs after 5 months in cold storage (T. M. Schettini, *unpublished*). Durner et al (10) reported that tasters in New Jersey consistently rated four SRCs—Freedom (Fig. 2C), Liberty (Fig. 2D), Prima, and Priscilla—better than the standard cultivar Delicious. Similar results were reported by J. M. Clements et al (*unpublished*) in a Vermont market. It thus appears that consumers might accept many of the SRCs if they were aggressively marketed in commercial channels.

The SRCs now available represent a wide range of fruit types, maturity dates, and postharvest storage potential. Like other apple cultivars, they are likely to vary substantially in adaptability to different growing conditions. A priority in our SARE projects has been the establishment of SRC plantings in diverse commercial orchards to evaluate cultivar performance in the different pest complexes, soil types, mesoclimates, and markets of the Northeast. Providing reliable information on the quality and performance of these new cultivars and establishing test plantings in commercial orchards may actually be necessary to attain grower acceptance. Establishing a modern high-density apple orchard and bringing it into production usually costs more than $20,000/ha, and the financial risk is high even for plantings of standard cultivars. Most fruit growers are highly specialized and produce only a few cultivars for a specific market outlet. The present apple marketing system is based on the mass production of some 10 cultivars (all scab-susceptible) and demands consistent year-round deliveries of fruit uniform in size, appearance, taste, texture, and shelf life. These factors all work against the adoption of new cultivars by commercial growers.

On the other hand, consumers today are much more interested in trying new foods and fruit cultivars than in past years. In recent years, a few growers have profited greatly by anticipating the next "hot" new apple cultivars, because these often command substantially more than the conventional types in wholesale markets. Following the recent successes of Braeburn, Fuji, and Gala (all introductions from scientific breeding programs), growers are much more interested in new cultivars. A market structure and feasibility study of SRCs in the Northeast (21) indicated that cultivar novelty could provide an important marketing advantage for SRCs, because a pesticide-conscious public and produce industry might be receptive to new apple cultivars that require few or no fungicides and taste as good as or better than the conventional favorites. However, this market analysis also suggested that because of the intense competition for produce shelf space in most markets, sales promotions and commitments by growers will be essential to provide adequate fruit for specific retail outlets.

Significant savings in fungicide application costs may result from production of disease-resistant cultivars. A microeconomic analysis by Abrahams (1) indicated that growers in the Northeast might save $475/ha annually by producing SRCs instead of McIntosh or Empire apples. However, the estimated market value of a typical 35 Mg/ha (725 bu/acre at $8/bu) apple crop is more than $14,300. The saving in fungicide costs for SRCs therefore represents only 3% of the crop value and could easily be offset by equivalent differences in the market value or productivity of a particular cultivar. To provide meaningful economic advantages over the standard cultivars, therefore, the SRCs must excel in every other important attribute. A central component in our SARE apple projects has involved replicated plantings of selected SRCs in five northeastern states, along with Empire, a productive, high-quality apple well adapted to the region, as a standard control for comparing tree vigor, hardiness, productivity, and other essential attributes. To date, it appears that yield and tree establishment of several of the SRCs compare favorably with those of Empire.

Problems and Benefits

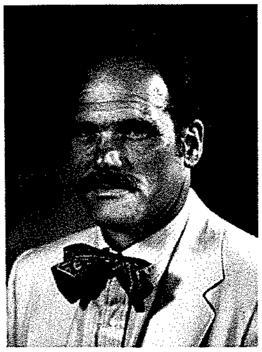
Several other important diseases of apple may limit the widespread adoption of scab-resistant cultivars. Some SRCs have also been bred and selected for resistance or field tolerance to other prevalent diseases, such as powdery mildew, cedar apple and quince rusts, and fire blight. The cultivars with this multiple disease-resistance should provide the greatest opportunities for reducing fungicide use in northeastern orchards, because those resistant only to apple scab will still need several fungicide applications each season to protect trees and fruit from rusts and powdery mildew in areas where these are perennial problems (26). Morever, certain other "minor" or "summer" fruit diseases may also become significant problems in SRC orchards where fungicide treatments are substantially reduced (Fig. 3). These include black rot and white rot caused by *Botryosphaeria* spp., bitter rot caused by *Colletotrichum* spp., sooty blotch caused by *Gloeodes pomigena* (Schwein.) Colby, and flyspeck caused by *Schizothyrium pomi* (Mont. & Fr.) Arx. Prior to the development of broad-spectrum fungicides, these now "minor" diseases were often major problems. In recent decades, they have been coincidentally suppressed by fungicides targeted at scab and the other major apple diseases.

A priority of the Northeast SARE projects has been to evaluate the extent to which minor fruit diseases might become a problem in SRC orchards. Several experiments in New York and Massachusetts have evaluated cultural practices—e.g., summer pruning, planting densities, and training systems that increase air circulation and reduce humidity in the tree canopy—as methods to reduce the incidence of summer diseases. Observations to date indicate that in certain regions and summers, sooty blotch and flyspeck are likely to cause serious problems in SRC orchards. Dur-

Table 3. Percentage of fruit with flyspeck and sooty blotch and mean yields of cv. Liberty apples (planted on M.9 rootstock in 1987) in relation to tree planting density, ground cover management, fungicide treatments, and fruit position in dry (1991) and wet (1992) years in Hudson Valley, New York

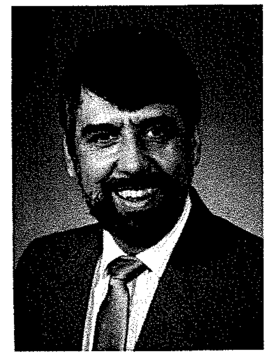
		Flyspeck (%)		Sooty blotch (%)		Mean yield (t/ha)	
Treatment	Comparison	1991	1992	1991	1992	1991	1992
Tree density	1,400/ha	11.1	62.2	0.8	18.8	11.9	27.9
	2,300/ha	11.7	64.1	2.0	20.3	20.3*[a]	42.2*
Ground cover	Mowed	9.8	62.4	0.7	17.6	14.5	35.1
	Unmowed	13.2	64.0	2.1	21.5	17.8	35.0
Fungicide	Sprayed[b]	1.6	45.2	0.0	4.3	17.4	36.3
	Unsprayed	28.6*	79.4*	5.3*	42.2*	14.9	33.8
Fruit position	Upper limbs	...[c]	48.3	...	8.8	...	...
	Lower limbs	...	67.7*	...	33.2*	...	...

[a] Significantly different at $P < 0.05$.
[b] Benzimidazole + captan fungicides in mid-June, mid-July, and mid-August.
[c] Not evaluated.



I. A. Merwin

S. K. Brown



D. A. Rosenberger

D. R. Cooley

L. P. Berkett

Dr. Merwin was raised on a farm in New York's Hudson Valley and received his B.A. (1969) from Reed College in Portland, Oregon. After a year traveling in South America on a Watson Fellowship, he worked as a gardener and operating engineer in Golden Gate Park, San Francisco, California, for 12 years. He then completed a Ph.D. (1990) in pomology, plant pathology, and ecology at Cornell University and shortly thereafter was appointed assistant professor with research and teaching responsibilities in the Department of Fruit and Vegetable Science at Cornell. His research interests include orchard agroecology, IPM, environmental impacts of fruit production, biological control of plant-parasitic nematodes, orchard floor management, and international agriculture. His primary role in the Northeast LISA-SARE projects has been the horticultural evaluation and management of scab-resistant apples.

Dr. Brown received her B.S. (1978) at the University of Connecticut, M.S. (1980) at Rutgers University, and Ph.D. (1984) in genetics at the University of California at Davis. In 1985, she joined the tree fruit breeding program at the New York State Agricultural Experiment Station in Geneva, where she is currently an associate professor in the Department of Horticultural Sciences. Her research program involves quantitative and qualitative genetic studies aimed at understanding and improving apple germ plasm, utilizing traditional and molecular approaches. Her role in the Northeast SARE apple projects has involved the breeding, selection, and field evaluation of disease-resistant apples.

Dr. Rosenberger received his B.A. degree (1969) from Goshen College, Goshen, Indiana, spent 2 years doing rural development work in Algeria, then completed his Ph.D. (1977) at Michigan State University, East Lansing. In 1977, he joined the faculty in the Department of Plant Pathology at Cornell's Agricultural Experiment Station in Geneva and became the research and extension tree fruit pathologist at Cornell's Hudson Valley Laboratory in Highland, New York. He was appointed superintendent of the Hudson Valley Laboratory in 1990. Dr. Rosenberger conducts applied research on the biology and chemical control of fungal pathogens of tree fruits. In 1988, he helped organize the five-state Northeast Sustainable Apple Production Project, which has been funded by the USDA through its programs for Low-Input Sustainable Agriculture (LISA) and Sustainable Agriculture Research and Education (SARE). Within this project, Dr. Rosenberger has concentrated on developing disease management strategies for scab-resistant apple cultivars.

Dr. Cooley received his A.B. degree (1974) at Harvard College, M.S. (1978) at the University of Vermont, and Ph.D. (1986) in plant pathology at the University of Massachusetts. He is currently assistant professor of plant pathology at the University of Massachusetts. His research specialty is management of fruit diseases, and he has worked in a number of areas, including interactions between air pollutants and fungal pathogens, computer applications for decision support in disease management, and chemical management of plant diseases. His present research involves disease ecology and biointensive IPM of strawberry and apple pathosystems, and his major role in the Northeast SARE apple projects has been alternative management strategies for the so-called summer diseases.

Dr. Berkett received a B.A. degree in biology from Gettysburg (PA) College, a M.S. degree in entomology from the University of Maine at Orono, and a Ph.D. in plant pathology from The Pennsylvania State University. During all three degrees, she was involved in IPM in apple production, gaining experience in commercial orchards and at PSU's Fruit Research Laboratory, Biglerville, where she worked with Dean Asquith, entomologist, and, more recently, with Kenneth D. Hickey, plant pathologist. For the past 5 years, Dr. Berkett has been the overall project coordinator for the USDA SARE Project on the Development of Sustainable Apple Production Systems for the Northeast. Recently, she was appointed chairperson of the Department of Plant and Soil Science at the University of Vermont, Burlington, where she has been a faculty member for 10 years, with primary responsibilities for IPM research and extension on apples.

ing two summers in New York's Hudson Valley, much of the fruit from unsprayed Liberty trees was unmarketable because of sooty blotch or flyspeck blemishes (Table 3). Reducing tree planting density or close mowing of the orchard ground cover to increase air circulation in the tree canopy did not significantly reduce the incidence of these diseases; there was more diseased fruit in the wet summer of 1992 and on lower branches within the trees. In another study, summer pruning did significantly reduce the incidence of flyspeck in a Massachusetts orchard with less disease pressure (D. R. Cooley, *unpublished*). We have also observed severe black rot, sooty blotch, and flyspeck infections on some of the other SRCs in our SARE plantings not receiving fungicides. There may be fewer problems in cooler, drier regions or summers, but it appears that the SRCs will require broad-spectrum fungicide sprays to control these fruit diseases in certain regions or during unusually humid summers.

On the positive side, there may be arthropod pest management benefits associated with reduced fungicide use in scab-resistant apple orchards. Researchers in many regions have noted that some of the fungicides used for scab control adversely affect predators of insect and mite pests. Eliminating early-season fungicides has in some cases reduced the need for miticide sprays later in the season (14) and increased the populations of predatory stigmaeid and phytoseiid mites (5). From a more holistic perspective, project participants are also adapting the "environmental impact quotient" computer model of Kovach et al (18), integrating toxicological, edaphic, economic, and non-point source pollution databases to assess subtle or long-term impacts on the farm or regional agroecosystem that may accrue from the shift to low- or zero-fungicide apple production.

Growing cultivars genetically resistant to diseases is a widely utilized and effective management practice in many crops. Given the environmental, health, and economic concerns related to fungicide use, the important question is whether SRCs are a viable alternative option for commercial apple production. To find the answer we must determine the climatic and edaphic adaptability of the SRCs, their relative productivity under commercial orchard conditions, and their optimal harvest dates, storage conditions, and market niches. We should also develop low chemical input systems for insect and weed management that complement the SRC's reduced fungicide input requirements. Providing such multifaceted information for a five-state region has required innovative organizational and research tactics. The Northeast SARE apple projects involve 22 principal investigators spanning the disciplines of economics, entomology, horticulture, plant pathology, plant breeding, and soil science. The logistical demands of integrating projects in these different disciplines have been formidable, but we believe the effort is essential for developing a database to enable rapid deployment of SRCs. Coordinated extension efforts must also be mounted to transfer on-farm research information quickly to other growers and regions. If successful, our projects will determine the relative strengths and weaknesses of the SRCs and may facilitate their acceptance by growers, the produce industry, and the general public. This could help reduce fungicide usage by northeastern fruit growers and provide alternative fruit cultivars and production systems for the future.

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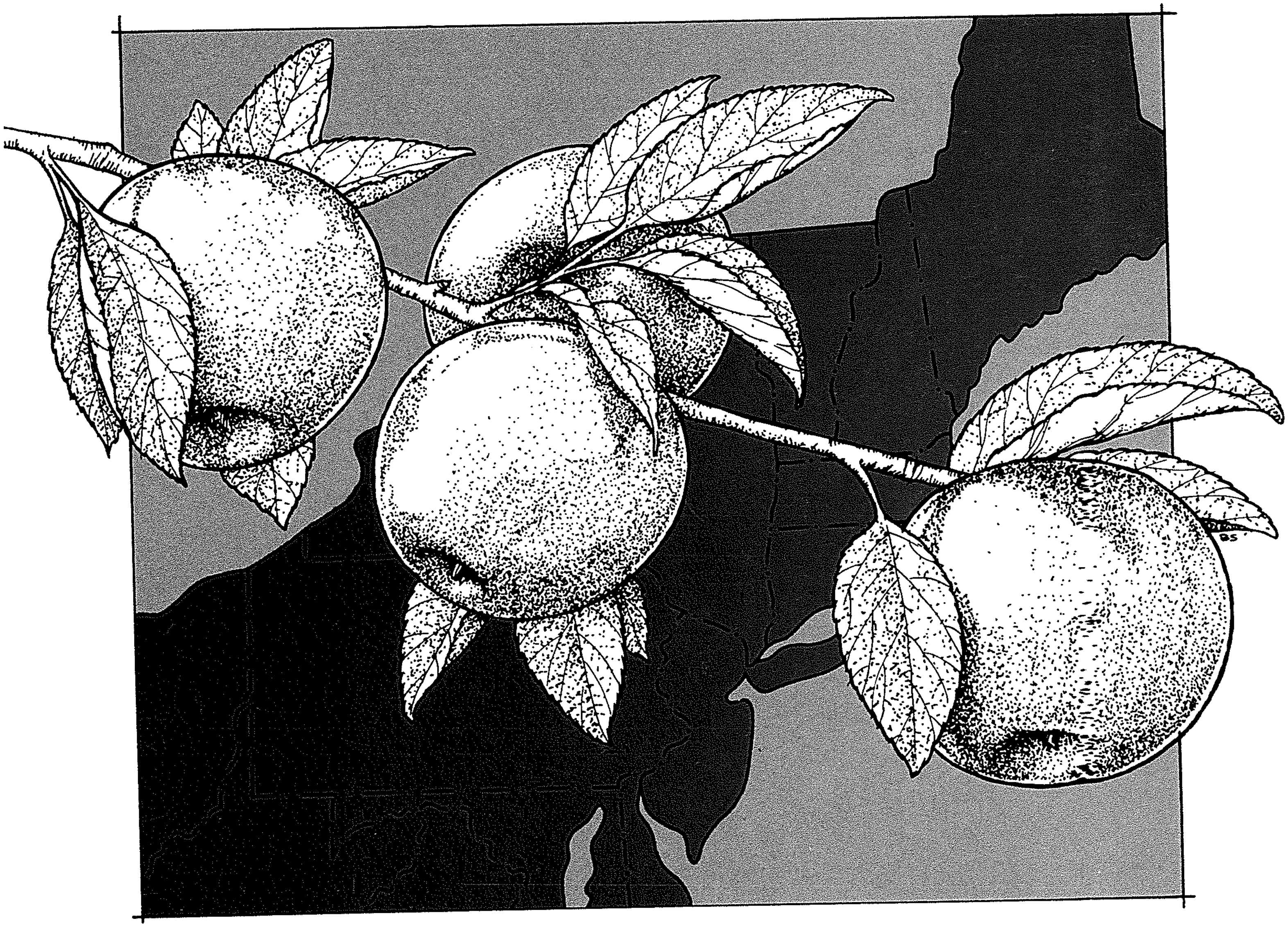

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Management Guide for Low-Input Sustainable Apple Production

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PART I: ECONOMIC FACTORS AFFECTING APPLE PRODUCTION
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PART II: HORTICULTURAL PRACTICES
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INTRODUCTION

by Lorraine Berkett, University of Vermont
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Northeast Apple Production: An Important Part of the Region's Agricultural Diversity

Apples are the most extensively grown deciduous fruit in the Northeast, a region that includes New England, New York and the Mid-Atlantic States. More than 166,000 acres are in commercial production and its annual yield of fresh and processing fruit represents one-third of the nation's harvest. Apples are an economically important crop, valued at more than $214 million, and the apple industry is a significant component of the region's diverse agricultural community.

LISA and Northeast Apple Production

Apple orchards are complex ecosystems that require intensive management to produce high quality fruit. Tree growth and fruit production are intricately affected by environmental factors such as insects, mites, disease-causing organisms, weeds, and vertebrates such as voles and deer. Through integrated pest management (IPM), apple growers in the Northeast have significantly reduced their overall use of pesticides while still producing high quality fruit. This has been accomplished primarily by monitoring pest populations and environmental conditions to determine when pest threshold levels are reached; by encouraging biological control by natural predators and parasites; and by adopting pesticide application techniques such as alternate middle spraying and border row spraying, which optimize effectiveness and help to reduce the nontarget effects of pesticides.

Reducing farmers' dependence on certain kinds of purchased inputs while increasing profits, reducing environmental hazards, and ensuring sustainable agriculture for the future are goals of the Low-Input/Sustainable Agriculture (LISA) program established in 1987 by the United States Department of Agriculture (USDA). For the past ten years, orchardists in the Northeast, through IPM, have been progressing toward low-input/sustainable apple production. They have been adopting practices that address environmental matters and that enhance their farms' profitability. Serious concerns about environmental and health impacts of apple production practices still exist however, and although IPM practitioners have reduced insecticide and miticide use, fungicides have been less affected.

In the Northeast, most fungicide treatments are directed at controlling apple scab, a disease caused by the fungus *Venturia inaequalis*. Apple scab is the major disease of apples in the Northeast. It can be devastating, causing reduced yields or making the apples unfit for fresh market sale or for storage. Current apple scab control methods depend on repeated fungicide applications to prevent or eradicate infections. Future fungicide options may be jeopardized, however, due to the development of fungicide resistance and to economic and environmental factors that may lead to the loss of some fungicides that are now considered essential. Because all commercial apple cultivars are susceptible to apple scab, and production of marketable fruit is dependent on controlling the disease, it is imperative to the continued viability of the apple industry in the Northeast to develop alternative disease control strategies that address economic, health, and environmental concerns. The USDA LISA program affords the opportunity for research into alternative management strategies and promotes educational programs that disseminate the information generated through research.

The Northeast LISA Apple Production Project

With support from the USDA LISA program, a network of researchers and extension/outreach personnel was organized in the Northeast to develop low-input sustainable apple production systems that utilize disease-resistant apple cultivars (DRCs) and IPM techniques, and to disseminate the information generated by this comprehensive, multidisciplinary research and education program to farmers and other research and extension/outreach personnel. The cornerstone of this five-state cooperative research effort is a long-term orchard evaluation of DRCs at sites with diverse environmental features. DRCs offer a biological alternative to the use of fungicides because they are resistant to apple scab and other diseases. The DRC research/demonstration orchards were designed to provide basic horticultural data on tree growth and development, yield potential, fruit size and color, and other factors that will be used to determine commercial acceptability and potential of DRCs.

Researchers at the five cooperating institutions — Cornell University, the University of Massachusetts, Rodale Research Center, Rutgers University, and the University of Vermont — are also conducting complementary research to determine fruit storageability, fresh market potential, consumer appeal, and profitability; and to determine the impact of low-input apple production on the Northeast's apple industry. In addition, new biological, cultural, and ecological approaches to pest management, as well as new horticultural practices, are being examined in research/demonstration orchards at university and private research facilities and in growers' orchards.

Providing information to apple growers is a major objective of the Northeast LISA Apple Production Project. Cooperators in the project incorporate information on low-input production practices into their educational programs and generate a newsletter, the *Northeast Lisa Apple Newsletter*, for apple growers, ag-industry personnel, members of the general public, and researchers and educators in universities and government and private organizations within and outside the Northeast region. Also, the *Management Guide for Low-Input Sustainable Apple Production* is a product of the cooperative efforts by members of the project.

The Purpose of the Management Guide for Low-Input Sustainable Apple Production

This publication may be used as a primary source of information for commercial apple growers who want to incorporate changes in their production systems. It is a compilation of information from many sources on practices that address the goals and philosophy of LISA. This guide is not the last word on low-input sustainable apple production but is, rather, a beginning. Research now underway will generate information and expand our knowledge of the economic profitability of low-input production systems, and provide insight into the complex apple ecosystem of the Northeast. Although the emphasis is on incorporating disease-resistant apple cultivars into production systems, many of the cultural and pest management practices outlined in the *Management Guide* are applicable to orchards with standard cultivars.

In a sense, the label "low-input" is a misnomer. Production systems that incorporate these practices will require higher management input. Minimizing or optimizing the use of purchased inputs, such as pesticides and fertilizers, will require informed and often complex decision making by the apple grower. The challenge is to make economically and environmentally sound decisions that satisfy all the demands of a dynamic, ever-changing system.

Are We Giving Up IPM for LISA?

No! IPM is a critical, essential component in LISA. The philosophies behind both are similar and compatible: both advocate practices that minimize environmental hazards and enhance profitability. LISA, however, encompasses more than pest management; it embraces all aspects of the farming enterprise. Also, with LISA, traditional farming systems are being more critically examined and possibly redefined, in response to current economic, environmental, and health concerns. No matter what form low-input production systems will take, however, their success, in part, will rely on continued development and adoption of innovative IPM.

Acknowledgements

We would like to acknowledge the support of the USDA LISA programs and each of the participating institutions, which have provided additional funds to make this long-term, comprehensive, multidisciplinary project possible. We also acknowledge the support of the apple growers in the Northeast who endorse our research and educational project and are actively involved in it.

Thanks are extended especially to the people, in addition to those listed here, who contributed their expertise and time as orchardists, scientists, educators, reviewers, and photographers to make the *Management Guide* concise, informative, and attractive. We gratefully acknowledge the editorial expertise of Patricia A. Wittig, Rodale Research Center, in the preparation of this publication.

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PART I: ECONOMIC FACTORS AFFECTING APPLE PRODUCTION

by Mark Castaldi and Lois Schertz Willett, Cornell University

INTRODUCTION

The information in this section deals with two broad areas of economics: microeconomics and macroeconomics. Microeconomics refers primarily to factors that affect individual farms. The types of factors evaluated include production costs, profitability, and the allocation of resources. Macroeconomics, in contrast, is used to evaluate key factors that affect an entire industry or part of an industry. The types of factors often evaluated by macroeconomics include supply and demand in the industry, and market prices. By incorporating both branches of economics into the analyses, it will be possible to determine how low-input production systems will impact individual farms and the fruit industry as a whole.

MICROECONOMIC FACTORS

The cost figures presented here pertain to full-time, commercial orchard operations averaging 120 to 150 acres. Production costs, establishment costs, and capital requirements for a smaller or part-time operation may be significantly different. In general, smaller farms are more labor intensive and require smaller initial capital investments in machinery, equipment, and buildings. Due to the high degree of labor often associated with small farms, production costs as a whole tend to be higher than they are for a larger farm producing a similar product.

There are as yet very few data on the economic feasibility of commercial, low-input apple production systems, but growers may find the following information about establishment and production costs of conventional systems useful. As more economic data are collected for low-input systems, the following questions will be addressed:

* What are the costs of low-input systems compared to conventional systems?
* Are low-input systems profitable?
* How do the profits from low-input systems compare with profits from conventional production systems?

Economics of Orchard Establishment

Commercial tree fruit production today requires an initial investment of $15,000 to $25,000 per acre for land, machinery, equipment, and buildings. Also, agrichemical and labor expenses represent a large proportion of total production costs. The economics of any production system — such as a low-input system — that may significantly change either of these inputs should be carefully evaluated.

Agricultural economists have determined that the initial outlay to establish an orchard ranges from $12,000 to $17,000 per acre, depending on cultivar, production system, yield, packout, and prices received. The figures presented here were estimated for New York's Hudson Valley, but are applicable to all of the Northeast. Orchard establishment time is the period between site preparation and the time when full production is achieved (usually nine years). The figures were calculated for a medium density (180 trees/acre), free standing, semidwarf production system.

Summaries of total costs, revenues, and returns are provided in Table 1 and Figure 1. Annual establishment costs ranged from $1,100 to $2,900 per acre. During the establishment period, total costs and revenues per acre amounted to $16,000 and $13,420, respectively. The resulting net cost was $2,580. Negative returns ranging from $(2,000) to $(575) per acre occurred during the first five years of operation. Negative returns create a need for additional funds from owner equity, bank debt, or profits from other, established, orchard acreage.

Based on these costs of establishment and on future cash flows, the net present value (NPV) was approximately $5,000 per acre. The NPV is a measurement of the overall profitability and present worth of a new orchard. The higher the NPV, the greater the profitability of a new orchard. The single factor having the largest impact on NPV is early production. The more quickly a new orchard comes into production, the higher the NPV and overall profitability will be.

Table 1: Summary of total and net costs during each of the establishment years

Establishment Year	Yield (Bu/acre)	Total[z] Revenues	Total Cost	Total Return
Site Preparation	0	0	$1,500	$(1,500)
Planting	0	0	$2,000	$(2,000)
2	0	0	$1,100	$(1,100)
3	40	$220	$1,200	$(980)
4	150	$825	$1,400	$(575)
5	350	$1,925	$1,600	$325
6	500	$2,750	$1,900	$850
7	650	$3,575	$2,400	$175
8	750	$4,125	$2,900	$1225
Total	2440	$13,420	$16,000	$(2,580)

[z]Based on an orchard run price of $5.50 per bushel.

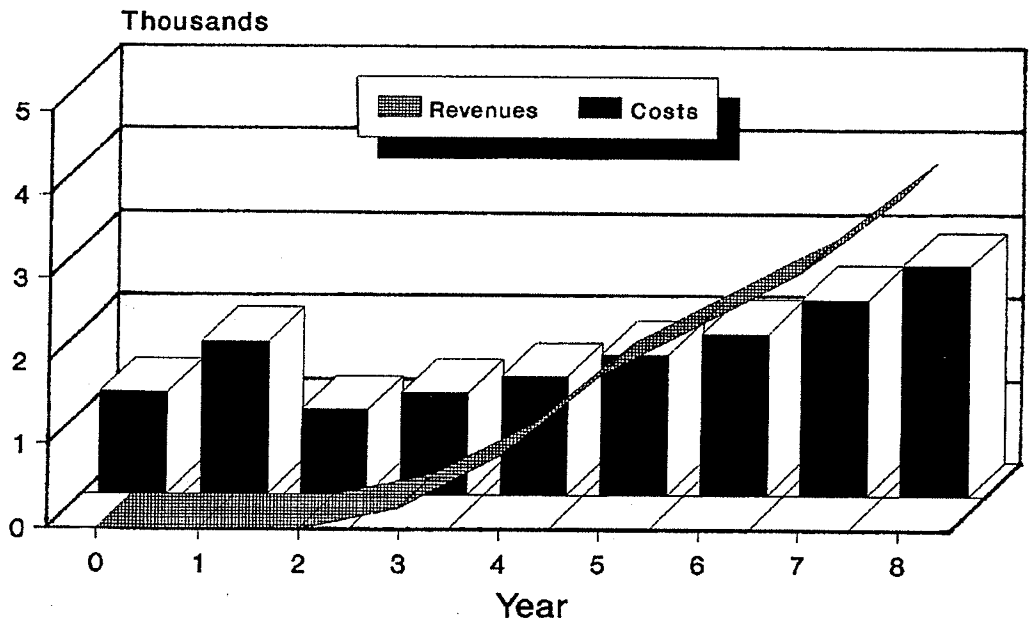

Figure 1: Costs and revenues ($/acre) during establishment years

A second economic tool used to evaluate a new orchard is the payback period. The payback period is the amount of time needed to recover the initial investment. The payback period for the systems evaluated in the Hudson Valley was 10.2 years. The payback period, like the NPV, will be affected greatly by early production.

For example, a 10% reduction in per-acre yield in years 3 through 8 reduced the NPV by more than 40%. Similarly, a one-year delay in production reduced the NPV by more than $1,500 and increased the payback period by more than two years. Because early production affects orchard profitability so greatly, it is crucial to evaluate and monitor the marketable yields that can be achieved' through low-input production systems. If production is delayed or reduced, total profitability can be lowered significantly.

Table 2 provides a summary of the total agrichemical costs incurred during the orchard establishment period (nine years). These costs totaled $1,850 per acre, or approximately 12% of total establishment costs. The two most expensive components of the total agrichemical cost were fertilizers and insecticides, which respectively cost $495 and $470 per acre. Total fungicide costs were $330, herbicide costs were $195, and other chemical costs were $360 per acre. In addition, total nonharvest labor, which accounted for nearly 15% of total establishment costs, were $2,300 per acre.

Table 2: Summary of total chemical and labor costs during establishment years

Cost Category	Total cost ($/acre)	% of Total Estab. Cost
Fertilizer	$495	3.21%
Insecticides[z]	$470	3.05%
Herbicides	$195	1.27%
Fungicides	$330	2.14%
Other[y]	$360	2.34%
Total Chemicals	$1,850	12.01%
Labor[x]	$2,300	14.94%

[z]Includes miticides and spray oil
[y]Includes thinning material, lime, stop scald, and rodenticides
[x]Nonharvest labor

Costs and Returns at Full Production

The Growing and Harvesting Cost Study, started in 1970, is an ongoing, comprehensive economic analysis of apple production in both the Hudson and Champlain Valleys. The primary purpose of this study is to determine total production costs on per acre and per bushel bases. Results from this study indicate that total production costs for fresh market apples are approximately $4.27 per bushel, or $2,500 per acre, with an average yield of 600 bushels per acre.

A summary of typical production costs is presented in Table 3, but costs will vary widely depending on yield and cultivar. Total spray materials and preharvest labor costs, respectively, account for 10.72% and 10.48% of the total costs. More importantly, total harvest costs can account for 25% to 35% of total costs. With such a high proportion of fixed costs that are unaffected by yield, a small change in yield can have a large impact on cost per bushel.

Table 3: Summary of production costs for fresh market apples at full production[z]

COST CATEGORY	Cost Per Unit		
Variable Costs:	$/acre	$/bushel	% of Total[y]
Preharvest			
Repairs	162	.28	6.48%
Fuel & Electric	81	.14	3.24%
Materials	268	.47	10.72%
Labor	262	.46	10.48%
Total Preharvest Costs	773	1.34	30.92%
Harvest			
Labor	543	.93	21.72%
Rental	27	.05	1.08%
Other	70	.12	2.80%
Total Harvest Costs	640	1.11	25.60%
Total Variable Costs	1413	2.46	56.52%
Fixed Costs:			
Interest on Investment	423	.74	16.92%
Depreciation	298	.50	11.92%
Taxes	39	.07	1.56%
Interest	51	.10	2.04%
Insurance	39	.07	1.56%
Office	49	.09	1.96%
Management	188	.31	7.52%
Total Fixed Costs	1087	1.81	48.48%
TOTAL COSTS	$2,500	$4.27	100.00%
Nonbearing Maintenance	203	.35	

[z]Based on an average yield of 600 bushels per acre
[y]Based on $/acre; does not include nonbearing maintenance costs

Figure 2 presents costs per bushel at various levels of production. For example, for unpacked apples at a yield of 200 bushels per acre, total cost per bushel is $8.30. In contrast, at a yield of 600 bushels per acre, total cost per bushel drops to $4.05, a difference of $4.25.

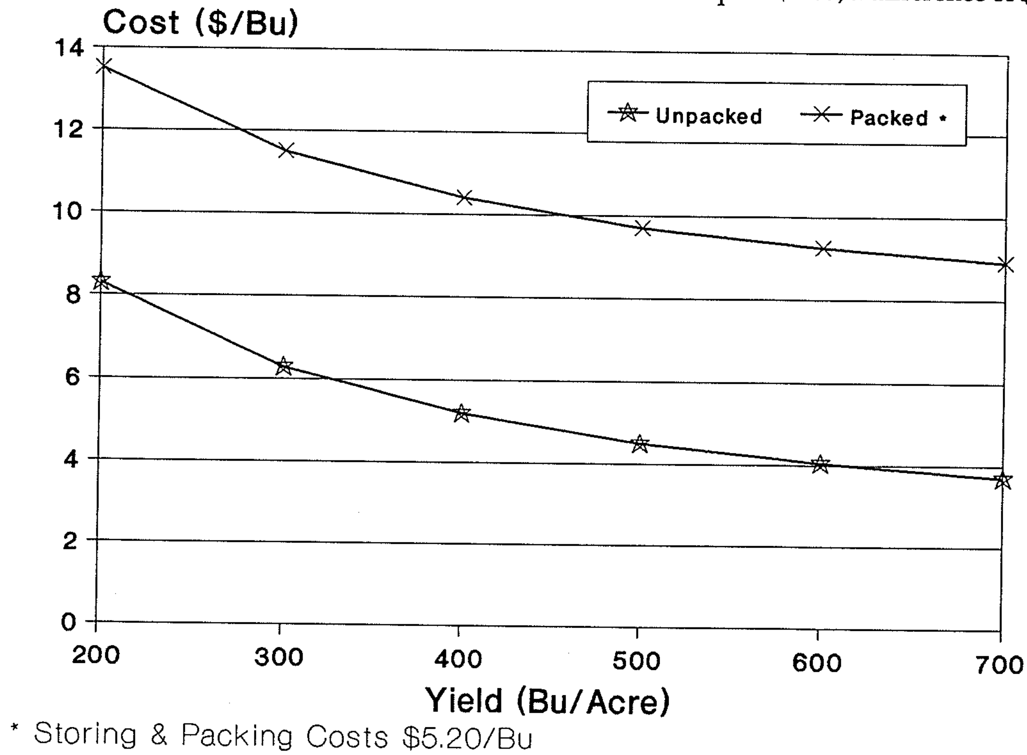

Figure 2: Cost per bushel for different levels of production (bushels/acre)

Break Even Point

Another way to analyze cost figures is to estimate the minimum prices that a grower would need to receive to break even. When evaluating the potential profitability of low-input systems, consider the impact of reduced yields on total production costs per bushel.

An additional economic factor for a fully mature orchard is the minimum yield needed to break even. Figure 3 presents the break even yield. Given existing production costs, prices, and packouts, a yield of approximately 400 bushels per acre is needed to break even. Because the break even point is dependent on all three factors, their separate impacts should be evaluated.

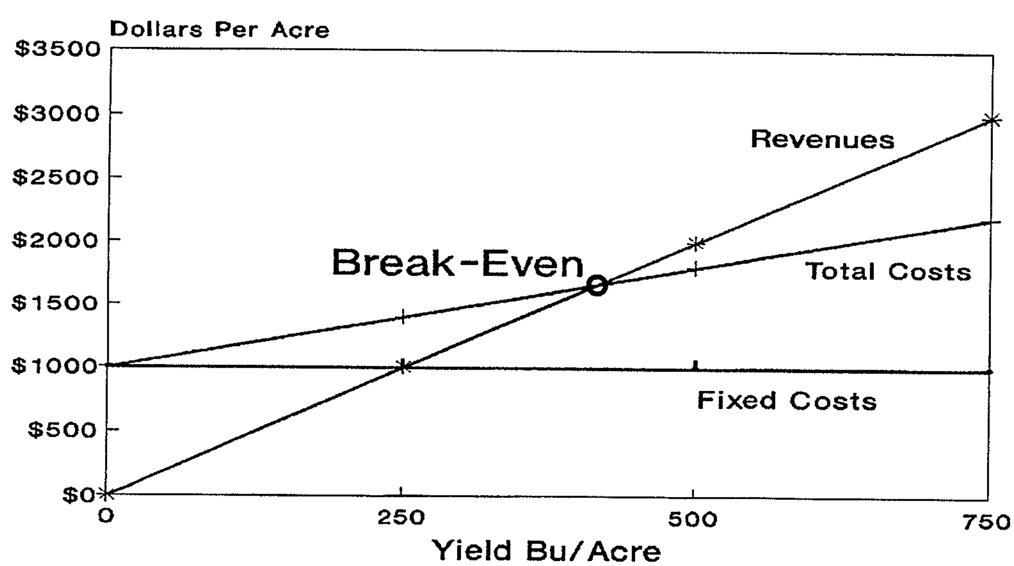

Figure 3: Minimum yield needed to break even

Figure 4 provides a summary of the break even point at different prices and packouts and illustrates how critical packout, or fruit quality, is to overall profitability and changes in break even point. For example, a 10% reduction in packout increases the minimum yield needed to break even by more than 21%. Because packout greatly influences profitability, the economic evaluation of any low-input production system must include this variable in the analysis.

Orchard profitability is linked directly to early production, high yields, fruit quality, and efficient labor utilization. Growers interested in adopting low-input production systems will need to address each of these four factors. It is possible that low-input production systems could be more expensive to establish and operate than conventional systems. The reduction in agrichemical costs could be more than offset by higher labor costs, reduced yields, delayed production, and poorer fruit quality. Growers and economists will need also to determine if low-input fruit will command a high enough price to adequately compensate the grower for any possible increased costs and risks incurred. The determination of future market prices for low-input fruit is one of the areas covered by macroeconomic analyses.

MACROECONOMIC FACTORS

While individual growers will want to determine how low-input production systems will impact the profitability of their farms, industry officials and policy makers will wish to evaluate the broader impacts on both the Northeast regional and national apple industries. To accomodate this end, an economic model is being developed for forecasting and policy analysis. This model may be used to help predict changes in the whole industry brought about by the introduction of low-input apple production systems.

The model being developed will incorporate eighteen equations that employ variables pertinent to the apple industry. These variables include factors such as cost of production, market price, apple usage, acreage, yield per acre, and the market prices of other fruits. Although the equations are simplifications of reality, they do represent the supply and demand relationships in the industry. The primary source of information will be time series data, which will be used to forecast the quantity of apples produced, the price of those apples, and the amount of apples in storage that will be carried over to the next time period. The model will also be used to simulate the effects of changes in the apple industry's costs of production brought about by the introduction of low-input apple production systems.

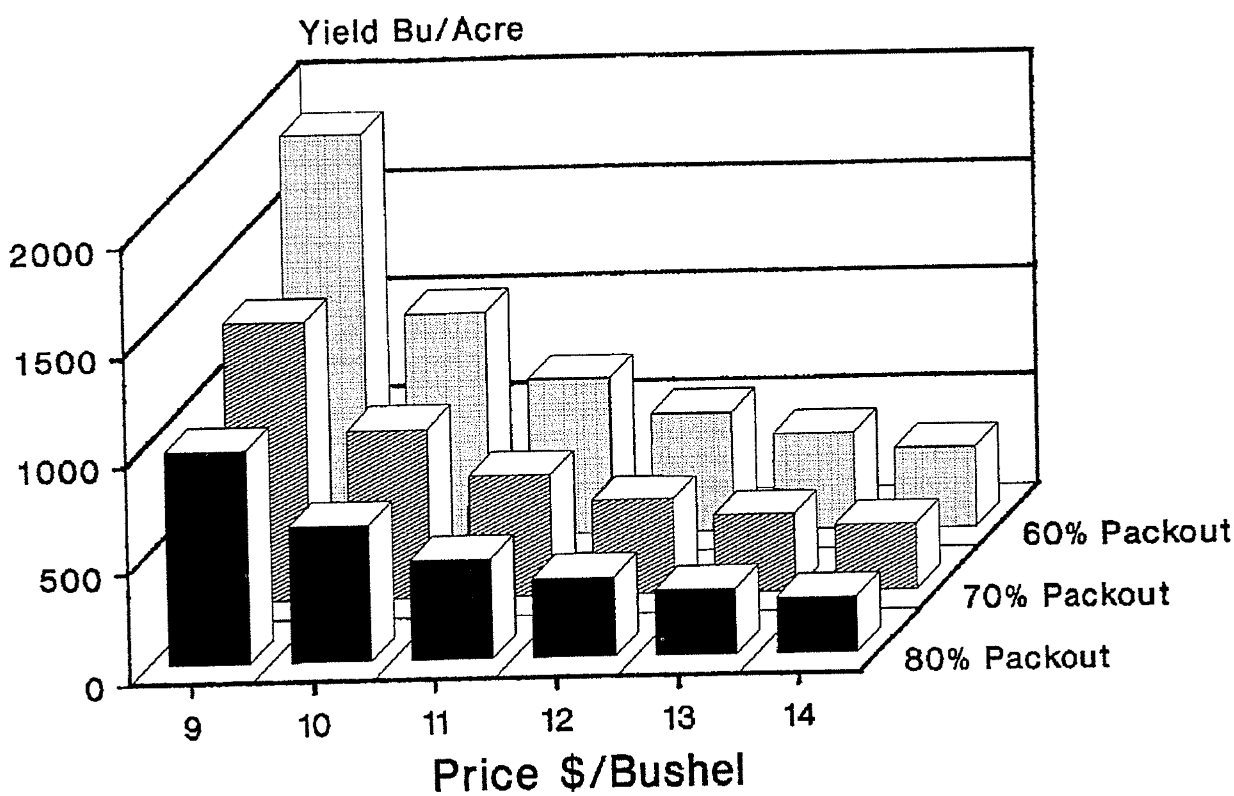

Figure 4: Yields needed to break even at different prices and packouts

NOTES

PART II: HORTICULTURAL PRACTICES

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INTRODUCTION

The horticultural information presented here is drawn largely from current, proven pomological practices in the Northeast and focuses on growing disease-resistant cultivars (DRCs). These practices should help growers establish quality apple production and profitability from low-input apple operations. Much of the information is excerpted from the *New England Apple Production Guide* and from low-input sustainable apple research trials and grower experiences. Suggested reading references are included in Appendix I and you may contact your local office of the Cooperative Extension Service for additional advice and for the most current information on low-input sustainable apple operations in your area.

DISEASE-RESISTANT CULTIVARS

A grower's choice of cultivars will greatly affect the success of the orchard enterprise. When choosing cultivars consider market demand, succession of ripening periods, adaptability to climate, productiveness, and storage life.

Disease-resistant cultivars and numbered selections available for commercial plantings are listed in Tables 4 and 5. All are "field immune" to apple scab and have varying degrees of resistance to powdery mildew, cedar apple rust and fire blight (see Part III: Apple Disease Management), but are not resistant to insect damage (see Part IV: Insect and Mite Management).

Pollination

Most of the disease-resistant cultivars, except 'Sir Prize' and NY 66305-139, produce viable pollen. DRCs have not been studied as pollinators in orchards, but have been used successfully as pollen parents in breeding.

Most apple cultivars, probably including DRCs, are self-unfruitful and require cross-pollination to set a commercial crop. Two means are available for obtaining cross pollination: planting more than one cultivar, or planting disease-resistant crabapple pollinators that are compatible with commercial apple cultivars. The flower color of the pollinator should be similar to flowers of the cultivar to be fertilized because individual bees tend to visit flowers of like color. Ideal crab pollinators have small, white, cup-shaped flowers.

If you select other cultivars as pollinators, each should be evaluated for the age at which it begins to flower; its period of bloom; the viability of the pollen produced; its tendency to flower annually; any cross-incompatibilities; and its adaptability value in the region.

Tables 4 and 5 include most of the DRC cultivars grown in the Northeast. These are generally suitable cross-pollinators, but their bloom periods do not coincide every year. During years when prebloom temperatures are high, all cultivars are apt to bloom at the same time; when prebloom temperatures are low, seven or more days may elapse between early and late-blooming cultivars. Bloom periods of the cultivars listed in the early and midseason blooming groups overlap enough to provide cross-pollination in most seasons; the same is true for cultivars in the midseason and late-blooming categories. Do not rely on an early-blooming cultivar to cross-pollinate a late-blooming cultivar, or vice versa.

In lower-density plantings, the pollinating cultivar may be set either in solid rows or interplanted with the main cultivars. When the pollinating cultivar is set in solid rows, alternate one or two rows of the pollinator with four rows of the main cultivars. Where interplanting is used, every third tree in every third row should be a pollinator.

Orchardists usually rent colonies of honey bees for pollen dispersal. An average of at least one, but preferably two, colonies per acre should be placed in the orchard before 10 percent king bloom. The hives may be arranged singly or in groups of four at various locations. Grouping is preferred because when colonies compete with each other, bee activity increases. Bees can set a crop in two days when the temperature is at least 65°F and it is partly sunny. After full bloom, remove the bees as soon as possible to continue your spray program.

