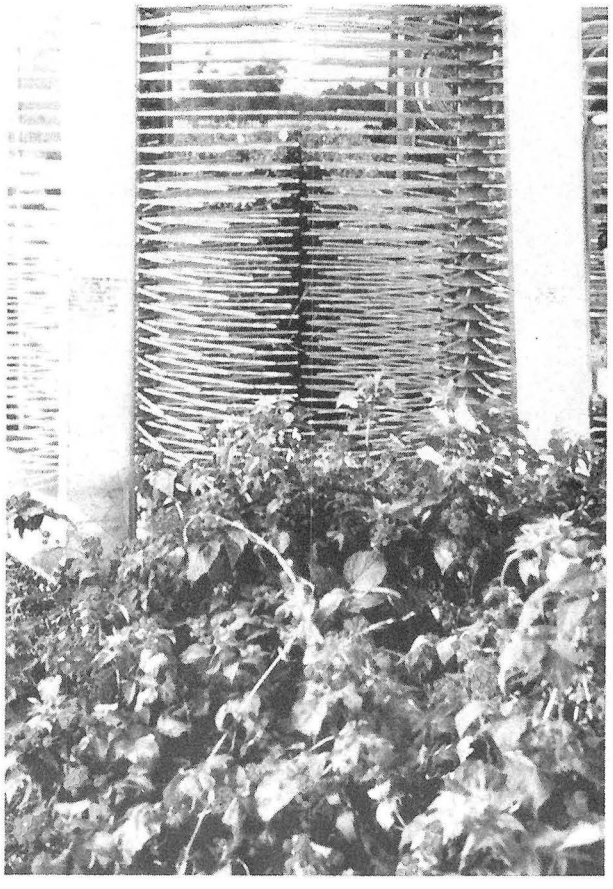
Fruit Crops
A Summary of Research
1998



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In Partnership With Ohio State University Extension

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Reports of Original Research
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Cover Photo: A Littau mechanical berry harvester harvesting 'Heritage' red raspberries.

Almost all of Ohio's bramble and blueberry acreage is currently harvested by hand. However, during a recent strategic planning exercise, members of the Ohio Fruit Growers Society and their collaborators identified the acquisition of mechanical harvesting capabilities and the development of a berry-processing industry as one of four interrelated primary components necessary for the growth and long-term stability of the small-fruit industry in Ohio. In order to determine the feasibility of mechanical harvesting in Ohio, growers and Ohio State University researchers tested a Littau FR9508 mechanical harvester on black raspberries, red raspberries, blackberries, and blueberries in both research and production fields. Funds for this research were provided by growers, the Ohio Department of Agriculture, and The Ohio State University.

Salaries and research support were provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center and Ohio State University Extension of The Ohio State University's College of Food, Agricultural, and Environmental Sciences. Additional grant support was provided by the organizations and companies listed in the individual research reports.

Contents

Pesticide Deposition in Orchards: Effects of Pesticide Type, Tree Canopy, Timing, Cultivar, and Leaf Type

Franklin R. Hall, Jane A. Cooper, and David C. Ferree

Introduction

Pesticides are expected to continue to play a major role for the foreseeable future in protecting most crop systems from insect and disease damage. Increased concern about pesticide pollution (drift and groundwater contamination) and development of pesticide resistance combined with recent advances in low-volume spraying and integrated pest management (IPM) make it even more important that the correct amount of pesticide is applied to the target.

Orchard spraying is generally regarded as an inefficient, although usually effective, process. In the orchard, the target is complex; it may be an insect, a pathogen, or a mite, or it could be the leaves, or the fruit, or more. In addition, the target location within the canopy varies, e.g., outside edges of canopy or inside top center. Tree size and shape change during an individual growing season as well as during the span of the tree's age. Most sprays applied by traditional techniques produce a satisfactory biological result. However, a large proportion of the pesticide may never reach its intended target due to factors such as tree density, seasonal growth patterns, pruning/management characteristics, the differential retention properties of leaves from different cultivars, and sprayer-to-tree size mismatch (8,9).

This report summarizes the findings from a large project designed to determine the major parameters — for example, apple-orchard geometry, cultivar, leaf type, spray timing, and pesticide type — governing within-canopy and off-target pesticide movement.

Materials and Methods

General

The nine-year-old apple orchard (*Malus domestica* Borkh) used in this study consisted of four blocks of trees containing an array of cultivars and management systems. 'Smoothee Golden Delicious' and 'Lawspur Rome Beauty' were established either in a four-wire trellis hedgerow trained as oblique palmettes on M.9 rootstock, or freestanding trained as a central leader on M.7 rootstock. A three-tree plot of each combination was established at the recommended spacing for that cultivar and rootstock ('Smoothee' — M.7, 4.5 m x 6 m; M.9, 2.5 x 3.5 m.; 'Lawspur' — M.7, 3.5 x 5 m; M9, 2 x 3.5 m), and two plots of three trees were established in each row at half the recommended row spacing. Trees in the plots at half spacing (i.e., close spacing) were either root-pruned (annually at full bloom) or mechanically hedged (annually in mid-August) to achieve additional tree size control. The cultivars 'Smoothee' and 'Lawspur,' the systems' trellis and central leader, and the treatments of wide and close spacings were compared.

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An application of 1% calcium nitrate (used to mimic the application of a pesticide) at 748 liters per hectare was made using a Swanson airblast sprayer. Application was made from the west side of the canopy only, with the sprayer passing as close to each tree as possible without actually touching the canopy. Sprays were applied in April, June, and November of a single growing season.

All three trees of each plot were sprayed, but only the center tree was used for these assessments. Each plot was replicated once in each of the four blocks.

Tree canopy volumes (hence, spray collection efficiencies) can change substantially during an individual season as well as during the life span of the trees because of rootstock/cultivar interactions. One estimate of target volume and, therefore, spray volumes and delivery characteristics needed to treat a canopy is the leaf area index (LAI) which is the ratio of total area of foliage divided by the ground area (7). LAIs were developed for each planting in these studies.

Targets

Plastic tape (0.05 m wide and 2.4 m long) was used to detect calcium nitrate passing through the canopy. The tape was placed in an aluminum holder on the east (nonspray) side of the canopy, behind the center of the tree and the same distance as the radius of the widest canopy in the study. The center of the tape was positioned at the same height as the center of the tree, i.e., approximately 1.5 m for trellis and 2 m for freestanding canopies. The conductivity of each tape was plotted as a trace using a "tape-washing machine" (developed by the USDA-Application Technology Research Unit [ATRU], Wooster). This was converted into amount of calcium nitrate per cm^2 tape using a calibration curve.

Leaves and pipe cleaners were used as targets to measure within-canopy deposition. Three four-leaf samples from each of four trees were taken at random from each of the west, the middle, and the east third of each canopy, at approximately the same height as the center of the tree. All targets were removed after each spray pass, taken back to the laboratory after spray completion, and stored in a refrigerator until analysis. Each sample was shaken together with 10 ml of tap water for 20 seconds, and the conductivity of the resultant solution measured using a hand-held conductivity meter. The amount of calcium nitrate per cm^2 leaf surface was calculated using the regression equation from a previously obtained calibration curve, and from measuring the area of leaves using a LI-3000 (LI-COR, Lincoln, Nebr.) portable area meter.

Pipe cleaners were used as "pseudo-leaves" to measure within-canopy deposition when the leaves were very small or absent (April and November, respectively). Pipe cleaners were analyzed in the same way as leaves.

Pesticide Retention

Retention trials were carried out at three times during a growing season, at post-petal-fall (May), full foliage (July), and pre-harvest (October). Shoots and spurs were selected at random from individual trees, but the fifth leaf from the base of a shoot was always sampled, as was the fifth leaf in the rosette pattern of any spur. Leaves were stored flat in plastic bags in the laboratory until sprayed.

Six pesticides (three emulsifiable concentrates and three wettable/dry flowable powders) were chosen as representative of pesticides presently used by orchard growers (Table 1). All were applied at concentrations within the rate range recommended on the label. Tap water was sprayed as a seventh treatment.

Immediately before spraying, the weight of each individual leaf was determined using a

Table 1. Pesticide Treatments.

Treatment	Application Rate
1. Fenvalerate (Pydrin 2E)	0.625 ml/L
2. Permethrin (Ambush 2E)	0.318 ml/L
3. Fenarimol (Rubigan EC)	0.234 ml/L
4. Myclobutanil (Nova W)	0.117 g/L
5. Benomyl (Benlate DF)	0.225 g/L
6. Mancozeb (Manzate DF)	2.397 g/L
7. Water	—

Mettler PM460 Balance. Leaves were positioned (in a support, as per Cooper and Hall [5]) under an 8001-E nozzle and sprayed to runoff. Eight replicate leaves were sprayed from each of the cultivars, 'Smoothee,' 'Oregon Spur,' 'Empire,' and 'Lawspur.' Leaves were reweighed after 30 seconds of simulated air current, and leaf areas were measured with the LI-3000.

Equilibrium surface tension of each pesticide was measured using the DuNouy ring method. Data was analyzed using ANOVA with mean separation using LSD (14). Estimation of leaf hair density and statistical analysis were performed as per Hall *et al.*, (10).

Results and Discussion

Canopy Deposition

Table 2 shows a decrease in within-canopy spray deposit as the distance from the sprayer increased, with approximately 50% less deposit on the east side of trellis canopies compared to more than 60% in the larger central leader canopies for the July timing only.

More spray was deposited on leaves from trellis trees than central leader trees and on 'Smoothee' leaves than 'Lawspur.' This can be explained by the leaf-area-index (LAI) data in Table 3 which shows a higher LAI value (and thus a greater density of leaves to "capture" more spray) for both 'Smoothee' and the trellis system. Significantly more spray was deposited on wide-spaced trees than close-spaced ones in this July study.

The quantity of pesticide retained on a leaf depends upon many complex factors, including the nature of the foliar surface, the physicochemical properties of the spray solution, and the application method used. As Table 4 indicates, retention was influenced by pesticide type and formulation. Those pesticides formulated as emulsifiable concentrates (ECs) were retained less than those formulated as dry flowables (DF) or wettables (W). This study indicates that when apple leaves are sprayed to run-off, the quantity of spray retained is closely related to equilibrium surface tension, with a decrease in surface tension corresponding to a decrease in retention. Under other spraying conditions — for example, when not spraying to run-off — the use of a surfactant could result in an increased deposit.

In an overview presentation of within-canopy deposition data (Table 5), pipe cleaners clearly showed the superior capture efficiency vs. leaf or tape (Table 6) methodologies. There were also differences in wide vs. close plant-

Table 2. Within-Canopy Deposition of Calcium Nitrate on Apple Leaves at the July Timing.

	Calcium Nitrate ($\mu g/cm^2$) Deposition at Various Target Sites			
Factor	**West[z]**	**Center**	**East**	**Mean of 3 Sites**
Cultivar/System				
Smoothee/Trellis	22.5	16.7	11.2	16.8 a[y]
Lawspur/Trellis	20.6	15.9	9.5	15.4 ab
Lawspur/Central Leader	17.8	12.9	6.5	12.4 b
Spacing				
Wide	21.3	16.3	10.4	16.0 a
Close	19.2	14.0	7.8	13.7 b

[z] "Sprayer side" of canopy.
[y] Means within columns followed by a common letter do not differ significantly at the 5% level (Duncan's multiple range test).

Table 3. Leaf Area Indices (LAI) Per Section and Mean Canopy Spread.

Factor	LAI	Mean Canopy Spread (cm^2)
Cultivar		
Smoothee	0.98 a[z]	—
Lawspur	0.67 b	—
System		
Trellis	1.02 a	—
Central Leader	0.79 b	—
Cultivar/System		
Smoothee/Trellis	—	210 b
Lawspur/Trellis	—	180 b
Lawspur/Central Leader	—	300 a
Spacing		
Wide	0.70 b	250
Close	0.97 a	220

[z] Means within columns followed by a common letter do not differ significantly at the 5% level (Duncan's multiple range test).

Table 4. Retention and Surface Tension of Pesticide Treatments.

Treatment	Retention (mg/cm^2)	Equilibrium Surface Tension (dynes/cm)
1. Fenvalerate (Pydrin 2E)	6.02 d[z]	45.5
2. Permethrin (Ambush 2E)	6.49 cd	35.4
3. Fenarimol (Rubigan EC)	6.97 cd	54.9
4. Myclobutanil (Nova W)	6.99 cd	57.0
5. Benomyl (Benlate DF)	7.19 bc	60.5
6. Mancozeb (Manzate DF)	8.06 ab	62.8
7. Water	8.62 a	72.1

[z] Means within columns followed by a common letter do not differ significantly at the 5% level (Duncan's multiple range test).

Table 5. Summary of Within-Canopy Spray Deposition Trends.

	Calcium Nitrate (μg/cm²) Deposition at Various Times				
Factor	April Pipe Cleaners	July Pipe Cleaners	July Leaves	September Leaves	November Pipe Cleaners
Spacing					
Wide	149.9	162.5	16.0	5.2	190.2
Close	153.5	148.6	13.7	6.3	188.4
Cultivar/System					
Smoothee/Trellis	149.4	151.8	16.8	7.1	205.4
Lawspur/Trellis	164.0	152.8	15.4	6.4	186.0
Lawspur/Central Leader	141.7	162.0	12.4	3.6	176.4
Target Site					
West	172.5	173.4	20.3	11.2	234.4
Center	150.2	151.6	15.1	3.5	177.8
East	132.4	141.7	9.1	2.5	155.6
F-Significance					
Spacing	NS[z]	NS	NS	NS	NS
Cultivar/System	*	NS	*	NS	NS
Target Site	***	***	***	***	***

[z] NS, *, *** = Nonsignificant or significant at $P \geq 0.05$ or 0.001, respectively.

ings, system, and target site (near sprayer vs. opposite side of tree). The pipe cleaner data also demonstrated the lack of foliar interference with increased spray capture in November when leaves were absent.

Off-Target Deposition

Off-target data (Table 6) generally showed increased spray drift from wide- compared to close-planted systems, 'Smoothee' trellis vs. 'Lawspur' trellis, and November timing vs. in-season sprays. Drift generally decreased as distance from target trees increased, which follows accepted spray drift deposition rules.

Spray Retention

The amount of spray retained on the leaves during the study decreased at each subsequent application, with 30% more being retained at the start of the season than at the end (Table 7). This corresponded to a 60% decrease in the number of leaf hairs during the study, with the density decreasing dramatically at the October application. In the five months between the first and last spray applications, the apple leaves would have undergone physiological changes as the leaf changed from newly emerged to mature to pre-senescent. In addition, the leaves would have experienced environmental changes (e.g., abrasion) or damage by pests or disease.

Table 6. Summary of Off-Target Spray Deposition Trends.

Factor	Deposition on Pipe Cleaners (April)			Deposition on Tapes (July, Sept., and Nov.)	
	Through Canopy[z] (μg/cm²)	Drift[y] (μg/cm²)	Wide-Spaced Drift[x] (μg/cm²)	Through Canopy[z] (μg/cm²)	Drift[y] (μg/cm²)
Spacing					
Wide	25.8	32.8	—	4.6	3.5
Close	27.8	29.9	—	3.6	2.5
Cultivar/System					
Smoothee/Trellis	25.5	36.5	34.6	3.4	3.5
Lawspur/Trellis	29.7	26.1	25.3	3.4	2.5
Lawspur/Central Leader	25.3	—	—	5.5	—
Timing					
July	—	—	—	2.3	1.3
September	—	—	—	3.1	1.5
November	—	—	—	6.9	6.3
Downwind Distance					
2 m	—	34.9	36.7	—	3.7
4 m	—	36.8	34.4	—	2.8
6 m	—	22.2	26.7	—	2.6
12 m	—	—	21.9	—	—
F-Significance					
Spacing	NS[w]	—	—	NS	NS
Cultivar/System	NS	—	—	**	NS
Timing	—	—	—	***	***
Downwind Distance	—	—	—	—	NS

[z] 2 m.
[y] 2, 4, and 6 m.
[x] Wide space only.
[w] NS, **, *** = Nonsignificant or significant at $P \geq 0.01$ or 0.001, respectively.

Other authors have reported changes in pesticide retention with the age of the leaf, and that the effect was species specific. Bukovac *et al.* (4) found the chemical composition and pesticide retention of a peach-leaf surface to vary with the age of the leaf. Baker (2) noted that environmental conditions can modify the size and distribution of the surface wax structure. In many species, the epicuticular wax system of young leaves is less well-developed than that of older leaves, and the quantity of wax increases as the leaf ages (3, 4, 12, 15).

In addition, aphids, for example, generally feed preferentially on younger leaves; leaf miners occupy slightly older leaves; and various apple diseases possess similar preferential infection sites. While it is currently accepted theorem that cultivars differ in susceptibility to pests and diseases, there remains a lack of organized crop protection guidelines illustrating the complex interactions between pest density, cul-

Table 7. Spray Retention and Leaf Hair Density on Each of the Variables.

	Spray Retention (mg/cm²)				Leaf Hair Density (hairs/mm²)			
	Experiment Timing				Experiment Timing			
Factor	**May**	**July**	**October**	**Mean**	**May**	**July**	**October**	**Mean**
Leaf Surface								
Abaxial	10.81	11.55	9.41	10.59	44.8	41.0	19.1	35.0
Adaxial	6.07	3.01	2.31	3.80	3.3	1.0	0.4	1.6
Leaf Type								
Shoot	8.89	7.63	5.95	7.49	27.6	26.7	10.6	21.6
Spur	7.99	6.93	5.76	6.89	20.5	15.4	8.9	14.9
Cultivar								
Empire	10.5	10.4	9.6	10.2	37.4	33.4	16.1	29.0
Oregon Spur	9.1	7.6	5.9	7.6	31.4	23.5	12.9	22.6
Lawspur	7.0	6.0	4.2	5.7	14.4	15.2	4.2	11.3
Smoothee	7.1	5.1	3.7	5.3	13.0	12.1	5.8	10.3
Timing Means	8.4	7.3	5.9	24.1	21.1	9.8		
F-Significance								
Leaf Surface	—	—	—	***z	—	—	—	—
Leaf Type	—	—	—	***	—	—	—	—
Cultivar	—	—	—	***	—	—	—	—

z *** = Significant at $P \geq 0.001$.

tivar tolerance to pests (damage sensitivity), and pesticide retention advantages offered by specific actives, adjuvant, and spray-delivery combinations.

From a chemical perspective, Hartley and Graham-Bryce (11) provide fundamental information about pesticide characteristics and pesticide/leaf-surface phenomena. Forshey (7) briefly summarizes some of the major studies of growth regulators where retention, penetration, and growth responses are measured in/on apple and other tree fruit leaves. The parameter that showed the largest difference in spray retention in these studies was leaf surface (Table 7). Significantly more spray was retained on the abaxial than the adaxial surface. This corresponded to the abaxial surface having a much denser covering of leaf hairs.