Tables 4 and 5 also include cultivars' and numbered selections' tree and fruit characteristics. Research is underway in the Northeast to evaluate and develop recommendations for producing, harvesting, storing, and marketing

Tables 4 and 5:

[y] 0 = no crop; 1 = very light crop; 2 = light crop; 3 = medium 4 = full crop; 5 = overloaded. Information supplied by R. C. Lamb, New York State Agricultural Experiment Station.

[x] The harvest periods on pp. 10-15 cover the Northeast geographical area from Vermont to Pennsylvania. Those on p. 16 refer to selections grown in Indiana. DAFB = days after full bloom. For example, 'Williams Pride' is harvestable 90 to 100 days after full bloom.

Table 4:

[z] Available tree performance and fruit characteristic information

Table 5:

[z] Information on pp. 14-15 supplied by R. C. Lamb, New York State Agricultural Experiment Station, Geneva, NY. Most Selections are available from New York State Fruit Testing Cooperative Association, Geneva, NY. Co-ops 27, 29, 30, and 31 will be available for test plantings by 1991 or 1992. Information on pp. 16-17 provided by J. Crosby, Purdue University.

Table 4: Disease-Resistant Apple Cultivars: Tree Performance and Fruit Characteristics[z]

CULTIVAR (By harvest period)	PARENTAGE	TREE GROWTH HABIT	BLOOM PERIOD; FRUIT SET	PRODUCTIVITY[y]	HARVEST PERIOD[x] (DAFB)	FRUIT SIZE (AVG.)
EARLY SEASON						
Williams Pride	PRI 1018-101 X NJ 50	Spreading, vigorous, sturdy Similar to McIntosh	Early to midseason Very heavy, annual	—	Aug. 10 to Aug. 20 (90-100)	2.5" to 3.0"
Redfree	Raritan X PRI 1018-101	Somewhat upright, vigorous, sturdy Similar to Delicious	Late midseason (w/Delicious); Average, annual	3.0	Aug. 15 to Aug. 30 (90-105)	2.5" to 3.0"
Dayton	NJ 123249 X PRI 1235x100	Upright, moderate vigor Similar to Delicious	Midseason; Moderate, annual	—	Aug. 15 to Aug. 30 (100-110)	2.75" to 3.25"
Prima	PRI 14-510 X NJ 123249	Moderate vigor, easy to train & prune Similar to semi-spur McIntosh	Midseason; Moderate, annual	3.0	Aug. 25 to Sept. 15 (100-120)	2.5" to 3.5"
MIDSEASON						
Novamac	McIntosh X PRI 1018-3	Moderate vigor Similar to McIntosh	Midseason	2.7	Sept. 10 to Sept.15 (110-115)	3.0"
Jonafree	855-102 X NJ 31	Vigorous, moderate spreading, sturdy Similar to Jonathan	Mid to late (w/Delicious) annual; Fruit borne on spurs	3.3	Sept. 10 to Oct. 1 (120-130)	2.5" to 3.0"

FRUIT SHAPE	SKIN COLOR; TEXTURE	FLESH COLOR; TEXTURE	FLAVOR	MAX. COLD STORAGE	COMMENTS
Oblate to round, uniform	90% red-purple; Medium thick, slight wax	Light cream-straw color; Medium grain, crisp, juicy	Very good, spicy, subacid, full flavored	6 weeks	* Somewhat uneven ripening * Water core a problem when overripened * Promising, fine quality summer dessert apple * Prone to bitter pit under conditions conducive to this disorder
Oblate	90 - 100% dark red on yellow; Smooth, glossy	Light cream-straw color; Medium grain, juicy	Good, mildly subacid	8 weeks	* Good quality early dessert apple * Attractive to birds (early red color) * Somewhat uneven ripening * Some biennial tendency & dieback observed in VT * Question cold hardiness in some areas on some specific rootstocks such as MM. 106
Round to slightly oblate	Up to 90% bright medium red; Smooth, very glossy, moderately tough, thin	Cream-straw color; Crisp, juicy, firm, fine grain	Very good, subacid to mild, similar to Prima	4 weeks	* Attractive, glossy red * Good early to midseason apple for fresh dessert use
Round to oblate, ribbed	70 - 80% dark red-orange, w/green yellow	Straw color; Firm, crisp	Subacid, fruity	4 weeks	* Uneven ripening: requires two or more pickings * Harvest before peak maturity for optimum quality and storage life * Moderate to low cold hardiness
Oblate	70% red stripes on green	Cream-white	Tart, similar to McIntosh	2 - 3 months	* Flavor and texture similar to McIntosh
Oblate, irregular	90% red stripes; Slightly thick, slightly tough, dry, waxy	White to light straw color; Fine grain, crisp, slightly tough until fully ripe	Very good, subacid to tart, Moderately rich	10 weeks	* May need thinning during years w/ good pollination and heavy fruitset * Compares favorably with Jonathan but with less acid

Table 4, continued

CULTIVAR (By harvest period)	PARENTAGE	TREE GROWTH HABIT	BLOOM PERIOD; FRUIT SET	PRODUCTIVITY[y]	HARVEST PERIOD[x] (DAFB)	FRUIT SIZE (AVG.)
LATE SEASON						
Priscilla	Starking Delicious X PRI 610-2	Vigorous, moderate spreading, somewhat weak, thin branched Similar to Delicious	Mid to late season; Moderate to heavy annual or biennial if previous year's crop is heavy	3.6	Sept. 15 to Oct. 5 (120-135)	2.5" to 2.75"
Freedom	NY 18492 X NY 49821-46	Vigorous & spreading, stout branched Similar to Delicious	Midseason; Moderate annual	2.7	Sept. 25 to Oct. 5 (125-135)	3.0" to 3.25"
Liberty	PRI 54-12 X Macoun	Round top, moderate to high vigor, benefits from training Similar to spur McIntosh	Early to midseason (before Mcintosh); Moderate to heavy annual	3.4	Sept. 25 to Oct. 5 (125-135)	2.5" to 3.25"
Nova Easygro	Spartan X PRI 565	Moderately vigorous, spreading, moderately thin wood	Midseason (w/McIntosh); Average, may be biennial	2.8	Sept. 20 to Oct. 5 (125-135)	2.5" to 3.0"
Sir Prize	Tetraploid Golden Delicious X PRI 14-152	Vigorous, sturdy	Midseason; Very good fruit set, annual	3.0	Sept. 25 to Oct. 10 (130-140)	2.5" to 3.5"
Macfree	McIntosh X PRI 48-177	Moderately vigorous, spreading, fruit borne throughout	Midseason; Average, annual	3.3	Oct. 5 to Oct. 15 (135-150)	2.75"

FRUIT SHAPE	SKIN COLOR; TEXTURE	FLESH COLOR; TEXTURE	FLAVOR	MAX. COLD STORAGE	COMMENTS
Oblate to conical	70-90% dark red blush over yellow-green; Smooth	Creamy yellow; Medium grain, crisp, juicy	Very good, sweet, spicy	2 - 3 months	* Moderate to heavy fruitset; thinning often needed to attain adequate size * Small average fruit size is a drawback
Oblate	80% red stripes on yellow-green; Prominent lenticels	Light cream; Tender, juicy, slightly coarse	Very good, sprightly, subacid, sweet	4 - 6 weeks	* Precocious * Reliably large fruit * Has scored well in taste tests
Oblate to conical	90% dark red stripes on green-yellow; Thin, slightly tough, smooth, glossy	Nearly white; Slightly coarse, crisp, juicy	Very good, sprightly, subacid, sweet	10 weeks, 3 - 4 months in CA	* Precocious, very productive * May require thinning * Fruit maintains high quality in CA storage; comparable to McIntosh or Empire * Has scored well in taste tests
Oblate to slightly conical, regular	80% dark red on green-yellow; Lenticels noticeable	White-cream; Slightly coarse, firm crisp	Pleasant, subacid, juicy, sweet	3 months	* Sensitive to russetting
Oblate to conical, ribbed	Lemon-yellow, slight red blush; Smooth	Lemon-yellow; Fine grain, crisp, tender	Tangy, acid, full-rich	8 months	* Bruises very easily, unsuitable for standard commercial packing * Suitable only for direct consumer sale or pick-your-own * Triploid
Round to slightly conical	75% medium red over green-yellow	White tinged with green; Firm, moderately coarse	Pleasant, moderately acid, tart	3 months	* Fruit quality appears to improve in storage

Table 5: Disease-Resistant Apple Selections: Tree Performance and Fruit Characteristics[z]

SELECTION (By harvest period)	PARENTAGE	TREE GROWTH HABIT	BLOOM PERIOD; FRUIT SET	PRODUCTIVITY[y]	HARVEST PERIOD[x] (DAFB)	FRUIT SIZE (AVG.)
EARLY SEASON						
NY 66305-139	NY 55140-9 X NY 45500-3	Moderately vigorous	Early - midseason	2.7	Aug. 15 (80-90)	2.9"
NY 74828-12	D 523 X Jonamac	Moderately vigorous	Midseason	2.7	Sept. 18 (120)	3.0"
MIDSEASON						
NY 66305-289	NY 55140-9 X NY 45500-3	Low to moderate vigor	Midseason	2.4	Sept. 19 (120)	2.75"
NY 75414-1	Liberty X Macspur	Low to moderate vigor, spur-type	Midseason; Heavy	3.5	Sept. 22 (125)	2.75" to 3.0"
LATE SEASON						
NY 61345-2	Spartan X NY 53705-21	Vigorous, upright, rounded	Midseason; Heavy	3.2	Oct. 5 (135)	2.75" to 3.0"
NY 74840-1	NY 58524-1 X Empire	Moderate vigor	Midseason	2.6	Oct. 10 (135)	3.1"
NY 65707-19	Spartan X NY 140-9	Moderately vigorous	Midseason, Moderately heavy	3.0	Oct. 5 - Oct. 10 (135-140)	2.9"
NY 73334-35	Liberty X Delicious	Moderate to high vigor, spur-type	Midseason	2.8	Oct. 9 - Oct. 12 (145)	3.25"
NY 75441-67	Prima X Spartan	Low to moderate vigor	Midseason	2.2	Oct. 15 (150)	3.25"

FRUIT SHAPE	SKIN COLOR; TEXTURE	FLESH COLOR; TEXTURE	FLAVOR	MAX. COLD STORAGE	COMMENTS
Oblate	75% red striped	White; Tender, fine grain, juicy	Sprightly, subacid	2 months	* Good quality, early apple for fresh market
Symmetric oblate	90% red with yellow-green; Smooth	White with green tinges; Soft	Sweet but bland, good aroma	2 months	* Excellent red color for a McIntosh-type apple
Oblate	80% red stripes; Smooth	White-cream; Crisp, juicy	Subacid, sprightly	2 - 3 months	* Another early McIntosh-type apple
Symmetric oblate	75 - 85% red stripes	White-cream; Medium fine grain, crisp	Sweet, fruity	2 - 3 months	* McIntosh-type with relatively low vigor
Oblate	80% red stripes on green-yellow, prominent lenticels; Thick	White cream; Medium grain, juicy, crisp	Tart, sweet, woody	3 months; CA long storage if harvested early	* Fruit may split and crack as maturity approaches
Very oblate	90% red stripes, dark maroon; Thick	Cream with green tinge; Moderately coarse, juicy	Subacid, mild, tart	3 - 4 months	* Productive, McIntosh-type
Oblate, slightly conical	80% red stripes with green-yellow	White-cream; Medium coarse	Sweet-tart	4 months	* Compares favorably to Liberty in fruit quality and growth habit
Oblate, irregular	80% dark red			4 months	* Vigorous and productive with large fruit
Oblate	80% red stripes on green; Slightly thick	White with green tinge; Medium grain	Tart-sweet pleasant	5 months	* Late McIntosh-type with good fruit size

Table 5, continued

SELECTION (By harvest period)	PARENTAGE	TREE GROWTH HABIT	BLOOM PERIOD; FRUIT SET	PRODUCTIVITY[y]	HARVEST PERIOD[x] (DAFB)	FRUIT SIZE (AVG.)
Co-op 27 (PWR37T131)	Illinois #2 (Winesap o.p.) X PRI 1042-100	Moderate vigor, upright, spur-type similar to spur-type Delicious	Early - midseason	Moderate to heavy annual cropping, uniformly moderate to large fruit	Oct. 5 - Oct. 10 (155-160)	2.9" to 3.0"
Co-op 29 (HCR14T125)	Golden Delicious X 1050 NJ 1	Moderate to high vigor, slightly upright, leggy branches, w/ some blind wood	Late - midseason	Moderate cropping, some biennial tendency	Oct. 10 - Oct. 15 (160-165)	2.75" to 3.1"
Co-op 30 (CLR4T38)	PRI 1661-2 X PRI 1661-1	Moderate to high vigor, spreading, round top, fruit borne uniformly throughout canopy	Late season	Moderate annual cropping of uniformly moderate to large fruit	Oct. 15 - Oct. 20 (165-170)	2.75" to 3.0"
Co-op 31 (PAR4T215)	Rock 41-112 X PRI 841-103	Moderate vigor, round top, spreading	Midseason	Moderate to heavy crop of variably sized fruit, biennial tendency	Oct. 10 - Oct. 15 (160-165)	2.6" to 2.9"

NOTE: Tree and fruit characteristics, pp. 16-17, based on observations made at Purdue University, West Lafayette, Indiana. Experiment Stations in the Northeast are currently establishing test plantings of these selections.

FRUIT SHAPE	SKIN COLOR; THICKNESS	FLESH COLOR; TEXTURE	FLAVOR	MAX. COLD STORAGE	COMMENTS
Oblate-round to short conic	Splashed and slightly striped, 70-90% med. to dark red over pale yellow to cream ground; Mod. thick	Cream; Firm to crisp and slightly tough, medium to slightly coarse grain, moderately juicy	Sprightly, subacid, slightly spicy	6 months	* Compares favorably to Winesap * Good quality winter storage apple * Uniform ripening and single harvest * Open calyx * Flesh may be slightly woody at harvest, mellowing in storage
Round to short conic	Slightly pink blush, 100% pale yellow, smooth skin, mod. to heavy stem-end russet; Thin, palatable	Cream to white; Very crisp and breaking, moderately coarse grain, juicy	Mildly to sprightly, subacid, slightly spicy, full flavored	5 - 6 months	* Good quality winter storage apple * Fruit borne in clusters * Retains quality in refrigerator storage longer than Golden Delicious * Remains crisp and breaking throughout life in storage * Slight to moderate susceptibility to powdery mildew
Round to elongate and occasionally oblong	Washed, 90% light to medium red, or slightly orange over green to deep yellow, smooth, bright; Thick	Cream; Crisp and breaking, medium to fine grained, juicy	Mildly to sprightly, subacid, slightly aromatic and spicy, akin to Spartan or Macoun	6 months	* Very good quality winter storage apple * Strong McIntosh parentage * Smooth commercial appearance * Good red color throughout canopy * Long storage life * Uniform cropping * Hangs well on the tree
Round and occasionally oblong	Splashed and striped, heavy scarf skin, medium to dark purple red, mottled w/ green some seasons	Cream; Crisp and breaking, coarse grained, juicy	Mildly subacid, slightly spicy and full flavored	6 - 7 months	* Good quality winter storage apple * Appearance has varied from attractive to unattractive in different seasons * Remains crisp and breaking throughout life in storage * Some tendency to dehydrate

ROOTSTOCKS

Apple cultivars do not grow true-to-type from seed, and are propagated asexually by grafting or budding. Hence, most apple trees consist of two distinct parts: the rootstock and the scion cultivar.

The most common rootstocks today are clonally propagated Malling (M.) and Malling-Merton (MM.) rootstocks. The degree of dwarfing induced by these rootstocks is shown in Table 6. Table 6 also summarizes the characteristics of the more commonly planted rootstocks. When deciding which rootstock(s) to use, it is very important to know the soil types of the land to be planted.

Rootstock performance and vigor are strongly affected by the soil environment (composition, drainage, rooting depth, etc.) and by the length of the growing season. Consider, too, factors such as tree anchorage and the need for tree support, cold hardiness, disease and pest resistance, and adaptability to specific site conditions and orchard management practices when selecting rootstocks.

The most important diseases affecting apple rootstocks are fire blight (*Erwinia amylovora*) and collar rot (*Phytophthora* spp). Fire blight can cause rapid death to trees on M.9 or M.26 rootstocks. Rootstock infection can occur on root suckers or burrknots. Often, however, it enters through bark cracks in the rootstock.

The Mark rootstock is a new, experimental rootstock whose performance is still being evaluated. Mark trees appear to have good anchorage, but should be staked anyway. Concerns about this rootstock include susceptibility to fireblight and reports of crown gall, tumors, and burrknots in test plantings.

The Novole rootstock was introduced in 1982 as a stock to produce full size, vigorous trees that are relatively unpalatable to voles. It is resistant to crown rot, fire blight, and tomato ringspot virus, and it is easily propagated by cuttings. Novole is suggested for use under a dwarfing interstem.

Rootstocks from virus-tested clones are becoming available and are free of known viruses. EMLA.111, EMLA.7, EMLA.26, etc. have the same characteristics as MM.111, M.7, and M.26, etc., except that they may be slightly more vigorous. EMLA is an abbreviation for East Malling-Long Ashton and identifies rootstocks derived from virus-free clones.

Table 6: Apple rootstocks and their characteristics (Letters denote estimate of value: A = excellent; E = poor)

Rootstock	Early bearing	Productivity	Anchorage	Collar rot resistance	Tolerance to: Wet soil	Tolerance to: Dryness	Tolerance to: Low T°	Dwarfing (% of seedling trees)[z]	Remarks and recommendations
Highly vigorous (90-100% standard)									
Standard	D	C	A	C -	C	B -	C	100	Not recommended
Medium vigor (60-85% of standard)									
MM.111	C -	B+	B+	B	C	A	B	80-90	A hardy stock
MM.106	A	A	B	C -	D	B	B -	75-90	Avoid poorly drained soils
M.7	A	B -	C	B-	C	B	C -	55-75	Suckers
Half-size and smaller (30-60% of standard)									
M.9	A+	A+	D	A+	D	C	B	30-50	Attractive to mice
M.26	A+	A+	C -	C -	C -	C	A	45-60	Fire blight susceptible
Mark	A+	A+	?	?	?	?	?	30-60	Inadequately tested

[z]Degree of dwarfing varies with cultivar and soil type.

PLANNING THE ORCHARD

Choosing an Orchard Site

Elevation

The first priority in choosing an orchard site is proper elevation. The orchard site should be situated high enough so that cold air will settle in the lower land around it (see Figure 5). On a cold, still night, the temperatures in valleys and low areas may be 5° to 10 °F colder than in the elevated lands around them. Such temperature variations can mean the difference between a successful crop and crop failure. Insufficient elevations and their related spring frosts and extreme winter temperatures can easily result in failed crops and eventual abandonment of the orchard. Sites surrounded by dense woods or other obstructions that impede the free movement of cold air out of the orchard should be avoided as well, unless a swath can be cut to allow cold air to move to lower levels.

Due to the danger of soil erosion, slopes with an incline of more than 15% should be avoided. It is also difficult and hazardous to move orchard equipment through established plantings on steep slopes.

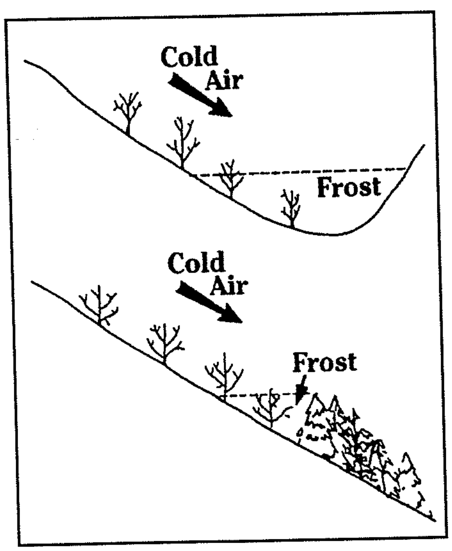


Figure 5: Cold air will flow to the lowest point and will accumulate where drainage is obstructed.

Soil

The ideal orchard soil is deep and well drained, yet retains moisture. The more darkly colored topsoil layer is usually well supplied with organic matter. The subsoil should be relatively light textured and uniformly brown, extending to a depth of 4' to 6'. The condition of the subsoil can be a limiting factor in apple production. If it is heavy and composed mostly of fine particles, water will not drain quickly, and oxygen, which is necessary for root development and growth, will be excluded. Tree growth and fruit production are very poor on such soils. (Tree roots can stand some submergence during the dormant season, providing water drains away by the time growth starts in spring.)

To help determine if the land is suitable for growing fruit trees, a backhoe or auger should be used to expose the subsoil at depths of 4' to 6'. Subsoils that are mottled in color, have prominent gray streaks, or have a compact gray layer close to the surface are poorly drained and should be avoided. Subsoils composed of coarse gravel are too well drained, and trees planted there will suffer from drought unless they are routinely irrigated.

Special Pest Considerations

Summer Diseases

Site selection has important implications for controlling certain pests throughout the life of the orchard. Apples grown in low sites with poor air drainage (therefore, a humid microclimate) are subject to summer diseases such as sooty blotch and flyspeck. These diseases are more prevalent in more southerly locales and occur more frequently along borders with woodlots and brushy hedgerows than in areas well separated from alternate hosts. Because summer diseases are potential disease problems in DRC plantings, sites that are favorable for sooty blotch and fly speck should be avoided.

Phytophthora

Many orchardists must cope with less than ideal soils. If soils are not well drained, extra precautions are needed to minimize potential damage from *Phytophthora*, root and crown rot, and other problems associated with wet sites. In marginally drained soils where installing drainage is not viable, trees will grow better if planted on broad ridges or raised beds. Planting trees on ridges helps keep the crowns above the soil's saturation zone. The ridge must be wide enough to prevent excessive root suckering and rapid lateral penetration of frost, which might injure roots in fall. Consult local tree fruit Extension personnel about constructing raised beds and using appropriate rootstocks.

The choice of rootstocks is also limited if trees are planted in marginally drained soils. Trees on standard rootstocks will perform best in wet soils. *Phytophthora*-susceptible rootstocks, such as M.26 and MM.106, should not be used.

Apple Replant Disease

To reduce the use of plant protectants, growers may decide to replant sites with disease-resistant apple cultivars. Trees may not do well on old orchard sites, however, due to apple replant disease (ARD), which adversely affects tree development and crop performance. ARD is caused by soil-borne organisms, including certain parasitic nematodes, fungi, and bacteria; and by abiotic factors such as toxic chemicals produced by old roots, unbalanced soil nutrition, and impaired soil structure.

Some parasitic nematodes and soil-borne microorganisms cause swollen and distorted roots; others cause dark-colored lesions and kill many feeder roots. Aboveground symptoms are poor, stunted tree growth and development; foliage wilting and yellowing; and poor yields. The level of severity depends on orchard age, previous host crops, soil type, and the extent of damage on old tree roots. Trees may remain severely stunted for years or for their entire lives.

Although the vigor of most apple trees improves with age, trees with replant injuries rarely become as productive as healthy trees on sites with few pest nematodes. In the Northeast, ARD is one of the most economically serious apple industry problems. Profitability in a replant orchard can be delayed fifteen years or more, and sometimes is never achieved.

Soil and feeder root samples may be collected from the old orchard and sent to a nematode diagnostic laboratory for analysis. For more information about ARD sampling, parasitic nematode assays, and possible seedling stunting bioassays, contact your local Cooperative Extension Service office. Based on the results of ARD and soil nutritional assays, one or more of the following may be recommended for preparing low-input orchard sites:

1. Liming to raise soil pH
2. Adding organic matter to row strips
3. Cover cropping with sudangrass, perennial ryegrass, or creeping red fescue to reduce potential root lesion nematode problems
4. Adding other nutrients before or at the time of planting
5. Removing dandelion weeds if dagger nematodes are a problem

Additional preplant practices that may be necessary include:

1. Subsoiling to break up hardpan
2. Improving drainage by tiling or ditching
3. Soil leveling

The first four years are most important in combating ARD, and the following are critical for initial success on all sites:

1. Using only top quality nursery stock
2. Establishing an irrigation program during the non-bearing years
3. Maintaining ideal tree nutrition (achieved by monitoring nutrient levels in foliage and soils)
4. Controlling weeds within tree rows
5. Maintaining 4% to 5% organic matter in the topsoil
6. Monitoring and controlling nematodes when necessary

Powdery Mildew

Cultivars that are highly susceptible to powdery mildew should not be mixed with mildew-resistant cultivars in the same planting. Mildew-susceptible cultivars provide mildew inoculum for cultivars that would otherwise escape infection. Even disease-resistant cultivars, such as 'Liberty', can become heavily infected with secondary mildew if they are planted close to cultivars that provide an abundance of inoculum. If mildew-susceptible cultivars must be included in a planting, they should be planted in solid rows so that, if necessary, mildewcide sprays can be applied to individual cultivars without treating an entire block.

Wildlife

Wildlife damage is a potential threat to orchard health. Sites where deer populations are high will require deer repellents and possibly fencing. Sites adjacent to abandoned meadows and other vole and rabbit refuges are likely to have more severe problems from immigration of these pests.

Deer

Deer can cause significant injury and setbacks to apple orchards. Injury to young plantings can be devastating, especially from repeated deer browsing during both dormant and growing seasons. Injury to older, fruiting trees usually consists of browse damage to vegetative shoots, flower buds, and spurs, and although this damage may be significant, long term crop losses are rare.

There are several management options to alter deer feeding patterns and minimize damage, but areas with large deer populations and past crop damage will require a management program that includes fencing. Often, fencing must be put up before the orchard is established.

A variety of repellents have been developed to deter deer. All are effective to some degree for short-term control, but none are effective in situations of moderate to heavy deer pressure. Noncommercial repellents may be tried where pest pressure from deer is low: Human hair — available from barber shops and beauty salons — can be hung from outer tree branches in fine mesh bags placed 30" above the ground. Place at least two large handfuls of hair in each bag and space them no more than 3' apart around the tree. Deodorant soap bars may likewise be hung with wire from tree branches to repel deer. Leave the soap bar wrappers on to reduce weathering and prolong usefulness. Periodic sprays — in spring, midsummer and fall — of eggwash (one egg per gallon of water) has proven effective in detering deer browsing.

Rabbits

Rabbits, especially cottontails, often cause serious damage to young apple trees. Damage usually includes extensive bark removal and severe clipping of lateral shoots. Habitat management is an effective population control measure. Eliminate overgrown ditches, brushy fence rows, and stone walls, which provide rabbits with food and protection from predators. Orchard perimeter fencing, or 1" to 1 1/2" mesh hardware cloth that extends 3' above the average snow depth is also effective against rabbits.

Trees can also be protected from rabbits and meadow voles by quarter-inch galvanized hardware cloth tree guards that extend 2' above the average snow depth and 3" to 6" below the soil surface. Cut the cloth large enough to completely encircle the trunk and allow room for ten or more years' growth. Secure the seam with short pieces of wire, leaving no gaps through which rodents can enter.

Several types of plastic and paper tree guards are available, as well. They are easier to handle than wire guards, but are disadvantageous for various reasons: Some perforated polyethylene and plastic mesh guards may be broken down by ultraviolet light and offer limited orchard lifespans; wraparound plastic guards are cheap and easy to install but must be removed each spring and re-installed each fall; and various borers seem to prefer trees with wraparound plastic or paper guards. Also, the bark beneath plastic guards remains tender and hardens slowly; the plastic may become brittle when weathered; and they are difficult to keep in place on trees with uneven trunks or swollen graft unions.

Voles

Meadow voles and pine voles, relatives of mice, are distinguished from each other mainly by tail and ear size (see Figure 6). Meadow voles inhabit orchard floors, developing a network of surface trails through the groundcover, and feed mostly on grasses and fleshy herbs. They do most of their tree damage during winter, when herbage is less abundant, but damage is possible at any time of year. They chew away areas of bark and cambium that can be reached from the ground, or from higher positions when snow is on the ground. In some soils they burrow, and sometimes girdle tree trunks several inches below ground.

Pine voles travel in surface trails or in runways 3' or more below ground, depending somewhat on soil conditions. They feed on bark and cambium, mostly below the soil line, and chew off small roots up to the diameter of a pencil. All commercial apple cultivars, as well as available rootstocks except Novole are susceptible to vole feeding.

Preventing vole population buildups is the most practical way to reduce tree injury:

1. Mow orchard floor groundcover frequently during the growing season and remove clumps of dead and decaying vegetation, which may provide shelter and nesting sites for voles.
2. Maintain a vegetation-free area within at least 3' of the tree trunks by shallowly cultivating the area, being wary of surface roots; or pile gravel around trunks.
3. Eliminate brush and thick vegetative cover around orchards.
4. Remove all fruit drops from the orchard.
5. In small orchards, place spring-type mouse traps in runways and pine vole tunnels, and check the traps daily.
6. Trample the snow around trunks to collapse snow runways.

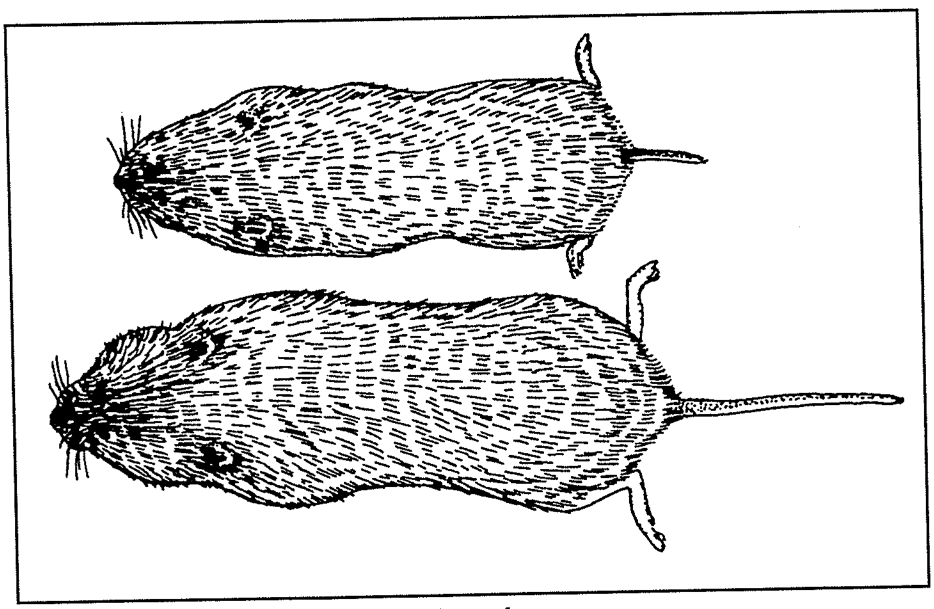


Figure 6: (top) pine vole, (bottom) meadow vole

Orchard Design

Tree Spacing

Tree spacing, or density, will vary depending on cultivars, rootstocks, orchard site, soil, tree training and pruning practices, nutrition, and methods of marketing, among other factors. Table 6A presents general guidelines for planting densities, the number of trees in each category of density, and the rootstock and interstem combinations that can be used in each density. Alleys, 8' wide, should be allotted for orchard travel and harvest operations. If 7' alleys are preferred, decrease the spacing between rows by 1' (for example, decrease a 16' x 24' spacing to 16' x 23'). Small scale tractors and orchard equipment are readily available for use in high density orchards. As planting density increases, correct matches between soil, cultivar, and rootstock become even more important.

Table 6A: Rootstocks used for different tree densities

Density	Number of trees per acre	Rootstocks that can be used in each density[z]
Low	Fewer than 110	Standard, MM.111, MM.106, M.7
Medium	110-250	MM.106, M.7, M.26, Mark
High	250 or more	M.9

[z]Cultivar vigor and soil type influence tree spacing.

Purchasing Trees

High quality trees are the foundation of a successful orchard. When purchasing trees, follow these suggestions:

1. Plan ahead (a year or two is best) to ensure that all of the trees you want will be available.
2. Choose trees for their qualities, rather than price. One-year-old trees, 4' to 6' tall and at least 1/2" to 5/8" diameter usually grow faster and better than shorter trees or trees of smaller diameter.
3. Insist on dormant, one-year-old, branched (feathered) trees, or whips budded 10" to 12" above the bottom of the rootstock. Trees budded lower than this may require permanent staking.
4. Refuse to accept second best even if you have to wait a year or more for quality trees. Waiting time can usually be well spent on site preparation.

If conditions are not suitable for planting, open the bundles and store the trees in a cool, well ventilated shady area or open shed. Keep the roots moist by covering them with wet soil, peat, or sawdust. Do not store trees along with apples or in a place where apples have been stored. Residual ethylene in the storage atmosphere might break the trees' dormancy, and when planted the trees may die or fail to grow properly.

PREPARING THE SITE

The orchard floor should be as smooth and rock-free as possible for easier maintenance and to prevent bruising apples as they are transported out of the orchard. Uneven orchard floors also make low mowing impossible and provide habitats for voles. Also, composting leaves with a flail mower to reduce scab inoculum is hindered by an uneven orchard floor.

Orchard Manuring

Whenever possible, plant apple trees in 4' to 6' wide, tilled strips, regardless of the soil management system followed later. Green manures may be planted when preparing soils for tree planting. Green manures can add organic matter and improve biological activity and productivity in orchard soils. Incorporating organic matter into the soil also modifies the structure, texture and moisture-holding capacities of soils; improves aeration; and provides a storehouse for nitrogen and other plant nutrients. Examples of good green manure crops include spring oats, buckwheat, and millet sewn as summer covers; and winter rye and hairy vetch as winter cover crops.

Legumes enrich the soil by "fixing," or securing, nitrogen in the soil through the activity of bacteria in root nodules. With a leguminous green manure planted in row strips, up to 135 lbs nitrogen/acre may be captured from the atmosphere and fixed. For example, a cover crop of hairy or common vetch (legumes) and spring oats could contribute 108 lbs nitrogen/acre, of which 30% to 40% would be available to newly planted trees, depending on the soil and climatic conditions.

Cow manure may be used with or without green manure crops to boost soil fertility levels and soil organic matter. Applications of 25 tons to 30 tons/acre are applied to row strips a year before planting, then plowed, disced or rototilled into the topsoil. Other manure fertilizers, including poultry, sheep, and horse manures, have not been tested widely and their benefits as organic sources are largely unknown.

Soil Reaction

Most soils in the Northeast are naturally acid. In most productive soils, the soil acids — clay and humic acid — are combined with bases such as calcium, magnesium, and potassium. Orchard soils should be in the pH range of 5.8 to 6.5. Growers should monitor the soil reaction regularly because, over time, some soils become progressively more acid and less productive. This occurs as calcium, magnesium, and potassium are lost by leaching or crop removal. The harmful effect of acidity is attributed mainly to excessive hydrogen ions, soluble aluminum, manganese, and iron and to deficiencies of calcium, phosphorus, or other essential nutrients. If soil tests indicate that the pH is too low, add lime to the orchard soil.

Liming

Chemically, lime brings about many complex changes in an acid soil. Liming can correct soil acidity and eliminate aluminum, iron, and manganese toxicity conditions. Overliming, however, creates iron, boron, and manganese deficiencies by making these nutrients less available to trees.

Biologically, lime influences soil organisms and thereby increases the effects of organic matter and nitrogen in the soil. The rate of turnover of these constituents is more important than the actual amounts present. Decay of organic matter and ammonification are accelerated by liming an acid soil. Nitrogen-fixing bacteria are stimulated, and nitrification — the change of ammonia nitrogen to nitrate nitrogen — proceeds more rapidly. Lime may also improve the physical structure of soils. However, attaining the desired pH in orchards can be a slow process because lime penetrates soil slowly.

Orchardists can use dolomitic or calcitic lime. Calcitic lime is usually preferred because it is more soluble and adds more calcium to the soil. If, however, the soil is deficient in magnesium, the orchardist can add dolomitic limestone; preferably one that contains at least 20% magnesium oxide (MgO).

On new orchard planting sites, the best time to apply lime is when the cover crops are planted, to incorporate it into the soil during discing. Lime may be spread in an established orchard whenever the soil is firm enough to support the spreader equipment and when there is no danger of knocking off fruit. Experiments have shown that heavy applications of lime penetrate more rapidly than lighter applications, so all of the required lime should be spread at once. However, no more than three to four tons of lime should be applied per acre in one annual application.

ESTABLISHING THE ORCHARD

Planting

Apple trees should be planted in spring as soon as the frost is out of the ground and the soil can be worked easily, usually beginning in April. Trees should be received from the nursery by early April. Late planting (after June 1) is a frequent cause of unsatisfactory tree growth.

For planting large numbers of trees, a tractor-operated tree planter should be considered. The soil should be in good, workable condition at planting; but do not plant in wet, soggy soil. Tree holes should be large enough to accommodate the entire root system. It should be deep and wide enough so the roots rest on the bottom without having to be "pinned down" with soil. On the other hand, if the hole is too deep, the tree may settle after planting, and the graft union will be below ground. Adding two to three pounds of high calcium lime per half bushel of soil that is to be returned to the planting hole may improve the calcium level of the trees for two or three years. Bring in some rich soil for planting hole backfill and add the lime to it if the orchard soil is poor.

Researchers are investigating planting hole treatments to benefit initial tree growth. Tree hole mixtures of 1:1 peat to topsoil and 2:1 topsoil to composted manure have dramatically increased tree growth the first year. No harmful effects have been observed, and these treatments may be considered when planting the orchard.

During planting, keep roots moist by covering them with wet burlap or canvas, or keep them in water. At planting, broken roots should be removed and the tree set in the hole so the largest roots are toward the prevailing wind. Plant the tree with a slight slant in the same direction. When planting, the graft union should be 2" above ground level after the tree settles. To compensate for settling, allow an additional 2" at planting. Adjust the planting depth as needed when using a tree planter.

After planting, compact the soil by tamping it around the roots to remove air pockets and keep roots in contact with moist soil. It is not necessary to water the trees unless the weather is extremely dry before and after planting.

Placing sand or gravel around the tree base after planting will help stabilize the tree. It will also help to keep the area dry and thus reduce the danger of collar rot. Do not remove soil from around the trunk, but place the gravel or sand on top of the soil. The scion will not root in these materials. (When a graft union is planted below the soil surface, the scion cultivar will root and cancel out the dwarfing effect of the rootstock.) When wind causes the trunk to sway, the gravel settles down and around the trunk, helping to stabilize the tree and abet crown and root disorders by preventing gaps around the trunk where water can collect.

Supporting Trees

Tree support is now accepted as standard procedure in many apple growing regions. The need for tree support depends on the rootstock, cultivar, soil type, and site. For example, all trees on M.9 need permanent support. Many trees on M.26 require support because leaders tend to lean. Use preservative-treated posts, 8' to 8 1/2' long, at least 2" to 2 1/2" in diameter at the base, and set 2' into the ground. Inexpensive metal posts or aluminum conduit can also be used. These should be 10' long and be driven 3' into the soil.

It may be advantageous to provide at least temporary (five or six growing seasons) support for all trees. Temporary tree support can be provided at planting time by driving 3'-long hardwood stakes or 8' metal posts 2' into the ground next to the trunk. Plastic ties, nylon ties, or wire can be used to fasten the trees to the posts.

MAINTAINING THE ORCHARD

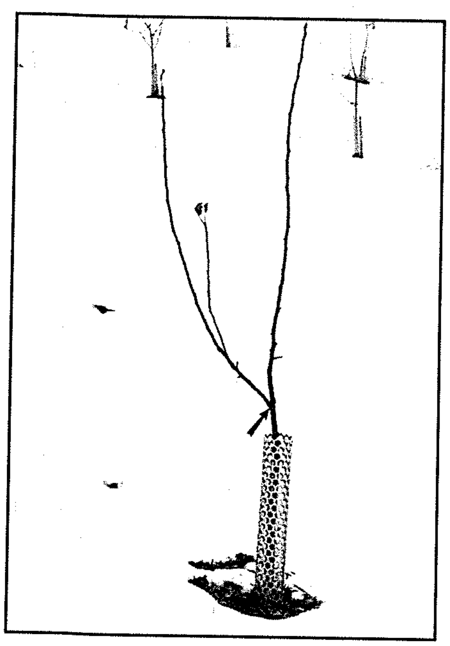
Care of Trees the First Year

Head (prune back) vigorous trees to a height of 36" to 40" above ground level. Weak trees are generally headed at 30" to 36". When newly planted trees are not headed severely enough, they develop framework branches (scaffolds) that are too high. Next pruning season, the trees may have to be headed again to induce branching at 20" to 30" above ground level.

If you receive well-feathered (branched) nursery trees, leave as many favorably positioned branches—if less vigorous than the trunk — on the trees as possible. The tree's trunk must always be larger in diameter and more vigorous than any scaffolds attached to it. Branches that are similar in size or larger will cause trees to be stunted. Also, when all branches are on one side of the trunk, they should be removed, as should any scaffolds with very steep crotch angles. If there are only one or two vigorous branches, they should be removed to prevent lopsided development of the tree (see Figures 7 and 8). If the tree being planted is branched, do not head or remove any more branches than necessary. Heading induces stunted branches with excessive vegetation and delays tree development.

After growth starts, remove the two or three shoots growing directly below the leader when they are 2" long to encourage central leader development. If these shoots remain, they will inhibit development of a strong central trunk.

Figure 7: This tree had one strong branch at planting that should have been removed. It now competes with the leader of the tree. The strong branch should be removed, and the leader should be headed at 28" to 30" to stimulate branch development.



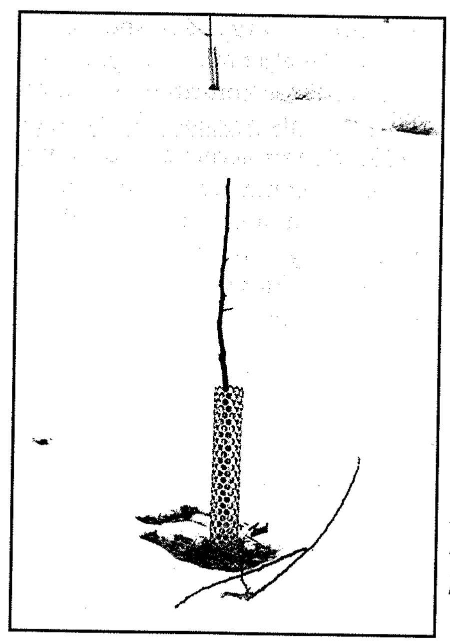


Figure 8: The same tree after pruning

Sunscald Protection

Because the bark of apple tree trunks expands on warm, sunny days in winter and contracts with freezing night temperatures, bark cracks and trunk splitting must be prevented. In late fall, paint the lower trunk and first tier of scaffold branches with a good grade of interior white latex paint, diluted to 15% with water. Repeat applications as needed for the first ten to fifteen years, or until older, rough trunk bark develops. The paint mixture can be applied easily with most hand operated or power driven sprayers.

Soil Management

A grower's orchard floor management system influences productivity as well as the life cycles of pest and beneficial organisms (see Part III: Apple Disease Management and Part IV: Insect and Mite Management). Management options include mechanical cultivation; grass management; or mulching with straw, plant residue, or plastic. These options may be employed within tree rows or over the entire orchard floor.

Trees planted in cultivated soil generally become established more quickly and grow more vigorously than trees planted directly in sod. Newly set apple trees and trees on rootstocks of M.26 vigor or less, usually do very poorly in grass sod within the tree row because of competition for moisture and nutrients. Even if a sod mulch system will be used later, clean cultivation—at least in root areas— should be practiced for the first three or four years.

Sod

The most common grass species now used as orchard sod cover in the Northeast are Kentucky bluegrass, creeping red fescue, smooth barnyardgrass, and companion mix (70% Elka perennial ryegrass/30% Ensylva red fescue). Companion mix is an especially good choice for replant sites because it suppresses parasitic nematode activity, is hardy, and provides good weed control. The heavily matted nature of a fescue cover may also provide a firmer operating surface, particularly in wet years. Creeping red fescue is a good choice because it requires less mowing and suppresses the influx of broadleaf weeds such as milkweed, clover, and goldenrod. Weeds, especially dandelion, may also serve as reservoirs of tomato ring spot virus (TmRSV), which is associated with a disease known as apple union necrosis or decline. Apple trees in orchards become infected with TmRSV through inoculation by dagger nematodes, which acquire the virus from previous trees, weed cover, or infected nursery stock.

Cultivation

Cultivation is practiced only in young plantings when land has been cleared from woods or when an old orchard site is renovated. The land must be fairly level and free of the tendency to erode. After a year or two the land between rows is reseeded so the groundcover will help control tarnished plant bugs.

Narrow strips on either side of the nonbearing tree rows are cultivated and the row middles are kept in permanent sod. After three or four years, when the trees become well established, the cultivated strips may be seeded with one of the grass mixtures previously mentioned, or allowed to reestablish natural grasses and weeds.

Mulching

Where available, organic mulches serve as sources of nitrogen and potassium while suppressing weeds and grasses, which compete with apple trees for water and nutrients. They are favored by growers who prefer not to use commercial fertilizers or herbicides. However, organic mulches are expensive and unwieldy to apply because large amounts of them — about 134 cubic yards per acre — are required. Grass mulches are not recommended for orchard use as they encourage vole nesting and bark feeding damage to trees, cause root development close to the surface, and harbor insects such as plum curculio. Hay mulch, on the other hand, can suppress grass and weed growth, while improving biological activity and soil structure, and conserving moisture.

A range of 1.20% to 1.80% potassium in the leaf is favorable for red fruit color development, and the need for this element is high in heavy-cropping trees; but excessive potassium supplied by hay mulch can suppress calcium uptake. Contact your Cooperative Extension office for leaf sampling kits and further information. Thus, when apple trees are heavily mulched, it is necessary to adjust fertilizer programs, especially after the mulch begins to decay. While mulches vary considerably in chemical content, the average hay mulch contains approximately 1% nitrogen, 0.5% phosphorous, and 1.3% potassium. On this basis, 33 pounds of hay mulch added to the soil is equivalent to 1 pound of ammonium nitrate.

Plastic mulches may provide some of the advantages of organic mulches at less expense. They are now being evaluated for economic feasibility and for their impacts on environmental factors, tree growth, insects, diseases, and voles. Some evaluations of plastic mulches in apple orchards have shown that trees there grow better than those grown on herbicide strips; however, little is as yet known about the costs, longevity, and practicality of using plastic mulches in the Northeast.

Nutrition

Apple trees require many mineral elements for proper growth and growers must be concerned with both excesses and deficiencies. For example, calcium deficiency is associated with some physiological disorders of apples such as bitter pit, cork spot, and senescent breakdown. These findings have stimulated more research into the roles of macroelements and microelements in the postharvest quality of fruits and their storage life. The scope of apple nutrition has widened from concern about the tree to achieving optimum nutrition for both trees and fruit. But the needs of trees and fruit may differ and compromises may be necessary.

Leaf analysis is an effective guide to economical and efficient fertilizer practices and is an aid when diagnosing specific problems in orchards. The leaves are usually analyzed for nitrogen, phosphorous, potassium, calcium, magnesium, manganese, iron, copper, boron, and zinc. The accuracy of the diagnosis depends upon the accuracy of the sample collection. If leaves are not carefully washed after collection, residues from nutrient sprays of calcium, manganese, magnesium, zinc, copper, and boron make analyses for these micronutrients meaningless. Check with your local Extension tree fruit specialist for information on apple leaf analysis programs and for a standard guide to fertilizing apple trees.

Fruit Thinning

The amount of resources available to apple trees during the growing season is limited. If a tree has a large number of fruit, each fruit will receive a small portion of those resources and will most likely be small. In addition, a tree with large numbers of fruit will have less energy available to developing flower buds the following year and will begin to bear on an every-other-year cycle (biennial bearing). If trees have a small number of fruit, however, each fruit will receive a larger portion of available resources and will be larger.

To obtain high yields, encourage good fruit size at harvest, and ensure adequate bloom the following year, a portion of the fruit that set will probably have to be removed early in the growing season. After the June drop period, fruit should be spaced approximately 5" to 8" apart. If they are closer, fruit must be removed. Hand thinning should be completed as early as possible (late June and early July) for maximum benefits.

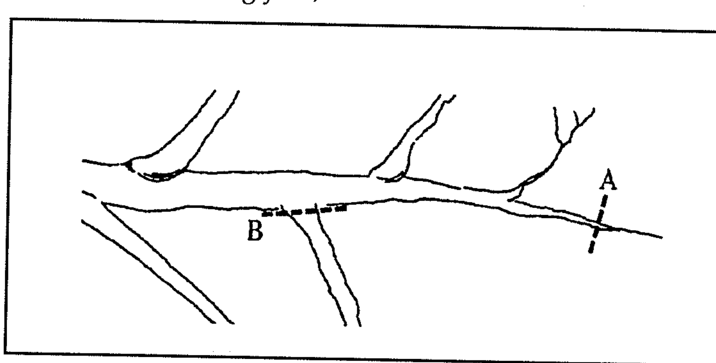


Figure 9: The two basic types of pruning cuts: A) heading cut and B) thinning cut

TREE TRAINING AND PRUNING PRACTICES

The practices described here are basically for developing conically shaped apple trees. This framework allows for larger, more vigorous and productive scaffolds in the bottom third, with shorter, weaker-yielding branches in the upper two thirds of the tree. In general, most vigorous cultivar/rootstock combinations will have a final form with permanent scaffold branches distinctly separated to allow uniform sunlight throughout the tree. Less vigorous, supported, cultivar/rootstock combinations require no distinct separation between tiers of branches. For recommendations on high-density, supported orchards, contact your Extension specialist. Semipermanent, weaker, fruiting scaffolds, which require periodic renewal, are maintained throughout the tree, most often in the top, and are later removed when they crowd or cause undue shading.

Types of Cuts

Most pruning cuts can be classified as heading or thinning cuts (see Figure 9).

Heading Cuts: Heading removes the growing point or terminal bud on a shoot. These buds are associated with apical dominance. Heading cuts are made in the current season's growth or one-year-old wood. These cuts are made to:

1. Encourage development of lateral branches
2. Stiffen central leaders

Thinning Cuts: A thinning cut removes an entire shoot or branch at its junction with another shoot, branch, or the trunk. These cuts are made to:

1. Direct growth in a different direction
2. Eliminate competition among branches
3. Remove vigorous, upright growth on branches or weak wood

Stubbing Cuts: Stubbing cuts are made sparingly into two-year-old or older wood. They differ from thinning cuts in that they are not necessarily made to a dominant side shoot. These cuts are made to:

1. Encourage the development of side shoots
2. Reduce the length of a limb
3. Stiffen branches

Pruning Free-standing Trees up to Bearing Age

Goals:

1. To develop a strong central trunk with nine to thirteen main scaffold branches, well separated vertically in three or four tiers. Some of these will be removed as the tree reaches maturity.
2. To develop scaffold branches with wide crotch angles (45° to 90°), which have many evenly spaced fruiting laterals of varying lengths. (note: Spur-type trees will not produce many lateral branches.)
3. To develop — as soon as possible — a tree capable of supporting a crop of apples.

Practices:

First Growing Season:

1. When the shoots are 6" to 8" long, select one of the upright-growing shoots below the heading cut as the extension of the leader (see Figure 10). A shoot growing in the direction of the prevailing wind is preferred. Remove shoots that compete with the leader.

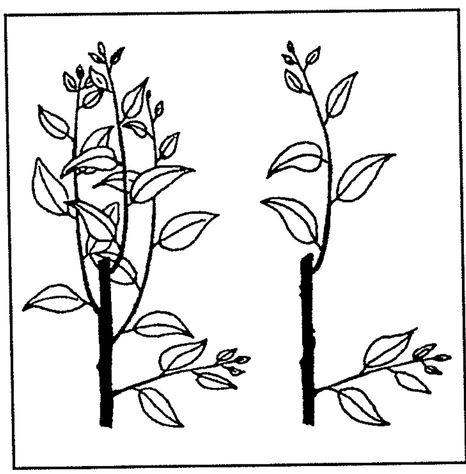


Figure 10: Before and after pruning in June of the year of planting, remove vigorous shoots that compete with the leader to ensure its dominance.

2. As scaffold limbs develop, establish wide crotch angles. Use devices such as spring-type clothespins or toothpicks to spread branches to desired positions (see Figures 11 and 12).
3. Do not allow branches — especially on the lower part of the tree — to develop at right angles to the travel or spray alley.
4. Remove low limbs that will interfere with the placement of mouse guards. Establish the first branch 22" to 24" above the soil.

Figure 11: Clothespins may be used on young apple trees to improve the angle of the branch union and prevent branch development problems. Attach the clothespins when the shoots are 4" to 8" long. The limbs will become fixed in the spread position in about two weeks.

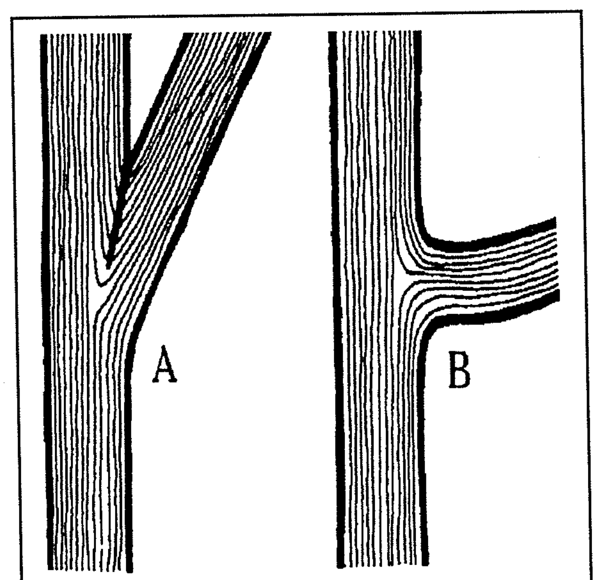


Figure 12: A narrow crotch angle (A) usually contains a bark inclusion that makes the crotch weak. A wide crotch angle (B) has annual rings of wood all around the junction of the scaffold branch and trunk. This increases crotch strength.

First Dormant Season:

1. Prune in early January or later.
2. Identify the central leader and remove competing branches. This may be done in June of the first growing season (see Figure 13).
3. Select three to five lower (only) permanent lateral branches—well spaced vertically around and smaller than the trunk—which will represent the bottom tier.
   a. If only one branch has developed or the branches are too high or too low, remove them at the trunk.
   b. If branches have developed on only one side of the tree, remove them at the trunk.
4. If the tip of the central leader is higher than 16" to 18" above the topmost potential scaffold limbs, head it back to 16" to 18" above these limbs. Cut it to a bud on the windward side. Heading will stiffen the leader and induce lateral branching below the cut. However, heading is not always necessary and may cause the central leader to develop a crook and lose its dominance.

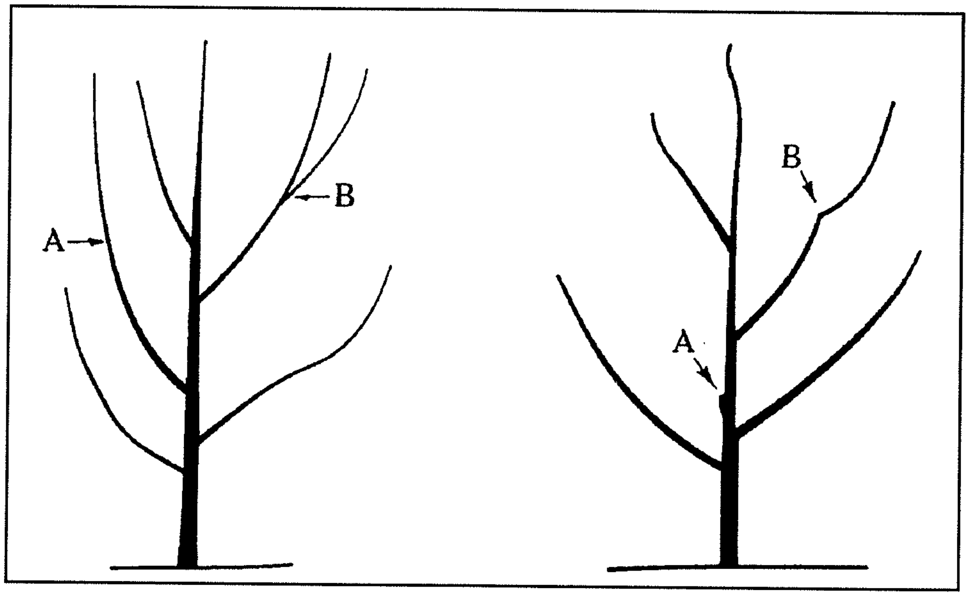


Figure 13: In the first drawing, branches A and B are competing with the leader. In the second drawing, Branch A has been removed and Branch B headed back to a side branch.

Second Growing Season:

1. If any scaffold or the central leader develops two or three vigorous terminal shoots, remove all but one.
2. Spread branches.

Second Dormant Season:

1. Continue to select scaffold branches in the two bottom tiers, leaving as many as possible without restricting the dominance of the central leader or development of competing scaffolds. Separate the two tiers by removing any unnecessary branches within 2' to 2 1/2' of each other along the trunk.
2. If necessary, make heading cuts to invigorate growth, to stiffen leaders or scaffolds, or to induce lateral branching on leaders (very rarely needed, especially with vigorous cultivars).

Third Growing Season:

1. Vigorous trees of productive cultivars may bloom and set fruit during the third growing season. Retain the fruit if the number is not too great, but remove those on the central leader, as their weight will cause the leader to bend out of position.
2. Continue to spread branches in the upper part of the tree.

Third Dormant Season:

1. Continue to train and prune to develop a strong central leader (see Figures 14 and 15), with two to three tiers of scaffold branches.
2. Develop a conic tree. The lower scaffold limbs should be larger and longer than the next higher scaffold limbs.
3. Leave some temporary scaffold branches to provide additional leaf area. These should be removed when they begin to interfere with the development of the central leader or permanent scaffold branches.
4. Branches on the tree's windward side are apt to "hug" the leader until cropping holds them down. Competition from extra limbs will help keep the branches horizontal, but to prevent restricting the central leader or inhibiting the development of desirable scaffold limbs, stub back the extra limbs. Stub pruning reduces the length of undesirable limbs by cutting back into two or three-year-old wood rather than removing them. Many of the stubbed branches will have to be removed or restricted again during the next pruning season.
5. Remove limbs that are less than 20" to 24" from the ground, that droop, or which interfere with mouse guards or cultural operations.
6. Continue limb spreading as necessary (see Figures 16 and 17).

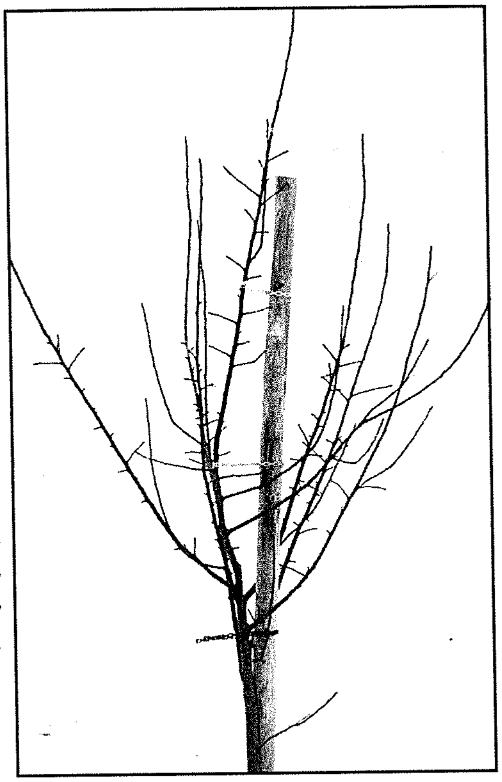


Figure 14: 'Liberty' on M.9 after three growing seasons in the orchard. The central leader should be headed to a competitive lateral. Repeated replacement of the central leader by a weaker, competitive lateral should weaken the growth in the upper part of the tree.

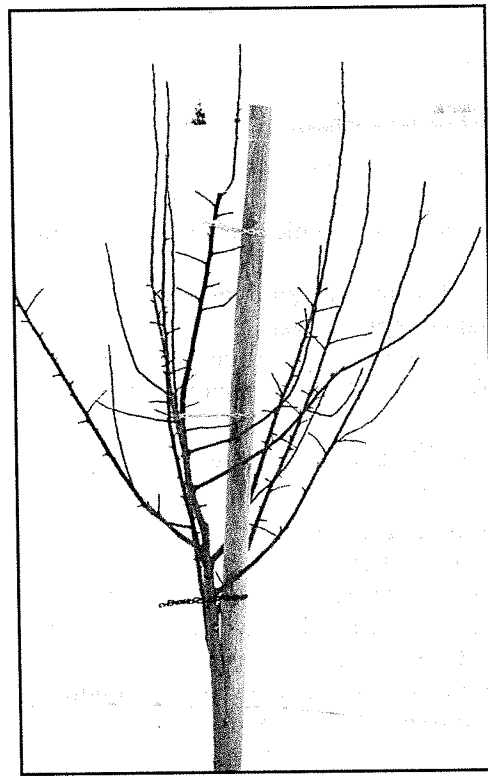


Figure 15: The same tree after pruning

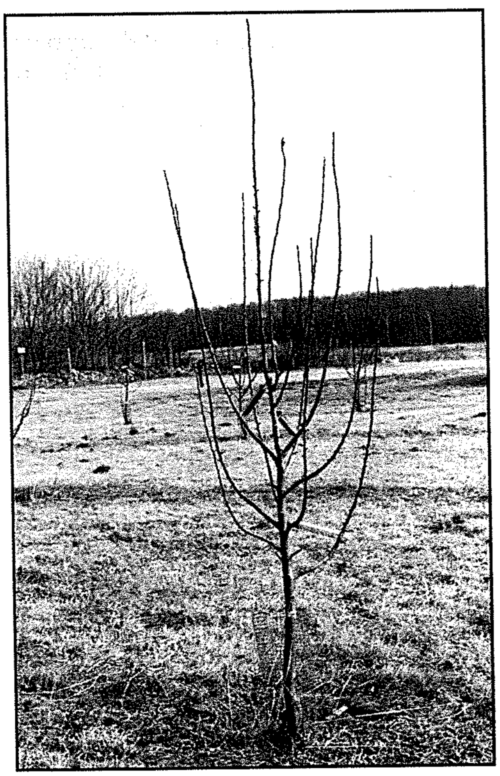


Figure 16: Vigorous, upright growth competes with the central leader.

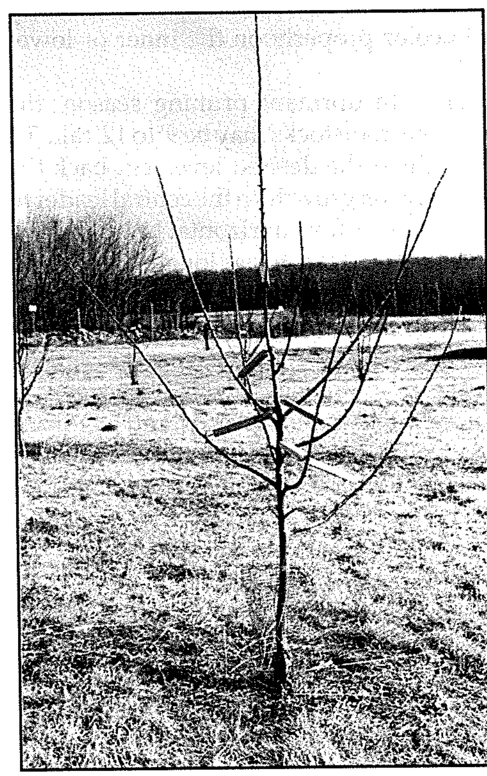


Figure 17: Using limb spreaders improves crotch angles, reduces terminal growth, favors flower bud formation, reduces competition with the central leader, and prevents lower scaffold branches from interfering with the growth of scaffold branches originating higher on the trunk.

Fourth Growing Season:

1. The framework on well-grown trees should be about 80% established. Inspect the tree. Remove only water sprouts and branches that are growing toward the center of the tree or are competing with permanent branches.

2. Trees on which development of strong central leaders has been difficult, or for which training has been neglected, may require staking to support the leader. This may be more practical than excessive pruning to reestablish the leader.

Pruning Bearing Trees

Goals:

1. To maintain high levels of light in the fruiting portions of the tree
2. To eliminate weak wood, which generally bears inferior fruit
3. To change direction and height of growth
4. To permit adequate spray coverage
5. To produce a crop with a large proportion of fruit that meets size, color, and quality requirements of the market

Practices During the Early Fruiting Years

1. Early, heavy cropping may stunt trees that are planted at wide spacings and on weaker rootstocks, such as M.26. It may be necessary to head the extension growth of the central leaders and the shoots of scaffold branches, or extensively thin the crop.
2. When trees are widely spaced, develop a framework that utilizes the space allotted for each tree.
3. On young, bearing trees, remove temporary scaffold branches; otherwise the trees will become too bushy for the fruit to color properly on the inner or lower branches.
4. By the fifth or sixth dormant pruning season, the leaders on vigorous rootstocks may be 9' to 12' tall. To contain tree height at the desired level, cut back the past season's extension growth on the central leader to a fork or tier of three or four horizontal branches.
5. As the branches on the trees grow longer, they bend downward under the stress of cropping, and terminal dominance is lost. Numerous water sprouts and vigorous upright shoots may be produced from buds on the upper sides of scaffold branches, even when trees are relatively young. The water sprouts and vigorous upright shoots require thinning out, but those that can serve as replacements for the drooping ends of branches can be retained.
6. Remove broken and diseased branches.
7. Eliminate branches with narrow crotch angles.
8. Eliminate crossing and parallel branches, which tend to shade.
9. Remove branches that are growing toward the center of the tree.
10. Vigorous, strong scaffold branches growing 30° to 50° from the vertical will have to be removed. If not removed, they will prevent the development of scaffold branches from the leader above them and the tree will become multi-leadered.

Practices for Older Bearing Trees (see Figures 18 and 19):

1. Remove water sprouts that are not needed to protect branches from sunscald, to provide additional fruiting wood, or to provide for branch renewal. Those retained for branch renewal generally require spreading.
2. Eliminate branches with narrow crotch angles.
3. Eliminate crossing and parallel branches that shade more desirable branches.
4. Remove weak, drooping branches that are severely shaded and have few fruiting spurs.
5. Remove branches that are growing toward the center of the tree.
6. Remove suckers that arise at the base of the tree.
7. Reduce the height of excessively tall trees by cutting back to strong, horizontal scaffolds originating at a lower level on the leader.
8. Frequently, a strong scaffold branch with a narrow crotch angle develops in the upper third of the tree. If this branch is not removed, the tree will become a multiple-leader tree. Trees of this type are much more difficult to prune when practicing containment pruning or lowering tree height.
9. Do containment pruning when it is necessary to restrict tree spread and height:
   a. Remove branches that crowd adjacent trees, or cut them back to a weaker side branch to maintain the desired outer profile of the tree rather than alleviate tree containment problems. Such cuts will produce vigorous growth, and by the end of the next growing season the pruned branch may extend as far as the orginal branch did before shortening, thus causing even more shading within the tree.
   b. Maintain conical tree shape by removing large limbs in the top third of the tree or by cutting back to a very much weaker side branch.
   c. Initiate a limb rotation program in the top third of the tree. Retain weak branches and spread desired water sprouts, which in turn may have to be removed when they become too large.

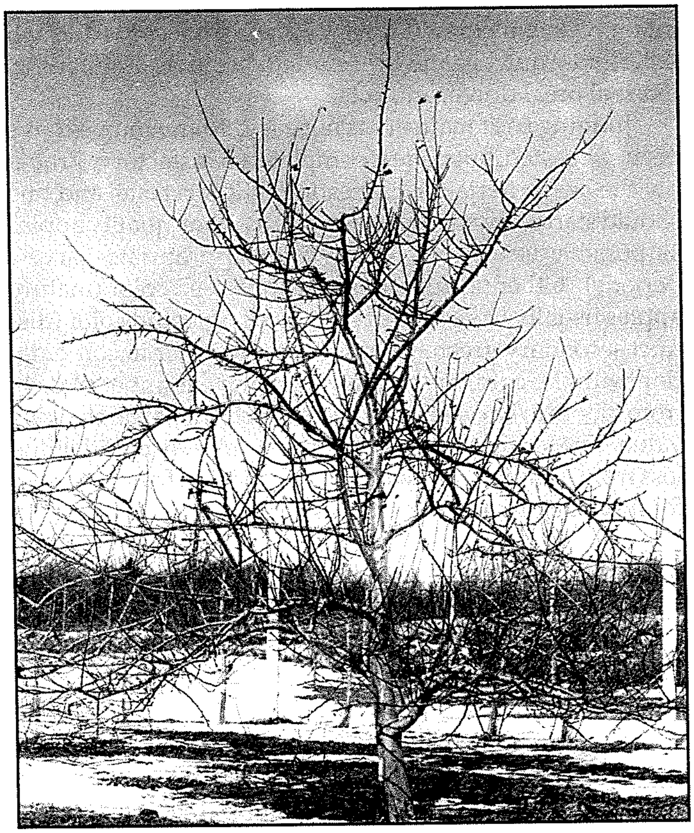


Figure 18: A nonpruned, mature, 'Delicious' tree

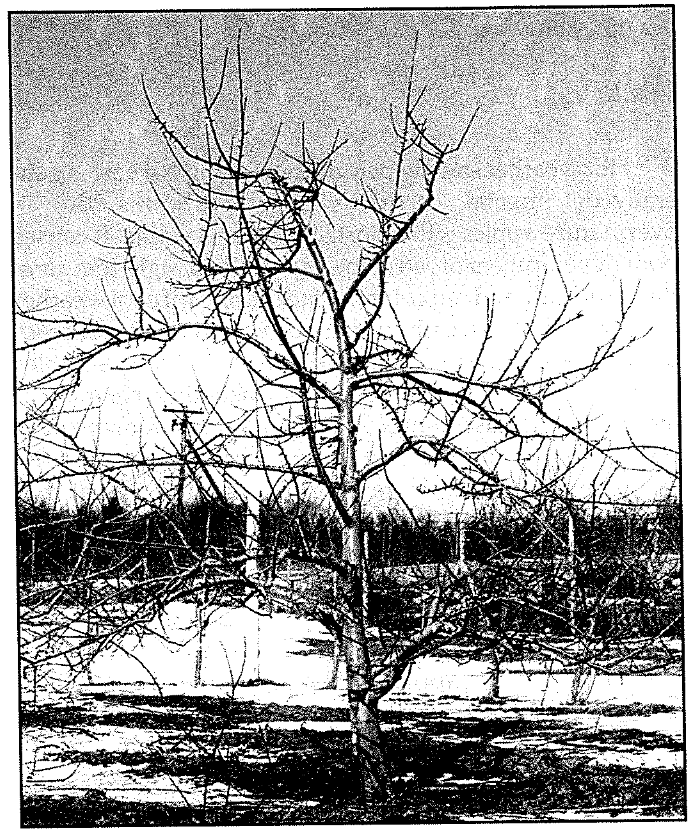


Figure 19: The same tree after pruning

10. Detailed pruning should be avoided whenever possible because of expense. Try instead to do bulk pruning (removing large limbs to "open up" the tree). Bulk pruning helps to eliminate pruning of the smaller fruiting wood along the main limbs.
11. Organize the pruning:
    a. Have an experienced pruner make big cuts and difficult pruning decisions.
    b. Work from the top of the tree downward.
    c. Finish the job from the ground with pole pruners, lopping shears, and hand shears.
    d. In large trees, develop a ladder hole to facilitate harvest.

Disposal of Prunings

Prunings from apple orchards should be either chopped in the row middles with a flail mower, or removed and burned. Pruned twigs left suspended in trees and larger prunings that are pushed into hedgerows or brush piles become heavily colonized by the fungi that cause black rot, bitter rot, and white rot fruit decays. The colonized brush provides ascospores and conidia that infect fruit during summer. Piled brush may continue to produce spores for six years after it is removed from the tree; but if brush is chopped into small pieces with a flail chopper, the pieces are quickly colonized by other fungi and decompose before they contribute to fruit infections.

HARVESTING

The harvest period is a hectic time in apple orchards. Attention must be directed to both labor management and fruit management. Some key factors in fruit management are the following:

Weather

Hot weather shortly before and during harvest is generally detrimental. It ripens fruit rapidly, resulting in overmature apples with shorter postharvest life. It causes poor development of red color, especially if night temperatures are high; and red color can fade rapidly if cool weather is followed by hot weather. It also directly increases susceptibility to scald, a physiological disorder that causes apples to turn brown after harvest. By hastening ripening it indirectly increases susceptibility to other storage and postharvest disorders. Hot, sunny weather increases the temperature of fruit, increasing the amount of heat that must be removed before fruit can be stored.

For late-maturing cultivars, a serious concern is the possibility of freezing. Apples freeze at about 28°F. If they freeze, do not pick or handle them until they are fully thawed, to prevent bruising. Unless the fruit temperature falls to about 22°F, apples will survive freezing; at about 22°F, lethal damage occurs, and they show browning and breakdown soon after they thaw. If browning and breakdown do not show up soon after thawing, the apples have survived the freezing; but any freezing causes softening and faster deterioration during storage. Frozen fruit can also quickly lose significant amounts of water. If apples freeze, dispose of them as quickly as possible.

Fruit Maturity

Maturity is the stage of development at harvest. If too immature at harvest, fruit will never develop top quality flavor and may be more subject to shriveling, scald, bitter pit, and brown core after harvest. Overmature fruit will deteriorate quickly and be more subject to flesh softening, internal breakdown, and rots.

Judging fruit maturity is not easy. Many indices have been suggested, but none is completely satisfactory. Probably the best criteria for harvesting DRCs is taste, and one should start early enough to harvest as many quality apples as possible (see Tables 4 and 5 for appropriate harvest periods). Other useful criteria include seed color (mature apples usually have dark brown seeds); ground color (distinct secondary green, yellow or off-red color in combination with the cultivar's actual skin color); number of days from bloom to harvest (see Tables 4 and 5); and starch index value. The loss of starch from 'Liberty' closely parallels the loss from 'Empire'. See your local Extension fruit specialist for more details about starch testing.

Storage

It is essential for quality maintenance that apples be cooled quickly and thoroughly after harvest. Ideally, they should be cooled to 32°F within 24 to 36 hours after harvest.

In general, the lower the temperature in storage, the slower apples ripen and lose quality, and the less water loss and decay. Late-season DRCs held in air storage at 32°F usually will retain quality into January. However, some DRCs may suffer low-temperature damage from prolonged storage at or near 32°F.

Controlled-atmosphere storage (CA) employs specially constructed rooms that can be sealed to maintain specific oxygen and carbon dioxide levels in the atmosphere. For 'Liberty' only, 3% oxygen and 2% to 5% carbon dioxide are recommended, with temperature maintained at 36° to 38°F and a relative humidity of 90% to 95%.

PART III: APPLE DISEASE MANAGEMENT

By David A. Rosenberger, Cornell University

INTRODUCTION

By definition, all disease-resistant cultivars are completely resistant to apple scab. Some DRCs also have complete or partial resistance to powdery mildew, cedar apple rust, quince rust, and fire blight. However, none of the DRCs are resistant to so-called minor diseases, which include frogeye leaf spot, black rot, bitter rot, white rot, sooty blotch, fly speck, and many other diseases rarely encountered in commercial orchards. DRCs can also be killed or severely damaged if the rootstocks are attacked by crown rot or fire blight. Thus, disease control strategies are still essential for plantings of DRCs.

The susceptibilities of the most common DRCs to some of the major diseases are shown in Table 7. Apple growers theoretically can avoid apple scab, cedar apple rust, powdery mildew, and fire blight by choosing cultivars with genetic resistance to these diseases. However, ratings for disease susceptibility of new cultivars are often based on limited observations. In some cases, cultivars that are resistant to a disease when grown in one region, may be susceptible to that disease when grown in other areas. For example, 'Liberty' exhibits resistance to powdery mildew in New York but is highly sensitive to mildew in Poland. Differences in disease resistance occur because of regional differences in pathogen strains, or because disease pressure was relatively low where the initial observations were made. Information on the susceptibilities of DRCs to various diseases in the Northeast will be updated as more facts become known.

A list of the most common apple diseases, the symptoms they cause, the time of year they occur, and the genus and species of the causal agents is provided in Table 8. The major diseases — scab, cedar apple rust, mildew, and fire blight — usually attack trees early in the season, and most affect both foliage and fruit. Minor diseases — except frogeye leaf spot — usually are more important during summer, affect fruit rather than foliage, increase in severity as apple orchards mature, and are more common in the hot, humid climates of the mid-Atlantic and southeastern United States. In orchards of standard cultivars, the minor diseases may be suppressed by fungicides used for apple scab. Minor diseases may become more important in DRC orchards that receive no fungicide sprays.

Control strategies for diseases that are most likely to afflict DRC plantings are presented in Section 1. Section 2 includes control strategies for scab, powdery mildew, rust diseases, and fire blight because most apple growers must still grapple with these common diseases of standard cultivars. Diseases are presented in alphabetical order because their relative importance varies with geographic area.

Recommendations for specific fungicides and application technologies are not included. For recommendations on appropriate crop protectants, rates, and application timings, growers should consult their local Cooperative Extension publications. When using fungicides or other crop protectants, always read the label before using the product. Use of crop protectants in any manner inconsistent with the product label is illegal.

Table 7: DRCs' Resistance Ratings (All are Resistant to Scab)

	Resistance to:		
VARIETY	RUST*	MILDEW	FIRE BLIGHT
Britegold	S	R	II
Freedom	S	R	R
Jonafree	S	R	II
Liberty	R	R	R
Macfree	R	M	II
Moira	R	S	II
Murray	R	R	R
Nova Easygro	R	R	R
Novamac	II	M	II
Prima	S	R	R
Priscilla	R	R	R
Redfree	R	R	II
Sir Prize	S	R	R
Trent	R	M	R

(Information adapted from data by R. C. Lamb, Cornell Univ.)

R=resistant; S=susceptible; M=moderate; II=insufficient information

	Resistance to:		
SELECTION	RUST*	MILDEW	FIRE BLIGHT
CO-OP 27	1	2	2
CO-OP 29	1	2	2
CO-OP 30	2	2	2
CO-OP 31[z]	4	2	2

(Information compiled by J. Crosby, Purdue University, based on 8 to 10 years of field observations of natural disease incidence occurring on one or more propagules at West Lafayette, IN.)

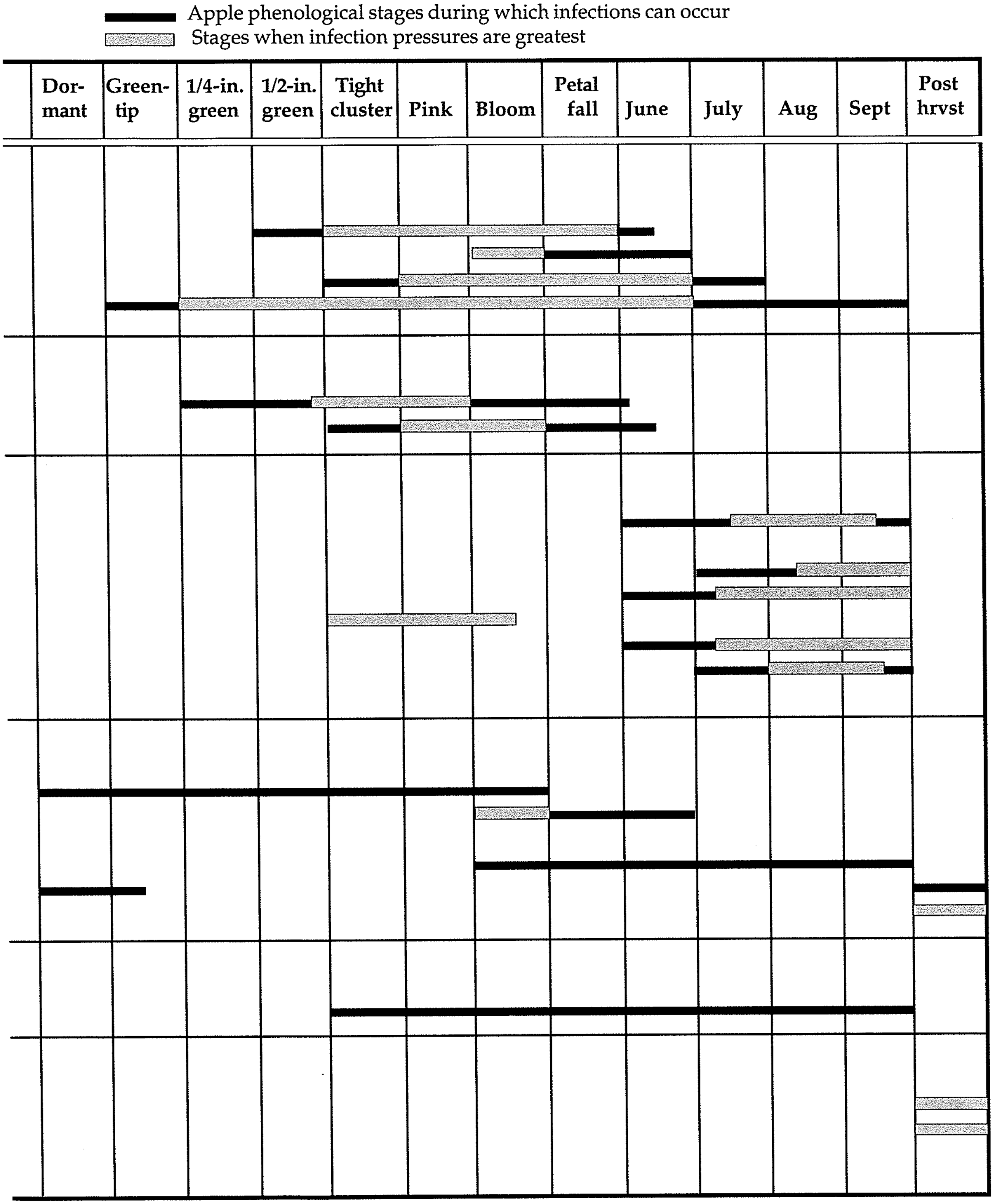
[z]Also susceptible to frogeye leaf spot

1=very resistant; no control needed
2=resistant; control only needed under high disease pressure
3=susceptible; control usually needed where disease is prevalent
4=very susceptible; control always needed where disease is prevalent

*Refers to cedar apple rust only. Resistance to quince rust generally is not known.

Table 8: The most common apple diseases in the northeastern United States; common names; causal organisms; common symptoms; and phenological stages during which infections can occur

Common name	Causal organism	Brief description of most common symptoms associated with the disease
Diseases affecting both leaves and fruit		
Cedar apple rust	*Gymnosporangium juniperi-virginianae*	*Orange spots on fruit & leaves
Fireblight	*Erwinia amylovora*	*Blackening of fruit and leaves; terminal shoot dieback
Powdery mildew	*Podosphaera leucotricha*	*White fungal growth on leaf surface; fruit russeting
Scab	*Venturia inaequalis*	*Brown/black spots on leaves and fruit
Diseases affecting only leaves		
Frogeye leaf spot	*Botryosphaeria obtusa*	*Circular dead spots, 1/8" diam., with tan centers
Hawthorne rust	*Gymnosporangium globosum*	*Orange lesions on leaves
Diseases affecting only fruit		
Bitter rot fruit decay	*Glomerella cingulatta*	*Circular, slightly sunken tan decay, sometimes with cream/orange sporulation in centers of lesions
Black rot fruit decay	*Botryosphaeria obtusa*	*Firm dark brown or black decay
Fly speck	*Zygophiala jamaicensis*	*Groups of very small, black dots on epidermis
Quince rust	*Gymnosporangium clavipes*	*Sunken areas in fruit w/ necrosis extending to carpels
Sooty blotch	*Gloeodes pomigena*	*Light gray to charcoal cloudy areas on epidermis
White rot fruit decay	*Botryosphaeria dothidia*	*Watery decay progressing through fruit in uneven pattern
Diseases causing cankers and twig diebacks		
Black rot canker	*Botryosphaeria obtusa*	*Light yellow/orange bark with black fruiting structures
Fireblight	*Erwinia amylovora*	*No fungal fruiting structures; bacterial ooze in late spring
Lightning damage	—	*Usually affects highest terminals on tree
Nectria canker	*Nectria cinnabarina*	*In crotches or at pruning cuts; orange/red fruiting structures
Nectria twig blight	*Nectria cinnabarina*	*Mostly on Rome trees; orange/red fruiting structures
Diseases attacking roots		
Crown rot	*Phytopthora* species	*Soft, reddish orange, dead bark at or slightly below soil line
Postharvest diseases		
Blue mold	*Penicillium* species	*Soft watery decay with musty odor, blue sporulation
Gray mold	*Botrytis cinerea*	*Soft decay with cider-like odor; spreads from fruit to fruit



Apple phenological stages during which infections can occur
Stages when infection pressures are greatest
Dor-mant
Green-tip
1/4-in. green
1/2-in. green
Tight cluster
Pink
Bloom
Petal fall
June
July
Aug
Sept
Post hrvst

SECTION 1: DISEASES COMMON TO DISEASE-RESISTANT AND STANDARD CULTIVARS

Cankers

The most common canker problems in the Northeast are fire blight cankers, black rot cankers, and Nectria cankers. Fire blight is discussed on page 46. The best control for cankers is pruning them out. Chemical sprays are not effective for eliminating organisms already established in cankers, nor for preventing cankers caused by the black rot and Nectria canker fungi in the Northeast.

Figure 20: Black rot canker on a large apple limb

Cankers can be difficult to identify, but black rot and Nectria cankers sometimes have distinctive characteristics. Black rot cankers are often reddish brown, slightly sunken, and may produce spores in black fruiting structures that develop at the lenticels (see Figure 20). Nectria cankers usually produce reddish, orange, or salmon-colored fruiting structures on affected wood (see Figure 21). Nectria trunk cankers occur in crotches or around pruning wounds. Nectria twig canker, also called Nectria twig blight, occurs primarily on the cultivar 'Rome Beauty' and rarely causes extensive damage. Nectria twig cankers girdle twigs in late June and cause twig dieback that is often mistaken for fire blight.

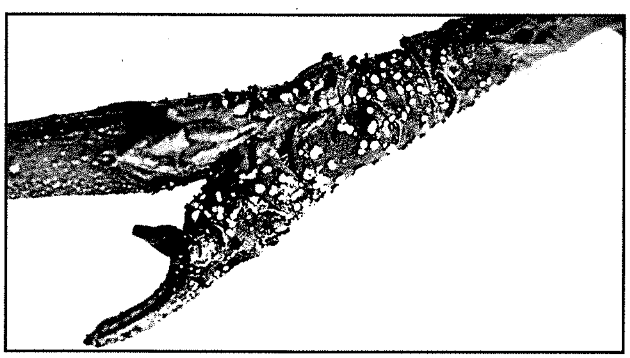


Figure 21: Fruiting structure of Nectria on 'Rome Beauty'. On the lower left is a fruit stem left after harvest, which the fungus invaded, thus causing the canker and killing the twig.

In the Northeast, most apple cankers develop where trees were injured by cold damage, by pruning, or by another pest. Nectria limb cankers are usually found at pruning cuts or in crotches where wood has been injured by cold damage. Nectria twig blight on 'Rome Beauty' originates in dying apple stems that remain on the tree after harvest. Black rot cankers can develop at pruning cuts if pruning is done in spring after bud break and if stubs are left during pruning. Pruning cuts made before bud break dry out before the black rot fungus becomes active in spring. Pruning cuts made without leaving a stub quickly callus and are seldom invaded.

Where many cankers occur in a planting, look for underlying factors that are making the trees unusually susceptible. For example, Nectria canker may occur where trees are too vigorous in fall and fail to harden adequately before winter. Chronic black rot canker may occur where trees are stressed by several years of drought, or when trees are grown in poorly drained soils. The cultivar 'Empire' may sustain winter damage when it is grown under high vigor, making it more susceptible than most other common cultivars to many canker diseases.

Crown Rot

Crown rot is most common where apples are planted in poorly drained sites. This fungal disease is caused by several species of *Phytophthora*, which can invade and kill the bark at or near the soil line. Infections rarely extend more than several inches above or below the soil line, but the trees may be girdled if infections involve the entire crown. Infected bark tissue, revealed by slicing with a knife, is usually reddish orange. Trees that are not completely girdled produce little vegetative growth, have light green to yellow foliage, and appear weak.

Avoid crown rot problems through careful site selection, or correct drainage problems by installing tiles and drainage ditches before planting. Saturated soil cannot be tolerated in apple orchards. When problems develop on established plantings, apply a fungicide drench to arrest the progression of crown rot and protect healthy trees. However, fungicide treatment is a stopgap measure for marginal areas and is no substitute for proper site selection or soil drainage improvements.

Standard, MM.111, and M.9 rootstocks are most resistant to infection by *Phytophthora*. M.26 rootstocks sometimes develop crown rot in eastern New York even when trees are planted in well drained sites; a problem not noted in New England.

Frogeye Leaf Spot

Frogeye leaf spot is a foliar disease caused by *Botryosphaeria obtusa*, the same organism that causes black rot fruit decay and black rot canker. Frogeye leaf spot is most severe in cultivars such as 'Cortland' and 'Northern Spy', which retain poorly pollinated or chemically thinned fruitlets that stop growing during June. Retained fruitlets are quickly colonized by the black rot fungus, remain on the tree over winter, and provide inoculum for leaf spot infections the following season (see Figure 22). Frogeye leaf spot can be controlled by applying appropriate fungicides before bloom. In most of the Northeast, fungicide control is usually not needed if cultivars do not retain thinned fruitlets. However, when left uncontrolled, frogeye leaf spot has caused severe defoliation of orchards in parts of Vermont and New Hampshire.

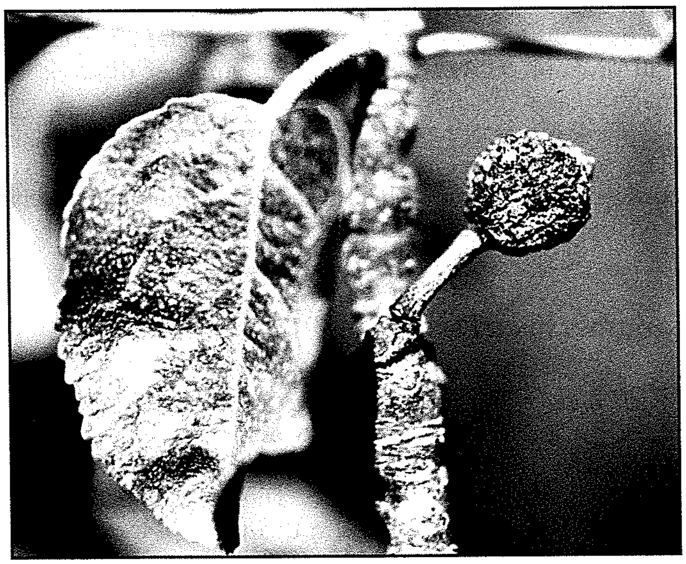


Figure 22: An apple leaf with frogeye leaf spot. The "mummy" next to the affected leaf is a source of inoculum.