Ennis *et al.* (6) found marked differences in the amount of spray retained by pubescent and glabrous soybean plants, with the pubescent plants retaining more spray than the glabrous ones. Bukovac *et al.* (4) showed the two surfaces of peach leaves to differ markedly in the composition of the epicuticular wax, and Anderson *et al.* (1) noted that the abaxial surface of wheat leaves was devoid of crystalline wax, whereas the adaxial surface was covered with platelets.

Table 8. Comparison of the Changes in Shoot and Spur Leaves During the Growing Season.

	Leaf Weight (g)			Leaf Area (cm^2)		
Leaf Type	May	July	October	May	July	October
Shoot	0.629 a[z]	0.653 a	0.639 a	23.2 a	22.5 a	22.6 a
Spur	0.300 b	0.393 b	0.415 b	10.4 b	13.7 b	14.9 b

[z] Means within columns followed by a common letter do not differ significantly at the 5% level (F-test).

Table 9. Covariate Analysis of Leaf Hairs of Three Experimental Variables.

Factor	Factor df	Factor MS ($X 10^{-5}$)	Error MS ($X 10^{-5}$)	F-Value	Pr > F
Leaf Hairs (LH)	1	78.0	0.2	406.84	0.0001
Timing (T)	2	0.2	0.2	1.03	0.3659
LH X T	2	7.5	0.2	38.86	0.0001
Leaf Hairs	1	78.0	0.5	158.97	0.0001
Cultivar (CV)	3	0.7	0.5	1.36	0.2693
LH X CV	3	0.6	0.5	1.17	0.3331
Leaf Hairs	1	78.0	0.5	150.34	0.0001
Leaf Type (LT)	1	0.4	0.4	0.84	0.3649
LH X LT	1	0.1	0.5	0.16	0.6874

There was a small, but significant, difference in the spray retention between shoot and spur leaves (Table 7). Spur leaves consistently retained slightly less spray throughout the season than shoot leaves, which corresponded with spur leaves having fewer leaf hairs than shoot leaves. In this study [and consistent with Schechter *et al.* (13)], shoot leaves were significantly heavier and larger than spur leaves at each of the three timings (Table 8).

Finally, the cultivars retained significantly different amounts of spray (Table 7). When the data were averaged over all three timings, 'Empire' retained twice as much spray as the cultivar 'Smoothee.' Again, the retention followed the trend of leaf-hair density, with an increase in pubescence corresponding to an increase in spray retention. An analysis of covariance (Table 9) showed there to be a significant correlation between number of leaf hairs and spray retention. However, there was only one variable, experiment timing, which gave a significant correlation with spray retention.

The obvious implication for crop protection is that rates may be able to be reduced by 50% on Empire. However, these studies were not designed for that objective, nor do data or retention consistently yield equivalent biological results. In addition, commercial apple plantings frequently contain a two- to three-cultivar mixture, thus complicating still further any crop protection decisions designed to reduce rates by cultivars. However, where solid blocks occur, rate reductions to take advantage of culti-

var susceptibility, pesticide retention data, and other factors, as well as modification of spray-timing intervals, could be utilized to optimize crop-protection strategies.

Conclusions

Growers can do much with information, technology, and equipment they already have on the farm. Although airblast sprayers are not easy to adjust, operations can be accomplished to improve delivery to the wide array of tree canopies and geometries. The problem is making growers aware of the need to do so (economic, environmental, and IPM advantages) and the potential that exists for their operation by:

- Matching sprayer delivery/canopy geometry for each block.
- Developing a block-by-block crop-protection strategy (the variation in cultivar susceptibility/tolerance to various pests is under-used by most growers).
- Recognizing that time of year, system/cultivar interactions, and pesticide type/cultivar/leaf interactions all play key roles in effective spray-capture efficiencies.

An intimate knowledge of these relationships combined with historical information on cultivar/pest infestation histories and cultivar susceptibilities will aid in making effective crop protection decisions and developing successful IPM strategies.

Keeping pesticides on target — i.e., defining that target and making appropriate adjustments in spray-delivery protocols throughout a growing season — is going to be a very important issue for the tree fruit grower as the next century approaches. Faced with increasing spray costs, increasing regulations, and public pressure to use less (pesticides), management strategies that address these issues will clearly pay dividends for the grower who is willing to invest the management expertise to solve these problems.

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The Influence of a Synthetic Foraging Attractant, Bee-Scent™, on the Number of Honey Bees Visiting Apple Blossoms and on Subsequent Fruit Production

James E. Tew and David C. Ferree

Abstract

In three of the four years monitored, Bee-Scent™ influenced the number of honey bees foraging in treated apple orchards but did not seem to dependably increase the numbers of pollen-collecting foraging honey bees. Subsequent analysis of fruit quality and quantity was also positively influenced by Bee-Scent™ applications.

Introduction

Throughout the decade of the 1990s, honey-bee populations — both managed and feral — dropped precipitously because of chronic parasitism by newly introduced Varroa mites *(Varroa jacobsoni)* and Tracheal mites *(Acarapis woodi)*. Pollination concerns have been expressed both by beekeepers and fruit-and-vegetable growers as honey-bee populations have dwindled over the years.

As early as 1901, Sladen (8) described the function of the Nasonov gland (the scent gland) as one that functioned to produce chemicals that were attractive to other honey bees. Early pollinator attractants were essentially composed of scented sugared water. Rajotte and Fell (7), Burgett and Fisher (3), and Tew and Ferree (9) all reported that mixtures of scented sugar water were not effective in increasing fruit set on various crops. In 1965, Boch and Shearer (2) suggested that synthetic Nasonov gland secretions could possibly be used to attract bees to marginal crops. By 1987, Free *et al.* (4) reported that lures containing the synthetic components (E)- and (Z)-citrals, geraniol, nerolic, and geranic acids were effective in attracting honey-bee swarms and indicated that the attractant may have other uses. Bee-Scent™ is a commercially produced synthetic Nasonov pheromone. Mayer *et al.* (5) was able to show significant improvement in apple set after applying Bee-Scent™.

A series of studies was conducted over a four-year period (1991, 1993, 1994, 1995) to determine the effectiveness of Bee-Scent™, a commercially available honey-bee attractant, on foraging honey bees in two Ohio apple orchards. To compile data, various outdoor studies were implemented to monitor the activities of honey bees foraging on 'RedChief Delicious' apples after being treated with Bee-Scent™. Also, within greenhouse conditions, honey-bee foraging studies were conducted on potted apple trees to test the effective attractive distance from treated trees and the persistence of Bee-Scent™. Fruit set and size distribution were also monitored each year.

Materials and Methods

Outdoor Tests

All test sequences conducted outdoors had several criteria in common. Two orchards, approximately two miles apart, were used as needed in these studies. The first plot, located

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at The Ohio State University/Ohio Agricultural Research and Development Center (OARDC) Horticulture Unit 2, was a 3.2 acre block of 'RedChief Delicious' that was laid out north to south. At the beginning of the study (1991), the trees in Hort Unit 2 were seven years old and were set on MM.111 rootstock spaced 4.0 x 5.5 m. Tree pollenizers in Unit 2 were 'Golden Delicious,' 'Melrose,' and 'Rome Beauty.'

The second plot was located at OARDC's Snyder Farm and consisted of a four-acre plot planted in groups of four cultivars — 'Rome Beauty,' 'Golden Delicious,' 'McIntosh,' and 'RedChief Delicious' — and was laid out east to west. In both orchards, unsprayed test controls were always placed on the opposite end of the respective orchard from the tested trees. Both orchards allowed for approximately 300 feet separation between controls and treatments.

In all four test years, Bee-Scent™ was applied at 2 qts. per acre with an air-blast sprayer set to deliver 100 gal. per acre. Bee-Scent™ was applied when 10–20% of the king blooms were open. Fifteen trees were randomly selected in the sprayed and control areas; these trees were used in obtaining detailed measurements of bee behavior and fruit development.

In all outdoor test sequences, when king blooms were 10–20% open, bee hives were moved within 75 feet of the orchard. Three hives, averaging 35,000 bees per colony, having similar brood populations and similar food reserves, were positioned on either end of the respective test orchard. Therefore, six hives were used in each test at rates of nearly two colonies per acre (unless otherwise noted).

Beginning 24 hours later, depending on weather conditions, foraging bee counts were made during the day, at approximately two-hour intervals, until 1600 hours. Bee counts were made by counting foraging bees in the tree canopy during a one-minute period. Pollen foragers are better pollinators than nectar foragers. However, it is difficult to determine if a bee is a pollen collector if the foraging trip has only recently begun. Regardless, in all tests except 1995, when possible, pollen foragers were counted separately. The same person was responsible for taking all foraging estimates.

Portions of each of the 15 designated trees, containing approximately 200 flower clusters, were tagged and counted at bloom and later in the season when the final crop was harvested. All fruit from each tree were graded on an FMC weight size, and the number of fruit in each of the four size classes was determined. A sample of 10–25 apples from the box size 100–113 were measured for their length-diameter ratio. Fruit were cut and seeds counted.

Though similar in many respects, each of the four trials had some objectives unique to that particular study. These unique objectives are described here.

In 1991 and 1993, outdoor studies were conducted only in the Unit 2 orchard.

1993 Greenhouse Observations

On February 7 and March 8, 1993, dormant, potted apple trees were moved into a heated greenhouse to force blooming. During all subsequent tests, greenhouse ventilation systems were turned off. Three separate greenhouse apple pollination studies were set up and are discussed here.