Lightning Damage

Lightning damage is often confused with fire blight. The tree or limb "fried" by a direct hit is easy to recognize, but lightning often does not kill an entire limb or tree. A small discharge may kill only the highest terminals or the central leader. Shoot dieback caused by lightning may happen suddenly, or twigs may show no immediate injury and then slowly die back a week or several weeks later.

Watch for these characteristics of lightning damage:

1. Only the highest terminals or leader in the tree are affected.
2. Only one tree, several adjacent trees, or occasionally five to ten trees in a circle up to 50 feet in diameter show the damage.
3. Browning of the pith in young shoots often extends down beyond the damaged wood.
4. Shoots may sometimes be severely injured but not killed by an electrical charge. These shoots will be stunted and may die later. The affected terminals may not be the highest points in the tree by the time dieback occurs. A tangential cut through the stunted shoot may reveal a brown ring in the wood where the lightning injury occurred.

Postharvest Diseases

The most common postharvest decays are blue mold and gray mold, but many other fungi can cause losses during storage, especially if fruit are bruised or overmature. The fungi causing blue mold and gray mold enter the fruit at wounds. Incidence of these decays should be very low if fruit are harvested at the right time, are properly handled to avoid bruising, and are moved into storage without a postharvest drench treatment. Problems occur when fruit are drenched with antioxidants after harvest to control scald. The drench solutions accumulate and disperse spores left on the bins from the previous season and from soil sticking to bins.

If postharvest drenches are used for scald control, include a fungicide in the solution to control blue mold and gray mold. Fungicide resistant strains of *Penicillium* and *Botrytis* are now common in most storage areas, so supplement postharvest fungicide treatments with these measures to minimize exposure to decay fungi:

1. During harvest, always place bins and boxes on sod rather than bare ground in the orchard.
2. Disinfect bins that contained badly decayed fruit the previous season.
3. If drench solutions are used, avoid getting soil into the solutions.
4. Harvest fruit at the proper maturity level and avoid bruising during harvest, transport, and packing operations.
5. Cool fruit rapidly after harvest to minimize opportunities for decays to become established.

Summer Diseases: Sooty Blotch and Fly Speck

Sooty blotch and fly speck (SBFS) are fungal diseases that cause superficial infections on fruit which, when extensive, make fruit look unappetizing (see Figure 23). Disease incidence can be reduced by cultural strategies that lower humidity and promote rapid drying in the tree canopy. These include keeping grass mowed during summer and keeping trees well pruned. Tree spacing within and between rows should allow air movement between all trees. Removing adjacent woods or cutting breaks in hedgerows may improve air flow in the orchard. Fungicide protection during summer is essential in some areas.

Figure 23: An example of fly speck damage

SBFS often occur together because they have similar (and numerous) wild hosts. SBFS are most prevalent in southern growing areas, are of moderate importance in Connecticut and New York's Hudson Valley, and are only sporadically important in western New York and northern New England. They are favored by temperatures between 65° and 80°F and by high humidity; conditions which coincide most frequently when nighttime temperatures remain above 65° to 70°F during summer, or during extended warm rainy periods. SBFS symptoms can develop within 14 days from infection under ideal conditions, but symptom development is arrested by high temperatures and low relative humidity. Thus, the period between infection and symptom development ranges from 25 to more than 60 days in the Northeast. SBFS infections not yet visible at harvest can develop during cold storage.

Protectant fungicides applied in late May and early June for apple scab can help suppress early infections by the SBFS fungi in commercial orchards. If summer diseases become a severe problem in orchards of unsprayed DRCs, spring dormant sprays of copper or lime-sulfur may help eradicate overwintering infections that became established on twigs the previous season. Where the climate favors summer diseases, a minimum of two summer benzimidazole sprays, one in late June and one in late July, will probably be needed to protect fruit of DRCs. The benzimidazole fungicides have both protectant and limited eradicant activity against sooty blotch and fly speck. However, a preharvest benzimidazole spray cannot be used as a single application "cleanup" spray because the benzimidazoles will not eradicate old infections established early in the summer even if they have not yet developed visible symptoms. Although benzimidazoles are the best choice for controlling SBFS, they may adversely affect predatory mites and earthworm populations. If benzimidazoles are not used, three or four applications of protectant fungicides will probably be needed to control summer diseases in many areas south of Massachusetts.

Tank mixes of benzimidazoles and protectant fungicides may be desirable where control of bitter rot also is a concern. In addition, such tank mixes may help to prevent development of resistance to benzimidozoles by SBFS.

Summer Fruit Decays

The most common summer fruit decays are black rot, white rot, and bitter rot. In some areas, controlling these diseases requires a combination of sanitation measures and protectant fungicide treatments. The fungi causing summer fruit decays overwinter in dead twigs, mummified fruit, fruit stems in apple trees, dead wood on other hosts in adjacent woodlands, and in two-year-old apple prunings left suspended in trees or pushed into hedgerows. Mummified, hand thinned fruit or windfalls have also been identified as sources of bitter rot inoculum. Keep inoculum levels low by removing dead wood from trees during pruning, and burn or chop brush after pruning. Chopped brush is quickly colonized by many saprophytic fungi and does not harbor harmful fungi. Mummified fruit should be removed from trees during winter pruning, and any hand thinned fruit should be left only in the row middles where they will be chopped with a mower or crushed by orchard spraying and harvesting operations. If many decayed fruit remain on the orchard floor after harvest, rake them into row middles and pulverize them with a flail mower before winter.

It is often difficult to differentiate between black rot, white rot, and bitter rot. Bitter rot (see Figure 24) sometimes produces slightly sunken lesions with distinct orange or cream-colored sporulation, and the decay penetrates to the apple core in a V-shaped pattern. (When bitter rot develops in cold storage, the orange sporulation is not evident.) White rot is a watery decay when it develops during warm weather, whereas black rot is a firm dark decay. Under cool fall conditions, however, both white rot and black rot produce nearly identical, firm, dark decays.

Black rot, white rot, and bitter rot usually appear only in late summer in the Northeast. However, black rot fruit infections can occur anytime after bud break. Early fruit infections appear as tiny purple or black flecks. They often go unrecognized because the affected fruit usually do not decay until the fruit begins to ripen before harvest. No fungicide sprays are usually needed for these diseases in northern New England or in northern New York because infections are favored by warm, rainy periods (greater than 68°F for black rot, and 78°F for white rot and bitter rot). In New Jersey, Pennsylvania, and southern New York, at least one July or August fungicide spray may be needed to control late-season bitter rot and black rot. Also, a petal fall and/or first cover spray may be needed to protect DRCs from early-season black rot infections that remain quiescent until fruit ripening begins. Because bitter rot can cause latent infections that develop in cold storage, preventing this disease is especially important for apples that will be stored.

SECTION 2: DISEASES COMMON IN STANDARD CULTIVARS

Throughout the Northeast, apple scab is the most important disease on standard apple cultivars. Scab can be controlled with fungicides, but these add significantly to the cost and complexity of apple production. Both the obvious scab control costs (fungicides and application) and the hidden costs (increased complexity in management) can be eliminated if scab-resistant cultivars are grown instead of cultivars, like 'McIntosh' and 'Cortland', that are highly susceptible to scab (see Figure 25). A major step toward reducing inputs in apple production will occur if growers can change from scab-susceptible cultivars to DRCs.

Switching apple cultivars is a long, slow process. Most growers still need information on cost effective control strategies for apple scab, rusts, mildew, and fire blight in non-DRC orchards. This section reviews the biology and controls for these major apple diseases. The susceptibilities of the major commercial cultivars are shown in Table 9.

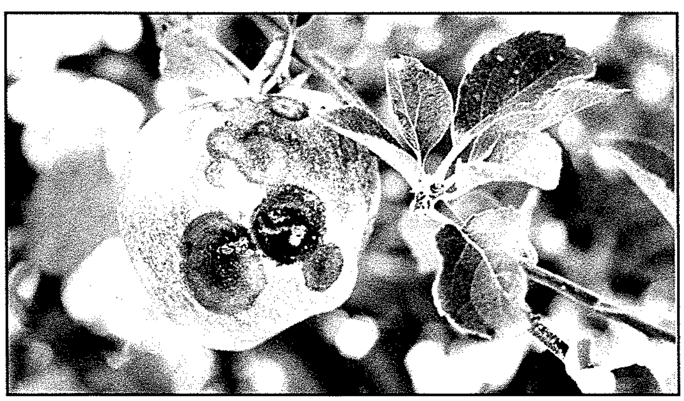


Figure 24: These bitter rot lesions are on a 'Gala' apple. The fungus produces spores toward the centers of lesions. Spores are spread to other fruit by insects and by rain.

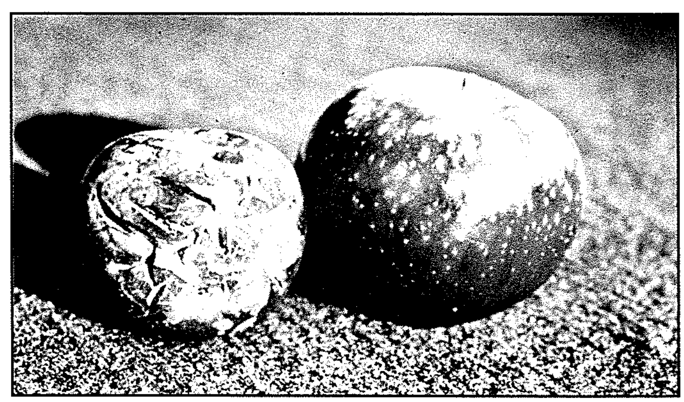
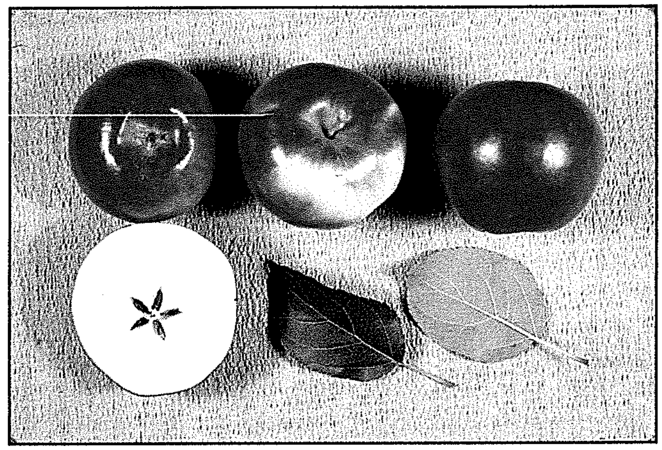


Figure 25: A scab-infected 'McIntosh' (left) and a DRC (right). Neither received fungicide treatments.

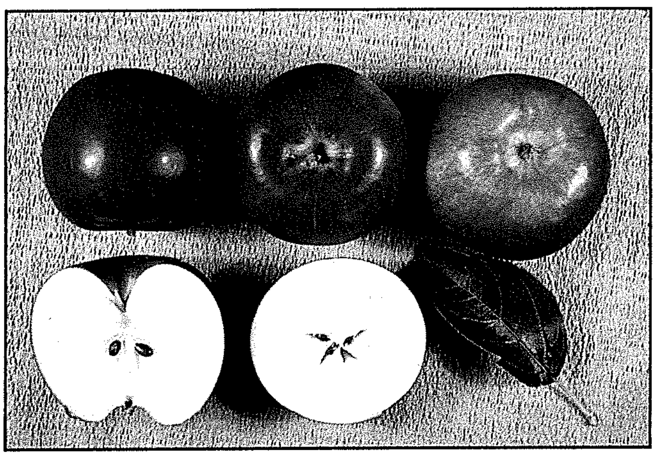
EXAMPLES OF DISEASE-RESISTANT CULTIVARS AND NUMBERED SELECTIONS

EARLY SEASON

WILLIAMS PRIDE



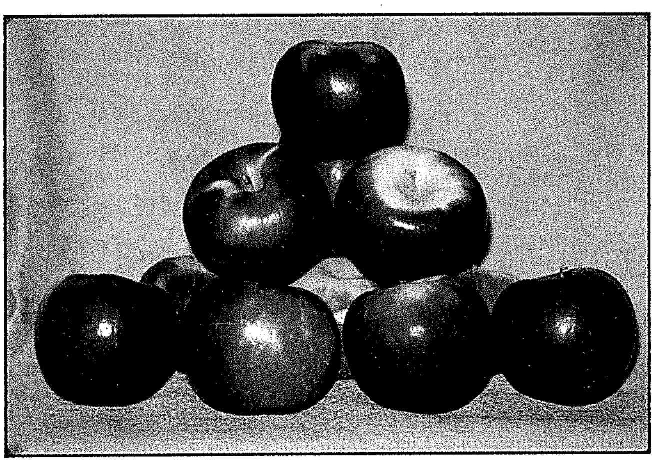
DAYTON



REDFREE

PRIMA

MIDSEASON

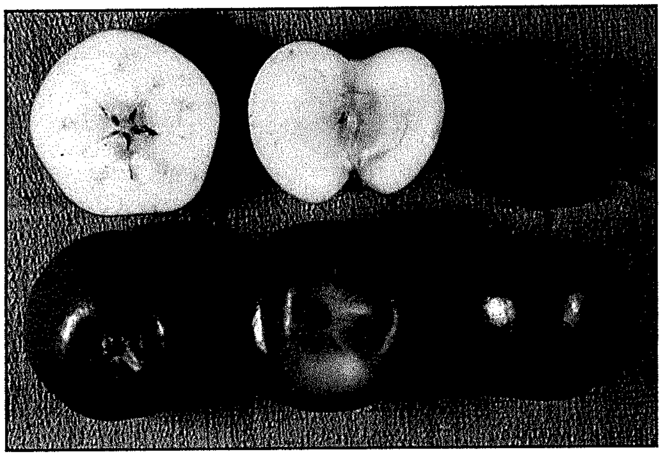


JONAFREE

NY 75414-1

Photo courtesy NYSAES

LATE SEASON



PRISCILLA

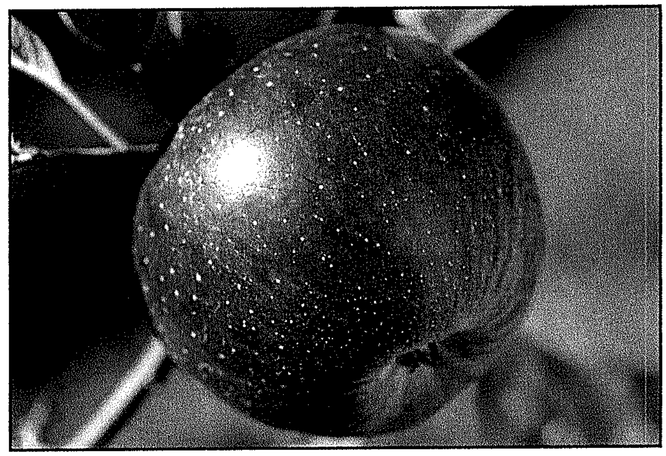
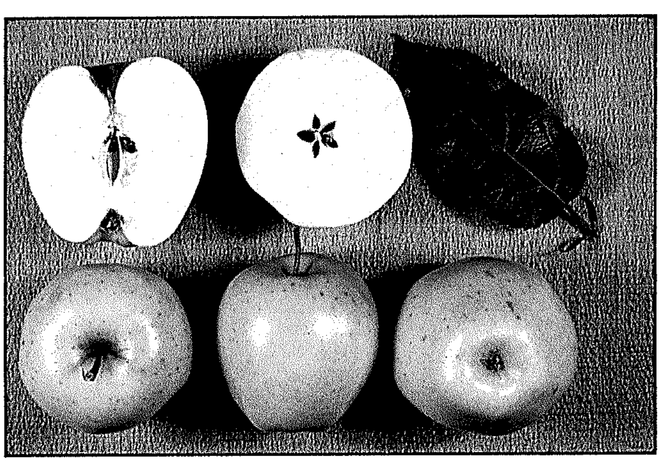


Photo courtesy NYSAES

FREEDOM

LIBERTY

NOVA EASYGRO



SIR PRIZE

Photo courtesy Anthony Rodale

NY 74840-1

Table 9: Resistance of common apple cultivars to the most important diseases in the Northeast

Apple Cultivar	Resistance rating: Scab	Cedar Apple Rust	Quince Rust	Fire Blight	Powdery Mildew
Baldwin	3	1	2	3	4
Barry	3	2	-	4	–
Beacon	3	3	-	3	–
Ben Davis	3	3	2	4	3
Britemac	3	2	-	2	3
Burgundy	3	3	-	4	–
Carroll	3	2	-	2	–
Cortland	4	3	3	3	4
Delicious	3	1	3	2	2
Early McIntosh	3	2	-	2	–
Empire	4	2	2	2	3
Gloster	3	3	-	2	–
Golden Delicious	3	4	3	3	3
Granny Smith	3	2	-	4	4
Gravenstein Holly	3	1	-	3	–
Idared	3	3	2	4	3
Jamba	3	3	-	2	–
Jerseymac	4	1	-	3	–
Jonagold	4	3	3	4	3
Jonamac	3	2	3	3	3
Jonathan	3	4	1	4	4
Julyred	4	3	-	3	3
Lodi	3	4	2	4	2
Macoun	4	2	2	3	3
McIntosh	4	1	2	3	3
Milton	3	1	2	3	3
Mollies Delicious	3	1	-	3	–
Monroe	3	3	-	3	3
Mutsu	4	3	2	4	4
Niagara	4	2	-	4	2
Northern Spy	3	3	2	2	3
Paulared	3	2	1	3	3
Puritan	3	2	3	3	3
Quinte	3	3	2	3	3
Raritan	3	3	-	4	–
Rhode Island Greening	3	3	2	4	3
Rome Beauty	4	4	3	4	3
Scotia	3	2	-	3	–
Spartan	3	2	2	3	2
Spigold	4	4	3	4	3
Spijon	3	3	3	3	3
Stark Bounty	3	3	-	2	–
Stark Splendor	3	3	-	2	–
Starkspur Earliblaze	3	2	-	3	–
Stayman	4	3	2	2	3
Summerred	3	4	-	3	3
Twenty Ounce	3	4	1	4	3
Tydeman	3	1	-	3	2
Viking	3	2	-	2	–
Wayne	3	3	-	3	3
Wealthy	3	3	2	3	3
Wellington	3	2	-	2	3
Williams	3	2	-	2	–
York Imperial	3	4	1	4	3

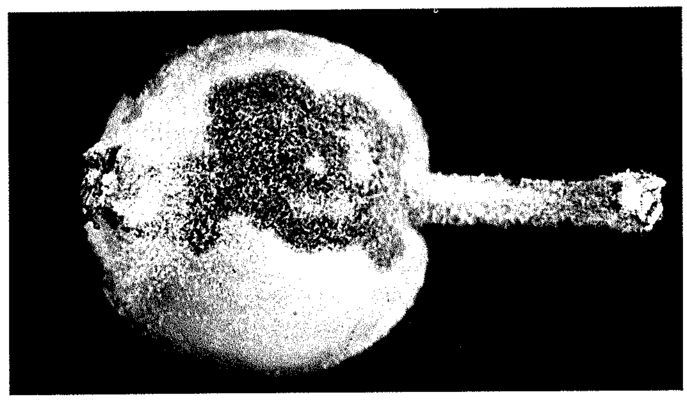
Key to resistance rating:

1=very resistant. No control needed. (Very few cultivars in this category for any disease.)
2=resistant. Control only needed under high disease pressure.
3=susceptible. Control usually needed where disease is prevalent.
4=very susceptible. Control always needed where disease is prevalent. These cultivars should receive first priority when control is called for.

Apple Scab

Scab biology and early-season control:

The key to effective scab control is preventing scab infections from getting established early in the season. Primary scab infections are caused mostly by ascospores, and occur from green-tip until the ascospore supply is depleted, usually by late May to mid-June. Ascospores are produced in fallen leaves that overwinter on the orchard floor. They are released from the leaf litter during rain periods and can infect new leaves and fruit. The scab lesions appear nine to seventeen days after infections occur (see Figures 26A, 26B, and 26C). Secondary spores called conidia are produced in scab lesions on leaves and fruit, are dispersed by splashing rain and wind, and can cause additional infections. Apple fruit can become infected at any time after bud break because fruit sepals are exposed at green-tip. The period of greatest risk for fruit infections is from tight cluster to about a week after petal fall. After petal fall, fruit gradually become more resistant to infection, but fruit infections can occur any time until harvest.



Figures 26A and 26B: Examples of apple scab lesions on fruit

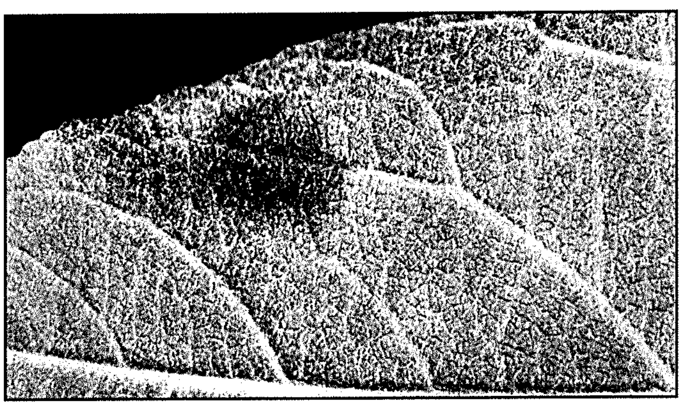


Figure 26C: An apple scab lesion on the underside of a leaf

If spores are prevented from infecting leaves and fruit early in the season, no further scab control measures are needed after the supply of ascospores is depleted. However, if early-season infections are not controlled, additional fungicide protection is needed through summer to protect against secondary infections by conidia. The number of conidia produced by just a few early-season scab lesions is much greater than the total number of ascospores produced in an entire acre of leaf litter in most clean, commercial orchards.

Secondary spread of apple scab during summer increases both the risk of getting scab on fruit and the amount of inoculum that will overwinter in the orchard. If scab is not under control by late summer, numerous light tan scab lesions may develop on the undersides of leaves. These tan lesions turn gray or black as they age and produce abundant conidia. The conidia can cause fruit infections that are invisible at harvest but which develop into small scab lesions, called pinpoint scab or storage scab, after apples are placed in cold storage. Because fruit gradually become more resistant to infection after petal fall, pinpoint scab is a problem only in orchards with abundant inoculum. Minimum wetting periods of 24 to 48 hours, at optimum temperatures, are required for fruit to become infected in late summer.

Orchards with many scab-infected leaves in autumn are subject to massive ascospore discharges the following spring. Conidia also overwinter beneath bud scales in orchards where conidia were abundant the previous summer. Early-season infections from either source can start epidemics that are difficult to control even with the best fungicides. In some seasons, overwintering conidia may cause infections before ascospores mature in spring. Overwintering conidia have been found only in orchards with severe scab the preceding season, and they are not thought to be important in orchards where scab is well controlled. However, the risks inherent in orchards with overwintering conidia should provide incentive for controlling early-season scab and keeping inoculum levels low (see Figure 27).

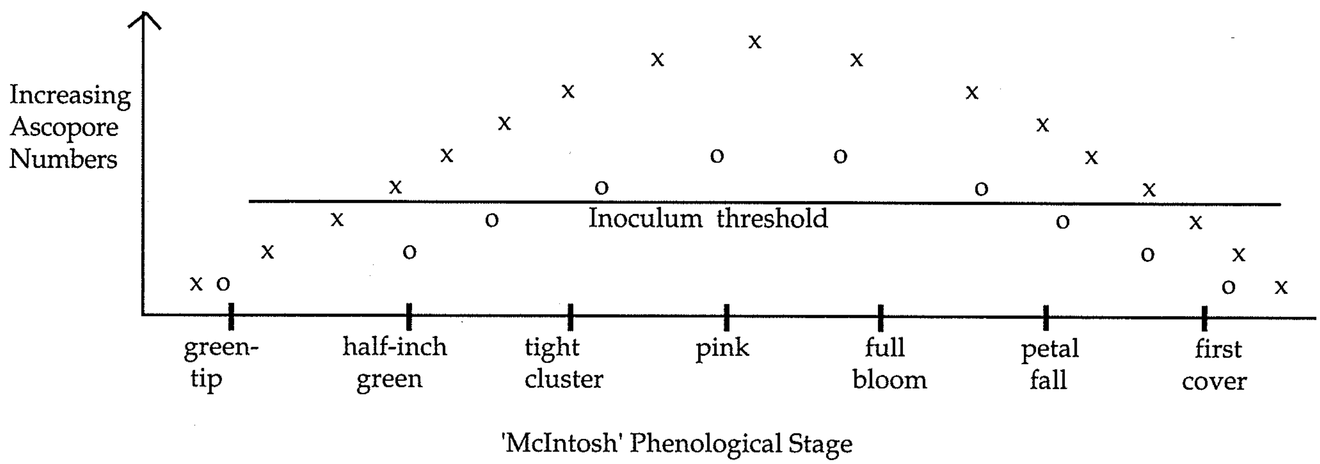


Figure 27: Scab inoculum levels help to determine when the first apple scab spray is needed in spring. Plotting the numbers of scab spores released over time during the primary scab infection period results in a bell-shaped curve. The number of spores is low at green-tip, peaks near pink or full bloom, and drops back to zero by about first cover. The amount of overwintering inoculum in the orchard determines the height of the curve. Ascospore concentrations in commercial orchards must reach a theoretical threshold level before a scab problem will develop. In the graph, the high-inoculum orchard (X) will reach the threshold before the low-inoculum orchard (O). Because the first spray must be applied when ascospore numbers reach the threshold, the high-inoculum orchard will need a spray before half-inch green, while the low-inoculum orchard will not need a spray until after tight cluster. Although we still have no way to define or measure the theoretical threshold, experiments conducted in two states over four seasons have confirmed that apple scab sprays can be safely delayed until tight cluster in low-inoculum orchards. To minimize the risks involved in delaying spring fungicide applications, sterol-inhibitor fungicides should be used in the first 2 to 3 applications when spraying is initiated at tight cluster.

Apple scab fungicides:

The only feasible way to control apple scab in orchards of standard cultivars is with repeated applications of fungicides. The fungicides available as of June 1990 can be broadly classified as protectants; benzimidazoles and dodine; or sterol inhibitors (SI). Protectant fungicides, such as captan, sulfur, and the dithiocarbamates (thiram, ferbam and ziram), protect fruit and foliage by preventing spore germination. They cannot arrest lesion development after infection occurs. Due to the changing regulatory status of many fungicides, consult your Cooperative Extension Service representative for current recommendations.

Dodine and benzimidazole fungicides have a combination of protectant and eradicant activity against fungi and limited systemic activity in apple leaves and fruit. Because they can penetrate into leaves and fruit, these fungicides can attack fungi after they have grown into the host tissue and can "burn out" scab infections. If they are used continually for several years, however, the apple scab fungus and many other fungi develop resistance, leaving the benzimidazoles and dodine ineffective.

The SI fungicides registered for apple scab also provide eradicant, or kickback, activity. Most SIs provide at least 48 hours of kickback, and some as much as 96 hours. This means that SI fungicides can be applied 48 to 96 hours after an infection period and provide control of apple scab. The SIs differ considerably in their eradicant capabilities, protectant activities, and in their effectiveness against other apple diseases. Because recommendations on how to use SI fungicides vary significantly by state and region, readers should consult their local Cooperative Extension Service for more details on how to use SI fungicides.

Many of the fungicides labeled for apple scab also control other apple diseases, and insecticides and miticides are often tank mixed with fungicides. Optimum timing of fungicide sprays may vary depending on the other diseases and insects to be controlled with the same tank-mixed application. However, timing of fungicide sprays, especially early in the season, is usually determined by the optimum timing for scab control.

Timing sprays for primary scab:

Strategies have been developed to optimize the timing of fungicide applications and thereby decrease the number of applications needed per season. Apple scab has traditionally been controlled by protecting susceptible tissue with fungicides starting when buds are at green-tip and continuing through the season until all ascospores are released, usually by late May to mid-June. However, in orchards with low inoculum levels, scab sprays often are not needed before tight cluster, and the risk of infection from ascospores may be quite low after petal fall (see Figure 27). The role of inoculum levels in determining when to initiate sprays is discussed further on page 45.

Protectant fungicide sprays must be applied at intervals of approximately seven days during the primary scab season because growing clusters and terminals are constantly producing new leaf and fruit surfaces that require protection. If a combination of protectant and SI fungicides is used, the spray interval can be extended to ten days. In practice, the seven-day protectant and ten-day SI/protectant schedules can be modified to take advantage of weather predictions. If a protectant program is used and no rain is predicted on days 7, 8, and 9 after the last application, the next application can be made just before the next rain. The SI/protectant combination provides approximately five to six days of protection and four to five days of eradicant activity. Using this program, the interval can be extended one day for each day without infection, on days 6 through 9 after the last application. With SI/protectant combinations, the interval should never exceed 14 days, because some lesions partially inactivated by the SIs may not be controlled without a second spray.

The SI fungicides can also be used on a postinfection schedule, wherein fungicides are only applied after infection periods occur. This approach can reduce the number of fungicide applications needed per season, because many predicted rains fail to develop, or wetting periods are too cool or too short to be scab infection periods. By waiting to spray until after a scab infection period actually occurs, growers can avoid extra sprays that would be applied if they sprayed according to weather predictions. However, using a postinfection fungicide program may result in extra trips through the orchard because it is often difficult to time postinfection sprays to coincide with essential insecticide treatments. Also, extended rainy or windy weather can sometimes interfere with postinfection applications, which must be made within the 48 to 96 hour kickback period of SI fungicides.

Identifying scab infection periods:

A grower using a postinfection spray program must be able to accurately identify apple scab infection periods. The minimum wetting period required for scab infection to occur at various temperatures can be determined from the Mills' Table (see Table 10). Most ascospores are released during daylight hours, so some researchers have therefore proposed that when wetting begins at night, the hours of wetting before daylight should not be included in wetting period estimates. However, in orchards with unusually high inoculum levels, the small percentage of spores released at night may be enough to cause economic losses. Unusual environmental conditions may also cause occasional large, nighttime spore releases. Therefore, the safest approach is to include nighttime hours in the wetting period.

Various methods are used to determine the duration of wetting periods and the mean temperature during them. Many growers make their determinations by carefully observing temperatures throughout rain periods and by shaking tree branches or running their hands over terminals to see when water can no longer be dislodged from buds or leaves. Recording hygrothermographs and leaf wetness meters provide continuous records of wetting events and temperatures on seven-day charts. A more expensive alternative is a microprocessor based scab predictor. These units record environmental data, provide details of the infection period, and list basic recommendations on the fungicides that might be appropriate for postinfection activity. Vendors of hygrothermographs and scab-predicting microprocessors are listed in Appendix II.

Table 10: "Mills' Chart": Temperature and moisture requirements for apple scab infection periods as determined by Mills and modified by A. L. Jones.

Avg. Temp. (F)	**Hours wetting required for infection** — From primary inoculum (ascospores): *Light Infection*	*Moderate Infection*	*Heavy Infection*	From secondary inoculum (conidia)	Days required for lesions to appear
78	13	17	26	8.7	-
77	11	14	21	7.3	-
76	9.5	12	19	6.3	-
63-75	9	12	18	5.9	9
62	9	12	19	5.9	10
61	9	13	20	5.9	10
60	9.5	13	20	6.3	11
59	10	13	21	6.6	12
58	10	14	21	6.6	12
57	10	14	22	6.6	13
56	11	15	22	7.3	13
55	11	16	24	7.3	14
54	11.5	16	24	7.7	14
53	12	17	25	7.9	15
52	12	18	26	7.9	15
51	13	18	27	8.7	16
50	14	19	29	9.3	16
49	14.5	20	30	9.7	17
48	15	20	30	9.9	17
47	15	23	35	11.3	-
46	16	24	37	12.6	-
45	17	26	40	13.3	-
44	19	28	43	14.6	-
43	21	30	47	16.5	-
42	23	33	50	19.9	-
41	26	37	53	-	-
40	29	41	56	-	-
39	33	45	60	-	-
38	37	50	64	-	-
37	41	55	68	-	-
33-36	48	72	96	-	-

Controlling secondary scab:

If scab lesions appear on foliage or fruit, additional fungicide sprays may be needed at 14-day intervals throughout summer, or until scab lesions are inactivated. When scab lesions are noted before mid-June, use fungicides with eradicant and antisporulant activity to reduce secondary spread. SI fungicides are probably the best choice as eradicants. The benzimidazoles are more effective eradicants than SIs, but should not be used as eradicants if they have already been used in the orchard for more than two to three years, because the orchard may contain benzimidazole-resistant isolates of scab. Hot weather (temperatures in the high 80s) contributes to inactivation of lesions and reduces germination of conidia. Captan, used during hot weather, inactivates scab and is the recommended eradicant for applications after mid-June, when temperatures are usually high.

Lesions that are not burned out with eradicant fungicides sometimes become active again during cool, wet fall weather. If extended wet fall weather is predicted, orchards with high inoculum may need an additional fungicide spray during September to protect fruit from infection.

Copper and sulfur sprays to control scab:

Growers wishing to produce apples for certification as "organic produce" are limited to copper, sulfur, and liquid lime-sulfur for disease control. Because of the limitations of copper and sulfur fungicides, organic growers should limit apple production to DRCs, if at all possible. Definitely avoid apple cultivars like 'McIntosh', 'Cortland', and 'Jerseymac', which are highly susceptible to apple scab. If scab-susceptible cultivars are grown, special efforts should be made to keep inoculum levels low in these orchards.

Copper and sulfur spray materials have distinct limitations and disadvantages, compared to synthetic fungicides. Sulfur is incompatible with oil, provides poor residual activity, acidifies soil when used in seasonal programs, and is phytotoxic to fruit and foliage in hot weather. The extremely caustic nature of liquid lime-sulfur makes it an effective scab eradicant but also dangerous to apply and somewhat phytotoxic to foliage. Copper fungicides can cause severe fruit russetting under certain conditions if used after half-inch green.

Copper sprays generally provide better residual activity than sulfur sprays and should be used for at least the first scab spray at green-tip to half-inch green. (An early copper spray is also recommended for fire blight prevention and for copper nutrition.) Some copper compounds are labeled for additional protectant sprays at seven to ten-day intervals. Organic farmers can use copper until at least tight cluster if the organic fruit can be sold with surface russetting. Using copper instead of sulfur during prebloom should reduce the risk of apple scab getting established early in the season, when fruit are especially susceptible to infection.

To control scab with sulfur sprays, applications must be made before or during almost every primary infection period. A rainfall exceeding one inch may cause sulfur to become ineffective, making reapplication necessary. When sulfur was a commonly used control measure, most growers also had dust applicators to apply sulfur dusts during rain, when necessary. If trees are actively growing, sulfur applications more than five days old will not provide adequate protection during the next infection period even if there are no intervening rains.

In severe scab years, sulfur will almost inevitably fail to provide adequate scab control on scab sensitive cultivars such as 'McIntosh'. Then, organic growers should switch from sulfur to liquid lime-sulfur when scab lesions first appear on foliage. Liquid lime-sulfur is phytotoxic and reduces both leaf size and yield, but it burns out exposed scab lesions and keeps conidial inoculum at reasonable levels. Liquid lime-sulfur is not an effective eradicant until scab lesions break through the leaf surface and become visible. Therefore, several applications are usually needed because some infections will still be invisible and protected within the leaf when the first lime-sulfur application is made. After two or three lime-sulfur applications, the sulfur program can be resumed. Avoid spraying sulfur compounds during hot weather because they will burn fruit. Additional details on how to control scab with sulfur and lime-sulfur are available in old literature. For example, Art Burrill provided an excellent summary of how to use sulfur for scab control in his 1945 article, "Practical Use of Our Newer Knowledge of Apple Scab Control," published in the Proceedings of the 90th Annual Meeting of the New York State Horticultural Society, pages 9 to 16.

Phytotoxicity from sulfur sprays is an especially severe problem during summer. Copper sprays may control summer diseases and late-season apple scab without producing leaf burn. However, no copper compounds are currently labeled for application after petal fall, and additional research will be needed to determine the efficacy and safety (*vis-a-vis* phytotoxicity) of copper sprays during summer.

"...organic growers should limit apple production to DRCs..."

Reducing scab inoculum levels:

Apple scab is much easier to control in orchards with low inoculum levels than in orchards that had severe apple scab the preceding year. In orchards with low inoculum, apple scab sprays may not be needed before tight cluster, especially if SI fungicides are used at tight cluster and again at pink and petal fall to assure eradication of the few infections that might occur before tight cluster. The reason early-season apple scab sprays are not needed in orchards with low inoculum is illustrated in Figure 27, p. 42. Inoculum sources outside the orchard are comparatively unimportant because few ascospores travel more than 100 feet from where they were released. Nevertheless, orchards next to very large inoculum sources, such as newly abandoned orchards, will be affected by these external sources. Here, early sprays may be essential, especially when SIs are not used at tight cluster and pink.

Low inoculum levels can best be maintained by protecting leaves from infection during the season. However, if scab is not well controlled during the season, the amount of scab that overwinters in leaves can be reduced several ways. Removing fallen leaves by raking or vacuuming is effective, but is practical only in very small plantings. After leaf drop in fall, the natural disintegration of leaves can be speeded by applying nitrogen fertilizers, by chopping leaves with a flail mower, or by a combination of nitrogen application and leaf chopping. The rates of nitrogen required and potential adverse effects of fall nitrogen applications have not been fully evaluated. Several fungicides, including the benzimidazoles and some SIs, will also prevent ascospore formation in fallen leaves if they are sprayed on leaves during late summer or in fall. But late-season fungicide applications may slow leaf decomposition by reducing colonization of the leaves by saprophytes, and may speed development of fungicide-resistant isolates of the apple scab fungus. More research is needed to determine the most cost effective and ecologically sound method for reducing scab inoculum.

The number of ascospores found in spore traps usually drops dramatically at the same time that grass in the orchard ground cover begins to grow (usually around full bloom to petal fall). This may be caused by unknown biological phenomena, or the growing ground cover may be trapping many of the spores released from old leaves before they can become airborne. Assuming that the ground cover does trap some of the spores, this effect can be maximized if orchards are not mowed until the supply of ascospores is depleted in late May to mid-June. The spore-trapping effect of growing groundcover is probably negligible if a significant portion of the leaf litter is on bare ground beneath trees.

Practical approaches to minimizing apple scab sprays:

The following approach to apple scab control has not been tested in its entirety, but it is a proposal designed to capitalize on our knowledge of the scab fungus biology. The proposal is described step-by-step starting in fall, after harvest:

1. Postharvest activities: After leaves have dropped, mow the orchard a final time to pulverize fallen leaves and hasten their disintegration. Mow with an offset mower that reaches all the way to the trunk beneath trees. If trees are grown in an herbicide treated strip, an alternative is to use a hydraulically driven, rubber-paddled brush rake to sweep leaf litter from beneath trees into the row middles where it can be more effectively chopped by the mower. Removing leaves from beneath trees and low mowing will also help eliminate meadow vole cover and reduce overwintering windfall fruit, which can harbor the bitter rot fungus.
2. Spring activities: Apply a copper spray at green-tip to quarter-inch green where fire blight is a concern. Where copper is not needed, delay scab sprays until tight cluster, unless the orchard had severe scab the previous season. Orchards with severe scab the previous season need regular fungicide sprays starting at green-tip, to protect against early ascospores and to guard against infections from conidia overwintering in buds. In orchards with low inoculum, sprays can be delayed until tight cluster if at least three sprays of SI fungicides are then applied between tight cluster and petal fall.
3. Late spring activities: Do not mow orchards until early to mid-June, to maximize the spore trapping effect of the groundcover. Removing leaf litter from beneath trees with a brush rake in the fall will assure that most surviving leaf litter is in the sodded row middles. If the orchard shows no primary scab three weeks after the end of the primary scab season, scab control for the season has been completed. The only additional fungicides needed are those required for controlling summer diseases and summer fruit decays.
4. Late summer activities: Although the benzimidazoles have some ecological disadvantages, they are very effective for providing extended control of summer diseases and black rot fruit decay, especially when applied in the last spray during August. A benzimidazole in the August spray may have the fringe benefit of helping to prevent ascospore formation in any scab-infected leaves. The effect on ascospore inhibition will be minimal if resistant isolates are common in the orchard.

Fire Blight

Fire blight is a bacterial disease that causes terminal shoots, spurs, and fruit clusters to turn brown or black and die. Fire blight susceptibility of various cultivars is shown in Tables 7 (p. 33) and 9 (p. 40). Although cultivars' susceptibilities vary, most can be severely damaged by fire blight if conditions are unusually favorable for infection. Many of the dwarfing rootstocks, including M.9 and M.26, are very sensitive to fire blight. When these rootstocks become infected the entire tree usually dies.

A combination of sanitation measures and streptomycin sprays to protect blossoms from infections is used to control fire blight. The primary infection site is blossoms. Bacteria are spread from blossom to blossom by splashing rain, bees, and other pollinating insects. The bacteria can infect the blossoms if temperatures are above 65°F and if moisture (or high relative humidity) is present. The first symptoms of blossom blight are blackening of the flower pistil and then wilting and blackening of the entire flower. The infection spreads rapidly to the supporting shoots and often kills entire shoots beyond the infection sites. Shoot dieback is frequently the first symptom detected by growers and usually occurs two to three weeks after petal fall. The killed terminal shoots often have a distinctive "shepherd's crook" at the growing end (see Figures 28 and 29).

Sucking insects feeding on infected terminals can spread the blight bacteria to new terminals within the orchard, initiating additional shoot blight. Fire blight from blighted blossoms and terminals can spread through the wood into the trunk and older limbs, where the bacteria persist in cankers. The canker margin is indistinct when cankers are actively expanding. The cankered area appears slightly sunken after canker expansion ceases. The bacteria stop spreading between trees and in trees when terminal growth stops. Infections spread faster and cause more damage in vigorous trees than in low vigor trees.

Many fire blight epidemics can be prevented if growers carefully scout their orchards for fire blight each summer. In the Hudson Valley, apple orchards with no history of fire blight rarely develop blossom blight unless there was a low incidence of shoot blight the preceding season. The initial shoot blight is presumably introduced by insect vectors, usually appears in midsummer, and usually consists of only a few blighted terminals; as few as two or three strikes per 50-acre block. When a few blighted terminals are found in summer, or if fire blight affects neighboring orchards, take the following precautions:

1. Be sure the fire blight is correctly identified. Lightning damage and Nectria twig blight are frequently mistaken for fire blight.
2. Remove the affected shoots as soon as they are noted. This can eliminate much, but not necessarily all, of the inoculum for next season.
3. Apply a copper spray at green-tip to quarter-inch green the next spring. The copper spray helps reduce populations of blight bacteria surviving on the plant surface or oozing from cankers. Annual copper sprays may be needed for orchards with highly susceptible cultivars and/or rootstocks.
4. Orchards containing blight susceptible cultivars and/or rootstocks should be protected with streptomycin if weather conditions favor blight infection during bloom. Resistant cultivars such as 'Delicious' (see Table 9, p. 40) may not require streptomycin sprays unless the trees are young, unusually vigorous, or if blossoms were injured by late frosts.

Figure 28: The early symptoms of fire blight on a terminal shoot. Note the drop of bacteria ooze near the tip of the shoot and the blackening along the veins of the top leaf.

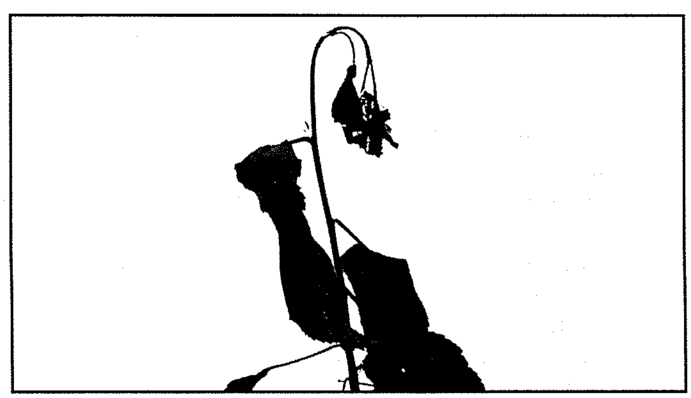


Figure 29: A shepherd's crook: The next sign of shoot dieback due to fire blight

When streptomycin sprays are needed, apply them either just before -- or within 24 hours after -- blight infection periods. Blossom blight infection periods in the Northeast are often characterized by hot, humid weather, as with spring thunderstorms. Streptomycin protects only the flowers that are open when it is applied. It is less effective when other blossoms open after the streptomycin application but before the next infection period. Avoid this problem by applying streptomycin as an eradicant spray within 24 hours after an infection period.

Scientists are uncertain whether fire blight bacteria are disseminated in pollen inserts that sometimes are put into bee hives to promote cross-pollination. The likelihood that fire blight is spread with purchased pollen is probably low, but avoid using pollen inserts nevertheless because most of this pollen is collected from western United States, where streptomycin-resistant fire blight is prevalent. The risk of introducing streptomycin-resistant fire blight into eastern United States outweighs the benefits of pollen inserts.

Hail storms create wounds that can be invaded by fire blight, so apply streptomycin within 24 hours after a hail storm in areas where blight was present the previous year. Prebloom frost damage might also contribute to severe fire blight outbreaks in orchards with high inoculum. Although this theory has not yet been proven, it may be prudent to apply streptomycin within 24 hours of any damaging frosts between tight cluster and petal fall in orchards that had severe fire blight either of the previous two seasons.

When large blocks of trees are severely affected by fire blight, it is difficult to determine whether removing fire blight strikes as they appear during summer is cost effective. In mature apple orchards that are not overly vigorous and do not include trees on M.9 or M.26 rootstocks, fire blight can often be left to run its course without endangering the tree. Older, nonvigorous trees will wall off the cankers before they spread very far in larger limbs. There is less risk of spreading the blight bacteria if pruning is delayed until winter, and winter pruning can be accomplished more efficiently because pruning tools need not be disinfected between cuts if pruning is done when trees are fully dormant.

Generally, remove fire blight strikes during summer only if the following conditions exist:

1. The infections are in young, vigorous trees, where significant damage to the central leader and scaffold limbs will often occur if blight is not removed as it develops.
2. The infections are in dwarfing trees on highly sensitive rootstocks, such as M.9 or M.26, in which case the entire rootstock will die if exposed to inoculum from scion infections.
3. The number of infections in older trees is limited and can easily be removed.

Remove infected shoots during the growing season only on dry, sunny days. Make the cuts 8" to 10" below the visible canker. Disinfect the cutting tools between each cut, using 70% alcohol or 10% bleach, to avoid spreading the bacteria.

When blight appears in an orchard, sucking insects should be controlled as long as the trees continue growing, to minimize secondary spread to new terminal shoots. Aphids and leafhoppers transmit fire blight, but their efficiency as disease vectors has not been determined. The usual control thresholds for aphids and leafhoppers are based on their feeding damage to trees and are not valid when they may be transmitting fire blight. Other cultural measures to reduce tree vigor — such as allowing grass to compete with the trees and eliminating nitrogen applications the following year — may help minimize fire blight damage.

Powdery Mildew

Powdery mildew can often be ignored on all except highly susceptible cultivars. Many of the DRCs have been rated as resistant to mildew in the Northeast (see Table 7, p. 33, for information on susceptibility of DRCs and Table 9, p. 40, for susceptibility of standard cultivars). However, susceptibility ratings for DRCs may change as more information becomes available.

Mildew probably will not cause economic losses in yield or return bloom until more than 20% of the terminal leaves are infected (see Figure 30). This economic threshold most likely varies among cultivars, geographical locations, and seasonal environmental differences, but it provides some indication that trees can tolerate considerable mildew.

Apple fruit can become infected with mildew at pink. Fruit infections become evident later in the season, as netlike russet lines on the fruit surface (see Figure 31). The conditions that favor fruit infection have not been determined, but severe infection of 'McIntosh' has been noted as far north as the Hudson Valley in some years. Fungicide protection is therefore recommended at pink in blocks where mildew inoculum is unusually high. Fruit are resistant to infection after bloom.

Where fungicide protection is needed, control mildew either with protectant fungicides starting at tight cluster, or with SI fungicides starting at pink. The pink, bloom, petal fall, and first cover sprays are most critical for controlling mildew, but fungicide protection is needed until terminal buds are set if complete control is desired. Powdery mildew is resistant to benzimidazole fungicides in some regions.

Figure 30: Powdery mildew as it appears on terminal leaves (left). The shoot on the right is unaffected.

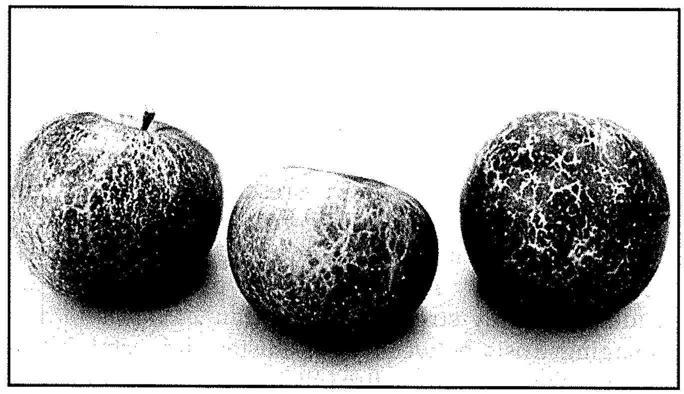


Figure 31: This example of netlike russetting is on 'Jonathan' apples. Similar russetting, caused by mildew, can occur when fruit becomes infected at the pink stage of bud development.

Figure 32: Cedar apple rust appears on cedar trees as an orange, moplike mass like this during spring rains. Spores are carried by wind from these cedar galls to the green apple tissue, where they can infect and cause cedar apple rust lesions on fruit and on leaves.

Rust Diseases

Rust diseases can be controlled by planting rust-resistant apple cultivars, by removing cedar trees near the orchard, and/or by using fungicides. The three rust diseases of apples in the Northeast are cedar apple rust, quince rust, and hawthorn rust, but hawthorn rust is relatively unimportant. All the rust diseases have cedar as an alternate host (see Figure 32), and inoculum can be reduced if cedars within 500' of the orchard are removed.

Many standard apple cultivars are partially or totally resistant to cedar apple rust (see Table 9, p. 40), but fewer cultivars are resistant to quince rust. Susceptibility ratings for quince rust may be unreliable because it occurs only sporadically and severity of infection on different cultivars is often related to the phenological stage of the cultivar during the infection period. Quince rust is most prevalent in years when wetting periods of three to four days and mean temperature greater than 46°F occur between tight cluster and bloom.

Some of the DRCs are not resistant to cedar apple rust (see Table 7 on p. 33, and Figure 33). These should be avoided in areas where rust diseases are prevalent because numerous fungicide sprays will be required to control rust. Even some cultivars listed as resistant to cedar apple rust will develop small orange lesions or necrotic flecks on leaves before the rust fungi stop growing. Under severe conditions, this can cause some defoliation, and may contribute to later infections by leaf-spotting fungi (*Botryosphaeria, Alternaria*).

The minimum wetting periods required for infection by cedar apple rust are given in Table 11. Fruit are susceptible to infection by cedar apple rust and quince rust from tight cluster to about petal fall. Because of this narrow window, fruit infections are less common than foliar infections. Infection requirements for cedar apple rust are similar to those for scab, so no special rust sprays are required if fungicides applied for apple scab are also active against rust. The SI fungicides have eradicant activity against cedar apple rust but the dithiocarbamate fungicides have only protectant activity. Eradicant sprays are especially useful for areas that usually have minimal rust infections but which may need fungicide protection if long wetting periods occur during the period of fruit susceptibility. Eradicant activity of SI fungicides against quince rust has not been evaluated.

Figure 33: The effect of cedar apple rust on the leaves of 'Prima'

Table 11: Temperature and moisture requirements for cedar apple rust infection periods.

Temperature (C)	Temperature (F)	Hours Wetting Required: A Basidiospore Formation	B Infection: Light	B Infection: Severe
2	36	-	24	-
4	39	-	12	24
6	43	-	8	10
8	46	7	6	7
10	50	5	5	6
12	54	4	4	5
14	57	4	3	5
16	61	4	3	4
18	64	4	3	4
20	68	4	2	4
22	72	4	2	4
24	75	4	2	4
26	79	-	-	-
28	82	-	-	-
30	86	-	-	-

No basidiospores form at these temperatures

Light infection -- unlikely to cause economic loss

No infections have been observed at these temperatures

Note: Use this table only when determining cedar apple rust infection on susceptible apple cultivars that are located close to eastern red cedars.

Instructions (Using hourly temperature records):
Basidiospores are formed when the temperature during a wetting period averages 52 - 77 °F for four continious hours. It takes slightly longer when the temperature averages 45 - 52 °F (column A). Once you have determined basidiospores were formed, determine if infection has taken place (columns B). Average the temperature starting at the time when you determined basidiospores had been formed. The hours listed in columns B are the minimum hours required for light or severe infection.

NOTES

PART IV: INSECT AND MITE MANAGEMENT

by Dean Polk, Rutgers University

INTRODUCTION

Arthropod pests can be divided into two groups: direct and indirect pests. Direct pests affect the fruit directly, making it inedible or unmarketable. Apple maggot, codling moth, green fruitworm, leafrollers, plum curculio, and rosy apple aphid are direct pests. Marketability of fruit with surface defects caused by direct pests will depend on the clientele.

Indirect pests attack foliage and decrease tree vigor. They indirectly affect productivity. Indirect pests include green apple aphids, mites, and leafminers. San Jose scale and leafhoppers may be both direct and indirect pests depending on their population levels and where they are found.

Because indirect pests do not injure the fruit directly, higher populations of them can be tolerated. Allowing populations of these pests to exist encourages increased populations of beneficial predators and parasites. This in turn often leads to reduced needs for insecticide or miticide use.

The most economical pest control methods evolve from sound integrated pest management practices; beginning with proper monitoring and recognition of pests and beneficials. It also entails tolerating certain levels of indirect pests and applying treatments only when they are economically justified. An integrated system may include using various monitoring and modeling methods in addition to exploiting natural enemies of pests, proper sanitaion maintenance, mass trapping, mating disruption, and reduced pesticide applications. In this section, key pests and beneficials are discussed.

PEST DESCRIPTIONS

Codling Moth (CM) - *Cydia pomonella* (L)

Figure 34: Codling moth larva in fruit

Description:

Larvae are up to 1" long and are pinkish with brown heads. Adult moths are 1/2" long, are grayish brown with lighter gray horizontal lines and characteristic copper-colored wing tips. Wings are held tent shaped at rest. Eggs are small, flat and white; nearly transparent. They are laid singly on leaves, twigs, or fruit buds.

Life History:

CM has two, sometimes three, generations per year. It overwinters as a fully developed larva in a silk cocoon under loose bark on tree trunks, in nearby wood piles, or on baskets or crates. It pupates during bloom, with first generation moths emerging at the end of petal fall. Egg laying begins when night temperatures remain above 62°F. Most eggs are laid two to six weeks after bloom, and require eight to fourteen days to hatch. Larvae tunnel into the fruit near the calyx end and feed inside the apple for three to five weeks. They then exit the fruit and search for pupation sites on the trunk or large branches of the tree. Second generation adults emerge during mid to late July before starting the cycle over.

Figure 35: Codling moth adult

Damage:

1. Deep entries occur where larvae eat through the skin, into the side or blossom end of fruit. Larvae feed on the seed cavity, and brown frass (excrement) is easily seen in the entry hole.
2. Stings occur where larvae died before entering the fruit or moved to another fruit before feeding.

Apple Maggot (AM) - *Rhagoletis pomonella* (Walsh)

Description:

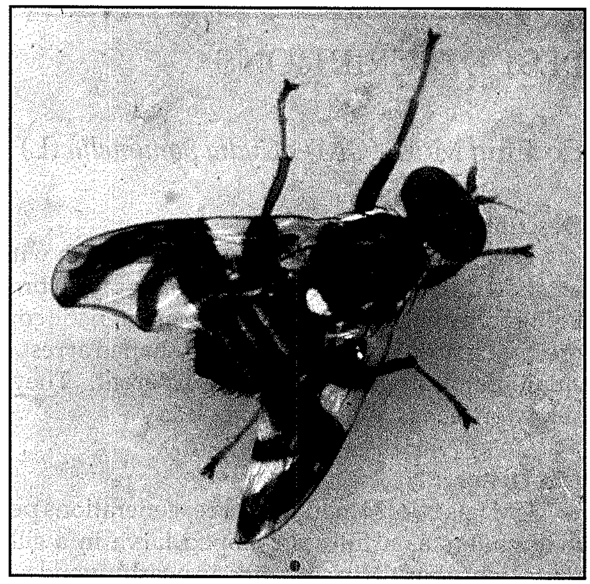
Apple maggot eggs are elliptical, translucent white, and very small (less than 1/16"). Females lay eggs singly in punctures made in the fruit skin. Larvae are yellowish white, 1/4" long, and have dark jaws at the pointed head end. The adult apple maggot fly is a small (1/4"), black fly with yellow legs, white stripes across the abdomen, and dark bands resembling a "W" across the wings.

Life History:

AM overwinter as yellowish/brown pupae in the top 2" to 3" of soil under trees with infested apples. Adult apple maggot flies (AMF) emerge from soil from mid-June until September. Upon emergence, AMF are sexually immature and require seven to ten days before successful mating and egg laying can take place. After females mate, they are attracted to the fruit in which they will lay their eggs, often laying many eggs on a single fruit. Eggs hatch in about three to seven days, after which larvae tunnel through the fruit for fourteen to thirty days. Mature maggots leave the dropped, mature fruit and enter the soil, where they pupate.

Damage:

1. Sunken dimples are seen on the fruit surface where the flesh surrounding oviposition scars failed to mature.
2. Feeding maggots leave brown trails of broken-down tissue throughout the fruit.



Figures 36A and 36B: Apple maggot adult female ovipositing on fruit, and a closeup of the adult apple maggot

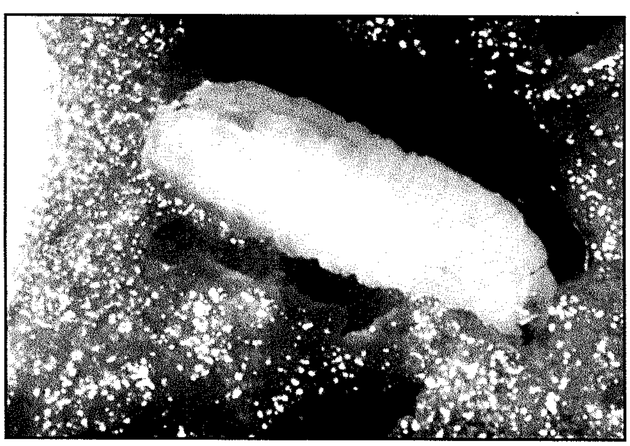


Figure 37: Larva of the apple maggot in fruit

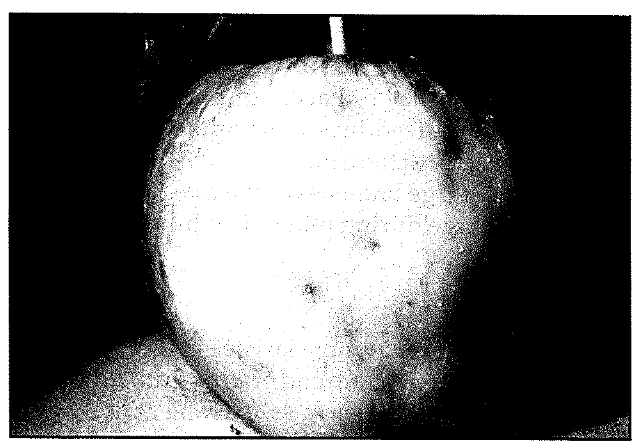


Figure 38: Entry marks left on fruit by the apple maggot

Plum Curculio (PC) - *Conotrachelus nenuphar* (Herbst)

Description:

Elliptical, grayish white eggs are laid beneath crescent-shaped slits in the fruit skin. The larvae are white, legless, 1/4" long, slightly curved, and tapered at both ends. The head end is brown with a light brown shield behind the head. The PC adult beetle is small (1/5"), mottled grey, brown, and black, with rows of ridges along the length of its back, and mouth parts at the end of its long, curved snout.

Life History:

Adult beetles emerge from overwintering sites in hedge-rows or brush piles and migrate into trees beginning at apple bloom and continuing for as long as 6 weeks. After moving into the orchard, both sexes feed on foliage and flower parts. Egg laying starts as soon as the fruit forms. The female makes a small cavity beneath the fruit surface, turns and lays an egg in the cavity, then makes a crescent-shaped cut around and beneath the cavity. After six to seven days the eggs hatch and larvae bore toward the center of the fruit while feeding. After sixteen days, full grown larvae leave the fruit and enter the soil to pupate. New adults start emerging in mid to late July and can continue into September. Adults occasionally feed on maturing apples until they enter overwintering sites. There is only one generation per year in New England, but a partial second generation in areas further south.

Damage:

1. Early damage appears as protruding bumps caused by feeding. Crescent-shaped oviposition scars are left where eggs were laid.
2. Internal feeding is caused by developing larvae.
3. Premature fruit drop (June to July) caused by internal larval feeding occurs.
4. Deep, round feeding spots are caused by late summer and fall feeding by newly emerged adults.

Figure 39: A plum curculio larva in the fruit

Figure 40: Plum curculio adults

San Jose Scale (SJS) - *Quadraspidiotus perniciosus* (Comstock)

Description:

Adult scales are very small (1/16"), round (female), or oval (male), and gray in color, with a raised point in their center. Winged males are minute, reddish brown insects with pointed abdomens, long antennae, and little wing venation. The very tiny nymphs, also called crawlers, are bright yellow and oval.

Life History:

San Jose Scale has two complete generations and a partial third one per year in the Northeast. Immature scales overwinter on twigs and branches in the orchard, beneath a waxy, protective covering. Near bloom time, winged males emerge to mate with stationary females. In mid to late June, several hundred live-born young, called crawlers, are produced by each female. Crawlers settle down after a few hours and insert their mouth parts into the plant tissue or fruit. As they mature and molt over the next five to seven weeks, they secrete a waxy covering which darkens and hardens as they mature. The second generation male flight period begins in early to mid-July, and active crawlers are produced by early to mid-August. A partial third generation may develop depending on fall temperatures.

Damage:

Reduced vigor, thin foliage, cracked and dying branches, and eventually tree death will result if a heavy SJS population goes unattended. On the fruit, a reddish purple ring will develop around each spot where a scale has settled.

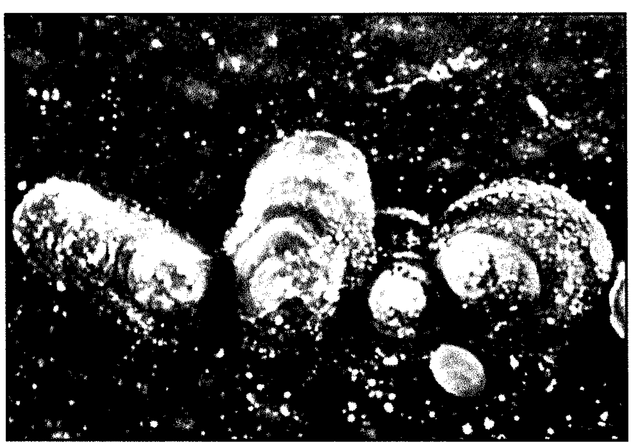


Figure 41: San Jose scale females and crawlers

Aphids

Rosy Apple Aphid (RAA) - *Dysaphis plantaginea* (Passerini)
Green Apple Aphid or Apple Aphid (GAA) - *Aphis pomi* De Geer
Spirea aphid - *Aphis citricola* (De Geer)
Wooly Apple Aphid (WAA) - *Eriosoma lanigerum* (Hausmann)

Description:

Eggs of all four species are bright yellow when laid, gradually turn greenish yellow, then shiny jet black. The adults, however, do look different.

GAA and spirea aphids are yellowish green with black cornicles (pipelike protrusions) at the abdominal end. The RAA is pinkish grey with longer cornicles and antennae. The WAA is the same color as the RAA; however, it is usually hidden under a mass of white, cottony secretion.

Life History:

RAA, GAA, and spirea aphids have similar life cycles: overwintering as eggs which hatch into the first generation of wingless females in spring. Hatch is usually completed just after the half-inch green stage of bud development. Females give birth, without mating, to living young. Several wingless female generations are produced, and by the third to fourth generation, there are winged offspring. Here the similarity between the species stops. Winged females of RAA migrate to nearby weeds and produce more wingless females that do not need to mate to produce offspring. In late summer to early fall, winged females are again produced, which migrate back to apple. There male and female offspring are produced, which mate and lay eggs that overwinter. GAA and spirea aphids stay in the orchard the entire season.

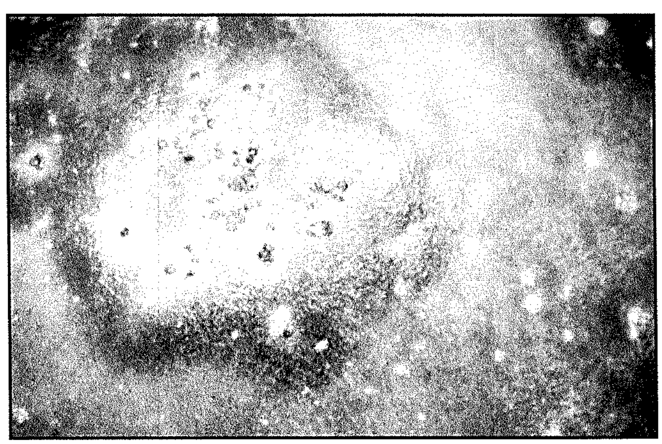


Figure 42: San Jose scale on fruit

WAA has a different life cycle. Its alternate hosts include elm, pear, hawthorn and mountain ash. It may overwinter as eggs or young nymphs. Eggs overwinter on elm bark and hatch in spring. After two to three generations, winged females migrate to apple and complete several generations. Young nymphs may also overwinter on apple roots. Several generations may be produced on the roots, before winged forms of both sexes migrate back to elm, where mating takes place and overwintering eggs are laid.

Damage:

RAA (nymphs and adults) suck sap from the leaves, causing leaf curling. Feeding in fruit clusters causes fruit to become stunted and malformed. GAA and spirea aphids feed on water sprouts and on terminal leaf growth. Extremely heavy infestations may result in honeydew dripped on the fruit, which may act as a medium for fungal sooty mold. High populations may also reduce overall tree growth or stimulate lateral branching in young trees. WAA suck plant juices from roots, branches and shoots, often causing galls and abnormal swelling. High populations of WAA can reduce tree growth and vigor.

Figure 43: Overwintering aphid eggs

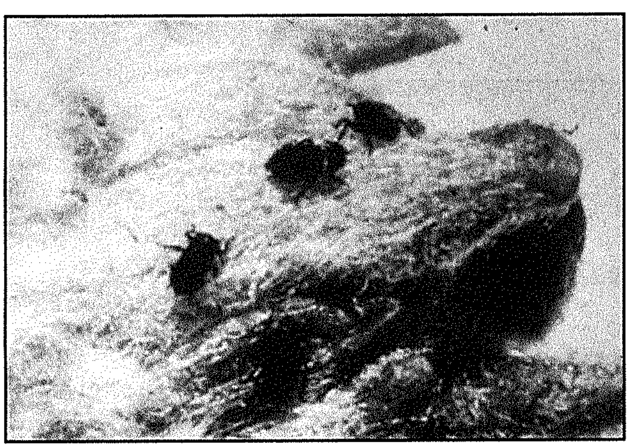


Figure 44: Aphid nymphs hatching at green-tip

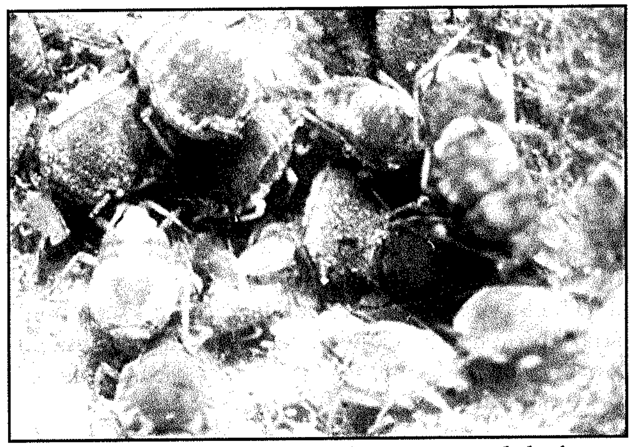


Figure 45: Rosy apple aphid colony on an apple leaf

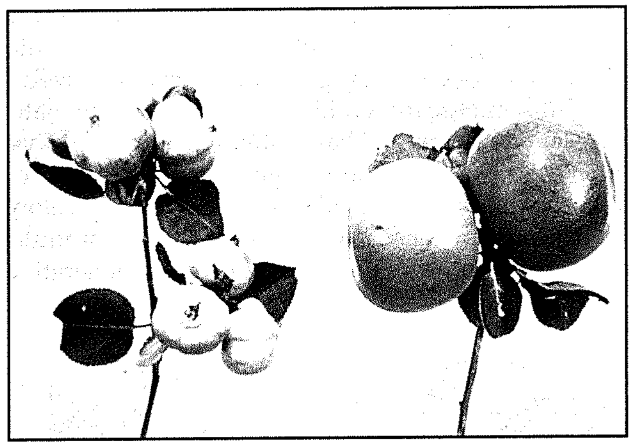


Figure 46: Rosy apple aphid damage (left) compared to non-damaged fruit

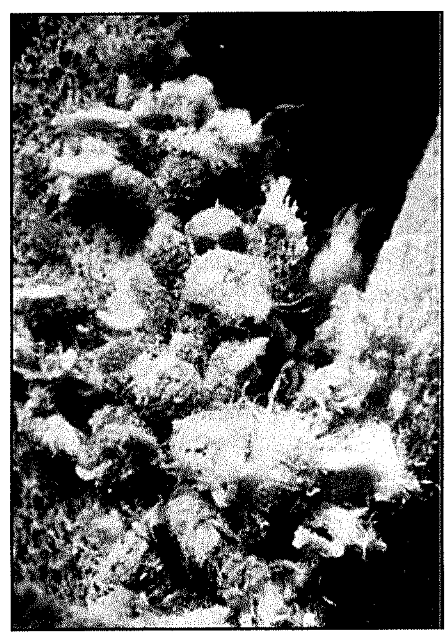


Figure 47: A wooly apple aphid colony

Obliquebanded Leafroller (OBLR) - *Choristoneura rosaceana* (Harris)

Description:

The adult obliquebanded leafroller is 1/2" to 9/16" long, tan with bands of various shades of brown across its fore-wings. The larva is large and robust, with a green body and a dark brown to black head, legs, and thoracic shield. OBLR eggs are laid in masses covered by a dull greenish yellow cement.

Life History:

Half grown OBLR larvae overwinter beneath bark fragments or between twig crotches. In spring the larvae feed on opening buds and later on developing fruit. Pupation occurs at the feeding site and lasts ten to twelve days. Adults emerge from mid-June to early July to mate. Eggs are laid on leaves and hatch after ten to twelve days. Summer larvae feed on the foliage along the midrib or another large leaf vein, but will also attack fruit. Development is complete by early August. A second flight of adults appears late in summer. The resulting second generation larvae feed briefly before finding overwintering sites.

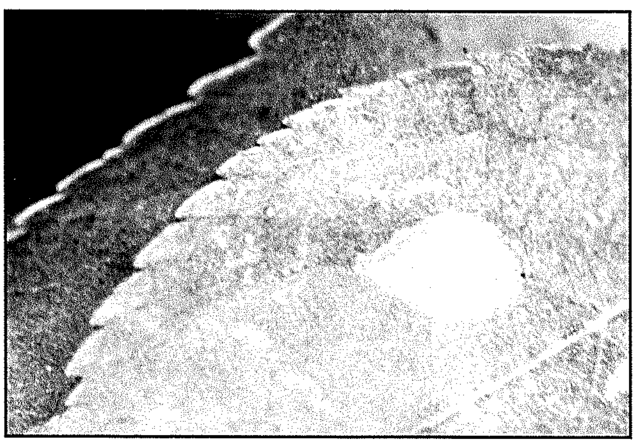


Figure 48: The larvae have already hatched from this leafroller egg mass on the upper surface of a leaf.

Damage:

Depending on which generation causes the damage, injury may take one of two forms:

1. Overwintering larvae may injure developing buds during spring. Early fruit feeding will appear as deep, deformed corky areas, and may be similar to catfacing insect damage or green fruitworm injury.
2. Summer fruit feeding will not deform the fruit. Injury will be a wandering type of surface injury similar to RBLR feeding, but slightly deeper.

Figure 49: An obliquebanded leafroller larva

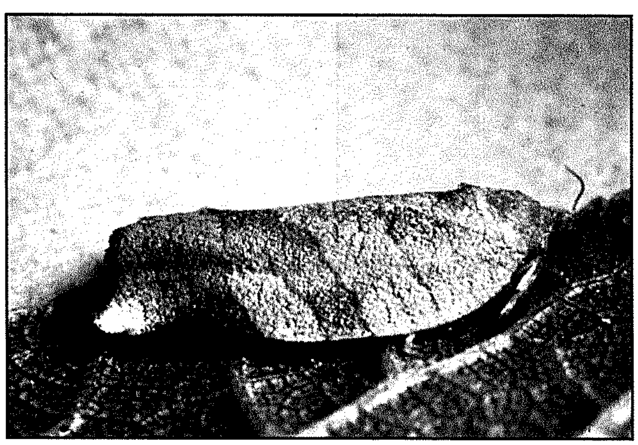


Figure 50: An obliquebanded leafroller adult

Redbanded Leafroller (RBLR) - *Argyrotaenia velutinana* (Walker)

Description:

The redbanded leafroller adult is a small moth, about 3/8" long, and is brown with reddish brown bands across the forewings. The larva is usually light green with a light green head and thoracic shield. RBLR eggs are laid in oval masses containing about fifty cream-colored, disc-shaped eggs.

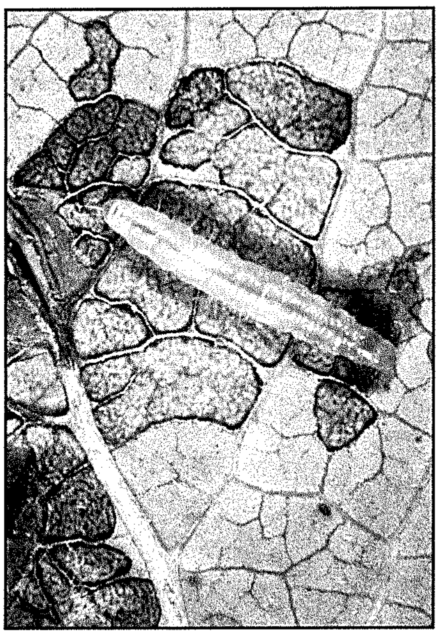


Figure 51: This redbanded leafroller larva is feeding on a leaf.

Life History:

RBLR overwinter as pupae in folded leaves on the ground beneath the tree. Adults emerge soon after the first green tissue appears, and are most plentiful during the pink bud stage. They begin to lay eggs on the bark of main limbs shortly after emergence. Eggs hatch, and larvae feed on foliage and developing fruit from bloom through June. Larvae pupate in a rolled leaf, and emerge as adults after ten to fourteen days (mid to late July), which mate and lay eggs for the next generation. These eggs hatch from mid-July to early August. A third generation is present in the mid-Atlantic region, but farther north only two generations develop.

Damage:

RBLR larvae cause feeding damage to foliage and fruit. Feeding injury on fruit is characterized by shallow feeding depressions or winding burrows on the fruit surface.

Figure 53: An adult redbanded leafroller

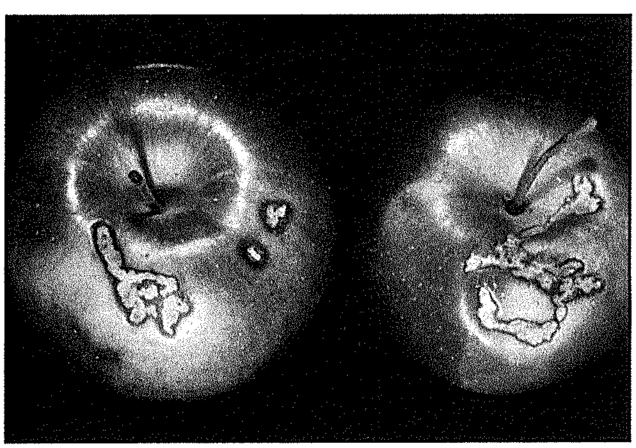


Figure 52: The damage to these fruit is the result of redbanded leafroller larval feeding.

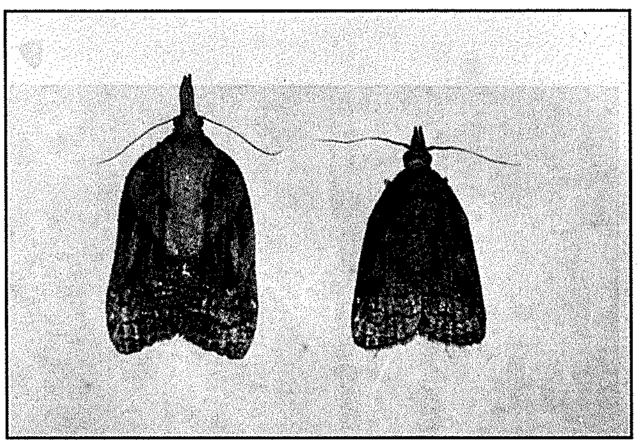
Tufted Apple Budmoth (TABM) *Platynota idaeusalis* (Walker)
Variegated Leafroller (VLR) *Platynota flavedana* Clemens

Description:

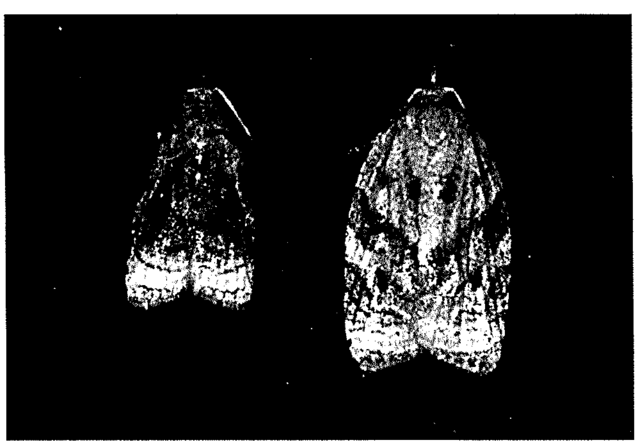
The adult tufted apple budmoth is 1/2" long and inconspicuously patterned with various shades of grey and brown. It has a tufted section of scales near the middle of each forewing, from which it is named. Eggs are laid on leaf surfaces in masses which at first are green, covered with a white coating. The masses later turn yellow to copperish. Young larvae are yellowish brown when they first hatch, but later turn greenish brown to tan, with a dark brown thoracic shield. VLR adults are similar in appearance to TABM, except that they are a mottled brown. Larvae of the two species differ in that the VLR larva is apple green with an amber to light brown thoracic shield.

Life History:

Both species overwinter as partially grown larvae among leaf litter on the orchard floor. Both species have similar life histories, but VLR activity begins slightly later in the season than TABM activity. TABM activity is described here, because TABM is often more common than VLR. As buds open in spring, larvae become active, feeding on developing groundcover vegetation. Larvae pupate from early to mid-May in southern Pennsylvania and New Jersey. Adults start to emerge by mid-May and continue through June. Mating and egg laying take place from the last of May through most of June and early July. Through most of this period, larvae of various ages feed first on the foliage, then on the fruit. A second adult flight takes place in late July through August and early September. Feeding by second brood larvae continues through most of August and the first half of September. Much of the second brood larval generation will overwinter as partially grown and mature larvae.



Figures 54A and 54B: Tufted apple budmoth adults (top photograph), and variegated leafrollers (bottom). In both cases the male specimens are smaller than females.



Damage:

Young larvae feed along major leaf veins, up to but not through the upper leaf surface. More mature larvae feed on leaves inside a lengthwise fold in the leaf that it has constructed using silk threads. Larvae feed on fruit in a manner similar to that of RBLR; however, while RBLR feeding is a continuous trail, TABM feeding is spotty and often interrupted between feedings. Feeding injury is usually seen where a cut leaf has been attached against an apple by the larva. Feeding damage by the second brood is usually more severe, as most feeding occurs in clusters on the fruit shoulder, an area protected from spray contact.

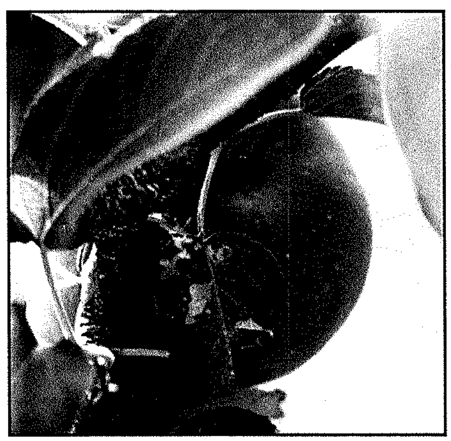
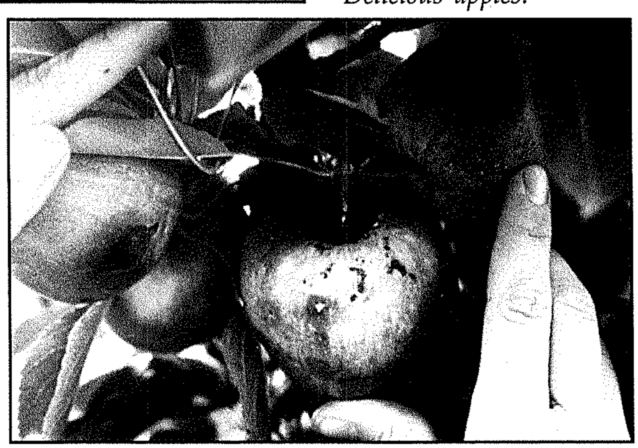


Figure 55: There is a TABM feeding site between this leaf and the apple.

Figure 56: This TABM feeding damage occurred in a cluster of 'Spur Red Delicious' apples.



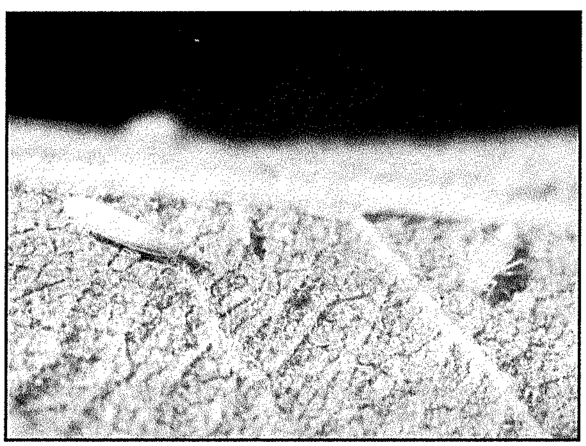
White Apple Leafhopper (WALH) - *Typhlocyba pomaria* McAtee

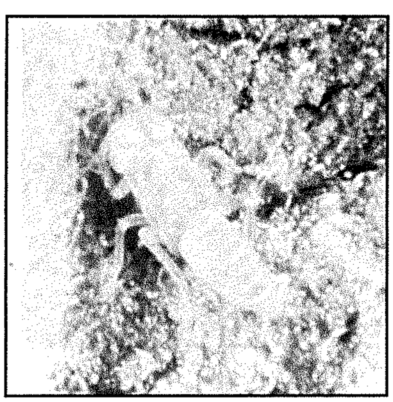
Description:

White, elongate, cylindrical eggs are laid in the twigs of apple trees by the third generation of WALH adults. These hatch at pink, and nymphs can be found feeding through bloom. First and second generation eggs are laid on the lower leaf surface, along a vein. The nymphs, which vary in size from about 1/32" to 3/32" long, are white when first hatched, but turn yellow as they age. WALH adults are faint yellow to white and are approximately 1/8" long.

Life History:

WALH has two generations per year. They overwinter as eggs, which begin to hatch just before bloom and continue for ten to fourteen days. Nymphs feed on the undersides of leaves from bloom through early June. Most nymphs feed on the same leaf throughout their development. Adults are present in early June, and lay eggs through the rest of the month and into July. The second generation nymphs begin hatching in early August. Adults are present by the end of the month, but peak activity of both stages is usually seen by early to mid-September. Adults remain in the orchard through October.





Figures 57A and 57B: (top) Adult and nymph White apple leafhopper; and (bottom) a WALH nymph, greatly enlarged

Damage:

Feeding depletes chlorophyll and sap from the leaves, causing white stippling on upper leaf surfaces. In severe cases, the entire leaf may look mottled or silvery. Intensive feeding reduces tree vigor, and may affect bud formation early in the season or cause poorly colored fruit and premature drop later in the season. If allowed to accumulate, WALH excrement dries on the fruit surface and is very difficult to remove.

Figure 58: WALH feeding injury to apple leaves appears as white stipling on the upper leaf surface.

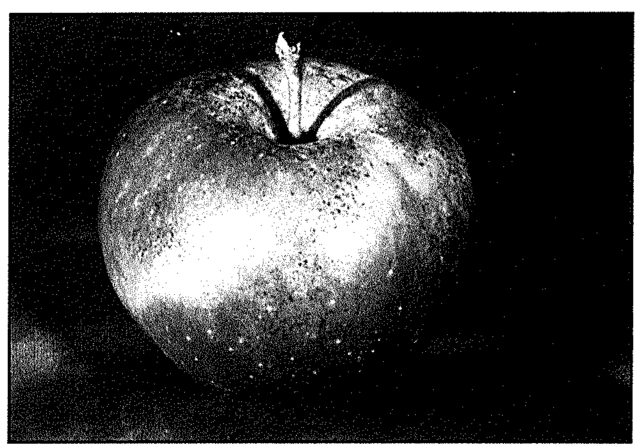


Figure 59: WALH excrement on fruit

European Red Mite (ERM) - *Panonychus ulmi* (Koch)

Description:

Eggs are extremely tiny and turn from bright red to deep orange as they age. The young nymphs are lemon yellow to light orange and darken as they mature. The adult female is velvety red, with four rows of setae (hairs) and white spots on its back, while the male is smaller, narrower, and lighter in color.

Life History:

ERM overwinter as eggs on roughened bark areas on the smaller branches of trees, particularly on fruit spurs. Egg hatch occurs between pink and petal fall, after which the tiny nymphs crawl to the leaves and begin feeding at once. After eight or nine days, the immature ERM molt into adults. There are between five and nine generations of ERM per season. The entire life cycle may take as little as ten to twelve days. Depending on weather conditions and heat, ERM can be found feeding on leaves through September.

Damage:

Both immature and adult ERM suck leaf fluids and chlorophyll from the leaves as they feed. This activity results in the "bronzing" of foliage, from which slightly damaged leaves will recover, but severely damaged ones will not. A severe mite infestation will cause reduced photosynthesis and fruit size, some leaf drop, and a reduction in fruit set the following year.

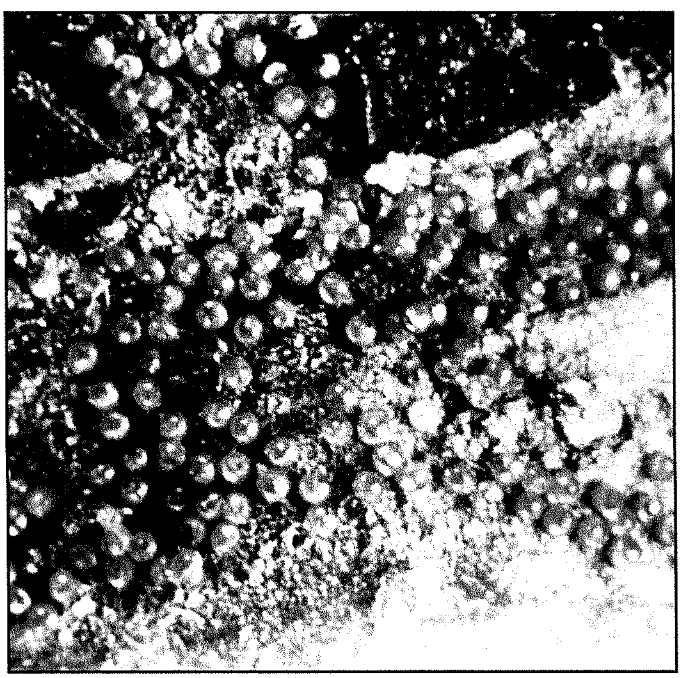


Figure 60: European red mite eggs

Twospotted Spider Mite (TSM) - *Tetranychus urticae* Koch

Description:

Eggs are light yellow to cream colored, smooth, and about the same size as ERM eggs. Adults are yellowish green with a dark spot on either side of the abdomen. Like ERM, the female TSM is larger than the male. Although TSM also have setae on their backs, they are not as pronounced as those on ERM.

Life History:

Adult females overwinter on bark near the bottom of the tree or on the orchard floor in groundcover. TSM will feed on weeds and other ground hosts during spring. As the temperature increases and groundcover dries, TSM move into the trees. They are first seen in the lower center of the tree, and gradually move out over the entire tree. Development time for each generation is about the same as that required for ERM.

Damage:

Damage is similar to that caused by ERM.