Test 1 (March 6)

Five clusters on six control trees and five clusters on six treated trees were marked with plastic ribbon. While shielding all remaining parts of the trees, treatment clusters were sprayed with a hand sprayer, applying Bee-Scent™ at a dilution rate of 1.43 ml per 500 ml water (2 qts. per 150 gal.). Controls were shielded and sprayed with water. All trees were allowed to dry for one hour before being moved into a different greenhouse, where they were randomly positioned approximately 25 feet apart around the greenhouse. A double-story honey-bee hive, containing approximately 15,000 to 20,000 bees, approximately 40 square inches of open brood, and ample honey stores, was placed in the middle of the greenhouse on March 2, 1993. Experienced honey-bee foragers had been eliminated from the colony. Bee-forager activity was observed for six replications with each replication lasting 15 minutes.

Test 2 (March 8)

Four potted trees were completely sprayed with Bee-Scent™ while four other trees were sprayed with water to serve as controls. After a nine-minute observation (divided into three-minute intervals) was taken, trees were moved

to the opposite side of the greenhouse to observe variations within foraging behavior caused by specific location in the greenhouse. The nine-minute count was subdivided into three-minute intervals to observe bee-forager dynamics.

Test 3 (March 29)

Four trees were completely sprayed with Bee-Scent™ (dilution rate 1.4 ml per 500 ml) once while four more trees were retreated daily. Four trees sprayed with water served as controls. Two sets of six clusters each were labeled and monitored for three days after applications. Treatment control trees were rotated after nine minutes to observe bee foraging behavior. Counts were taken at three-minute intervals within the nine-minute count to observe bee-forager dynamics. The same bee hive was used as in Test 1.

1994 Observations

The outdoor studies for this year followed the general methods discussed earlier but with one major change. Rather than only applying Bee-Scent™ once at king bloom, applications were made every other day until peak bloom. The Snyder Farm orchard was used. No greenhouse studies were conducted in 1994.

1995 Observations

The outdoor studies for this year followed the general methods discussed previously but with one major change. In light of the general reduction of the feral population of honey bees, observations were taken to determine if an application of Bee-Scent™ could positively affect fruit set when only 50% of a normal foraging honey-bee population was moved into an orchard (one-half colony per acre rather than the traditional one colony per acre). One-half colony per acre was supplied to the Snyder Farm orchard, while two full colonies per acre were supplied to the Unit 2 orchard. Though weather cannot be used as an excuse, it was a significant factor during the 1995 season. The blooming season was abnormally wet with orchards being constantly wet and muddy.

Results and Discussion

1991 Results

During the 1991 test period, 426 bees were counted on 262 treated trees for an average of 2.5 bees per tree (Table 1). On 165 control trees, 262 bees were observed, averaging 1.7 bees per tree. The difference between means of the total bees on trees was highly significant ($P > 0.0004$). Of the 426 bees foraging on treated trees, 297 (average 1.8 pollen foragers per tree)

Table 1. The Influence of Bee-Scent™ on Honeybee Pollination and Subsequent Fruit Production When Applied Once to 'RedChief Delicious' Apple Trees in 1991.

	Honeybee Foraging Activity[z]			Pollination and Fruit Production[y]					
Treatment	Bees/ Min/ Tree	Pollen-Foragers/ Min/ Tree	Pollen-Foragers (%)	Fruit Set (%)	Drops (lbs/tree)	Picks (lbs/tree)	Fruit Wt. (g)	Fruit Length/ Diameter[x]	Seed Number/ Fruit[x]
Control	1.7 b[w]	1.0 b	59.9	57.5 b	17.6	57.1	154 a	0.85	5.40
Bee-Scent™	2.5 a	1.8 a	69.7	75.4 a	22.2	47.5	135 b	0.85	6.08

[z] Foraging activity observed on April 26, 27, and 28, respectively.
[y] Pollination and fruit production data were obtained from a 15-tree subsample in control and treated plots. Approximately 200 flower clusters per tree were tagged on each tree at bloom for subsequent determination of yield per size data.
[x] Fruit shape and seed number were obtained from a sub-subsample of 10–25 fruit.
[w] Mean separation by the LSD statistic ($P = 0.05$). Values within columns without letters are not significantly different.

were pollen-collecting bees while 157 (average 1.0 pollen foragers per tree) of the 262 bees observed on control trees were pollen-collecting bees.

The difference between pollen forager means was again significant ($P > 0.0011$). However, pollen foragers as a percent of total bees in each group was not significantly different. In the treated group, 69.7% were pollen foragers, while 59.9% of the bees in the control group were pollen foragers ($P < 0.26$).

Fruit set on test trees was significantly increased by nearly 18%, and fruit size with a greater fruit set was reduced by 13% (Table 1). However, because of the severe drought that began in late spring and continued through harvest, fruit size of all fruit was reduced and yields did not differ. The fruit shape or seed content was not influenced by Bee-Scent™.

A correlation analysis revealed the expected significant relationships among the yield components — higher rates of fruit set were related to an increase in drops by weight ($r = +0.57$) and to increased numbers of seeds per fruit ($r = +0.46$) and decreased average fruit weight ($r = -0.66$); the weight of drops was also negatively correlated to the average fruit weight ($r = -0.63$). Perhaps the most interesting of these relationships was the relationship between number of seeds and difference in fruit set that resulted from the Bee-Scent™ application.

1993 Results

Greenhouse Tests

In general, greenhouse tests were inconclusive. Initially, honey bees foraged erratically. Since novice bees were used in the study, this was expected. However, once bees learned to work apple blossoms, numbers and intensity were so great that trends and effects were lost. Interestingly, honey bees were enticed to begin foraging only after a very high concentration of Bee-Scent™ (50% concentrate dilution) was applied to four trees. Bee attraction to blossoms was immediate. From that instant until the end of testing, forager activity on either controls or treated trees, in all tests, was intense. In Test 1, there was no difference between any of the tested treatment means, though there were some differences in bee activity on different days (Table 2, Figure 1A).

In Test 2, there appeared to be no difference in location within the greenhouse or in attractiveness throughout the three-day test period. Results from Test 3 (Table 3) are also inconclusive. Bee-Scent™ applied only once each day (three days total) attracted no more bees than the controls. There was a delay in foragers finding blossoms, but that was expected.

Orchard Tests

Overall, treated trees averaged 5.5 bees per tree, which was significantly different from

Table 2. The Influence of Bee-Scent™ on Honeybee Foraging Behavior When Applied Once to Open Flower Clusters of 'Golden Delicious' Apple (Greenhouse Test 1, 1993).

Factor	No. Feeding Visits per 15 Min.	No. Visits per 15 Min. Without Feeding
Treatment		
Control	78.9	6.5
Bee-Scent™	77.1	5.8
Persistence (days from spray)		
0	54.2 b[z]	7.1 a
1	104.2 a	4.3 b
2	75.5 b	7.0 a

[z] Mean separation by the LSD statistic ($P = 0.05$). Values within columns within factors without letters are not significantly different.

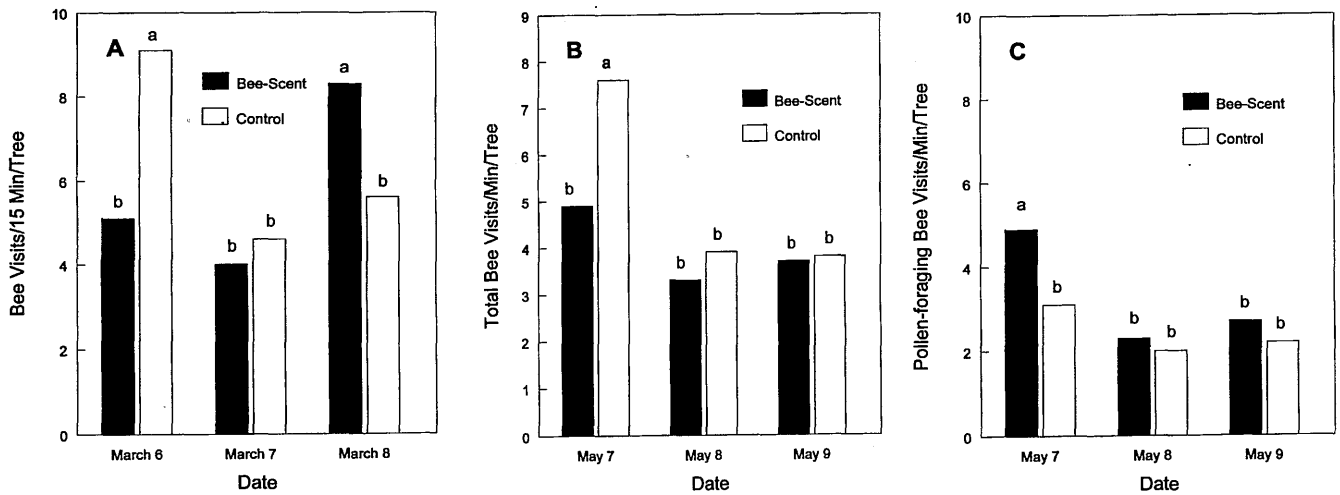

Figure 1. A. Number of bee visits per 15 minutes per tree per day to Bee-Scent™-treated and control 'Golden Delicious' trees (Greenhouse Test 1, 1993). B. Number of bee visits per minute per tree per day to Bee-Scent™-treated and control 'RedChief Delicious' trees (Orchard Test, 1993). C. Number of pollen-foraging bee visits per minute per tree per day to Bee-Scent™-treated and control 'RedChief Delicious' trees (Orchard Test, 1993).

Table 3. The Influence of Bee-Scent™ on Honeybee Foraging Behavior When Applied Once or on Three Successive Days to 'Golden Delicious' Apple Trees (Greenhouse Test 3, 1993).

	Bee Foraging Activity per 3-Minute Period		
Treatment	**Period 1**	**Period 2**	**Period 3**
Control	48.5	140.5	79.5
Bee-Scent™ Applied Once	54.2	152.2	157.5
Bee-Scent™ Applied 3X	45.2	158.7	78.0

Table 4. The Influence of Bee-Scent™ on Honeybee Foraging Behavior and Subsequent Fruit Production When Applied Once to 'RedChief Delicious' Apple Trees in 1993.

	Honeybee Foraging Activity[z]			Pollination and Fruit Production[y]						
Treatment	**Bees/ Min/ Tree**	**Pollen-foragers/ Min/ Tree**	**Pollen-foragers (%)**	**Yield (lbs/ tree)**	**Fruit Set (%)**	**No. Fruit/ Tree**	**Fruit Wt. (g)**	**Fruit Length/ Diameter[x]**	**Viable Seeds/ Fruit[x]**	**Shriveled Seeds/ Fruit[x]**
Control	4.1 b[w]	2.5 b	56.5	104.8 b	67.2	690 b	99.8 b	0.96 a	6.4	0.5 b
Bee-Scent™	5.5 a	3.5 a	57.3	150.5 a	72.5	818 a	110.8 a	0.92 b	6.4	1.1 a

[z] Foraging activity observed on May 7, 8, and 9, respectively.
[y] Pollination and fruit-production data were obtained from a 15-tree subsample in control and treated plots. Approximately 200 flower clusters per tree were tagged on each tree at bloom for subsequent determination of yield per size data.
[x] Fruit shape and seed number were obtained from a sub-subsample of 10–25 fruit.
[w] Mean separation by the LSD statistic ($P = 0.05$). Values within columns without letters are not significantly different.

control trees, which averaged 4.1 bees per tree (Table 4). When evaluated on a daily basis, mean foraging observations were different on the first day (May 7, 1993) but not the following two days (Figure 1B). Trees treated with Bee-Scent™ averaged 7.6 bees per tree while control trees averaged 4.9 bees per tree on May 7. Also, pollen collectors were present in greater numbers on treated trees (3.5 foragers per tree) than on control trees (2.5 bees per tree) (Figure 1C). Again when evaluated on a daily basis, on the first day (May 7), mean pollen foragers on treated trees (4.9 foragers per tree) differed from the mean pollen foragers on control trees (3.1 foragers per tree) while means from the remaining two days were not different (Table 4). Pollen foragers as a percent of total bees in each group was not significantly different (57.3% treatment, 56.5% control).

Fruit Set and Distribution

Spray of Bee-Scent™ increased yield per tree, average fruit weight, and number of shriveled seeds (Table 4). Fruit from treated trees were less elongated. Fruit size was increased, and the percentage culled mostly for inadequate size was decreased by 50%, resulting in nearly doubling the value of fruit from treated trees (Table 5). Commercial growers also experienced extremely small fruit size in 1993 because of a combination of weather factors that resulted in inadequate chemical thinning and overcropping. It is interesting here that even though yield was increased, salable apples were also due to increased size. This was likely caused by the increased seed numbers early in the season during the cell-division period.

1994 Results

Orchard Tests

Multiple applications of Bee-Scent™ appeared to have minimal effect on increasing honey-bee pollinator activity when compared to single applications (as per label instructions). Though the trend shown by the data tended to support multiple applications, the differences were not significant. In the Snyder Orchard, 13.9 bees were observed foraging on untreated trees while 18.4 bees were observed foraging on treated trees. Within the Unit 2 orchard, 40.6 bees were observed forging on untreated trees while 59.5 bees were observed on treated trees (Figure 2A). However, there was a difference when data from both orchards were combined and analyzed. Combined treated means of 36.2 foraging bees per tree were different ($P >$ 0.0054) from combined untreated means of 23.8 bees per tree (Table 6). In all aspects of this study, numbers of pollen-collecting bees appeared to be statistically unaffected by Bee-Scent™ applications though there was again a trend in favor of treated trees. Combined data from both orchards yielded means of 15.7 pollen-collecting bees per untreated tree while treated means of pollen-collecting bees was 23.2 per tree (Figure 2B).

Fruit Set and Distribution

Applications of Bee-Scent™ at bloom to 'RedChief' and 'Smoothee Golden Delicious'

Table 5. The Influence of Bee-Scent™ Applied Once During Flowering on Fruit Size Distribution of 'RedChief Delicious' Apple at Harvest in 1993.

	Weight (lbs per tree)				Weight (% of total yield)				
	Fruit Diameter Range (mm)				Fruit Diameter Range (mm)				
Treatment	>80	80-73	73-57	Cull	>80	80-73	73-57	Cull	Value ($)
Control	0.1	0.5 b[z]	30.5 b	73.7 a	0.1	0.4 b	28.5 b	70.9 a	7.57 b
Bee-Scent™	0.2	11.5 a	92.6 a	46.2 b	0.1	7.1 a	60.8 a	31.9 b	15.79 a

[z] Mean separation by the LSD statistic ($P = 0.05$). Values within columns without letters are not significantly different.

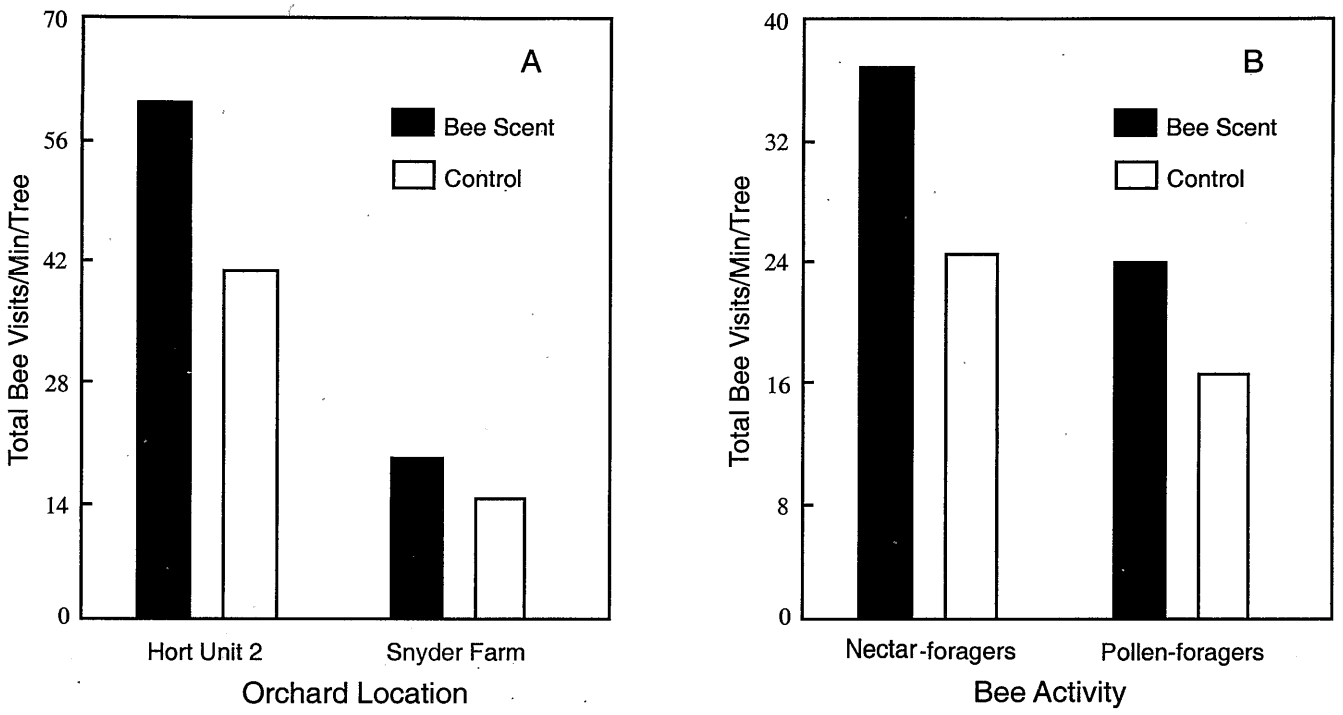

Figure 2. A: Number of bee visits per minute per tree per day to Bee-Scent™-treated and control trees. B: Number of nectar and pollen-foraging bee visits per minute per tree per day to Bee-Scent™-treated and control trees (all cultivars, Orchard Test at both sites combined, 1994).

Table 6. The Influence of Bee-Scent™ on Fruit Set, Fruit Weight, Seed Number, and Seed Viability After Multiple Applications to 'RedChief Delicious' and 'Golden Delicious' Trees During Flowering in 1994.

Location	Cultivar	Treatment	Fruit Set (%)	Fruit Wt. (g)	Fruit Shape (L/D)	Seeds/ Fruit	Viable Seeds/ Fruit	Shriveled Seeds/ Fruit
Hort Unit 2[z]	RedChief Delicious	Control	97	154 a[y]	0.92	5.7 b	6.1	0.2
		Bee-Scent™	100	135 b	0.89	6.6 a	6.1	0.5
Snyder Farm[x]	RedChief Delicious	Control	87	145	0.85	6.0 b	n.d.	n.d.
		Bee-Scent™	86	124	0.90	8.1 a	n.d.	n.d.
Snyder Farm[x]	Golden Delicious	Control	77	163	0.84 b	6.5 b	n.d.	n.d.
		Bee-Scent™	100	104	0.90 a	8.1 a	n.d.	n.d.