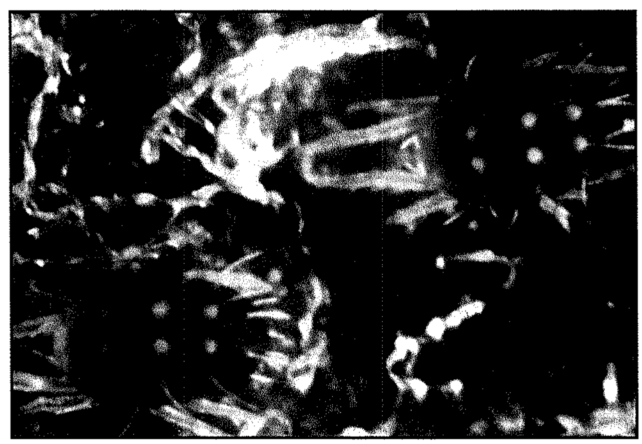


Figure 61: European red mite adults

Figure 62: Twospotted spider mite adult

Leafminers (LM)

Spotted Tentiform Leafminer (STLM) - *Phyllonorycter blancardella* (Fabricius)
Apple Blotch Leafminer (ABLM) - *Phyllonorycter crataegella* (Clemens)

Description:

Hemispherical, clear eggs are laid singularly and attached randomly to lower apple leaf surfaces. The first three larval stages are called sap feeders, and are less than 1/16" long, clear to pale yellow, flattened, with no jaws or legs. The last two larval stages are referred to as tissue feeders. They are approximately 1/8" to 3/16" long and are darker yellow and more caterpillarlike, with legs. The adult STLM or ABLM is a small (about 1/4"), light brown moth with white markings on its wings.

Mines appear first as U-shaped mines visible from only the underside of the leaf. As larvae molt to the tissue-feeding stage, they feed on the inside of the upper leaf surface. This leaves a spotted, tentlike mine when viewed from above.

Life History:

STLM and ABLM have three or more generations per year. They overwinter on the ground as pupae, in leaf mines from the previous year. First generation adults emerge from mid to late April (PA & NJ) and late April or early May farther north. Eggs are laid within a day of emergence, and hatch in five to sixteen days. Upon hatching, larvae enter and begin mining the leaves. First brood larvae pupate within the mine by early June. The second adult flight occurs in early July with a third flight in mid to late August. A partial fourth generation may be present in southern locations or during prolonged warm seasons.

Damage:

High populations can result in severe defoliation, reduced fruit growth, reduced terminal growth, early leaf and fruit drop, and reduced fruit set the following season.

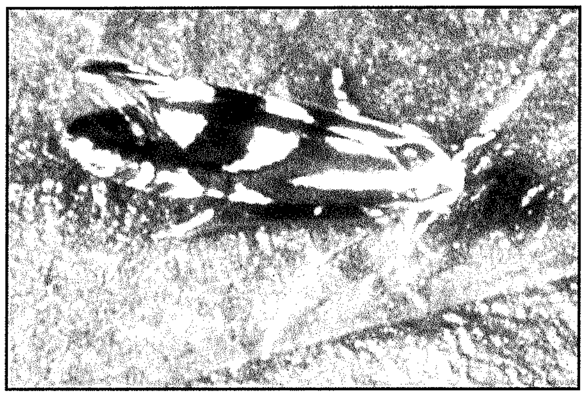


Figure 63 (above): An adult spotted tentiform leafminer

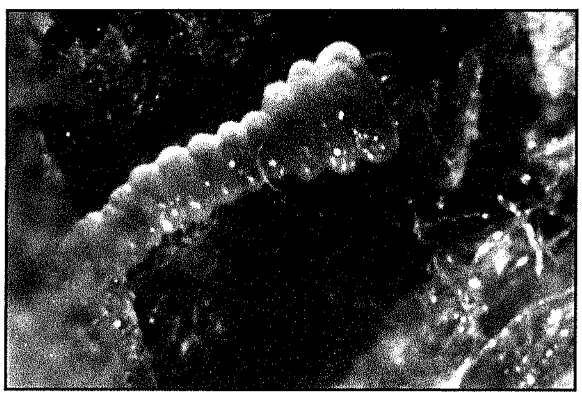


Figure 64: A young sap-feeding larva of STLM

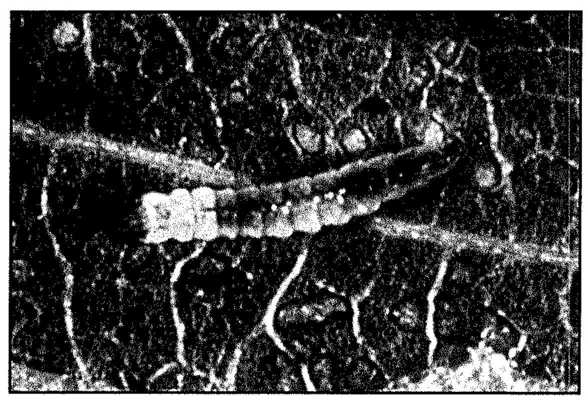


Figure 65: The tissue-feeding stage of STLM

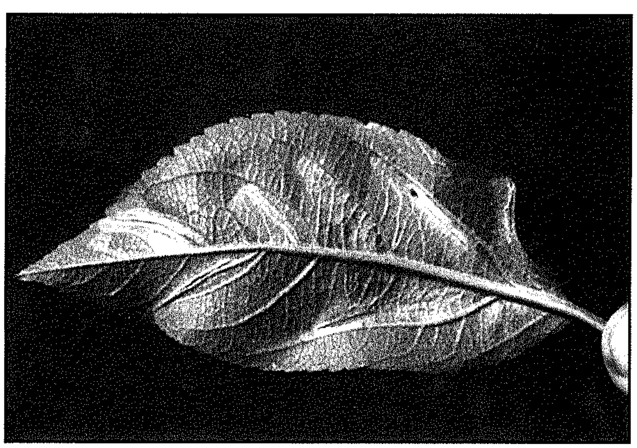


Figure 66: STLM mines on an upper leaf surface

Figure 67: STLM mines seen on the underside of a leaf

Tarnished Plant Bug (TPB) - *Lygus lineolaris* (Palisot de Beauvois)

Description:

TPB eggs, which are inserted into stems and leaf petioles, are elongate and curved, less than 1/8" in length. The pale yellowish green nymph is oval and 3/16" to 5/16" long. The adult, like the nymph, feeds by sucking plant sap from stems, leaves, buds, and fruits. It is about 1/4" long, flattened, oval, and brown with mottled spots of yellow, white, rust, and black. There is a clear yellowish triangle on the wing tip.

Life History:

TPB overwinter as adults in protected places under leaf litter, stones, or bark. They become active in early spring, feeding on developing buds, causing damage to terminal shoots and fruit. TPB has a wide host range, and lays its eggs in many weeds and legume crops, including vetch, alfalfa, and clover. Eggs are also laid on fruit buds and developing fruit. Eggs can hatch after ten days. Both nymphs and adults have piercing, sucking mouth parts and feed on plant sap. In the Northeast, second generation adults appear in late July to August, with a third generation in September. Up to five generations are possible in southern latitudes.

Damage:

Overwintering adults feed most actively on apple buds during the pink and blossom stages. Injured buds will not usually develop, and drop from the tree. Early feeding on the fruit results in small, deep, sunken areas usually near the calyx end. Injury is often conical and heavily russetted.

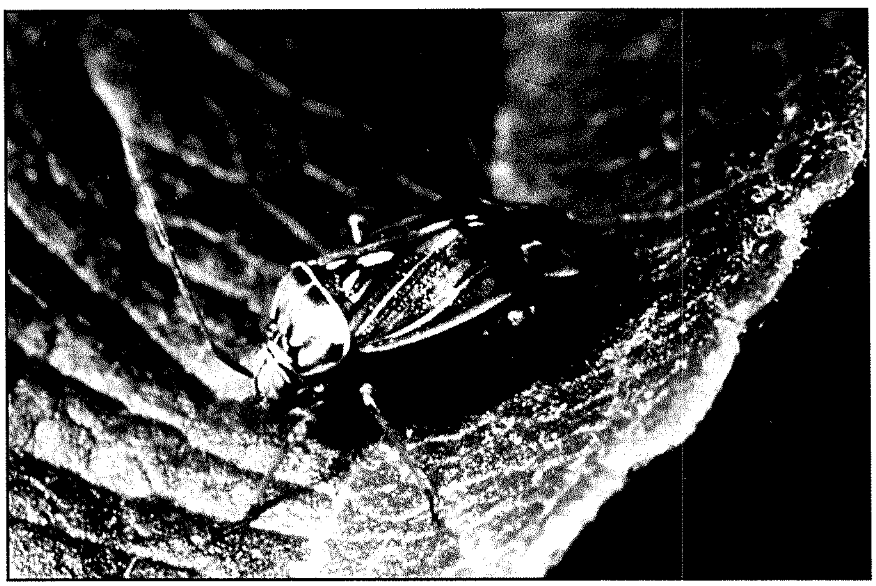


Figure 68: An adult tarnished plant bug

Figure 69: The sunken, damaged areas on these apples are the result of early feeding by TPB on the fruit.

Green Fruitworms (GFW) - Several species

Speckled Green Fruitworm - *Orthosia hibisci* Gn.
Humped Green Fruitworm - *Amphipyra pyramidoides*

Description:

Round GFW eggs are grayish white with ridges. The larvae are usually large and robust and are varying shades of green, with yellowish white longitudinal stripes. The adults vary in color but are generally brown to grayish brown and mottled, with a wingspan of 1 1/2".

Life History:

Eggs are laid in early spring and hatch at half-inch green. Young larvae feed on unfolded leaves, while larger larvae attack the developing fruit up to 3/4" in diameter. Larvae then drop to the ground and pupate in the soil. Adult emergence occurs in mid to late summer, depending on the species. The speckled green fruitworm overwinters in the pupal stage underground; while the humped green fruitworm overwinters in the egg stage. Other species overwinter as adults.

Damage:

Most of the buds and blossoms abort when damaged by GFW larvae. Developing fruit that has been chewed near petal fall also drops prematurely. Those that remain develop deep, corky scars.

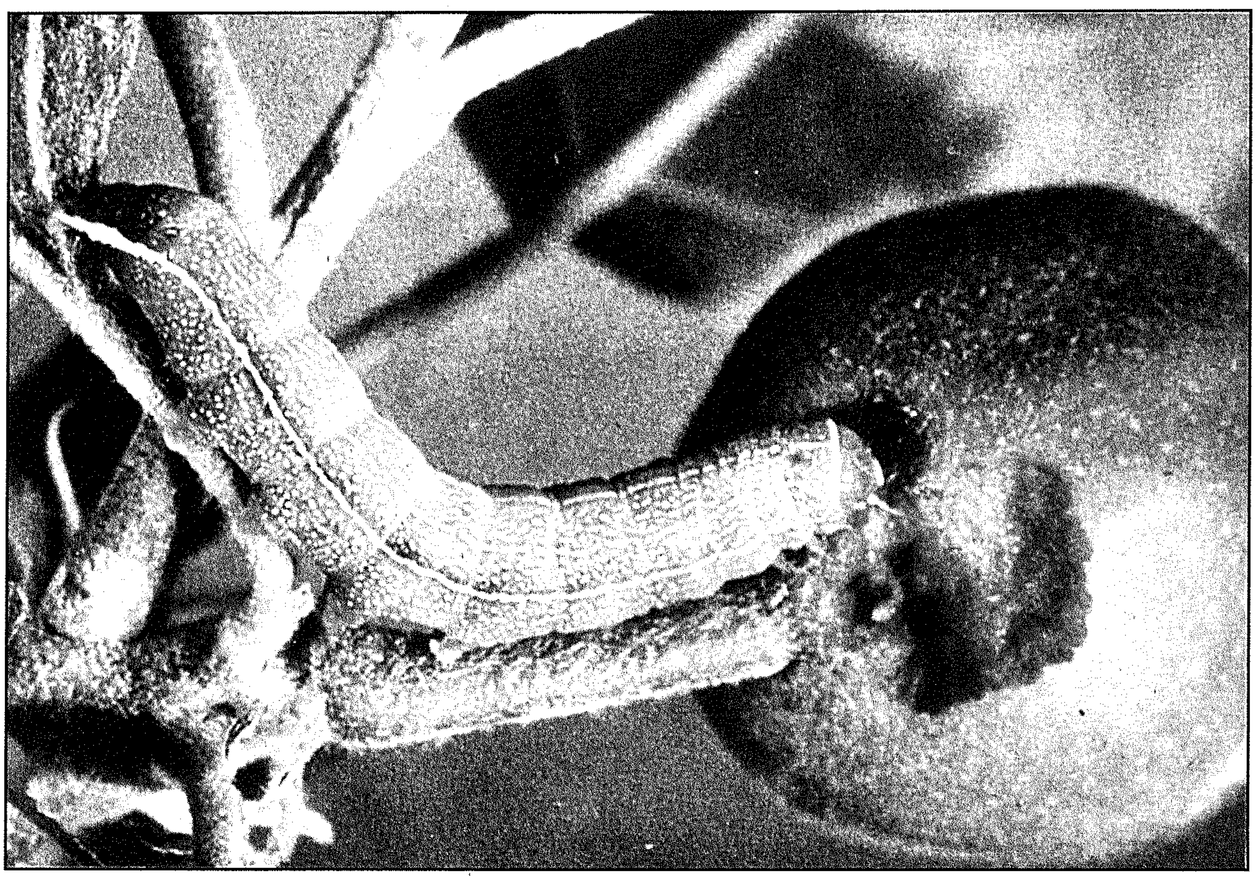


Figure 70: A green fruitworm larva feeding on an early fruit

European Apple Sawfly (EAS)- *Hoplocampa testudinea* (Klug)

Description:

The yellowish white EAS larvae are 1/2" long, and have a pair of legs on each thoracic body segment. The adult is a flylike insect, 1/3" long, with a dark brown body.

Life History:

EAS overwinter in the soil as mature larvae. In early spring they pupate and adults emerge at the pink stage of apple bud development. Females oviposit into developing fruit from bloom to petal fall. The larvae first tunnel under the skin around one fruit, then attack an adjacent fruit, burrowing into it. This fruit then drops to the ground where the larvae overwinter. There is only one generation per year.

Damage:

The female EAS makes a slit in the calyx end of the developing fruit in which to deposit her egg. The larva bores just under the skin and creates a winding tunnel, which leaves a corky ring around the fruit at harvest. Larvae may also tunnel straight through to the seed cavity, often causing premature fruit drop.

Figure 71: A European apple sawfly larva and early, damaged fruit

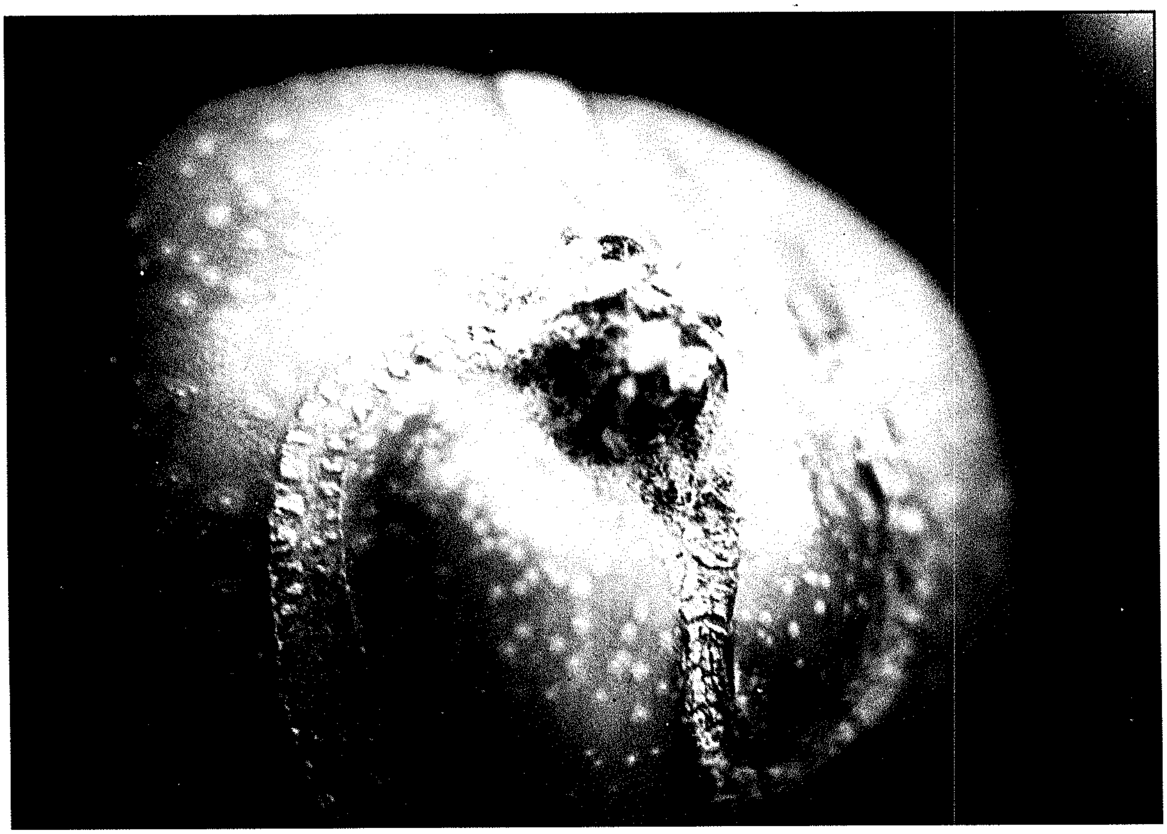


Figure 72: Early feeding by EAS larvae results in corky-looking damage to the fruit.

MONITORING

Trapping:

Pheromone traps (see Figure 73) are available for the leafroller complex, including obliquebanded leafroller, redbanded leafroller, tufted apple budmoth, and variegated leafroller. Codling moth, San Jose scale, and, to some extent, spotted tentiform leafminer can also be monitored this way. Visual and visual/floral scented traps are used to monitor European apple sawfly, apple maggot, spotted tentiform leafminer, and tarnished plant bug. Traps are usually used to refine spray timing or other methods of control, and may be used in conjunction with other monitoring methods. For some species of insects, such as apple maggot flies, codling moth, and European apple sawfly, enough information is known so that trap counts can be used to identify economic threshold or treatment levels.

Plant sampling, too, can be used for the leafroller complex, white apple leafhopper, and leafminers. Modeling systems are available for codling moth and San Jose scale.

Figure 73: Pheromone traps may be used to monitor arthropod pests and, in some cases, to help determine economic threshold or treatment levels.

Leafroller Complex

Traps should be placed in the orchard at least one week before adults start to fly (see Apple Calendar, back cover). At least two traps should be used for any one species, but no more than four or five need to be placed in large plantings of at least sixty acres. When trapping more than one species, all traps should be placed in one row to make the most efficient use of labor. Place each trap at head height on the outside of the tree, unobstructed by leaves or fruit. Make sure that direct contact by sprayers or other equipment is avoided. Traps for different species should be kept at least 30' apart within the row. Traps should be spaced evenly throughout tree blocks, avoiding border areas. Areas that have had previous infestations should receive special attention.

Treatments are usually timed to coincide with egg hatch or the occurance of young larvae. For RBLR, this occurs from just after the trap peak until catches bottom out in the first generation, and around the flight peaks for the second and third generations. TABM egg hatch occurs from the time the first flight peaks until its lowest point, and then again from the onset of the second flight until its peak. OBLR are usually treated at petal fall and again in July when young larvae are present.

Codling Moth

Traps should be placed in the center of the block before bloom, or in the manner described for leafrollers. Traps should be placed at head height on the outside of the tree. CM traps and traps for other species should be kept at least 30' apart. Monitoring is done through all generations, although the first flight is the most important. After the first flight, sprays should be applied only if trap catches exceed five moths per trap per week. Insecticides should be applied seven to ten days after this level is reached, and repeated at two-week intervals. Treatment for the first flight is usually done two weeks after petal fall. Treatments can also be timed with the aid of a degree day (D$^{o)}$ model (see p. 72), in which case a biofix point is determined as the time of the first adult catch.

San Jose Scale

Monitoring should be concentrated on blocks with a known or suspected history of infestation. Scale infestation is usually confined to several trees or small sections of the orchard. Therefore, traps should be hung in the infested area at pink, at a density of at least three traps per ten acres. Double sided sticky tape wrapped around an infested branch will aid monitoring of crawler activity. Crawlers will emerge four to six weeks after the start of the first male flight, and much sooner after the start of the second flight. Several methods of control are possible:

1. One spray when adults first emerge, and a second application when peak emergence is seen
2. Two sprays applied against the crawlers, one at first emergence and the second at peak emergence
3. The use of degree day (D°) modeling with the first male catch as a biofix point (see p. 72)
4. The use of oil plus an insecticide on a regular basis during the delayed dormant period

The first choice is least desirable, but adequate for mild infestations.

Leafminers

Both spotted tentiform (STLM) and apple blotch (ABLM) leafminers can be monitored with visual traps and pheromone traps. Traps function only as indicators of relative abundance, and as markers for the timing of leaf sampling. The first mines, caused by sap feeding, are usually visible about one week after peak adult flight.

Apple Maggot

Adult flies are monitored with either yellow sticky boards or sticky red spheres. Research has shown that yellow boards attract sexually immature flies, while red spheres attract mated adults that are ready to lay eggs. Because treatment decisions are based on controlling adults that are feeding or laying eggs on the fruit, red spheres are preferred in commercial orchards. The addition of synthetic apple volatile increases trap catches.

Traps should be placed by early to mid-June in the southern part of its range (southern PA and NJ), and by late June in New York and New England. Traps should be placed at head height, clearly visible, and 1' to 2' away from the nearest foliage or fruit. Traps should be placed on the outside one or two rows of a block, preferably bordering the woods or in earlier-maturing varieties such as 'Paulared' or 'Twenty Ounce'. A treatment level of five flies per trap per week can be used in New York and New England. Trap catches during the week following an application should be discounted because these adults are assumed to be benign if they landed on a sprayed apple.

European Apple Sawfly

Adults are attracted to blossoms, where mating, feeding, and egg laying take place. White sticky boards, which mimic blossom appearance, can be used to monitor adult emergence. Place the traps at pink on the outer two rows of a block, preferably near the woods on the southern edge of the orchard. Traps should be slightly above head height, between 1' and 3' from apple foliage, and facing out. Adults are active only from pink to shortly after bloom, so traps can be discarded two weeks after petal fall. Petal fall sprays for sawfly are justified when a cumulative trap catch from pink through petal fall reaches 4.5 to 5 per trap in orchards that receive no prebloom insecticide, and 5.5 to 6 per trap in orchards with prebloom insecticide.

Tarnished Plant Bug

Tarnished plant bugs (TPB) can be monitored with an adhesive coated, 6" x 8" board painted with white, non-UV-reflecting paint. Traps should be hung on the outside of the tree at knee height, about 1' from surrounding foliage. Traps should be placed at a density of one per three to five acres, with at least three per block. Groundcover should be present, but not covering the trap. The board mimics buds and blossoms, attracting and trapping overwintering adults. If boards attract a cumulative 2.4 TPB per trap through tight cluster, or 4.1 TPB per trap through late-pink, then treatment may be used. Since TPB are injurious to apple only through petal fall, traps may be removed at that time.

Results with these traps have been irregular in some areas, so growers may also monitor by using an insect sweep net. Take fifty 180° sweeps per sample site, sweeping deeply into as much cover crop as possible. Take one sample per five to six acres, and bias sampling toward areas of greater weed diversity and groundcover thickness. Monitoring should be done when the weather is dry, with temperatures above 50°F to 60°F, when TPB activity is greatest. If treatments are justified, then they should be applied during periods of TPB activity. Disturbing the groundcover by mowing or discing during TPB activity drives the insects into the fruiting area of the trees and should be avoided where TPB pressure is high.

Plant Sampling

Traps are not available for all insects. Other methods such as plant sampling may be used or combined with trap counts when possible, to determine what pests are present.

Aphids

Rosy apple aphids can be monitored in two stages: From bud break through tight cluster, record the number of aphid-infested buds per tree per ten-minute inspection. During the next six weeks, inspect ten trees, counting the colonies infesting each tree, and record the average number of colonies per tree. Treatment is justified if there is at least one infested bud or one colony per tree. Sampling may also be accomplished by examining ten fruit clusters in the interior canopy on each of ten trees. Treatment is justified when at least 1 percent of the clusters are infested.

Green apple aphids and spirea aphids should be monitored from tight cluster through mid-July, or slightly later in northern New York and New England. Sample five to ten vegetative terminals on each of ten trees, count the terminals infested with aphid colonies, and record this as a percent. Depending on the crop size, tree stress, and the market, treatment is generally called for when at least 50 percent of the sample is infested or if there is any honeydew on the fruit.

Woolly apple aphids can be monitored by examining at least five pruning cuts on each of ten trees. Counts may be taken from midsummer through harvest. This is a rare or sporadic pest in most areas, but treatment may be needed when at least 50 percent of the sample is infested.

Green Fruitworm

This is only an occasional pest in most areas of the Northeast. Usually, GFW are suppressed by the pink and petal fall sprays directed at other pests. If either of these sprays is deleted, GFW should be monitored between the pink and petal fall periods. Using a ten-tree sample, scan each entire tree for infested fruit bud clusters. Depending on market conditions, treatment may be needed if an average of two to three larvae per tree are found.

Leafroller Complex:

Obliquebanded Leafroller
Redbanded Leafroller
Tufted Apple Budmoth
Variegated Leafroller

For OBLR, two sampling periods are required, one for each generation. Examine ten bud clusters per tree during bloom for signs of overwintered larvae. Look uniformly at all parts of the tree. Examine a maximum of 100 clusters and record the percent of clusters infested with live larvae. When 3 percent of the sample is infested, a treatment is usually justified.

Summer injury is usually more serious, because injured fruit remains on the tree. Summer monitoring should begin after 600D° base 43°F (see predictive modeling section for the method of degree day calculations, p. 72), after the first adult catch in pheromone traps. This usually occurs during early July. Examine ten leaf and fruit clusters per tree for summer larvae, and record the percent of the sample that is infested. Examine clusters from all parts of the tree, including the center. Summer injury will not cause fruit drop, but will appear as a surface injury. Some (3 percent to 10 percent or more) injury may be tolerated depending on the market. If the fruit is intended for the fresh market, use a 3 percent treatment level. If the fruit is intended for the process market, roughly 10 percent damage may be tolerated.

For RBLR, VLR and TABM, use a five-minute count per sample site, and record the number of unhatched egg masses seen per sample. Examine the smooth bark areas of twigs and branches for RBLR eggs in spring, and the upper leaf surfaces during the periods of trap catches in summer (RBLR & TABM). Egg masses found during June and August will usually be from TABM. RBLR egg masses may be found to some extent in July and again in late August. Fruit clusters should be examined beginning in late June. Include 200 fruit from a ten-tree sample, looking carefully at any folded leaves, or leaves that are webbed to the fruit surface. Young larvae may be found along the midrib of a webbed leaf, having not yet started to feed on the fruit. Treatments are applied during egg hatch, but if excess damage is seen, materials or application methods should be changed.

> *"...Intensive pesticide use can elevate a nonpest insect to pest status." (see page 71)*

Plum Curculio

Starting at petal fall and for the next two weeks, fruit should be checked for fresh egg-laying scars. Where there is a history of PC, trees should be examined daily, especially if temperatures exceed 60 °F for three days or 75 °F for two days. Sampling should be done near the perimeter of the orchard, or on rows bordering the woods.

PC adults can cause 100 percent injury to the fruit, so controls should be applied as soon as activity is detected. Controls are most effective when applied just before a period of warm weather. No more than two applications, seven to ten days apart, are usually needed.

Leafminers

Adults emerge starting at green-tip and immediately start to lay eggs on the undersides of leaves. Because this is often the only insect that needs to be treated at pink, an egg count used to assess treatment need is helpful. Larvae should be monitored by sampling twenty leaves per tree from ten trees. Data should be recorded as the average number of mines per leaf. For most varieties, treatment is justified when leafminers reach a level of 0.5 per leaf in the first generation and 1 per leaf in the second generation. For 'McIntosh', these levels are 0.07 to 0.1 per leaf (first generation) and 0.5 per leaf (second generation). Larvae are most susceptible to controls while in the sap-feeding stage, so fresh mines seen only on the undersides of leaves are the most critical to monitor.

White Apple Leafhopper

Two distinct sampling periods are required. Monitor from petal fall through late June for the first generation and from early August through the first half of September for the second generation. Nymphs may be found on the undersides of the leaves next to two to three-year-old wood. Examine twenty leaves per tree on each of ten trees for the presence of WALH nymphs, and record the average number of nymphs per leaf. Treat when levels reach 0.5 per leaf in the first generation, and at least 1 per leaf in the second generation.

European Red Mite and Twospotted Spider Mite

Before tight cluster, examine ten spurs per tree on each of ten trees, and record the number of spurs with overwintered eggs. If at least 10 percent of the sample has eggs, a dormant to delayed-dormant application of two-percent oil, or a tight cluster to pink application of one-percent oil will control early mite populations.

Summer populations of both mites can be monitored by either counting the motile mites per leaf on five intermediate-aged leaves from each of five to ten trees, or determining the percentage of leaves that are infested with one or more mites. The first method requires a detailed count of both immature and adult mites on both surfaces of each leaf. When using the second method, scan between twenty and one hundred leaves with a hand lens, and record the percentage of leaves with at least one immature or adult mite. Treatment thresholds will vary depending on the time of season. Crop load, water stress, and market value will also influence your decision. Use the following chart as a guide:

	Method 1	**Method 2**
DATE	**THRESHOLD**	**% LEAVES INFESTED**
Petal Fall - Late June	2.5 mites/leaf	62%
Late June - Mid-July	5 mites/leaf	76%
Mid-July - Early Aug	7.5 mites/leaf	85%
Mid Aug - Late Aug	10 mites/leaf	91%

USE OF NATURAL ENEMIES: BIOLOGICAL CONTROL

Mite Predators

Several predacious mites are common in commercial orchards. The most important species belong to the family Phytoseiidae. The most common mite of the family in the Northeast is *Amblyseius fallacis. A. fallacis* overwinters in groundcover beneath the tree. As twospotted mites move up the trees early in the season, they are followed by *A. fallacis* which feed on TSM or rust mites as their primary food source. As the predators move throughout the tree, they feed on European red mites (see Figure 74). Populations of 0.25 to 0.5 predators per leaf often help suppress populations of ERM. Under high ERM or TSM pressure, a ratio of 1 predator mite to 10 spider mites indicates that control of spider mites by predacious mites is likely to occur. Other predators in the genus *Typhlodromus* are also present in the Northeast. One species in the family Stigmaeidae, *Zetzellia mali,* is present in smaller numbers throughout the Northeast.

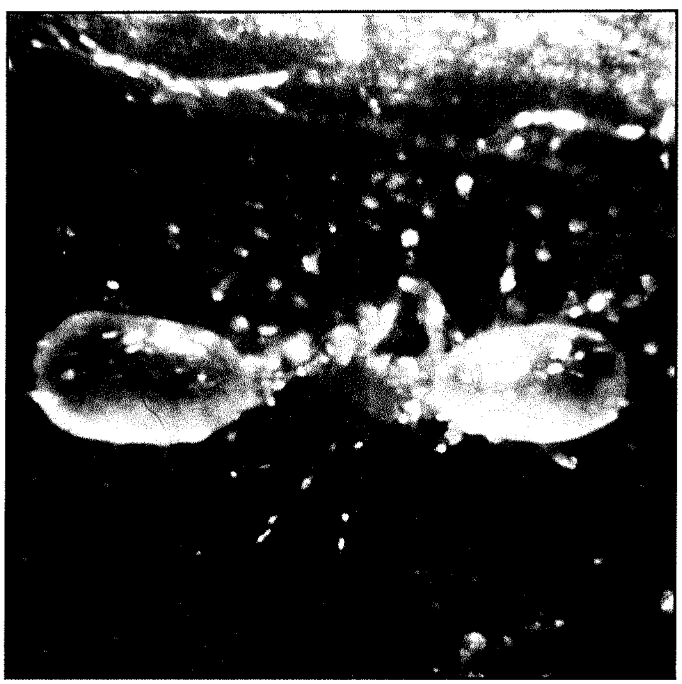


Figure 74: Predacious mite (Amblyseius fallacis) *feeding on a European red mite*

Amblyseius and *Typhlodromus* species are pear shaped, smooth, and often shiny. Their translucent color may vary from cream to tan, amber, or slightly reddish, depending on the type of mite on which they are feeding. On leaves, predators are fast moving, searching for prey. Eggs are often present at the same time as the mites, usually near the midribs on the undersides of leaves. Eggs are oblong to football shaped, shiny, smooth, colorless, and slightly translucent (see Figure 75). Predator eggs are larger than ERM or TSM eggs. *Z. mali* mites are slightly larger in front than in back. Adults are yellow to yellow red. Immatures are lemon yellow.

Figure 75: A predacious Typhlodromus *adult shown with eggs*

Stethorus punctum

The small, black lady beetle, *Stethorus punctum*, is the dominant mite predator throughout Pennsylvania, New Jersey, and much of the Cumberland-Shenandoah region. Adults are shiny black and round, about 1/16" long. Larvae are covered with some hair, are red to reddish gray, and grow to just over 1/8" long (see Figure 76). Larger larvae and adults (see Figure 77) will feed on up to 100 mites per day.

S. punctum overwinter in groundcover and near hedges and fence rows. Adults are seen early in the season, as ERM populations start to increase, but larger populations are usually not present until late June or early July.

S. punctum should be monitored by counting the adults and larvae seen in a three-minute count around the tree periphery. Do not count the pupae, since they are a non-feeding stage. Choose a tree (or two, if a dwarfing variety) that has a mite population representative of the general population. Compare the three-minute count to the number of mites per leaf on that tree. When a three-minute count is at least 2.5 times the number of mites per leaf, spider mites will be controlled in about a week. If mites are present in numbers greater than a threshold level, but beetles are present at less than a 2.5:1 ratio, then suppressive measures (rather than control measures) can be taken against the mite population. Suppressive measures include using a half rate of miticide or a half spray of miticide, or using an insecticide that suppresses mite populations.

The success of mite predators depends on the judicious use of minimal rates of selective pesticides (see table 12, p. 74). Application method is also important. Predator populations often increase faster under half sprays than under full cover or every-row treatments.

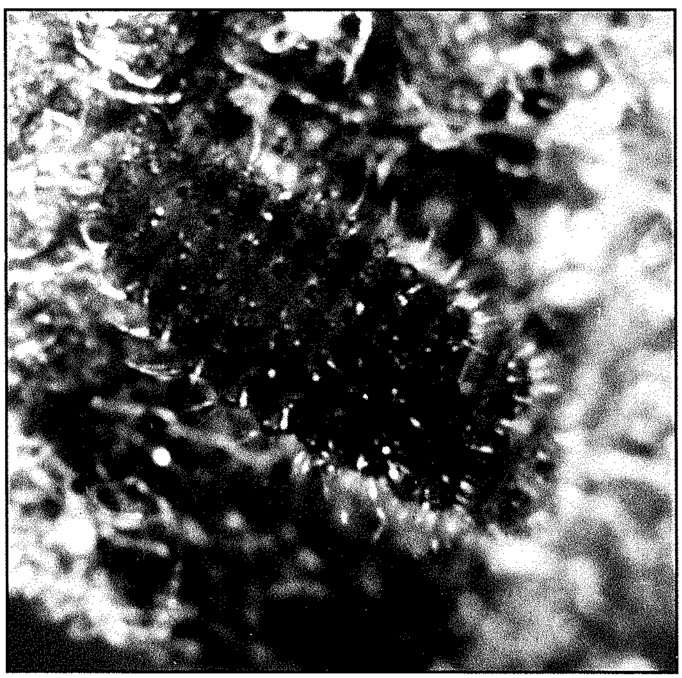


Figure 76: A Stethorus punctum *larva*

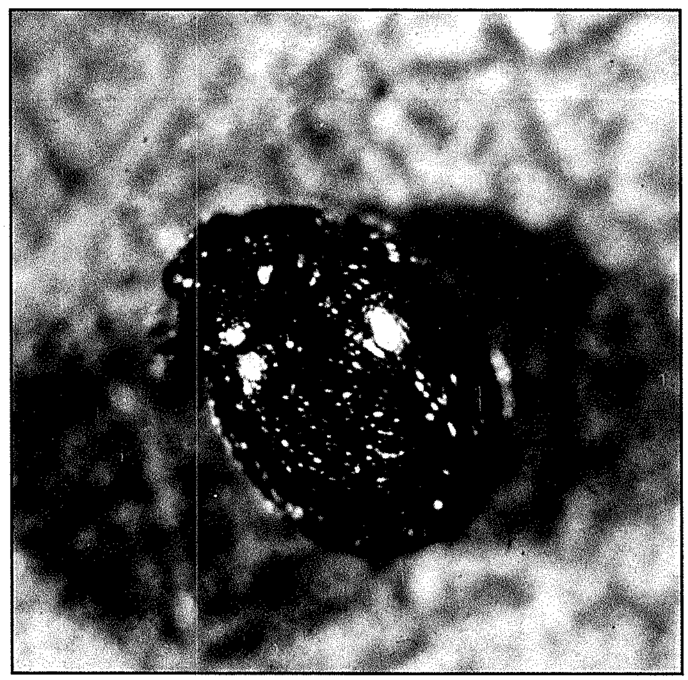


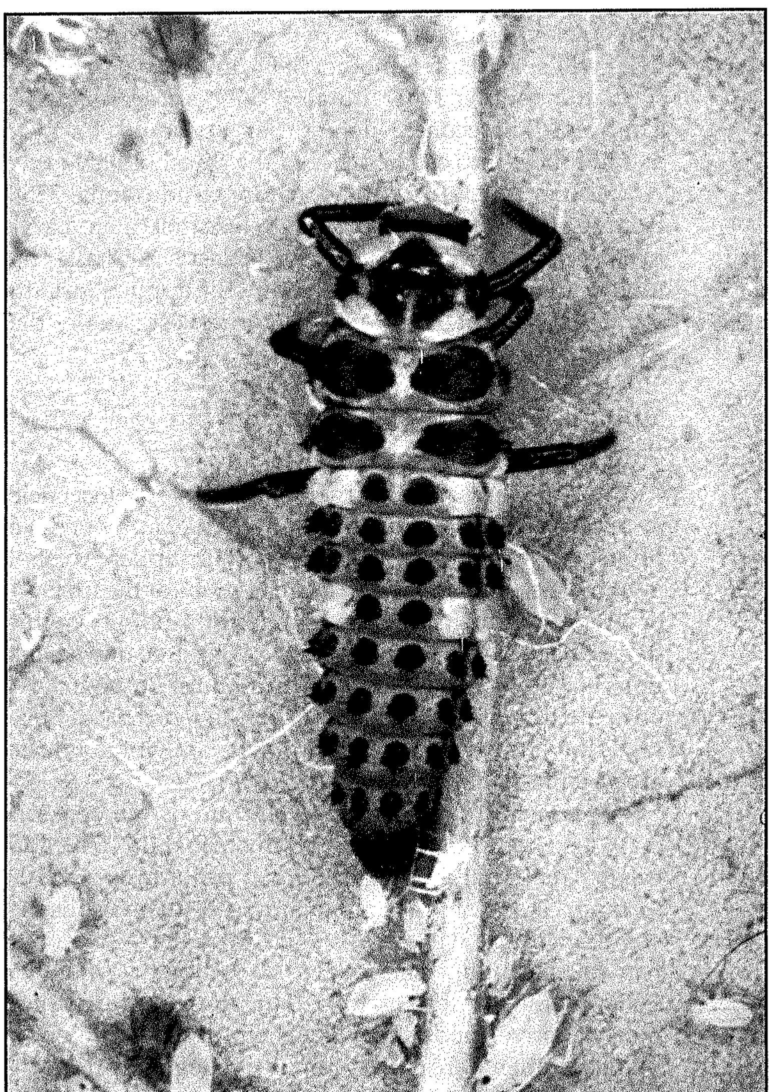
Figure 77: A Stethorus punctum *laby beetle adult*

Aphid Predators

Aphid predators are most effective against green apple aphids. Often, predators can completely control a green aphid population. However, since chemicals used for the control of other insects often disrupt predator populations, their effect is often decreased. If pesticide use is minimized during the first three weeks of June, the chances of successful biological control of GAA are increased.

Lady Beetles

There are many species of lady beetles in apple orchards. The convergent lady beetle, *Hippodamia convergens*, is the most common. Adults are orange or reddish orange, usually marked with patterns of black spots. Eggs are yellowish orange and spindle shaped. They are laid on end, grouped in compact clusters on leaves or twigs. The alligator-shaped larvae are blue black with orange markings (see Figure 78).



Photograph courtesy of Erwin Elsner

Figure 78: A lady beetle larva shown preying on aphids

True Bugs (Hemiptera)

These are general feeders and will attack aphids, spider mites, thrips, small caterpillers, leafhopper nymphs, and tarnished plant bug nymphs. The minute pirate bug is the most common, and is probably resistant to many common pesticides. The black and white adults are almost 1/8" long, somewhat flat, with a pronounced beak. Nabids or damsel bugs are from 3/8" to 1/2" long, tan to gray, and slender. The head is narrow, with a long beak curving under the body.

Flies

Larvae of several families of flies feed on aphids, mites, and other soft-bodied prey. Syrphids, cecidomyiids and chamaemyiids are all present in Northeast orchards. Syrphids, or hover flies, are the most common. Adults are nectar and pollen feeders, and mimic bees in appearance. They are metallic blue, green, or violet with yellow bands. The predaceous larvae look like green to greenish brown slugs, but are pointed at the front end.

Leafminer Parasites

There are four species of small, parasitic wasps that show promise as biological control agents of leafminers. Two of these wasps are native species. Two other species have been recently imported from New Zealand and Japan, and are the subjects of research in Ontario, New York, and Connecticut.

Leafminers represent a classic example of how intensive pesticide use can elevate a nonpest insect to pest status. Leafminer populations are naturally suppressed by parasites, so orchards that receive minimal or no insecticides do not experience leafminer problems. Only when insecticides for other pests kill the leafminer parasites do leafminers increase to pest status. Finding ways to minimize insecticide use will help augment parasite populations, so that leafminer populations can be suppressed.

Destruction or burial of leaves containing overwintering leafminer pupae is one suggested control method.

PREDICTIVE MODELING

Insect development models are usually driven by degree day (D°) accumulations, which use the insect's lower developmental threshold as a base temperature. Modeling is also used in conjunction with pheromone trapping. When used together, these systems help minimize insecticide use by indicating only applications that are strictly needed. Degree day calculations for each day are calculated as follows:

$$\frac{(T_{max} + T_{min})}{2} - T_{base} = D^{\circ}$$

T_{max} = the maximum temperature for that day
T_{min} = the minimum temperature for that day
T_{base} = the base temperature used for that insect or insect stage.

Different insects and different stages of the same insect may have different lower developmental threshold temperatures; hence, model calculations vary among insect pests. Modeling also takes into account the optimum temperature at which an insect will develop, and the maximum temperature that inhibits activity. Calculations may be made with the aid of a properly sheltered maximum-minimum thermometer, or by using a computerized D° accumulator.

Codling Moth

Temperature thresholds and degree day requirements are as follows:

			D° Requirement:	
Stage	**Min**	**Max**	**Avg**	**Range**
Adult; flight	55°F	80°F		
Adult; mating	60°F	80°F		50-250
Adult; egg laying	60°F	86°F		50-300
Egg to hatch	52°F	94°F	160	125-200
Hatch to mature larva	52°F	94°F	475	360-620
Pupation to emergence	52°F	90°F	400	240-585

For practical purposes, all D° calculations for codling moth can be made using 52°F as a base temperature. Accumulation is started when the first male moths are captured in the pheromone traps.

Egg laying for the first generation will normally begin after 50 D° are accumulated after the beginning of adult flight. More accumulation is needed in spring than in summer. This is because adult flight will start at 55°F, but egg laying will not start until temperatures reach at least 60° to 65°F during twilight. Egg hatch will start after at least an additional 125D° have accumulated after the start of egg laying (total after first moth catch = at least 175D°). Insecticides applied to control the overwintering generation should be applied between **175 and 200D°** after first moth catch. Controls should be expected to last about one week to ten days. Trap counts should be reevaluated at that time. If the catch exceeds the threshold level, another application is needed. Moth emergence from the first generation larvae will occur after an additional 725D° from the time of the first egg laying, or at least 775D° since first adult capture. Eggs will be laid after another 50D°, and larval hatch will start after another 125D° **(total = 950D° since first catch)**. Controls to kill second generation larvae should be applied at that time if trap catches exceed the threshold level.

Second generation larvae require an additional 725D° from egg to adult, or at least 1550D° since first catch. Larvae hatch after an additional 175D°, or at least 1725D° after first moth catch. Therefore, sprays should be applied just after **1725D°** if trap catches are high and harvest is more than two weeks away.

San Jose Scale

This model assists in targeting with a single insecticide application the first generation crawlers. The lower developmental threshold of SJS is 51°F, and the upper threshold is 90°F. Pheromone traps are used to monitor the first male emergence, which is used as the biofix point at which degree days start to be accumulated. Degree day calculations use 51°F as a base temperature, and are used to target only the first of two generations in the Northeast. Sticky tapes may be used to monitor crawler activity in infested areas, if pheromone traps are not available.

Treatment of the spring generation of San Jose scale crawlers should be done at 600 to 700D° after first adult catch. Treatment should be just after peak crawler activity in June. If sticky tapes alone are used, then application should coincide with 200 to 300D° after the first crawlers have been caught. Spray dates should be the same with either method. Although dormant treatments are still the most effective, modeling will be helpful where either dormant treatments are not used or are inadequate due to high insect pressure.