[z] Bee-Scent™ sprays applied by airblast sprayer on May 2 (when 10–15% of the flowers were open) and again on May 11 due to a long bloom period.
[y] Mean separation by the LSD statistic ($P = 0.05$). Within columns, values for specific cultivar per location combinations without letters are not significantly different.
[x] Bee-Scent™ sprays applied by airblast sprayer at two-day intervals beginning May 2 for a total of five applications.

had no effect on the percent of fruit set or fruit size (Table 6). Fruit size of Golden Delicious was reduced and, although the 24% increase in set was not significant statistically, the increase in crop was likely responsible for the reduction in size. Production in 1994 was very light in this plot (and over the eastern portion of the United States) due to the heavy crop in 1993 and drought conditions that resulted in reduced flower initiation.

Bee-Scent™ did improve the shape and seed content of both 'Delicious' and 'Golden Delicious' in this study at the Snyder Farm. In the study at Unit 2, 'RedChief Delicious' fruit set or shape was not influenced by applications of Bee-Scent™ (Table 6). Fruit weight was reduced and seed content increased. Fruit from these trees were harvested and graded. Bee-Scent™ treated trees tended to have smaller fruit-size distribution than untreated trees (Table 6). Since yield was not different between the treated and untreated trees, the authors have no explanation for this difference.

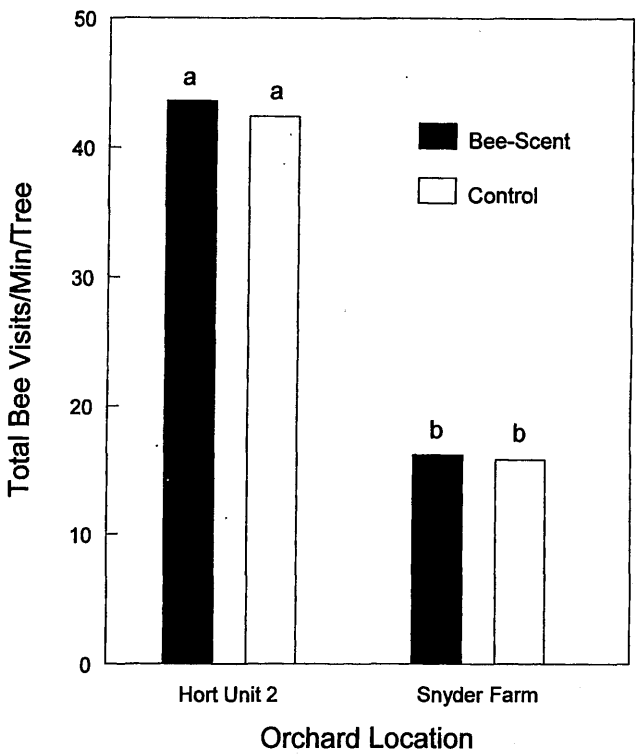

Figure 3. Number of bee visits per minute per tree per day to Bee-Scent™-treated and control trees (all cultivars, Orchard Tests at Hort Unit 2 and Snyder Farm, 1995).

1995 Results

Orchard Tests

During the 1995 season, Bee-Scent™ seemed to have no influence on bee forager populations when compared to controls (Figure 3). Hort Unit 2 averaged 43.6 foragers per tree, while control trees had a mean population of 42.4 bees per tree. The means were not different ($P < 0.65$). Though forager populations were smaller at the Snyder Farm orchard, as was expected, statistical results were similar. Snyder Farm treatment trees averaged 16.2 bees per tree while controls averaged 15.8 bees per tree ($P < 0.92$). When data was combined for both test orchards, significance did not increase. The combined means for treated trees was 29.9 while the combined means of untreated controls was 29.11. The combined means were not different ($P < 0.75$).

Due to the sizable difference in honey-bee populations, means between orchards were different. The mean number of foragers at Unit 2 (43.6 foragers) on treated trees was significantly greater than the mean number of bees on treated trees at the Snyder Farm (16.2 foragers) ($P > 0.022$). Controls were also significantly different. Unit 2 forager-bee populations averaged 42.4, while control populations at the Snyder Farm averaged 15.8 foragers ($P > 0.018$). Though Bee-Scent™ played no role, the significant difference between orchards supports the established concept that foragers from supplemental bee colonies (rented bee colonies) do tend to stay within the orchard to which they are moved. Also, during the 1995 season, continual heavy rains were a major factor.

Fruit Set and Size Distribution

In 1995, application of Bee-Scent™ increased the amounts of large- and medium-size fruit and decreased the amount of small fruit without changing the total yield of 'RedChief Delicious' (Table 7). Fruit set of 'RedChief Delicious' was significantly increased at Unit 2 (control 32% and Bee-Scent™ 52%) with a similar but nonsignificant trend at Snyder Farm (control 31%, Bee-Scent™ 37%).

Conclusions

Overall, Bee-Scent™ was effective in attracting more honey bees to treated orchards. This

Table 7. The Influence of Bee-Scent™ Applied Once During Flowering on Yield and Fruit-Size Distribution of 'RedChief Delicious' Apple at Harvest in 1995.

			Weight (lbs/tree)				Weight (% of total yield)				
			Fruit Diameter Range (mm)				Fruit Diameter Range (mm)				
Treatment	No. Fruit/ Tree	Yield (lbs/ tree)	>80	80–73	73–57	Cull	>80	80–73	73–57	Cull	Value ($)
Control	594	141.8	0.8 b[z]	7.8 b	99.1 a	34.0	0.6	7.0 b	69.0 a	23.3	12.90
Bee-Scent™	587	155.1	3.0 a	42.2 a	74.4 b	35.3	2.3	28.5 a	46.9 b	22.2	14.64

[z] Mean separation by the LSD statistic ($P = 0.05$). Values within columns without letters are not significantly different.

conclusion is supported by the results of studies performed by Mayer *et al.* (5) in Washington. His results showed a significant increase in bee activity in treated areas and in subsequent fruit set. However, Morse (6) said that Bee-Scent™ had not been effective on New York apples. Additionally, studies on other crops have yielded variable results. Ambrose *et al.* (1) found that Bee-Scent™ had no effect on improving set in cucumbers or watermelons.

Though application techniques varied during each test year, Bee-Scent™ was applied at the same period of bloom development in all four years and was compared with untreated trees. In 1991, 1993, and 1994, Bee-Scent™ increased the number of honey-bee foragers on apple blossoms significantly. Though weather is commonly a factor in all outdoor studies, the spring of 1995 was particularly wet and could readily justify the lack of success by Bee-Scent™ that year.

Whereas a trend did emerge toward increased pollen foragers, the data did not clearly show that Bee-Scent™ was effective in attracting more pollen foragers. During the 1991 and 1993 studies, there was a significant difference in the number of pollen foragers, but it could not be shown in 1994. Though the number of pollen gatherers may not always be increased, from the overall data collected it seems apparent that Bee-Scent™ is effective in attracting increased numbers of honey-bee foragers to treated orchards.

Greenhouse studies were unhelpful in determining persistence of Bee-Scent™ residue or of effective Bee-Scent™ bouquet area. This information would have been useful in increased understanding of the characteristics of Bee-Scent™ in outdoor orchard conditions. These questions still need to be studied.

The effects of Bee-Scent™ on fruit set and size distribution varied with season. In years with light crops and ample fruit size (1991 and 1994), there were no beneficial effects. However, in years where commercial growers faced significant problems of small fruit set (1993) or poor set (1995), applications provided significant advantages of improved fruit size and, in 1995, both improved set and fruit size. Fruit set tended to be improved on at least one cultivar in three of the four years the authors correlated tests. The results generally were associated with increased bee foraging.

Since positive benefits occurred in some years, growers may want to consider use of a synthetic bee pheromone attractant in years when problem conditions for pollination and fruit set are threatening. The reduction in feral bees means that growers will need to do everything possible to ensure pollination, including such cultural practices as having ample and strategically located cultivars, decreasing competing flowering plants such as dandelions, and bringing in sufficient strong colonies of bees.

Acknowledgments

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The Reliability of Three Traps vs. a Single Trap for Determining Population Levels of Codling Moth in Commercial Northern Ohio Apple Orchards

Ted W. Gastier

Introduction

Since the early 1700s, when Ohio's first apple trees were planted by French traders in the Maumee Valley, the apple industry in this state has flourished. In recent years, the Ohio apple crop has generated more than $25 million annually for Ohio farm families. However, the acreage devoted to apple production has declined since a time when almost every farm included an orchard.

To understand the reduction in apple acreage and the virtual disappearance of the apple from large areas of rural Ohio, one can look at the ravages of diseases and insects. According to Cutright (2), it is necessary to consider that "codling moth history is an integral part of the history of apple growing in the state." Among insect pests, he concluded "none have been more damaging than the codling moth. The increasing seriousness of codling moth attacks from 1870 to 1920 is shown as paralleling the decline of the farm orchard." Losses to the apple crop during this period of time were documented by annual reports of 13 horticultural societies.