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AN ECONOMETRIC ANALYSIS OF THE U.S. APPLE INDUSTRY

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AN ECONOMETRIC ANALYSIS OF THE U.S. APPLE INDUSTRY

Lois Schertz Willett

A dynamic national apple industry model is specified including relationships for bearing acres, production, utilization, and allocation to the fresh, canned, frozen, juice, dried and other markets. Demands in each of these markets are modeled. Model coefficients are obtained using Zellner's seemingly unrelated regression procedure and data from 1970 through 1990. Elasticities and flexibilities are compared with other studies. The model is used to project future production, utilization and prices under various industry scenarios of acreage, fresh exports and juice import prices.

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AN ECONOMETRIC ANALYSIS OF THE U.S. APPLE INDUSTRY

INTRODUCTION

Apples are grown in thirty-five of the fifty states in the nation. Nearly five hundred thousand acres are in commercial production yielding nearly ten billion pounds of fruit each year. This production is equivalent to over a billion dollars in revenue for the nation's apple growers (USDA). Ten states account for nearly 90 percent of the U.S. apple crop. Washington, New York and Michigan produce nearly 70 percent of the crop (Sparks et. al.) Apples are the most extensively grown deciduous fruit in the Northeast. More than 166,000 acres are in commercial production producing one-third of the nation's harvest (USDA LISA). Once produced, these apples are allocated to alternative product markets. Historically, the fresh market has claimed over fifty percent of the apple harvest. The processed market consists of those apples used for canning and freezing, juice, dried apples and other products.

The domestic apple industry has been faced with several economic issues over the past few years. Increased concern about chemicals used in the production process has affected the demand for the fruit. In 1989, the chemical alar was brought to national attention by a National Resources Defense Counsel report and the television program 60 Minutes. Alar was removed from the market and the apple industry launched a massive campaign to counteract the negative impacts of the publicity surrounding the issue.

In addition, the industry is faced with increasing juice imports. Since 1980, per capita juice imports have increased over twenty-five percent per year. Yet, per capita consumption of apple juice has increased less than six percent per year (USDA).

Furthermore, new apple varieties have been introduced. Some of these cultivars are disease resistant and would require less chemical applications, yet they do not have clear marketing channels. Encouraging growers to adopt these cultivars depends on the benefits associated with growing these varieties and the ability to market these varieties at roadside stands and to retail outlets.

One means of evaluating the potential impacts of changes in the apple industry and the profitability of the industry is to conceptualize a model of the industry, estimate that model, validate the model and use the model for analyzing alternative scenarios. Any model is a simplification of reality, yet it should capture the industry's key structural relationships. Model conceptualization would require an understanding of the industry structure as well as an understanding of the appropriate economic theory governing the decision making of the players in the industry. Consumer theory would be applicable in development of the demand for products. Firm theory would be the appropriate paradigm to use in the development of the supply of the products. Theory associated with market structure, and the role of competition should affect the modeler's development of the interaction of the supply and demand components of the model.

The objectives of this research are (1) to identify the factors affecting the supply and demand for U.S. apples, (2) to determine the degree of substitutability and complementarity of various apple products and (3) to estimate changes in domestic apple consumption, production and prices under various industry scenarios.

To achieve these objectives five steps were completed. First, data related to the apple industry were collected. These data, on acres, production, prices, utilization, imports and exports, are annual observations collected from secondary sources. Second, a model of the industry was conceptualized based upon the principles of economic theory. The model consists of three sectors. The supply sector includes relationships describing the acreage and production of apples. Equations in the allocation sector explicitly model the allocation of apple production to the fresh, canned, frozen, juice, dried and other markets. The demand sector includes demand equations derived from consumer utility theory for each product. Third, assumptions were made to prepare the model for econometric estimation. These assumptions relate to the characteristics of the individual equations, the characteristics of the error term, the relationships between the equations within a sector and the association between model sectors. The assumptions dictated the appropriate econometric technique used for model estimation. Model coefficients, their t ratios and equation statistics are presented. Model validation was completed in the fourth step. Model validation includes the evaluation of model coefficients and their associated t ratios, equation statistics, static and dynamic historical simulation and model forecasting for periods beyond the data set. Finally, simulation techniques were used to evaluate the impact of changes in acreage, fresh exports and juice import price on production, consumption and prices in the industry. In the simulations, population and income are assumed to increase at previous levels; yet, other exogenous variables are held constant. Several simulations were analyzed.

This report is organized as follows. The conceptual model of the national apple industry is presented in the next section. The development of each sector is based on relevant economic theory. The third section of this paper discusses the data used for analysis and the econometric estimation procedures. Coefficient estimates and elasticities and flexibilities are presented. Validation statistics for static and dynamic simulation are discussed. The next section of this paper identifies the potential impacts of changes in acreage, fresh exports and juice import price on the industry's production, allocation and utilization using simulation analyses. The final section of the paper includes a summary and conclusion.

STRUCTURAL MODEL

There have been several studies dealing with the apple industry. These studies date from an analysis of the production outlook of apples in Michigan in the mid-1950's (French) to the analysis of the demand for fresh apples in four import markets in the 1990's (Sparks et. al.). Tomek developed a supply-demand model of the industry using data from 1947 through 1966. The model included supply and demand equations for fresh apples, frozen and canned apples and other apple products. He used the model to forecast 1975 production, demand and prices. Hayward et. al. developed a model of the apple industry in Maine and the United States using data from 1960 through 1981. Their econometric model incorporates the rate of size-controlled tree adoption. Using data from 1952 through 1981, Baumes and Conway estimated an econometric model including demand, domestic market allocation, and margin equations for the fresh and processed market. Rae and Carman developed a detailed perennial crop supply model of the New Zealand apple industry using data from 1958 through 1972. In 1976, Piggott published an article comparing a perfectly competitive, monopolistic and quasi-monopolistic apple industry. Recently, Chaudry developed and estimated an econometric model of the industry that incorporates demand and allocation decision-making in various regions of the U.S. and during different time periods within the market year. He used data from 1959 through 1984 for his analysis. There have been other models of the apple industry that focus on interregional competition. Miller, Dunn and Garafola, and Fuchs et. al. are some examples.

Development of this structural model of the apple industry draws on the experience and results of other researchers. This model of the apple industry is composed of three sectors, the supply sector, the allocation sector and the demand sector. The supply sector includes relationships describing bearing acres, and yields per acre. Allocation of production is made to the fresh and processed markets. The processed product is then allocated to the canning, freezing, dried, juice and other product markets within the allocation sector. Demand functions for each of these products are specified in the demand sector. Net imports of all products are assumed to be exogenous with the exception of juice imports. The model includes an explicit relationship for this product. Functions relating the price of each product to the processed price and the average apple price are specified. Hence, the model of the industry presented here contributes to the research on the apple industry by providing a more detailed analysis of the allocation to various marketing outlets and the demand for these products. Furthermore, the model incorporates production of apples and the demand for juice imports in detail. Data used for model estimation covers a more recent period, 1970 through 1990, than previous studies. Each sector of the model will be discussed.

Supply Sector

Apples, a perennial crop, are produced by profit maximizing producers who are assumed to maximize the net revenue they receive from their outputs subject to the technical constraints imposed by their production function. Following the development of the perennial crop model by French and Matthews and French, King and Minami, the number of bearing acres in the current period is simply the number of bearing acres in the previous year less net removals in the current year as seen by

$$(1.0) \quad AB_t = AB_{t-1} - NR_t,$$

where AB and NR represent bearing acreage and net removals of acreage, respectively.

Net removals are from new plantings (N) in previous years coming into production less the acreage removed (R) from the earlier season. This relationship can be expressed as

$$(2.0) \quad NR_t = N_{t-k} - R_{t-1}.$$

In equation (2.0), k represents the length of time it takes apple acreage to become bearing. Acreage planted with standard cultivars can take as long as nine to ten years to come into full production. However, dwarf and semi-dwarf trees come into full production as early as four to five years following planting.

New plantings can be expressed as a function of the expected profitability (π^e) of the industry as seen in

$$(3.0) \quad N_{t-k} = f_3(\pi^e_{t-k}, \varepsilon_{3t-k}).$$

Industry profitability is a function of the price received for apples (PAD) and the cost of producing these apples (COPD) as seen by

$$(4.0) \quad \pi_t = f_4(PAD_t, COPD_t, \varepsilon_{4t}).$$

It is reasonable to assume that the profitability of alternative opportunities for the acreage, such as other agricultural products or housing developments (which is so prevalent in the Northeast region) may affect the number of new acreage planted. However, it is difficult to isolate all of the alternative opportunities that may be available to apple producers. Furthermore, these opportunities vary between region and over time.

A certain portion of bearing acreage is removed each year for reasons other than industry profitability. Acreage may be old and not producing to capacity or acreage could be removed periodically to make room for other crops or new apple plantings. Lagged bearing acreage is included in the following removal equation to capture this phenomenon. In addition, industry profitability plays a role in the number of removals. If profitability is high, some acreage may be kept in production even though its production is lower than desired. Hence the removal relationship is

$$\text{(5.0)} \qquad R_{t-1} = f_5(AB_{t-1}, \pi^e_{t-1}, \varepsilon_{5t-1}),$$

where variables are as defined previously.

Detailed data on removals, new plantings and age class of apples would allow for estimating relationships for new plantings, yields for each age class and removals of acreage. However, such detailed data are not often available. Hence, it is difficult to estimate econometrically these relationships. Substitution of equations (3.0) and (5.0) into equation (2.0), and equation (2.0) into equation (1.0) yields a new acreage relationship where bearing acreage is a function of lagged acreage, and measures of profitability. The function is

$$\text{(6.0)} \qquad AB_t = f_6(AB_{t-1}, \pi^e_{t-1}, \pi^e_{t-k}, \varepsilon_{6t}).$$

The error term in this equation is a composite of the random elements in the new plantings and the removals equations.

Apple yields vary by age of the acreage. Yields are low for the first few years, increase, level off and then decline as the acreage gets older. It would be desirable to have separate yield equations for each age class. However, it is not practical given data limitations. It does seem reasonable that yields are a function of expected apple profitability. If profitability is expected to increase, yields would expand. If profitability is expected to fall, yields may decrease. It is also reasonable that yields have increased over time due to technological advances in the production of apples. Hence, the relationship for apple yields is expressed as

$$\text{(7.0)} \qquad Y_t = f_7(\pi^e_t, T_t, \varepsilon_{7t}),$$

where T represents a time trend.

Once yields and bearing acreage are determined the total quantity of apples produced can be expressed as

$$\text{(8.0)} \qquad QPT_t = AB_t * Y_t,$$

where QPT is defined at the total quantity produced. Utilized production is a fraction of total production. All of the apples produced may not be harvested or discarded for economic or other reasons. Historically, this fraction has been 99 percent. Hence, utilized production (QPU) is defined as

(9.0) $QPU_t = 0.99 * QPT_t$.

In summary, the development of the supply sector of the model follows the perennial crop model developed by French and Matthews and French, King and Minami. This model is simplified due to data availability and ease of estimation. The final model specification consists of two stochastic equations, ((6.0) and (7.0)) for bearing acreage and yield and two non-stochastic equations ((8.0) and (9.0)) for total production and utilized production.

Allocation Sector

Once apples are produced, they are used in various markets. The domestic supply of apples is allocated to the fresh and processed markets. Model specification of allocation to various markets can be handled in a variety of ways. One alternative is to specify the actual quantity of a product allocated to a particular market as a function of the total supply and relative prices. Alternatively, the dependent variable could be the market share for that particular product. The market share, equivalent to the quantity allocated to a particular market divided by the total supply, is expressed as a function of the relative prices. Preliminary analyses of the data suggest the first specification is more appropriate for the apple industry. Hence, the allocation of apple production to the fresh market is determined by the total supply to be allocated and the expected relative prices in each market. The allocation of apples to the fresh market (QPUF) is expressed as

(10.0) $QPUF_t = f_{10}(QPU_t, PFD_t^e, PPD_t^e, \varepsilon_{10t})$.

If the total utilization of apples (QPU) were to increase, one would expect the fresh allocation to increase. An increase in the fresh price expected by producers (PFD) would increase the quantity allocated to the fresh market, all else equal. Since fresh apples can be diverted to processed markets, the expected average price of all processed apples (PPD) is included. An increase in this price would decrease the fresh allocation assuming no change in other variables.

The allocation of apples to the processed market (QPUP) is expressed algebraically as the remainder of that which did not go to the fresh market, as seen by

(11.0) $QPUP_t = QPU_t - QPUF_t$.

Processed apples can be diverted to five markets: canned, juice, dried, frozen and other. The predominant use of apples in the canning market is for apple sauce. However, apples are also used for pie fillings, apple butter and other canned products. Processed apples diverted to the juice market are used for apple juice, juice blends and for cider and vinegar. The dried market consists of those apples used for dried fruit. The frozen market includes apples used for frozen pies and other frozen products. The apples used in the other market are for products such as apple chips, apple breads, etc.

The allocation of apples to each processed market is a function of the total apples allocated to the processed market (QPUP) and the expected price of the product relative to the expected price of all processed products. If the total supply of apples to the processed market increased, more apples would be diverted to each processed outlet. If the expected price of a particular processed product increased relative to the average of all processed products, one would anticipate a larger quantity allocated to that particular market.

In the apple industry, juice is often the residual claimant of processed apples. However, nearly fifty percent of all processed apples are utilized for juice. Hence, for this model the quantity of processed apples utilized for juice is modeled explicitly. Frozen apples are assumed to be the residual since they claim a relatively small portion of the processed apple market. The allocation of apples to the canned (QPUC), juice (QPUJ), dried (QPUD) and other (QPUO) markets is expressed as

(12.0) $QPUC_t = f_{12}(QPUP_t, PCD^e_t, PPD^e_t, \varepsilon_{12t})$,

(13.0) $QPUJ_t = f_{13}(QPUP_t, PJD^e_t, PPD^e_t, \varepsilon_{13t})$,

(14.0) $QPUD_t = f_{14}(QPUP_t, PDD^e_t, PPD^e_t, \varepsilon_{14t})$, and

(15.0) $QPUO_t = f_{15}(QPUP_t, POD^e_t, PPD^e_t, \varepsilon_{15t})$

respectively. The allocation to the frozen market (QPUR) is equivalent to the total utilization of processed apples less the quantity allocated to each market as seen by

(16.0) $QPUR_t = QPUP_t - QPUC_t - QPUJ_t - QPUD_t - QPUO_t$.

Demand Sector

The final sector of the model identifies the demand for all apples in the United States. Consumer demand theory tells us that rational consumers maximize their utility subject to their budget constraint. It is this maximization that yields product demand functions. These functions can be expressed as price dependent functions of the quantity demanded, quantities of other products that are substitutes or complements, income and other variables that might shift the demand function. Alternatively, the demand functions can be expressed as quantity dependent functions of the price of the product, the prices of other products that are substitutes and complements, income and other demand shifters. Historically, demand functions have been expressed as price dependent functions because quantities have been assumed to be predetermined (Waugh).

In this model of the industry, the domestic demand for each apple product is expressed as a price dependent function of the per capita quantity of apples utilized in each market (QU--), income (PCED) and the per capita quantity of apples consumed in other markets (QU--) where -- refers to the market type with F, C, J, D, O, R referring to fresh, canned, juice, dried, other, and frozen respectively. In addition per capita quantities of other fruits, such as fresh oranges (QUFO) and orange juice (QUJO), hypothesized to be substitutes or complements, are included in the appropriate relationships. The demand relationships for each market are expressed as

(17.0) $PFD_t=f_{17}(QUF_t,QUC_t,QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, QUFO_t, \varepsilon_{17t})$,

(18.0) $PCD_t = f_{18}(QUF_t, QUC_t, QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, \varepsilon_{18t})$,

(19.0) $PJD_t = f_{19}(QUF_t,QUC_t,QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, QUJO_t, \varepsilon_{19t})$,

(20.0) $PDD_t = f_{20}(QUF_t, QUC_t, QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, \varepsilon_{20t})$,

(21.0) $POD_t = f_{21}(QUF_t, QUC_t, QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, \varepsilon_{21t})$, and

(22.0) $PRD_t = f_{22}(QUF_t, QUC_t, QUJ_t, QUD_t, QUO_t, QUR_t, PCED_t, \varepsilon_{22t})$.

Economic theory suggests an inverse relationship between the price and own quantity of each apple product. The coefficients on other quantities will depend on whether the goods are substitutes or complements. If the product is a substitute, the coefficient should be negative. If the product is a complement, the coefficient should be positive. If apple products are normal goods the coefficient on income (PCED) should be positive.

Pricing Relationships

Since the price of all processed products (PPD) determines the allocation of apples between the fresh and processed markets, a relationship is necessary for determining processed price. This price for all processing products is assumed to be a function of the price of each processed product as seen in

(23.0) $PPD_t = f_{23}(PCD_t, PJD_t, PDD_t, POD_t, PRD_t, \varepsilon_{23t})$,.

where prices are defined previously. A positive sign is anticipated for each coefficient.

The price of all apple products (PAD) affects the bearing acreage. Hence, its specification is expressed as a function of the price in the fresh market (PFD) and the average processed price (PPD) as seen by

(24.0) $PAD_t = f_{24}(PFD_t, PPD_t, \varepsilon_{24t})$.

A positive sign is expected for each coefficient.

Imports

Apple juice imports have increased significantly during the last twenty years. Hence it is unreasonable to assume juice imports are exogenous and will remain stable following the period of study. A stochastic relationship identifying the quantity of juice imports was included in the model. This function is expressed as

(25.0) $NIJ_t = f_{25}(PIJD_t, QPUJ_t, POP_t, \varepsilon_{25t})$,

where NIJ represents per capita juice imports, PIJD is the juice import price, QPUJ is the total domestic allocation of apples to the juice market, and POP is population. As the per capita quantity of apples allocated to juice in the domestic market increases, one would expect a smaller quantity of juice imports. If the import price of juice increases, one would anticipate a decrease in the quantity of juice imports. Hence negative coefficients are anticipated for these variables.

Utilization

The final model equations describe total consumption, or utilization, of each apple product. Utilization depends on the domestic allocation to that market (QPU--) and the net imports (NI--) of that product type. Hence, the total consumption of each product (QU--), expressed in per capita terms, can be identified as

(26.0) $QUF_t = QPUF_t/POP_t + NIF_t$,

(27.0) $QUC_t = QPUC_t/POP_t + NIC_t$,

(28.0) $QUJ_t = QPUJ_t/POP_t + NIJ_t$,

(29.0) $QUD_t = QPUD_t/POP_t + NID_t$,

(30.0) $QUO_t = QPUO_t/POP_t + NIO_t$, and

(31.0) $QUR_t = QPUR_t/POP_t + NIR_t$.

EMPIRICAL MODEL ESTIMATION AND VALIDATION

Model estimation requires an analysis of the theoretical model, substitution for all expected variables in the model specification, examination of the error terms within each model sector and across model sectors, collection of data and determination of the estimation technique. Once the model is estimated, the purpose of performing model validation is to provide the user with confidence that the model is adequate even though any model is a simplification of reality. To achieve this, model coefficients can be evaluated and compared with hypothesized signs and magnitudes. Equation summary statistics, such as the R^2 and the Durbin Watson statistic can be analyzed. Elasticities, flexibilities and model statistics from static and dynamic deterministic simulations can be evaluated. All of these measures generate confidence that the model is adequate and can be a helpful tool in evaluating scenarios. In this section, model estimation and validation issues are discussed.

Expected Price Formation

The structural model of the apple industry includes several expected prices and profitability variables. Alternative specifications were considered for these expected variables. The most prevalent expectation theories used in economics are the adaptive expectations theory and the rational expectations theory. Adaptive expectations assumes that expected prices are formed each year based on the discrepancy between the previous period's actual price and the expectation in the previous period (Nerlove). Rational expectations assume decision makers form their expectations as predictions of the relevant economic structure (Muth). Hence, it is the complete economic structure that determines the expectations.

The rational expectations model was considered inappropriate for the apple industry since complete economic structure is not known by all industry participants. The assumption of rational expectations would require the use of the complete system for estimation of each equation that incorporates an expectation variable. This would lead to a rather complex estimation technique (Willett). A modification of the adaptive expectations theory is used in the specification of the empirical model used for estimation. For each expected price or profitability, the price or profitability from a previous period is substituted for the expectation variable.

Bearing acreage (equation (6.0)) is a function of expected profitability in the previous period due to removals and a function of expected profitability in the kth previous period due to new plantings. Expected profitability is substituted by the price received for apples and an index of costs of production from these periods. The data are used to determine the value of k. As mentioned earlier, k could be nine for conventional plantings or four for dwarf or semi-dwarf plantings.

The yield relationship (equation (7.0)) is also a function of expected profitability. Because price and costs of production are not known when yield is determined, the price and costs of production from the previous period are substituted for expected profitability.

Each allocation equation (equations (10.0), (12.0), (13.0), (14.0), and (15.0)) is a function of expected prices of the relevant product and the expected average price of all processed products. The current prices are not known when the allocation decisions are made. Hence, the prices from the previous period are used as proxies.

Data

Data for the analysis, obtained from U.S. Department of Agriculture sources, are for the period 1971 through 1990. This period of analysis is a more recent period than previous studies. Data are annual values and reflect the crop year (August to July). All data series and their sources are listed in Appendices A and B. All monetary values in the model are deflated by the gross national product deflator. All quantity variables in the demand sector are expressed in per capita terms.

Empirical Model Structure

All equations in the model are assumed to be linear in the parameters. The supply sector, identifying the bearing acres, yield, total production and utilized production, are usually known at the beginning of the crop year and are independent of the allocation of the product to alternative outlets. Furthermore the allocation of the products is independent of the demands for each product, the pricing relationships and the demand for juice imports. Consequently, each model sector was considered independent of the other model sectors in the estimation process. Hence, the model was estimated as a block recursive system.

In the supply sector, the random error terms of the bearing acreage and yield equations, equations (6.0) and (7.0) are likely to be related. The allocation sector's random error terms for equations (10.0) through (16.0) may be related to each other. Furthermore, the random error terms of the demand sector, equations (17.0) through (22.0), are assumed to be associated. Zellner's seemingly unrelated regression method (Kmenta) was chosen to estimate each model sector: supply, allocation, and demand.

Due to the independence of the pricing relationships, equations (23.0) and (24.0), they were estimated by ordinary least squares. The juice import function, equation (25.0), was also estimated by ordinary least squares. The demand for imports is assumed to be determined after the allocation of the processed product to the juice market occurs.

Empirical Estimates

Coefficients, associated t statistics and equation statistics for the equations are presented in Table 1. Equation numbers in Table 1 refer to the theoretical equation developed in this report's Structural Model section. Variable definitions can be found in Table 2. All equations are as previously specified with the following exceptions.

Data indicated that the average price of apples from the ninth previous period was the most significant determinant of bearing acreage. Costs of production were not significant. Hence, PAD_{t-9} was substituted for the profitability measure in equation (6.0).

Analysis of the data revealed a significant decrease in the quantity of apples allocated to the other market sector. To capture this effect, a trend variable was included in equation (15.0).

The estimation of the demand sector revealed some variables with insignificant coefficients and coefficients with incorrect signs. Because the model was going to be used for simulation into the future, the insignificant variables with incorrect signs were omitted from the equations. The demand for dried and other apples appeared to shift in 1973-74 and again in 1976-79 perhaps due to the changing nature of demand from the oil situation in these years. The quantities of other apple products and income were not significant in these equations. Hence, these quantities were eliminated and dummy variables were included to capture the shifts in the 1970's. The demand for canned and frozen apple products appeared to shift in 1973-74 but not in 1976-79. Perhaps the oil impacts of the early 1970's were more significant than the late 1970's impact. Dummy variables for 1973-74 were included as shifters in these demand equations.

Table 1

U.S. Apple Industry Model 1971 - 1990

SUPPLY

Bearing Acres

(6.1) $AB_t = -72.947 + 1.162\ AB_{t-1} + 0.680\ PAD_{t-9}$ $\quad R^2 = 0.980 \quad Dh = -0.041$
$\qquad (-4.324) \quad (31.720) \quad (1.718)$

Yield

(7.1) $Y_t = 10.326 + 0.373\ T_t + 0.366\ PAD_{t-1}$ $\quad R^2 = 0.661 \quad DW = 1.930$
$\qquad (4.926) \quad (6.064) \quad (2.699)$

Production and Utilization

(8.1) $QPT_t = AB_t * Y_t$

(9.1) $QPU_t = 0.99 * QPT_t$

ALLOCATION

Fresh

(10.1) $QPUF_t = 195.458 + 0.535\ QPU_t + 399.778\ PFD_{t-1}/PPD_{t-1}$ $\quad R^2 = 0.950 \quad DW = 1.358$
$\qquad (0.625) \quad (17.832) \quad (0.233)$

Processed

(11.1) $QPUP_t = QPU_t - QPUF_t$

Canned

(12.1) $QPUC_t = 512.339 + 0.154\ QPUP_t + 132.893\ PCD_{t-1}/PPD_{t-1}$ $\quad R^2 = 0.567 \quad DW = 1.850$
$\qquad (3.574) \quad (4.796) \quad (1.461)$

Juice

(13.1) $QPUJ_t = -1254.635 + 0.792\ QPUP_t + 261.920\ PJD_{t-1}/PPD_{t-1}$ $\quad R^2 = 0.938 \quad DW = 1.486$
$\qquad (-6.087) \quad (17.377) \quad (1.584)$

Table 1 (continued)

U.S. Apple Industry Model 1971 - 1990

Dried

(14.1) $QPUD_t = \underset{(0.264)}{16.134} + \underset{(3.715)}{0.050}\, QPUP_t + \underset{(1.035)}{41.518}\, PDD_{t-1}/PPD_{t-1}$ $\quad R^2 = 0.417 \quad DW = 1.109$

Other

(15.1) $QPUO_t = \underset{(0.255)}{16.735} + \underset{(2.109)}{0.038}\, QPUP_t + \underset{(1.163)}{65.285}\, POD_{t-1}/PPD_{t-1} - \underset{(-3.948)}{8.927}\, T_t$ $\quad R^2 = 0.518 \quad DW = 2.361$

Frozen

(16.1) $QPUR_t = QPUP_t - QPUC_t - QPUJ_t - QPUD_t - QPUO_t$

DEMAND

Fresh Demand

(17.1) $PFD_t = \underset{(1.036)}{8.612} - \underset{(-5.915)}{1.485}\, QUF_t - \underset{(-4.122)}{0.761}\, QUJ_t + \underset{(1.390)}{2.016}\, QUD_t + \underset{(2.553)}{5.147}\, QUO_t + \underset{(3.878)}{0.100}\, PCED_t$ $\quad R^2 = 0.841 \quad DW = 1.869$

Canned Demand

(18.1) $PCD_t = \underset{(-0.743)}{-62.601} - \underset{(-0.603)}{3.430}\, QUC_t - \underset{(-4.695)}{11.870}\, QUF_t - \underset{(-5.210)}{9.895}\, QUJ_t + \underset{(2.812)}{40.706}\, QUD_t + \underset{(1.742)}{40.514}\, QUO_t$ $\quad R^2 = 0.900 \quad DW = 2.214$

$+ \underset{(4.739)}{1.247}\, PCED_t + \underset{(7.648)}{71.259}\, D734_t$

Juice Demand

(19.1) $PJD_t = -\underset{(-0.947)}{95.133} - \underset{(-4.638)}{10.619}\, QUJ_t - \underset{(-2.582)}{7.717}\, QUF_t + \underset{(1.943)}{31.047}\, QUD_t + \underset{(1.640)}{43.223}\, QUO_t + \underset{(3.348)}{1.057}\, PCED_t$ $\quad R^2 = 0.754 \quad DW = 2.321$

Table 1 (continued)

U.S. Apple Industry Model 1971 - 1990

Dried Demand

(20.1) $$PDD_t = \underset{(6.428)}{131.035} - \underset{(-1.462)}{30.003}\, QUD_t + \underset{(6.430)}{94.489}\, D734_t + \underset{(8.026)}{86.783}\, D769_t \qquad R^2 = 0.811 \quad DW = 1.798$$

Other Demand

(21.1) $$POD_t = \underset{(12.622)}{129.510} - \underset{(-2.547)}{53.447}\, QUO_t + \underset{(6.585)}{71.881}\, D734_t + \underset{(7.445)}{54.903}\, D769_t \qquad R^2 = 0.722 \quad DW = 2.083$$

Frozen Demand

(22.1) $$PRD_t = \underset{(-0.105)}{-11.399} - \underset{(-2.068)}{40.265}\, QUR_t - \underset{(-1.788)}{5.533}\, QUF_t - \underset{(-4.705)}{12.678}\, QUJ_t - \underset{(-2.099)}{68.112}\, QUO_t + \underset{(3.461)}{1.236}\, PCED_t \qquad R^2 = 0.823 \quad DW = 2.133$$

$$+ \underset{(8.750)}{119.421}\, D734_t$$

PRICE RELATIONSHIPS

Processing

(23.1) $$PPD_t = \underset{(-4.961)}{-9.687} + \underset{(7.505)}{0.356}\, PCD_t + \underset{(8.401)}{0.450}\, PJD_t + \underset{(4.892)}{0.194}\, PRD_t + \underset{(2.536)}{0.092}\, PDD_t - \underset{(-1.684)}{0.053}\, POD_t \qquad R^2 = 0.998 \quad DW = 2.574$$

Average Price

(24.1) $$PAD_t = \underset{(0.029)}{0.008} + \underset{(11.286)}{0.023}\, PPD_t + \underset{(19.397)}{0.559}\, PFD_t \qquad R^2 = 0.994 \quad DW = 1.449$$

IMPORTS

Juice

(25.1) $$NIJ_t = \underset{(1.817)}{3.410} - \underset{(-1.635)}{2.468}\, PIJD_t - \underset{(-2.048)}{0.536}\, QPUJ_t/POP_t + \underset{(8.158)}{0.746}\, T_t \qquad R^2 = 0.898 \quad DW = 1.296$$

Table 1 (continued)
U.S. Apple Industry Model 1971 - 1990

UTILIZATION

Fresh

(26.1) $QUF_t = QPUF_t/POP_t + NIF_t$

Canned

(27.1) $QUC_t = QPUC_t/POP_t + NIC_t$

Juice

(28.1) $QUJ_t = QPUJ_t/POP_t + NIJ_t$

Dried

(29.1) $QUD_t = QPUD_t/POP_t + NID_t$

Other

(30.1) $QUO_t = QPUO_t/POP_t + NIO_t$

Frozen

(31.1) $QUR_t = QPUR_t/POP_t + NIR_t$

Table 2
U.S. Apple Industry Model Variable Definitions

AB	Bearing Acres	(thousand acres)
D734	Dummy Variable for 1973-74 (1971-72=0, 1973-74=1, 1974-88=0)	
D769	Dummy Variable for 1976-79 (1971-75=0, 1976-79=1, 1980-88=0)	
NIC	Net Imports - Canned	(pounds/person)
NID	Net Imports - Dried	(pounds/person)
NIF	Net Imports - Fresh	(pounds/person)
NIJ	Net Imports - Juice	(pounds/person)
NIO	Net Imports - Other	(pounds/person)
NIR	Net Imports - Frozen	(pounds/person)
PAD	Average Grower Price - All	(1982 cents/pound)
PCD	Average Grower Price - Canned	(1982 $/ton)
PCED	Personal Consumption Expenditure for Food	(billion 1982$)
PDD	Average Grower Price - Dried	(1982 $/ton)
PFD	Average Grower Price - Fresh	(1982 cents/pound)
PIJD	Average Price - Juice Imports	(1982 $/gallon)
PJD	Average Grower Price - Juice and Cider	(1982 $/ton)
POD	Average Grower Price - Other	(1982 $/ton)
POP	Population	(million)
PPD	Average Grower Price - Processing	(1982 $/ton)
PRD	Average Grower Price - Frozen	(1982 $/ton)
QPT	Total Production	(million pounds)
QPU	Utilized Production	(million pounds)
QPUC	Canned Utilization	(million pounds)
QPUD	Dried Utilization	(million pounds)
QPUF	Fresh Utilization	(million pounds)
QPUJ	Juice and Cider Utilization	(million pounds)
QPUO	Other Utilization	(million pounds)
QPUP	Processed Utilization	(million pounds)
QPUR	Frozen Utilization	(million pounds)
QUC	Per Capita Utilization with Net Imports - Canned	(pounds/person)
QUD	Per Capita Utilization with Net Imports - Dry	(pounds/person)
QUF	Per Capita Utilization with Net Imports - Fresh	(pounds/person)
QUJ	Per Capita Utilization with Net Imports - Juice	(pounds/person)
QUO	Per Capita Utilization with Net Imports - Other	(pounds/person)
QUR	Per Capita Utilization with Net Imports - Frozen	(pounds/person)
T	Time Trend	(1971=1)
Y	Yield	(thousand pounds/acre)

All model equations, seen in Table 1, have coefficients consistent with the hypothesized signs and of reasonable magnitudes with the exception of equation (23.1). Variable t statistics are significant. Equation R^2's are reasonable and equation Durbin Watson statistics indicate either no autocorrelation or are inconclusive. In equation (23.1), an increase in the price of other apple products yields a decrease in the average price for all processing products. This phenomenon could be due to a reduction in the allocation of apples to the other market over the length of the sample.

Elasticities and Flexibilities

Demand and supply elasticities evaluated at the mean of the data set and at 1990, the last period in the data set, are presented in Table 3. The acreage elasticity ($\varepsilon_{AB_t\ PAD_{t-9}}$) indicates that the response of apple acreage to the changes in all apple prices is inelastic. Elasticities of supply, reflected by the allocation elasticities, are inelastic for all products when evaluated at the mean. Changes in these prices will generate a smaller percentage change in the quantity of apples allocated to each market. The fresh allocation elasticity ($\varepsilon_{QPUF_t\ PFD_{t-1}}$) is nearly zero when evaluated at the mean and 1990 values, supporting the notion that fresh supplies are largely pre-determined. The other product elasticity ($\varepsilon_{QPUO_t\ POD_{t-1}}$) is very inelastic when evaluated at the mean but elastic when evaluated at 1990 values. The change in elasticities reflects the large increase in the quantity of apples allocated to the other product market during the sample period. All supply elasticities are consistent with those found by Tomek.

Demand flexibilities, seen in Table 3, suggest the demands for fresh apples ($f_{PFD_t\ QUF_t}$) and apple juice ($f_{PJD_t\ QUJ_t}$) are inelastic. The demand for canned ($f_{PCD_t\ QUC_t}$), dried ($f_{PDD_t\ QUD_t}$), frozen ($f_{PRD_t\ QUR_t}$), and other apples ($f_{POD_t\ QUO_t}$) are elastic. French found the elasticity for all apples to be -1.19. Tomek estimated the own price elasticities for fresh, canned and other apples to be -0.81, -1.21 and -0.76 respectively. Huang estimated fresh apple demand to be inelastic with a measure of -0.20. Baumes and Conway found flexibilities for fresh and processed apples to be -0.36 and -0.69, respectively. Hayward et. al.'s estimate of the flexibility for all apples was -1.59. Miller's price elasticity for national apple demand was -0.59. While there is some variation among the elasticity and flexibility measures, those estimated in this study are within the range of other studies.

Table 3
Elasticities and Flexibilities for U.S. Apple Industry Model

		Mean	1990 Values
Supply Sector			
Bearing Acres	$\varepsilon_{AB_t\,PAD_{t-9}}$	0.021	0.017
Yield	$\varepsilon_{Y_t\,PAD_{t-1}}$	0.235	0.151
Allocation			
Fresh	$\varepsilon_{QPUF_t\,PFD_{t-1}}$	0.012	0.009
Canned	$\varepsilon_{QPUC_t\,PCD_{t-1}}$	0.128	0.126
Juice	$\varepsilon_{QPUJ_t\,PJD_{t-1}}$	0.131	0.093
Dried	$\varepsilon_{QPUD_t\,PDD_{t-1}}$	0.186	0.142
Other	$\varepsilon_{QPUO_t\,POD_{t-1}}$	0.099	1.185
Demand			
Fresh	$f_{PFD_t\,QUF_t}$	-1.650	-1.850
	$f_{PFD_t\,QUJ_t}$	-0.584	-0.962
	$f_{PFD_t\,QUD_t}$	0.121	0.105
	$f_{PFD_t\,QUO_t}$	0.154	0.088
	$f_{PFD_t\,PCED_t}$	2.430	2.870
Canned	$f_{PCD_t\,QUC_t}$	-0.125	-0.151
	$f_{PCD_t\,QUF_t}$	-1.499	-1.862
	$f_{PCD_t\,QUJ_t}$	-0.863	-1.575
	$f_{PCD_t\,QUD_t}$	0.279	0.268
	$f_{PCD_t\,QUO_t}$	0.137	0.087
	$f_{PCD_t\,PCED_t}$	3.456	4.520
Juice	$f_{PJD_t\,QUJ_t}$	-1.278	-2.398
	$f_{PJD_t\,QUF_t}$	-1.345	-1.717
	$f_{PJD_t\,QUD_t}$	0.293	0.290
	$f_{PJD_t\,QUO_t}$	0.202	0.131
	$f_{PJD_t\,PCED_t}$	4.042	5.435
Dried	$f_{PDD_t\,QUD_t}$	-0.230	-0.262
Other	$f_{POD_t\,QUO_t}$	-0.214	-0.133
Frozen	$f_{PRD_t\,QUR_t}$	-0.231	-0.373
	$f_{PRD_t\,QUF_t}$	-0.617	-0.833
	$f_{PRD_t\,QUJ_t}$	-0.976	-1.936
	$f_{PRD_t\,QUO_t}$	-0.204	-0.140
	$f_{PRD_t\,PCED_t}$	3.025	4.298
Imports			
Juice	$\varepsilon_{NIJ_t\,PIJD_t}$	-0.378	-0.117

Fresh, canned, juice and frozen apples are normal goods as indicated by their income flexibilities ($f_{PFD_t\,PCED_t}$, $f_{PCD_t\,PCED_t}$, $f_{PJD_t\,PCED_t}$, $f_{PRD_t\,PCED_t}$). Huang estimated the expenditure elasticity to be -0.35 implying an inferior good.

Cross-price flexibilities estimated with this study suggest that fresh apples and apple juice ($f_{PFD_t\,QUJ_t}$ and $f_{PJD_t\,QUF_t}$) are substitutes. Yet, fresh apples and dried apples ($f_{PFD_t\,QUD_t}$), fresh apples and other apple products ($f_{PFD_t\,QUO_t}$), juice and dried apples ($f_{PJD_t\,QUD_t}$), and juice and other apple products ($f_{PJD_t\,QUO_t}$) are complements. Fresh apples and juice are substitutes for canned apples ($f_{PCD_t\,QUF_t}$, $f_{PCD_t\,QUJ_t}$), while dried apples and other apple products are complements for canned apples ($f_{PCD_t\,QUD_t}$, $f_{PCD_t\,QUO_t}$). Fresh apples, juice, and other apple products are substitutes for frozen apple products ($f_{PRD_t\,QUF_t}$, $f_{PRD_t\,QUJ_t}$, $f_{PRD_t\,QUO_t}$). Tomek found other processed apples to be substitutes for fresh apples and for canning apples.

Static and Dynamic Simulation

Simulation, another method used to gain confidence in a model, places each endogenous variable only once on the left hand side of an equation. The right hand side variables must be exogenous variables, lagged endogenous variables or other endogenous variables that have been determined by a previous equation. In static, or one-period ahead, simulations the model computes the predicted values of current endogenous variables each period using the actual values of lagged endogenous variables. The dynamic simulation differs from the static simulation in that after the initial period, the model's predicted values of lagged endogenous variables are used to generate future values of the endogenous variables (Kost). Kost suggests evaluating simulation errors and inequality coefficients among other goodness-of-fit measures. Simulation errors, the measure of the deviation of the simulated variables from the true path of the variable, can be evaluated with various goodness of fit measures. These statistics are presented in Table 4.

As one might expect, the statistics indicate more error appears in the dynamic simulation. This phenomenon is due to the simulation using the predicted values of lagged endogenous variables each period rather than the actual values of lagged endogenous variables. The quantity of other apple products (QPUO), price of juice (PJD) and net imports of juice (NIJ) have large error statistics. Each of these variables had wide fluctuations during the sample period. So it is not unreasonable that the model's ability to simulate these values is not as accurate as for other variables.

SIMULATION ANALYSIS

A common means of analyzing the impacts of exogenous changes on the performance of an industry is through the use of simulation analysis (French and Willett, Nuckton, French and King). The user can determine the impacts of individual changes on the industry with a series of simulations that isolate the changes. The econometric model developed here is used to project the impacts of changes in the apple industry on acreage, production, utilization and prices of apple products. The analysis is performed by dynamic deterministic simulation. Several scenarios are analyzed.

Simulation Assumptions

First, a base case is established. In the base projections, it is assumed that (1) population continues to increase at a rate of 1.02 percent per year, the average growth rate for the last five years of the data set, (2) income increases at a rate of 1.01 percent per year, the average growth rate for the last five years of the data set, (3) net imports of fresh, canned, dried, frozen and other apple products remain at their 1990 levels, and (4) any long term changes in the industry reflected by trend variables in the model continue for the duration of the analysis. The model is allowed to determine the acreage, yields, quantities produced and allocated to each apple product, the prices of the apple products and the net imports of juice products. The base case is used as a means of comparison with other simulations. It provides a benchmark if there were no other changes in the industry.

The second scenario maintains the assumptions of the base case. However, the acreage devoted to apples is held at 1990 levels. Historically, apple bearing acreage decreased until 1975 when it reached a low of 395.6 thousand acres. Since that time acreage increased an average of 1.5 percent per year. It is questionable if bearing acreage will or can continue to increase at that rate in the future. Hence for this scenario, the impacts of no growth in bearing acreage are analyzed.

In the third scenario, the per capita level of fresh exports is assumed to increase by 10 percent in 1991. This assumption is coupled with the four assumptions of the base case. The impacts of an increase in fresh apple exports, from 2.270 pounds per person in 1990 to 2.497 pounds per person in 1991 and subsequent years, on apple production, utilization and prices of apple products are analyzed.

The fourth scenario maintains the assumptions of the base case with the additional assumption of a ten percent decrease in the price of juice imports in 1991. In 1991, the deflated import price of juice decreases from $.559 per gallon to $.503 per gallon. This decrease in juice price follows the general trend of the per unit value of juice imports since 1979. In 1979 juice imports reached a peak price of $1.28 per gallon. Since that time the price has decreased an average of 5.1 percent per year.

The fifth scenario combines the assumptions of the base case with acreage held constant and the per capita quantity of fresh exports increasing 10 percent in 1991. In the sixth scenario acreage is held at 1990 levels, the price of juice imports decreases 10 percent in 1991 and the assumptions of the base case are maintained. The seventh scenario continues the assumptions of the base case and assumes that the per capita quantity of fresh exports increases 10 percent in 1991 and the price of imported juice decreases 10 percent in 1991. The final scenario is a combination of all previous scenarios. The base case assumptions are coupled with acreage held at 1990 levels, a 10 percent increase in per capita fresh exports in 1991, and a 10 percent decrease in juice import prices in 1991.

The 1990 historical value of selected model variables and five year projections, resulting from each of these scenarios, are presented in Table 5.

Simulation 1: Population and Income

The base projections indicate an increase in bearing acres (AB) from 485.5 thousand acres in 1990 to 573.9 thousand acres in 1995, an increase of 3.6 percent per year. Yield (Y) per acre varies between 20.0 and 22.0 thousand pounds per acre. Total apple production (QPT) appears to be cyclical with increases in 1991, 1993 and 1995. However, apple production follows an increasing trend. Recall that the model specification states that bearing acreage is a function of prices from nine years earlier and that yield and the allocation of the production to each product market is a function of the previous year's price. The fluctuation in yields and total apple production is generated by the lags inherent in the system. Hence, when prices are high, more apples are produced and allocated to the various markets. This decreases the market price. The low price is the signal for the next period's production and the cycle continues.