Codling moth larvae are responsible for fruit injury commonly known as "wormy apple." Very little damage is tolerable, as consumers will reject apples infested with second generation larvae (worms). According to Wilson *et al.* *(7)*, control of codling moth is estimated to cost from $25 to $100 per acre, based on 1977 calculations. In research work by F. R. Hall in 1974 and cited by Wilson *et al.*, the dollar loss due to codling moth (without control measures) can be considerable. Based on 1993 dollars, a loss of $950 per acre might be expected on 'Golden Delicious,' $613 per acre on 'Jonathan,' and $350 per acre on 'Delicious,' if no control measures are attempted.

In addition to direct costs for control or potential loss without control, present-day spray schedules can exact a deadly cost on beneficial insects, including both predators and parasites of codling moth. The repeated use of insecticides to control codling moth can also lead to increased pressures from European red mite, as the spray applications can have a deleterious effect on populations of natural enemies of the mite.

Research in Ohio (2) from 1937 through 1963 indicated that "when considered either alone or in combination with the other climatic elements, temperature is the most important factor that influences codling moth behavior." Depending on temperature, Cutright showed that the emergence of the spring generation occurred during a period as short as 14 days and as long as 56 days. The summer brood emerged during a period of 32 to 75 days. A standard spray schedule based only on calendar date does not account for these wide variations in the presence of the codling moth adult.

Materials and Methods

During the 1991 through 1997 growing seasons, some 25 commercial apple blocks located in north central Ohio have been enrolled in an Integrated Pest Management (IPM) program. Supported by grower participation fees and various grant monies, the program included

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weekly orchard monitoring by paid scout/technicians and the trapping of codling moth *(Cydia pomonella)* adults. Sticky wing traps with pheromone lures (Pherocon® 1CP traps from Trece, Inc., and Scentry lures) were used to monitor adult males. Trap bottoms were replaced weekly during periods of moderate to high populations (more than three moths per trap per week) and bi-weekly during periods of light populations. Lures were replaced every four weeks.

One trap per block (approximately 10 acres) was used during the 1991 and 1992 seasons. Because of wide variations in trap catches within neighborhoods (from three to 14, for example), it was decided in 1993 to use three traps in each block, a practice that has been continued through the 1997 season. Because of the importance of keeping codling moth damage to a minimum, the determination of adult male populations has required a high degree of accuracy with the use of three traps rather than a single trap.

The pheromone traps have been used to establish moth emergence for the purpose of initiating degree-day accumulations (biofix), to confirm degree-day predictions, and to determine the adult population's relative size. This project has utilized a threshold of three adults per trap per week as the threshold to determine the need for control measures. A threshold of three is considered to be a moderate population level (5). Harvest surveys of fruit from each block have validated this threshold as adequate for protecting fruit quality. The Codling Moth Management Model (3) suggested a threshold of two to three adult males per week per trap. Further explanation of establishing the biofix for codling moth can be found in Rajotte *et al.* (6) and Brunner *et al.* (1).

Scouting reports, including records of trap catches for codling moth and other apple pests, are shared with participating growers through a weekly in-season newsletter. In addition, records are maintained and analyzed at the Ohio State University Extension office in Huron County, using Quattro Pro as a spreadsheet.

The reliability of trap catches is important in an IPM program for two reasons. A successful IPM program bases spray decisions on orchard conditions, rather than calendar schedules. Spray applications can be avoided when populations are below threshold levels; an erroneous trap catch count that missed on the low side could leave the apple fruit unprotected. The author's method of measuring reliability was to compare each of the weekly three trap counts in each production block with the average of the three. The catch count was considered to be out of tolerance if one or two values were not indicative of the relationship of the three-trap average to the threshold value of three.

Statistical analysis was done on those records considered (visually) out of tolerance during weeks when the overall average exceeded a count of three. The "Descriptive Statistics" tool within the "Analysis Tools Speedbar" of Quattro Pro v.5 was used to measure the confidence level for the values of the three trap catches. Confidence level establishes the trust that can be placed on a range of values being representative of the actual populations of adults. This is important because of potential fruit damage and loss from codling moth (as well as the environmental and economic cost of over spray).

Results and Discussion

The 1991 and 1992 growing seasons' records dealing with single trap/block records were considered only for determining a background of expected populations of codling moth (Figure 1). As was indicated earlier, the wide variation in populations within neighborhoods encouraged the use of multiple traps since 1993. Whether the decrease in weekly-average trap catches since instituting the three-trap regimen can be attributed to that change has only been suggested and not considered by this report. However, Table 1 does indicate the effects of averaging on the range of trap catches.

Block No. 1 was considered to be out of tolerance because the value "five" is greater than the threshold of three and the average was under three (Table 2). Block No. 2 was within tolerance as all values and the average were above threshold. Block No. 3 was outside of tolerance due to the "two." Block No. 4 was also outside of tolerance because of the "eight." Block No. 5 was within tolerance, as all values were below threshold. Figure 2 indicates that, over an entire season, most or all blocks are outside of tolerance by our determination. On a weekly basis,

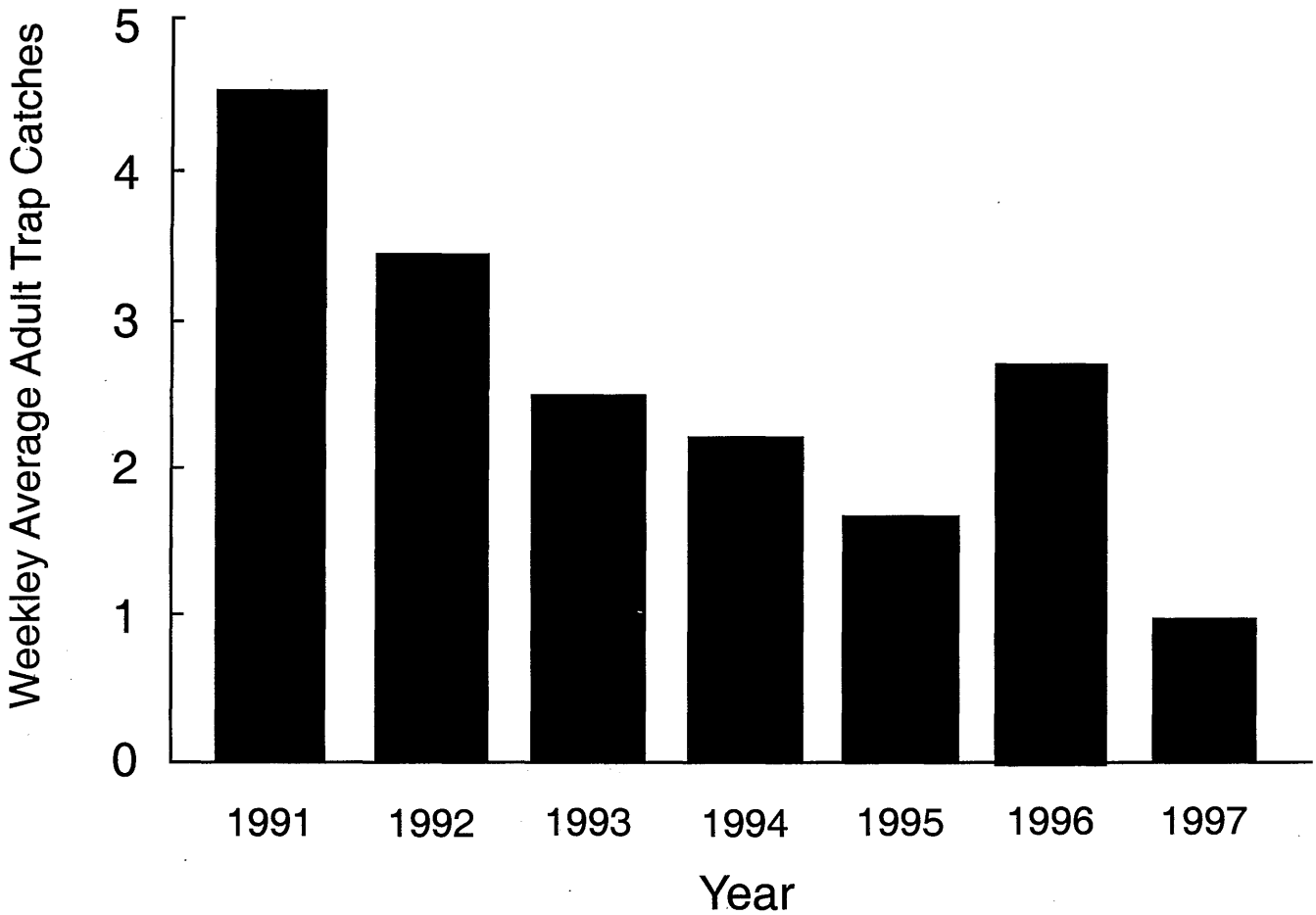

Figure 1. Historic codling moth catches in nine central Ohio apple orchards

Table 1. Extremes in Range of Codling Moth Trap Catches During Weeks of High Populations Across All Blocks.

Year	Single Trap	Mean of 3-Traps
1991	0 - 29	—
1992	1 - 19	—
1993	0 - 17	0.3 - 12.0
1994	0 - 21	1.3 - 19.0
1995	0 - 20	0.3 - 15.7
1996	0 - 22	0 - 14.3

Table 2. Actual Values to Show How the Catches Were Interpreted to Measure Reliability (Week of August 14, 1995).