Table 5

Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	**1** Population Income	**2** Population Income Acreage	**3** Population Income Fresh Exports	**4** Population Income Import Price	**5** Population Income Acreage Fresh Exports	**6** Population Income Acreage Import Price	**7** Population Income Fresh Exports Import Price	**8** Population Income Acreage Fresh Exports Import Price
Variables								
AB								
1990	485.5	485.5	485.5	485.5	485.5	485.5	485.5	485.5
1991	498.0	485.5	498.0	498.0	485.5	485.5	498.0	485.5
1992	512.6	485.5	512.6	512.6	485.5	485.5	512.6	485.5
1993	529.7	485.5	529.7	529.7	485.5	485.5	529.7	485.5
1994	549.8	485.5	549.8	549.8	485.5	485.5	549.8	485.5
1995	573.9	485.5	573.9	573.9	485.5	485.5	573.9	485.5
Y								
1990	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
1991	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
1992	20.2	20.4	20.3	20.2	20.5	20.4	20.3	20.5
1993	21.4	21.6	21.4	21.4	21.7	21.6	21.4	21.7
1994	20.5	21.1	20.5	20.4	21.1	21.0	20.5	21.1
1995	21.0	21.6	21.0	21.0	21.7	21.6	21.0	21.7
QPT								
1990	9696.8	9696.8	9696.8	9696.8	9696.8	9696.8	9696.8	9696.8
1991	10937.2	10662.6	10937.2	10937.2	10662.6	10662.6	10937.2	10662.6
1992	10361.0	9921.0	10404.9	10343.6	9962.6	9904.6	10387.5	9946.1
1993	11311.0	10500.1	11321.3	11312.9	10513.0	10499.5	11322.3	10511.8
1994	11243.6	10231.7	11287.3	11223.5	10268.4	10215.6	11267.9	10252.7
1995	12031.8	10503.1	12049.4	12031.0	10524.4	10497.7	12047.5	10518.5

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)

Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	**1** Population Income	**2** Population Income Acreage	**3** Population Income Fresh Exports	**4** Population Income Import Price	**5** Population Income Acreage Fresh Exports	**6** Population Income Acreage Import Price	**7** Population Income Fresh Exports Import Price	**8** Population Income Acreage Fresh Exports Import Price
Variables								
QPUF								
1990	5551.0	5551.0	5551.0	5551.0	5551.0	5551.0	5551.0	5551.0
1991	6048.5	5903.0	6048.5	6048.5	5903.0	5903.0	6048.5	5903.0
1992	5752.1	5518.0	5775.3	5744.0	5540.0	5510.2	5767.1	5532.2
1993	6248.8	5819.1	6254.5	6250.3	5826.1	5819.2	6255.5	5825.9
1994	6213.5	5676.6	6236.8	6203.7	5696.3	5668.7	6227.3	5688.5
1995	6628.3	5818.4	6637.9	6628.4	5829.9	5816.0	6637.4	5827.2
QPUP								
1990	4107.2	4107.2	4107.2	4107.2	4107.2	4107.2	4107.2	4107.2
1991	4779.4	4653.0	4779.4	4779.4	4653.0	4653.0	4779.4	4653.0
1992	4505.3	4303.9	4525.5	4496.2	4323.0	4295.3	4516.5	4314.5
1993	4949.1	4576.0	4953.6	4949.6	4581.7	4575.3	4953.6	4580.7
1994	4917.6	4452.7	4937.6	4907.6	4469.5	4444.7	4927.9	4461.7
1995	5283.2	4579.7	5291.0	5282.3	4589.3	4576.7	5289.6	4586.1
QPUC								
1990	1395.8	1395.8	1395.8	1395.8	1395.8	1395.8	1395.8	1395.8
1991	1407.1	1387.6	1407.1	1407.1	1387.6	1387.6	1407.1	1387.6
1992	1378.9	1346.7	1382.3	1378.9	1350.0	1346.7	1382.4	1349.8
1993	1444.0	1385.7	1445.0	1444.9	1386.8	1386.2	1445.7	1387.3
1994	1437.7	1364.8	1441.2	1437.2	1367.7	1364.3	1440.7	1367.3
1995	1493.2	1383.3	1494.7	1493.9	1385.0	1383.5	1495.3	1385.2

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)
Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	1	2	3	4	5	6	7	8
	Population Income	Population Income Acreage	Population Income Fresh Exports	Population Income Import Price	Population Income Acreage Fresh Exports	Population Income Acreage Import Price	Population Income Fresh Exports Import Price	Population Income Acreage Fresh Exports Import Price
Variables								
QPUJ								
1990	2075.8	2075.8	2075.8	2075.8	2075.8	2075.8	2075.8	2075.8
1991	2751.1	2651.0	2751.1	2751.1	2651.0	2651.0	2751.1	2651.0
1992	2484.1	2328.7	2502.2	2474.4	2345.6	2319.8	2492.7	2336.9
1993	2871.3	2573.6	2873.9	2871.8	2577.6	2573.0	2874.0	2576.7
1994	2824.1	2461.4	2841.4	2814.4	2475.6	2453.8	2832.0	2468.2
1995	3131.2	2572.0	3137.0	3130.3	2579.6	2569.2	3135.7	2576.6
QPUD								
1990	260.3	260.3	260.3	260.3	260.3	260.3	260.3	260.3
1991	292.4	286.1	292.4	292.4	286.1	286.1	292.4	286.1
1992	318.1	301.2	316.5	319.8	299.9	302.5	318.0	301.1
1993	310.5	289.3	310.8	310.7	289.4	289.4	310.9	289.6
1994	326.0	291.3	325.3	327.0	291.0	291.8	326.2	291.5
1995	331.4	289.9	331.5	331.7	289.0	289.1	331.8	289.2
QPUO								
1990	69.0	69.0	69.0	69.0	69.0	69.0	69.0	69.0
1991	77.4	72.9	77.4	77.4	72.9	72.9	77.4	72.9
1992	133.7	114.7	129.8	137.0	111.5	117.4	132.9	114.0
1993	91.6	75.3	92.2	91.4	75.7	75.3	92.1	75.7
1994	125.4	89.4	123.0	127.7	88.1	90.7	125.1	89.3
1995	112.2	77.0	112.4	112.4	76.9	77.3	112.6	77.2

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)
Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	1	2	3	4	5	6	7	8
	Population Income	Population Income Acreage	Population Income Fresh Exports	Population Income Import Price	Population Income Acreage Fresh Exports	Population Income Acreage Import Price	Population Income Fresh Exports Import Price	Population Income Acreage Fresh Exports Import Price
Variables								
QPUR								
1990	306.3	306.3	306.3	306.3	306.3	306.3	306.3	306.3
1991	251.3	255.4	251.3	251.3	255.4	255.4	251.3	255.4
1992	190.5	212.6	194.8	186.0	216.0	209.0	190.6	212.6
1993	231.6	252.2	231.7	230.8	252.3	251.3	230.8	251.4
1994	204.3	245.9	206.6	201.0	247.0	244.1	203.8	245.4
1995	215.1	258.5	215.4	214.0	258.8	257.6	214.2	257.9
PFD								
1990	15.89	15.89	15.89	15.89	15.89	15.89	15.89	15.89
1991	9.58	10.42	9.91	9.47	10.76	10.32	9.81	10.66
1992	13.81	14.87	13.90	13.85	14.98	14.88	13.93	14.99
1993	10.34	12.71	10.65	10.22	13.01	12.61	10.54	12.91
1994	12.22	14.77	12.35	12.23	14.95	14.75	12.36	14.93
1995	10.09	14.37	10.37	9.99	14.63	14.29	10.27	14.55
PCD								
1990	126.24	126.24	126.24	126.24	126.24	126.24	126.24	126.24
1991	72.23	79.36	74.93	70.87	82.06	80.00	73.56	80.69
1992	112.81	121.16	113.19	112.78	121.80	120.95	113.10	121.54
1993	83.07	102.90	85.57	81.62	105.27	101.56	84.16	103.96
1994	102.11	122.78	102.92	101.88	124.06	122.20	102.62	123.44
1995	85.09	120.61	87.27	83.79	122.63	119.48	86.02	121.52

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)

Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	1	2	3	4	5	6	7	8
	Population Income	Population Income Acreage	Population Income Fresh Exports	Population Income Import Price	Population Income Acreage Fresh Exports	Population Income Acreage Import Price	Population Income Fresh Exports Import Price	Population Income Acreage Fresh Exports Import Price
Variables								
PJD								
1990	88.97	88.97	88.97	88.97	88.97	88.97	88.97	88.97
1991	36.17	40.98	37.92	34.70	42.73	39.52	36.45	41.27
1992	69.62	74.39	69.47	69.34	74.48	73.93	69.13	73.98
1993	46.15	59.33	47.81	44.62	60.88	57.89	46.31	59.46
1994	62.42	75.00	62.68	61.92	75.66	74.19	62.12	74.82
1995	49.95	73.24	51.35	48.56	74.51	71.98	50.00	73.26
PDD								
1990	95.06	95.06	95.06	95.06	95.06	95.06	95.06	95.06
1991	102.65	103.40	102.65	102.65	103.40	103.40	102.65	103.40
1992	100.00	101.98	100.19	99.81	102.13	101.83	100.02	101.98
1993	101.25	103.71	101.23	101.24	103.69	103.70	101.21	103.67
1994	99.84	103.82	99.93	99.73	103.85	103.76	99.82	103.80
1995	99.61	104.43	99.60	99.58	104.42	104.41	99.57	104.39
POD								
1990	108.75	108.75	108.75	108.75	108.75	108.75	108.75	108.75
1991	113.44	114.40	113.44	113.44	114.40	114.40	113.44	114.40
1992	101.89	105.85	102.70	101.19	106.50	105.29	102.05	105.98
1993	110.85	114.20	110.72	110.88	114.13	114.20	110.74	114.12
1994	104.13	111.48	104.62	103.67	111.75	111.21	104.19	111.50
1995	107.06	114.18	107.03	107.02	114.20	114.10	106.98	114.13

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)

Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Population Income	Population Income Acreage	Population Income Fresh Exports	Population Income Import Price	Population Income Acreage Fresh Exports	Population Income Acreage Import Price	Population Income Fresh Exports Import Price	Population Income Acreage Fresh Exports Import Price
Variables								
PRD								
1990	131.56	131.56	131.56	131.56	131.56	131.56	131.56	131.56
1991	101.65	107.72	102.91	99.90	108.97	105.96	101.15	107.22
1992	117.13	127.32	117.82	115.58	128.01	125.78	116.30	126.49
1993	110.72	127.74	111.63	109.10	128.64	126.13	110.02	127.03
1994	116.44	138.89	117.07	114.97	139.58	137.41	115.61	138.09
1995	111.25	143.08	112.09	109.64	143.91	141.49	110.49	142.33
PPD								
1990	105.70	105.70	105.70	105.70	105.70	105.70	105.70	105.70
1991	55.56	61.46	57.55	54.07	63.45	59.97	56.06	61.96
1992	88.42	95.49	88.60	88.01	95.88	94.93	88.14	95.28
1993	65.68	82.02	67.49	64.15	83.73	80.58	66.00	82.32
1994	81.11	98.47	81.62	80.53	99.34	97.62	80.99	98.46
1995	68.25	97.63	69.82	66.85	99.08	96.35	68.46	97.81
PAD								
1990	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41
1991	6.63	7.23	6.86	6.54	7.47	7.14	6.77	7.38
1992	9.75	10.50	9.80	9.76	10.57	10.49	9.80	10.56
1993	7.28	8.99	7.50	7.18	9.19	8.89	7.40	9.10
1994	8.69	10.51	8.77	8.68	10.63	10.48	8.76	10.60
1995	7.20	10.27	7.39	7.12	10.45	10.19	7.31	10.37

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

Table 5 (continued)
Forecasts Using the U.S. Apple Industry Model

Scenarios[1]	1	2	3	4	5	6	7	8
	Population Income	Population Income Acreage	Population Income Fresh Exports	Population Income Import Price	Population Income Acreage Fresh Exports	Population Income Acreage Import Price	Population Income Fresh Exports Import Price	Population Income Acreage Fresh Exports Import Price
Variables								
NIJ								
1990	11.837	11.837	11.837	11.837	11.837	11.837	11.837	11.837
1991	11.147	11.358	11.147	11.285	11.358	11.496	11.285	11.496
1992	11.763	12.088	11.725	11.922	12.052	11.244	11.883	12.209
1993	11.015	11.630	11.010	11.152	11.622	11.770	10.148	11.762
1994	11.171	11.914	11.136	11.330	11.885	12.068	10.294	12.038
1995	10.608	11.741	10.596	10.748	11.725	11.884	10.737	11.869

1 Population = Increase of 1.02 % per year
Acreage = Held at 1990 levels
Import Price = Fixed 10% decrease in 1991
Income = Increase of 1.01 % per year
Fresh Exports = Fixed 10 % increase in 1991

With the increase in apple production in 1991, more apples are allocated to the fresh (QPUF) and processed markets (QPUP). However, the percentage of apples utilized for the fresh market (QPUF) remains constant at 55 percent of total production (QPT) from 1991 through 1995. There is an increase from 57.6 to 59.3 in the percentage of processed apples used for juice (QPUJ) from 1991 to 1995. Some of these juice apples come from the canned market (QPUC), as that market share of total processed products decreases from 29.4 percent in 1991 to 28.3 percent in 1995. Both processed apple prices (PPD) and fresh apple prices (PFD) are cyclical from 1991 through 1995 as they were during the sample period. The ratio of fresh prices (PFD) to processed prices (PPD) remains approximately 0.15 during the 5 years of simulation. The quantity of juice imports (NIJ) decreases from 11.8 pounds/person in 1991 to 10.6 pounds per person in 1995 in response to population increases, acreage increases, production fluctuations and price changes.

Scenario 2: Population and Income and Acreage

When acreage is held at 1990 values, there is a smaller increase in total production (QPT) when compared to Scenario 1. The 1995 total production (QPT) is 1,529 million pounds less when acreage is held constant. However, 55 percent of the total production still goes to the fresh market (QPUF). The quantity of apples allocated to the canned market (QPUC) is less when compared to Scenario 1. However, about 30 percent of all processed products goes to the canned market in this scenario. The juice market (QPUJ) receives a slightly smaller market share than in Scenario 1. Fresh apple prices (PFD) and processed apple prices (PPD) remain somewhat stronger in this scenario, yet maintain a ratio of 0.15 during the simulation. Due to lower production levels and less product going to the juice market, juice imports (NIJ) are nearly a pound per person higher in this scenario when compared to Scenario 1.

Scenario 3: Population and Income and Fresh Exports

An expansion of fresh apple exports may be one way to reduce the vulnerability of the apple industry to increasing juice imports. A 10 percent increase in fresh exports (NIF) in 1991 generates an increase in the price for fresh apples (PFD) and processed apple products (PPD). Price increases in apple products (PAD) generate higher production (QPT) and more apples allocated to the fresh market (QPUF) and processed markets (QPUP). In this scenario, prices of frozen (PRD), canned (PCD), juice (PJD) and fresh (PFD) apples are stronger than in Scenario 1. More apples are produced (QPT), yet acreage

(AB) remains at Scenario 1 values, due to lags in the system.

Scenario 4: Population and Income and Import Price

Decreasing prices of juice imports (PIJD) makes juice imports (NIJ) more attractive. In the scenario, there is an increase in the per capita quantity of juice imports (NIJ) when compared to Scenario 1. Increasing imports, puts downward pressure on juice price (PJD). Hence, the price of juice in 1995 is 2.8 percent lower than in Scenario 1. Lower juice prices and prices of all apple products (PAD) yield smaller production of apples (QPT) and smaller quantities of apples allocated to the fresh market (QPUF) and processed markets (QPUP). In 1995, the percent of processed apples allocated to the juice market (QPUJ) remains about 59 percent, as in Scenario 1.

Scenario 5: Population and Income, Acreage and Fresh Exports

When a scenario of population growth, income growth, and constant acreage (AB) is combined with an increase in fresh exports, there is an increase of 21.3 million pounds in total production (QPT) as evidenced by a comparison of Scenarios 2 and 5 in Table 5. More apples are allocated to the fresh market (QPUF) and processed markets (QPUP). In this scenario, prices of apple products (PAD) are higher than in Scenario 2. In 1995, prices of fresh apples (PFD) are nearly 2 percent higher and prices of processed apples (PPD) are nearly 1.5 percent higher.

Scenario 6: Population and Income, Acreage and Import Price

Under this scenario, the decrease in price of juice imports (PIJD) coupled with constant acreage (AB) generates a decrease of more than 12 percent in the total apples produced (QPT) by 1995 as seen by a comparison of Scenarios 6 and 4. Fewer apples are allocated to the fresh market (QPUF) and each of the processed markets (QPUP). Yet, the percentage of processed apples that go to the juice market (QPUJ) increases from 0.52 in Scenario 4 to 0.56 in Scenario 6. The prices of all apple products (PAD) are stronger when the import price decreases (PIJD) and apple acreage (AB) remains at 1990 levels.

Scenario 7: Population and Income, Fresh Exports and Import Price

In this scenario, the impacts of lower juice import prices (PIJD) are mitigated somewhat by increases in fresh exports (NIF). When an increase in fresh exports (NIF) is coupled with a decrease in the juice import price (PIJD) the quantity of juice imports (NIJ) is lower as seen by a comparison of Scenarios 7 and 4 in Table 5. Prices of fresh apples (PFD) and processed apple products (PPD) are stronger due to increased demand for fresh apples. The 1995 quantity allocated to the fresh market (QPUF) is 9 million pounds greater in Scenario 7 than in Scenario 4. However, the relative share of the fresh market to total production remains at 55 percent.

Scenario 8: Population and Income, Acreage, Fresh Exports and Import Price

The final scenario combines all previous assumptions. As expected, the constant acreage (AB) provides some limits on apple production (QPT). Hence, this scenario's apple production is less than if acreage were not controlled as in Scenario 7. The increase in fresh exports (NIF) generates demand for fresh apples, increases the quantity allocated to the fresh market (QPUF) and strengthens the price of fresh apples (PFD) as seen by a comparison of Scenarios 8 and 6. The lower price of juice imports (PIJD) leads to an increase in the quantity of juice imported (NIJ) and a decrease in the quantity of processed apples allocated to the juice market (QPUJ). Furthermore, a comparison of Scenarios 8 and 5 indicate that a decrease in the juice import price (PIJD) weakens the price received for juice (PJD) and the average price for all apple products (PAD).

SUMMARY AND CONCLUSIONS

The dynamic national apple industry model presented here includes relationships for bearing acres, production, utilization and allocation to the fresh, canned, frozen, juice, dried and other markets. Demand in each of the markets are modeled. Data from 1971 through 1990 are used in the estimation of the model. Zellner's seemingly unrelated regression procedure is used since each model sector was considered independent of the other model sectors.

All estimated model equations have coefficients consistent with the hypothesized signs and of reasonable magnitudes. Demand and supply elasticities evaluated at the mean of the data set indicate that changes in acreage are very inelastic with respect to price. The products' elasticities of supply, reflected by the allocation elasticities, are inelastic for all products. Demand flexibilities suggest the demand for fresh apples and apple juice are inelastic while the demand for canned, dried, frozen and other apples are elastic. Fresh, canned, juice and frozen apples are normal goods as indicated by their income flexibilities. Cross-price elasticities suggest that several apple products are substitutes. Static and dynamic simulations were used in model validation. Dynamic simulation errors were slightly higher than static simulation errors. Yet, both lend support to using the model to analyze changes in the industry.

Simulation analysis was used to analyze the impacts of exogenous changes on the performance of the apple industry. The base case assumes that (1) population continues to increase at a rate consistent with the last five years of the sample, (2) income increases at a rate consistent with the last five years of the sample, (3) net imports of all apple products, with the exception of juice, remain at 1990 values, and (4) any long term changes in the industry reflected by trend variables in the model continue for the duration of the analysis. The base case was compared with seven different scenarios where either acreage was assumed to remain at 1990 levels, fresh exports were increased 10 percent in 1991, and/or the price of juice imports decreased 10 percent in 1991. These scenarios indicate that constant acreage provides limits on apple production and thus strengthens prices of apple products. The increase in fresh exports generates demand for fresh apples, increases the quantity allocated to the fresh market and strengthens the price of fresh apples. The lower price of juice imports leads to an increase in the quantity of juice imported and a decrease in the quantity of processed apples allocated to the juice market. Furthermore, a decrease in the import price weakens the juice price and the average price of all apple products.

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APPENDIX A

DATA

APPENDIX A: DATA

	GNP Deflator DEF 1982=100	Population POP mil	PCE-food PCED bil 1982$
1960	30.9		
1961	31.2		
1962	31.9		
1963	32.4		
1964	32.9		
1965	33.8		
1966	35.0		
1967	35.9		
1968	37.7		
1969	39.8		
1970	42.0	205.052	334.5
1971	44.4	207.661	335.9
1972	46.5	209.896	344.2
1973	49.5	211.909	340.8
1974	54.0	213.854	336.6
1975	59.3	215.973	346.4
1976	63.1	218.035	363.6
1977	67.3	220.239	377.1
1978	72.2	222.585	379.6
1979	78.6	225.055	387.5
1980	85.7	227.757	394.9
1981	94.0	230.138	392.5
1982	100.0	232.520	398.8
1983	103.9	234.799	414.0
1984	107.7	237.001	422.8
1985	110.9	239.279	435.5
1986	113.8	241.625	447.1
1987	117.4	243.942	454.0
1988	121.3	246.328	462.2
1989	126.3	248.781	462.9
1990	131.5	251.523	457.5

APPENDIX A: DATA (continued)

	Bearing Acres AB thsnd acres	Index of Prices Paid by Farmers IPP 1982=100	Yield Acre Y thsnd lbs/acre
1960		29	
1961		29	
1962		30	
1963		30	
1964		30	
1965		30	
1966		31	
1967		31	
1968		31	
1969	402.4	33	
1970	402.5	35	15.9
1971	402.2	36	15.8
1972	405.2	39	14.5
1973	399.1	45	15.7
1974	396.0	51	16.6
1975	395.6	56	19.0
1976	403.2	60	16.1
1977	403.4	63	16.7
1978	404.3	68	18.8
1979	407.6	77	19.9
1980	412.2	87	21.4
1981	414.9	94	18.7
1982	418.3	100	19.4
1983	424.5	101	19.7
1984	422.9	103	19.7
1985	430.7	102	18.4
1986	442.4	100	17.8
1987	452.3	102	23.7
1988	463.6	107	19.7
1989	479.0	112	20.8
1990	485.5	116	20.0

APPENDIX A: DATA (continued)

	Total Production QPT mil lbs	Utilized Production QPU mil lbs	Fresh Utilization QPUF mil lbs	Processed Utilization QPUP mil lbs
1970	6397.7	6258.4	3531.5	2726.9
1971	6373.2	6082.7	3483.9	2598.8
1972	5878.8	5867.5	3342.0	2525.5
1973	6265.0	6251.5	3539.4	2712.1
1974	6579.7	6529.8	3690.5	2839.3
1975	7530.0	7102.6	4357.0	2745.6
1976	6472.2	6466.9	3915.8	2551.1
1977	6739.6	6710.0	3859.6	2850.4
1978	7596.9	7544.0	4210.4	3333.6
1979	8126.1	8101.2	4288.6	3812.6
1980	8818.4	8800.4	4934.1	3866.3
1981	7739.6	7692.9	4442.2	3250.7
1982	8122.0	8110.2	4536.7	3573.5
1983	8378.5	8357.9	4620.5	3737.4
1984	8324.0	8309.1	4654.6	3654.5
1985	7914.5	7826.8	4221.7	3605.1
1986	7859.0	7833.3	4463.6	3369.7
1987	10742.1	10451.3	5610.1	4841.2
1988	9128.0	9078.4	5238.3	3840.1
1989	9962.8	9917.4	5865.3	4052.1
1990	9696.8	9658.2	5551.0	4107.2

APPENDIX A: DATA (continued)

	Canned Utilization QPUC mil lbs	Juice & Cider Utilization QPUJ mil lbs	Frozen Utilization QPUR mil lbs	Dried Utilization QPUD mil lbs	Other Utilization QPUO mil lbs
1970	1158.5	1031.7	203.0	189.8	143.9
1971	1093.5	1087.0	190.5	96.2	131.6
1972	976.9	1028.6	235.3	148.6	136.1
1973	1255.4	822.2	259.2	247.7	127.6
1974	1225.6	1030.7	181.7	197.2	204.1
1975	1026.7	1191.6	206.6	229.5	91.2
1976	919.9	1109.1	220.4	229.3	72.4
1977	1075.9	1267.2	160.9	225.5	120.9
1978	1224.2	1494.6	207.4	221.0	186.4
1979	1336.7	1953.8	136.6	255.7	129.8
1980	1202.4	2136.9	167.5	194.7	164.8
1981	1002.4	1798.4	172.7	190.0	87.2
1982	1248.6	1807.8	190.8	209.9	116.4
1983	1204.4	1984.7	169.6	283.3	95.4
1984	1176.7	1888.8	198.1	288.6	102.3
1985	1255.4	1839.1	194.3	242.4	73.9
1986	1179.0	1643.1	257.3	199.4	90.9
1987	1305.8	2928.8	249.1	283.8	73.7
1988	1399.1	1823.6	265.7	285.0	66.7
1989	1320.4	2071.1	321.5	282.4	56.7
1990	1395.8	2075.8	306.3	260.3	69.0

APPENDIX A: DATA (continued)

	Average Grower Price-All PA c/lb	Average Grower Price-Fresh PF c/lb	Average Grower Price-Processing PP $/ton
1960	4.79		
1961	4.09		
1962	4.28		
1963	4.07		
1964	3.86		
1965	4.32		
1966	4.47		
1967	5.57		
1968	6.11		
1969	4.06		
1970	4.54	6.53	39.20
1971	4.92	6.97	43.40
1972	6.43	8.92	62.80
1973	8.80	10.70	125.00
1974	8.40	11.10	96.10
1975	6.50	8.80	56.80
1976	9.10	11.50	108.00
1977	10.60	13.80	122.00
1978	10.40	13.90	117.00
1979	10.90	15.40	114.00
1980	8.70	12.10	84.00
1981	11.10	15.40	102.00
1982	10.00	13.20	118.00
1983	10.50	14.80	104.00
1984	11.10	15.50	112.00
1985	11.70	17.30	103.00
1986	13.40	19.10	116.00
1987	8.60	12.70	79.30
1988	12.70	17.40	123.00
1989	10.40	13.90	107.00
1990	15.00	20.90	139.00

APPENDIX A: DATA (continued)

	Average Grower Price-Canned PC $/ton	Average Grower Price-Juice-Cider PJ $/ton	Average Grower Price-Frozen PR $/ton	Average Grower Price-Dried PD $/ton	Average Grower Price-Other PO $/ton
1970	47.90	27.90	53.40	33.2	37.3
1971	49.40	36.10	52.20	45.4	37.5
1972	67.40	55.70	76.00	68.6	42.4
1973	131.00	98.20	171.00	104.0	103.0
1974	123.00	64.70	121.00	99.7	64.8
1975	57.50	52.60	73.10	65.5	47.4
1976	120.00	91.60	143.00	105.0	114.0
1977	133.00	109.00	138.00	132.0	112.0
1978	119.00	110.00	126.00	154.0	115.0
1979	125.00	103.00	133.00	135.0	110.0
1980	97.40	73.70	112.00	78.7	91.0
1981	121.00	87.90	160.00	77.1	109.0
1982	132.00	103.00	143.00	132.0	123.0
1983	117.00	88.90	161.00	106.0	116.0
1984	137.00	88.20	151.00	123.0	133.0
1985	132.00	74.60	139.00	132.0	117.0
1986	132.00	96.50	150.00	123.0	125.0
1987	118.00	57.80	132.00	67.7	99.9
1988	152.00	95.70	164.00	106.0	131.0
1989	141.00	78.80	158.00	95.2	134.0
1990	166.00	117.00	173.00	125.0	143.0

APPENDIX A: DATA (continued)

	Average Grower Price-All PAD 82c/lb	Average Grower Price-Fresh PFD 82c/lb	Average Grower Price-Processing PPD 82$/ton
1960	15.50		
1961	13.11		
1962	13.42		
1963	12.56		
1964	11.73		
1965	12.78		
1966	12.77		
1967	15.52		
1968	16.21		
1969	10.20		
1970	10.81	15.55	93.33
1971	11.08	15.70	97.75
1972	13.83	19.18	135.05
1973	17.78	21.62	252.53
1974	15.56	20.56	177.96
1975	10.96	14.84	95.78
1976	14.42	18.23	171.16
1977	15.75	20.51	181.28
1978	14.40	19.25	162.05
1979	13.87	19.59	145.04
1980	10.15	14.12	98.02
1981	11.81	16.38	108.51
1982	10.00	13.20	118.00
1983	10.11	14.24	100.10
1984	10.31	14.39	103.99
1985	10.55	15.60	92.88
1986	11.78	16.78	101.93
1987	7.33	10.82	67.55
1988	10.47	14.34	101.40
1989	8.23	11.01	84.72
1990	11.41	15.89	105.70

APPENDIX A: DATA (continued)

	Average Grower Price-Canned PCD 82$/ton	Average Grower Price-Juice-Cider PJD 82$/ton	Average Grower Price-Frozen PRD 82$/ton	Average Grower Price-Dried PDD 82$/ton	Average Grower Price-Other POD 82$/ton
1970	114.05	66.43	127.14	79.05	88.81
1971	111.26	81.31	117.57	102.25	84.46
1972	144.95	119.78	163.44	147.53	91.18
1973	264.65	198.38	345.45	210.10	208.08
1974	227.78	119.81	224.07	184.63	120.00
1975	96.96	88.70	123.27	110.46	79.93
1976	190.17	145.17	226.62	166.40	180.67
1977	197.62	161.96	205.05	196.14	166.42
1978	164.82	152.35	174.52	213.30	159.28
1979	159.03	131.04	169.21	171.76	139.95
1980	113.65	86.00	130.69	91.83	106.18
1981	128.72	93.51	170.21	82.02	115.96
1982	132.00	103.00	143.00	132.00	123.00
1983	112.61	85.56	154.96	102.02	111.65
1984	127.21	81.89	140.20	114.21	123.49
1985	119.03	67.27	125.34	119.03	105.50
1986	115.99	84.80	131.81	108.08	109.84
1987	100.51	49.23	112.44	57.67	85.09
1988	125.31	78.90	135.20	87.39	108.00
1989	111.64	62.39	125.10	75.38	106.10
1990	126.24	88.97	131.56	95.06	108.75

APPENDIX A: DATA (continued)

	Per Cap Util w/ Net Imports Canned QUC lb/person	Per Cap Util w/ Net Imports Juice QUJ lb/person	Per Cap Util w/ Net Imports Frozen QUR lb/person	Per Cap Util w/ Net Imports Dry QUD lb/person	Per Cap Util w/ Net Imports Other QUO lb/person
1970	5.64	6.36	0.98	0.90	0.70
1971	5.27	7.02	0.91	0.48	0.63
1972	4.67	5.44	1.12	0.64	0.65
1973	5.97	4.63	1.22	1.12	0.60
1974	5.75	5.91	0.85	0.91	0.95
1975	4.75	6.87	0.95	1.04	0.42
1976	4.26	6.30	1.01	1.07	0.33
1977	4.88	7.87	0.73	0.99	0.55
1978	5.51	9.57	0.93	0.99	0.83
1979	5.92	10.63	0.60	1.11	0.57
1980	5.27	13.01	0.73	0.82	0.72
1981	4.35	11.53	0.75	0.82	0.38
1982	5.37	14.58	0.82	0.85	0.50
1983	5.13	15.83	0.72	1.21	0.41
1984	5.01	18.40	0.83	1.26	0.43
1985	5.26	18.42	0.81	1.15	0.31
1986	4.91	18.18	1.06	0.83	0.38
1987	5.38	19.43	1.02	1.21	0.30
1988	5.71	19.14	1.08	1.21	0.27
1989	5.34	17.42	1.29	1.11	0.23
1990	5.57	20.09	1.22	0.83	0.27

APPENDIX A: DATA (continued)

	Per Cap Util w/ Net Imports Fresh QUF lb/person	Per Cap Util +Imp-Exp Total QUT lb/person	Orange Fresh Per Capita Consumption QUFO pounds/person	FCOJ Per Capita Consumption QUJO pounds/person
1970	17.02	31.59	16.16	20.73
1971	16.42	30.73	15.72	24.22
1972	15.53	28.03	14.48	27.71
1973	16.13	29.66	14.44	26.86
1974	16.40	30.77	14.42	29.47
1975	19.49	33.52	15.88	32.78
1976	17.08	30.05	14.74	34.33
1977	16.52	31.54	13.44	34.12
1978	18.00	35.82	13.45	27.53
1979	17.24	36.08	12.61	30.31
1980	19.25	39.8	15.84	31.76
1981	17.23	35.04	13.59	30.14
1982	17.68	39.8	12.73	33.28
1983	18.49	41.79	16.12	38.85
1984	18.63	44.56	12.81	33.49
1985	17.52	43.48	12.31	36.24
1986	18.16	43.52	14.53	39.83
1987	21.34	48.69	14.01	35.92
1988	19.97	47.39	14.68	37.36
1989	21.57	46.96	13.41	30.17
1990	19.80	47.79	13.38	25.10

APPENDIX A: DATA (continued)

	Trend T	Dummy for 1973-74 D734	Dummy for 1976-79 D769
1970	0	0	0
1971	1	0	0
1972	2	0	0
1973	3	1	0
1974	4	1	0
1975	5	0	0
1976	6	0	1
1977	7	0	1
1978	8	0	1
1979	9	0	1
1980	10	0	0
1981	11	0	0
1982	12	0	0
1983	13	0	0
1984	14	0	0
1985	15	0	0
1986	16	0	0
1987	17	0	0
1988	18	0	0
1989	19	0	0
1990	20	0	0

APPENDIX A: DATA (continued)

	Fresh/Process Price Ratio PFDPPD (dimensionless)	Can/Process Price Ratio PCDPPD (dimensionless)	Juice/Process Price Ratio PJDPPD (dimensionless)	Dried/Process Price Ratio PDDPPD (dimensionless)	Other/Process Price Ratio PODPPD (dimensionless)
1970	0.167	1.222	0.712	0.847	0.952
1971	0.161	1.138	0.832	1.046	0.864
1972	0.142	1.073	0.887	1.092	0.675
1973	0.086	1.048	0.786	0.832	0.824
1974	0.116	1.280	0.673	1.037	0.674
1975	0.155	1.012	0.926	1.153	0.835
1976	0.106	1.111	0.848	0.972	1.056
1977	0.113	1.090	0.893	1.082	0.918
1978	0.119	1.017	0.940	1.316	0.983
1979	0.135	1.096	0.904	1.184	0.965
1980	0.144	1.160	0.877	0.937	1.083
1981	0.151	1.186	0.862	0.756	1.069
1982	0.112	1.119	0.873	1.119	1.042
1983	0.142	1.125	0.855	1.019	1.115
1984	0.138	1.223	0.788	1.098	1.188
1985	0.168	1.282	0.724	1.282	1.136
1986	0.165	1.138	0.832	1.060	1.078
1987	0.160	1.488	0.729	0.854	1.260
1988	0.141	1.236	0.778	0.862	1.065
1989	0.130	1.318	0.736	0.890	1.252
1990	0.150	1.194	0.842	0.899	1.029

APPENDIX A: DATA (continued)

	Net Imports Fresh NIF lbs/person	Net Imports Canned NIC lbs/person	Net Imports Frozen NIR lbs/person	Net Imports Dried NID lbs/person	Net Imports Other NIO lbs/person
1970	-0.202	-0.010	-0.010	-0.026	-0.002
1971	-0.357	0.004	-0.007	0.017	-0.004
1972	-0.392	0.016	-0.001	-0.068	0.002
1973	-0.572	0.046	-0.003	-0.049	-0.002
1974	-0.857	0.019	0.000	-0.012	-0.004
1975	-0.684	-0.004	-0.007	-0.023	-0.002
1976	-0.880	0.041	-0.001	0.018	-0.002
1977	-1.005	-0.005	-0.001	-0.034	0.001
1978	-0.916	0.010	-0.002	-0.003	-0.007
1979	-1.816	-0.019	-0.007	-0.026	-0.007
1980	-2.414	-0.009	-0.005	-0.035	-0.004
1981	-2.072	-0.006	0.000	-0.006	0.001
1982	-1.831	0.000	-0.001	-0.053	-0.001
1983	-1.189	0.001	-0.002	0.003	0.004
1984	-1.010	0.045	-0.006	0.042	-0.002
1985	-0.123	0.013	-0.002	0.137	0.001
1986	-0.313	0.031	-0.005	0.005	0.004
1987	-1.658	0.027	-0.001	0.047	-0.002
1988	-1.296	0.030	0.001	0.053	-0.001
1989	-2.006	0.033	-0.002	-0.025	0.002
1990	-2.270	0.021	0.002	-0.205	-0.004

APPENDIX B: SOURCES OF DATA

AB	Bearing Acres 1969: Johnson, Doyle C. Fruits and Nuts Bearing Acreage, 1947-83. USDA/NASS Statistical Bulletin Number 761. December 1987. Table 3. 1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 3. Page 10. 1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 3. Page 17.	(thousand acres)
D734	Dummy Variable for 1973-74 (1971-72=0, 1973-74=1, 1975-91=0)	
D769	Dummy Variable for 1976-79 (1971-75=0, 1976-79=1, 1980-91=0)	
DEF	GNP Deflator 1960-89: Economic Report of the President 1990, Table C-3 1990: Economic Report of the President 1991, Table B-3	(1982 = 100)
IPP	Index of Prices Paid by Farmers 1960-64: Agricultural Statistics 1967 1965-69: Agricultural Statistics 1977 1970-72: Agricultural Statistics 1981 1973-74: Agricultural Statistics 1988 1975-87: Agricultural Statistics 1990 1988-90: Agricultural Statistics 1991	(1977=100) or (1982=100)
NIC	Net Imports - Canned NIC=QUC-QPUC/POP	(lbs/person)
NID	Net Imports - Dried NID=QUD-QPUD/POP	(lbs/person)
NIF	Net Imports - Fresh NIF=QUF-QPUF/POP	(lbs/person)
NIJ	Net Imports - Juice NIJ=QUJ-QPUJ/POP	(lbs/person)
NIJT	Net Imports - Juice Total TSUSA #1651500 Apple/Pear Juice not over 1% alcohol 1970: Foreign Agricultural Trade of the United States Calendar Year Supplement 1970. 1971: Foreign Agricultural Trade of the United States Calendar Year Supplement 1972. 1972: Foreign Agricultural Trade of the United States Calendar Year Supplement 1973. 1973: Foreign Agricultural Trade of the United States Calendar Year Supplement 1974.	(thousand gallons)

APPENDIX B: SOURCES OF DATA (continued)

1974: Foreign Agricultural Trade of the United States Calendar Year Supplement 1975.
1975: Foreign Agricultural Trade of the United States Calendar Year Supplement 1976.
1976: Foreign Agricultural Trade of the United States Calendar Year Supplement 1977.
1977: Foreign Agricultural Trade of the United States Calendar Year Supplement 1978.
1978: Foreign Agricultural Trade of the United States Calendar Year Supplement 1979.
1979: Foreign Agricultural Trade of the United States Calendar Year Supplement 1980.
1980: Foreign Agricultural Trade of the United States Calendar Year Supplement 1981.
1981: Foreign Agricultural Trade of the United States Calendar Year Supplement 1982.
1982: Foreign Agricultural Trade of the United States Calendar Year Supplement 1984.
1983-85: Foreign Agricultural Trade of the United States Calendar Year Supplement 1985.
1986-88: Foreign Agricultural Trade of the United States Calendar Year Supplement 1989.
Harmonized Import Commodity 2009700000, 2009700010, 2009700020, 2009700090, 2009802000
1989-90: Foreign Agricultural Trade of the United States Calendar Year Supplement 1990.

NIO Net Imports - Other (lbs/person)
NIO=QUO-QPUO/POP

NIR Net Imports - Frozen (lbs/person)
NIR=QUR-QPUR/POP

NIV Net Import - Juice Value (thousand dollars)
TSUSA #1651500 Apple/Pear Juice not over 1% alcohol
1970: Foreign Agricultural Trade of the United States Calendar Year Supplement 1970.
1971: Foreign Agricultural Trade of the United States Calendar Year Supplement 1972.
1972: Foreign Agricultural Trade of the United States Calendar Year Supplement 1973.
1973: Foreign Agricultural Trade of the United States Calendar Year Supplement 1974.
1974: Foreign Agricultural Trade of the United States Calendar Year Supplement 1975.
1975: Foreign Agricultural Trade of the United States Calendar Year Supplement 1976.
1976: Foreign Agricultural Trade of the United States Calendar Year Supplement 1977.

APPENDIX B: SOURCES OF DATA (continued)

1977: Foreign Agricultural Trade of the United States Calendar Year Supplement 1978.
1978: Foreign Agricultural Trade of the United States Calendar Year Supplement 1979.
1979: Foreign Agricultural Trade of the United States Calendar Year Supplement 1980.
1980: Foreign Agricultural Trade of the United States Calendar Year Supplement 1981.
1981: Foreign Agricultural Trade of the United States Calendar Year Supplement 1982.
1982: Foreign Agricultural Trade of the United States Calendar Year Supplement 1984.
1983-85: Foreign Agricultural Trade of the United States Calendar Year Supplement 1985.
1986-88: Foreign Agricultural Trade of the United States Calendar Year Supplement 1989.
Harmonized Import Commodity 2009700000, 2009700010, 2009700020, 2009700090, 2009802000
1989-90: Foreign Agricultural Trade of the United States Calendar Year Supplement 1990.

PA — Average Grower Price - All (cents/lb)
1960-69: Agricultural Statistics 1977
1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.

PAD — Average Grower Price - All (1982 cents/lb)
PAD=PA/DEF*100

PC — Average Grower Price - Canned ($/ton)
1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.

PCD — Average Grower Price - Canned (1982 $/ton)
PCD=PC/DEF*100

PCDPPD — Average Grower Price Ratio - Canned to Process (dimensionless)
PCDPPD=PCD/PPD

PCED — Personal Consumption Expenditure for Food (billion 1982$)
1970-86: Economic Report of the President 1990, Table C-15
1987-90: Economic Report of the President 1991, Table B-15

APPENDIX B: SOURCES OF DATA (continued)

PD	Average Grower Price - Dried 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	($/ton)
PDD	Average Grower Price - Dried PDD=PD/DEF*100	(1982 $/ton)
PDDPPD	Average Grower Price Ratio - Dried to Process PDDPPD=PDD/PPD	(dimensionless)
PF	Average Grower Price - Fresh 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	(cents/lb)
PFD	Average Grower Price - Fresh PFD=PF/DEF*100	(1982 cents/lb)
PFDPPD	Average Grower Price Ratio - Fresh to Process PFDPPD=PFD/PPD	(dimensionless)
PIJ	Average Import Price - Juice PIJ=NIV/NIJT	($/gallon)
PIJD	Average Import Price - Juice PIJD=PIJ/DEF*100	(1982$/gallon)
PJ	Average Grower Price - Juice and Cider 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	($/ton)
PJD	Average Grower Price - Juice and Cider PJD=PJ/DEF*100	(1982 $/ton)
PJDPPD	Average Grower Price Ratio - Juice to Process PJDPPD=PJD/PPD	(dimensionless)

APPENDIX B: SOURCES OF DATA (continued)

PO	Average Grower Price - Other 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	($/ton)
POD	Average Grower Price - Other POD=PO/DEF*100	(1982 $/ton)
PODPPD	Average Grower Price Ratio - Other to Process PODPPD=POD/PPD	(dimensionless)
POP	Population 1970-86: Economic Report of the President 1990, Table C-31 1987-90: Economic Report of the President 1992, Table B-29	(million)
PP	Average Grower Price - Processing 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	($/ton)
PPD	Average Grower Price - Processing PPD=PP/DEF*100	(1982 $/ton)
PR	Average Grower Price - Frozen 1970-88: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18. 1989-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10 and 14. Pages 22 and 24.	($/ton)
PRD	Average Grower Price - Frozen PRD=PR/DEF*100	(1982 $/ton)
QPT	Total Production 1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 10. Page 16. 1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 10. Page 22.	(million pounds)

APPENDIX B: SOURCES OF DATA (continued)

QPU — Utilized Production (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 10. Page 16.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 10. Page 22.

QPUC — Canned Utilization (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.

QPUD — Dried Utilization (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.

QPUF — Fresh Utilization (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.

QPUJ — Juice and Cider Utilization (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.

QPUO — Other Utilization (million pounds)
1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.
1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.

APPENDIX B: SOURCES OF DATA (continued)

	1980-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	
QUJO	FCOJ Single Strength Per Capita Consumption 1970-78: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 108. Page 76. 1979-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 114. Page 77.	(pounds/person)
QUO	Per Capita Utilization with Net Imports - Other 1970-82: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 109. Page 77. 1983-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	(pounds/person)
QUR	Per Capita Utilization with Net Imports - Frozen 1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 109. Page 77. 1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	(pounds/person)
QUT	Per Capita Utilization with Net Imports - Total 1970-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	(pounds/person)
T	Time Trend	(1971=1)
Y	Yield Y=QPT/AB	(thousand lbs/acre)

APPENDIX B: SOURCES OF DATA (continued)

QPUP	Processed Utilization	(million pounds)
	1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.	
	1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.	
QPUR	Frozen Utilization	(million pounds)
	1970-87: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Tables 10 and 14. Pages 16 and 18.	
	1988-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Tables 10. Pages 22.	
QUC	Per Capita Utilization with Net Imports - Canned	(pounds/person)
	1970-81: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 109. Page 77.	
	1982-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	
QUD	Per Capita Utilization with Net Imports - Dry	(pounds/person)
	1970-86: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 109. Page 77.	
	1987-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	
QUF	Per Capita Utilization with Net Imports - Fresh	(pounds/person)
	1970-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 115. Page 78.	
QUFO	Fresh Orange Per Capita Consumption	(pounds/person)
	1970-80: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 77. Page 49.	
	1981-90: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-258 August 1991. Table 107. Page 74.	
QUJ	Per Capita Utilization with Net Imports - Juice	(pounds/person)
	1970-79: USDA/ERS/CED. Fruit and Tree Nuts Situation and Outlook Report Yearbook. TFS-254 August 1990. Table 109. Page 77.	

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