Block	Trap Counts	Mean of 3 Traps	Confidence Level
1	0, 5, 3	2.7	2.85
2	4, 5, 7	5.3	1.73
3	2,15, 8	8.3	7.36
4	0, 1, 8	3.0	4.93
5	0, 3, 1	1.3	1.73

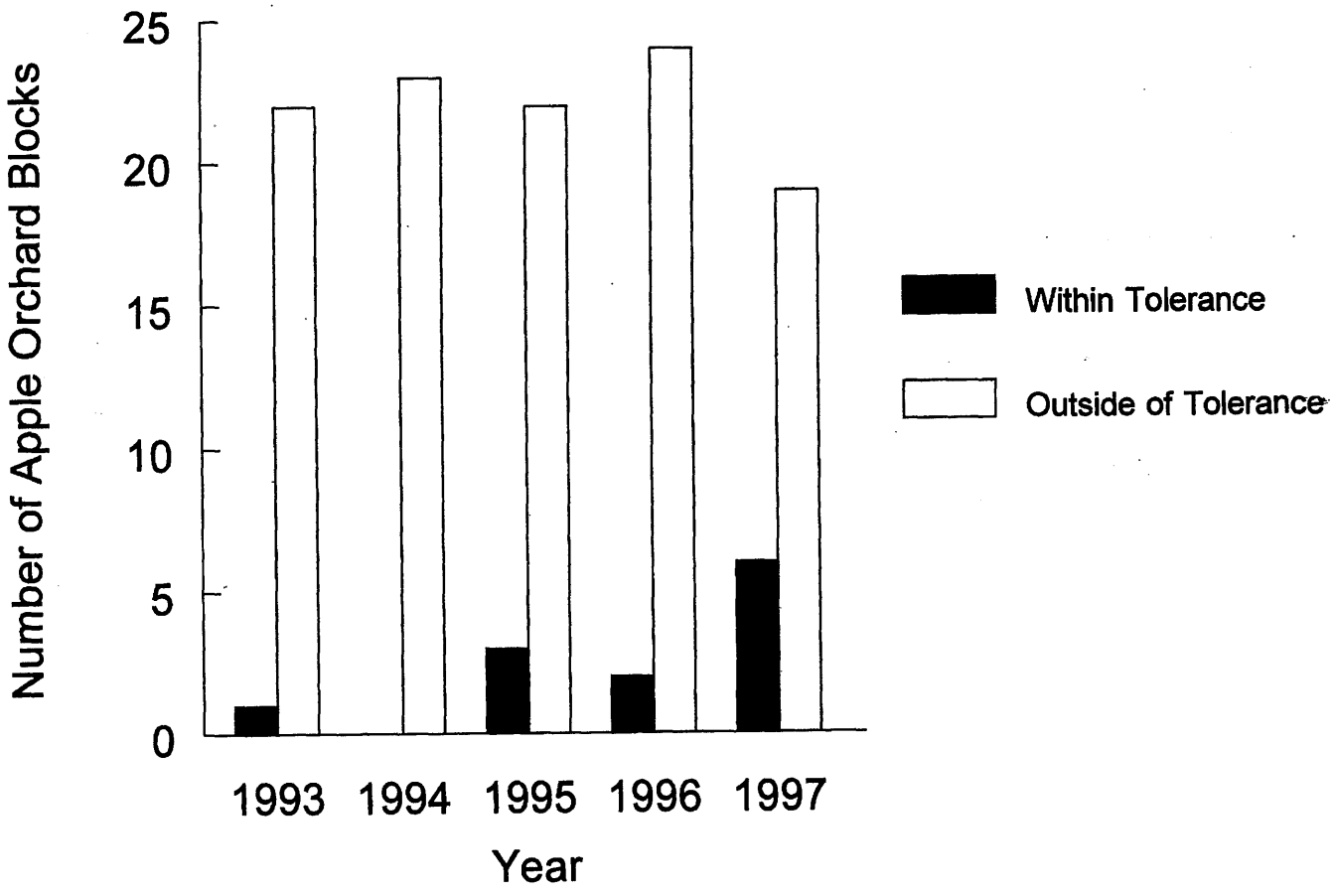

Figure 2. Blocks within and outside of tolerance observed during codling moth monitoring in north central Ohio.

those within tolerance in 1993 were 67%; in 1994, 62%; in 1995, 73%; in 1996, 63%; and 82% in 1997. During weeks when the average across all blocks exceeded the threshold, fewer blocks were within tolerance — in 1993, 56%; 1994, 44%; 1995, 64%; and 1996, 47%. The average across all blocks never reached the threshold values in 1997.

Yearly average confidence levels were calculated for those blocks out of tolerance as determined by visual inspection. Those values were 3.4148 in 1993, 3.2037 in 1994, 3.7056 for 1995, and 2.8764 for 1996. (No confidence levels were calculated for 1997 as weekly average catches never exceeded three across all 26 blocks.) As the confidence level, expressed as a positive number, increased above one, the reliability decreased.

Analysis of the trap catch numbers that were out of tolerance indicated that 41% were high readings and 59% were low readings. This can be interpreted by saying that three out of five times, when a single trap count was out of tolerance by being three or less when the average was greater than three, fruit would have been unprotected.

The additional cost of traps, lures, and scout time is estimated to be $33 per block. Based on Ohio Agricultural Statistics (4), this cost would be covered by 1% of the average per acre Ohio apple production.

Acknowledgments

The author wishes to acknowledge the cooperation and financial support of 21 farm families involved in this ongoing IPM program. The professional conduct of scout/technicians Gene Horner and Jim Mutchler also deserves public recognition for their dedication of service to the

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Evaluation of an Empirical Model for Predicting Sooty Blotch and Flyspeck of Apples in Ohio

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Introduction

Sooty blotch (SB) of apples, a disease complex caused by *Peltaster fructicola* Johnson, Sutton & Hodges, *Leptodontium elatius* (G. Mangenot) De Hoog, *Geastrumia polystigmatis* Batista and M. L. Farr, and other fungi (7, 8), and flyspeck (FS), caused by *Schizothyrium pomi* (Mont. and Fr.) Arx. (anamorph: *Zygophiala jamaicensis* E. Mason), are the most common summer diseases of apple (*Malus* x *domestica* Borkh.) in Ohio. Infections by fungi that cause these diseases may occur soon after petal fall (mid to late May to early June) in Ohio; however, symptoms generally do not appear until late July or August. The incidence and severity of sooty blotch and flyspeck are dependent upon moisture and temperature conditions (1, 6, 7, 10, 13). Brown and Sutton (2) reported that, in the mountainous apple-growing areas of North Carolina, the average daily temperatures from petal fall to harvest rarely fall outside the optimum range for the SB and the FS fungi. Therefore, symptom development is most likely dependent on the frequency of moisture and, to a lesser extent, on temperature. Similar temperature patterns occur in Ohio from petal fall to harvest.

Models have been developed for several apple diseases to warn that infection has occurred (4, 9). These models are based on measures of moisture (leaf wetness, rainfall, or relative humidity) and temperature. However, there are fewer models that predict the appearance of symptoms (11, 14). Brown and Sutton (2) have developed a model that predicts when symptoms of SB and FS first appear in the orchard. Their model is based on cumulated hours of wetting of four hours duration or greater, beginning with the first rain 10 days after petal fall. They suggest the use of a threshold of 200 or 225 hours of accumulated wetness to initiate a fungicide program for controlling SB and FS. The model does not consider temperature effects and has been validated at several locations in North Carolina (2) and in Kentucky (5).

In Ohio, SB and FS generally require a 10- to 14-day protectant fungicide program throughout the summer to provide effective control. During dry growing seasons, the spray interval can generally be extended; however, there is no scientific basis to determine how far spray intervals can be extended. By predicting when symptoms first appear in the orchard, Brown and Sutton's model could serve as a guide for initiating fungicide applications for controlling these diseases. In dry growing seasons, the use of such a model could result in reduced fungicide use. The objective of this study was to evaluate the model under Ohio conditions.

Materials and Methods

Validation studies were conducted during three growing seasons (1993, 1994, and 1995) in three orchards located at the Ohio Agricultural Research and Development Center's Snyder Farm on The Ohio State University's Wooster, Ohio, campus. One orchard (Mark orchard)

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consisted of four-tree blocks of the cultivars 'Delicious,' 'McIntosh,' 'Golden Delicious,' and 'Rome,' in that order from east to west, planted 3 m apart within the row with 9 m between rows. The wide spacing between rows was to facilitate the use of the orchard for fungicide screening trials. All trees were planted on Mark rootstock in 1986.

The second orchard (M.9 orchard) consisted of six-tree blocks of 'Liberty' alternated with 'McIntosh,' planted on M.9 rootstock in a high-density system trained to a three-wire trellis. Trees were spaced with 2.1 m between trees and 3.7 m between rows. The orchard was planted in 1989.

The third orchard was a 30-year-old abandoned orchard of the cultivar 'Cortland' on seedling rootstock. This orchard is situated on the northeast corner of the farm and is located approximately 500 m from the other test orchards. Unsprayed fruit in the abandoned orchard were also examined for SB and FS symptom development on the same schedule as the test orchards. The date of first symptom development was recorded for each disease in each orchard.

Cumulative hours of leaf wetness of four hours duration or greater, beginning with the first rain 10 days after petal fall, were recorded using a Belfort leaf-wetness recorder manufactured by Belfort Instruments Company, 727 S. Wolfe Street, Baltimore, Maryland 21231-3513. The instrument uses a hemp string as a sensing element and functions in a similar manner to the de Wit leaf wetness meter (12) that was used by Brown and Sutton to develop the SB and FS model (2). Changes in the length of string in response to wetting are recorded on a revolving seven-day chart. The instrument was placed near the center of the Mark orchard. It was placed on the north side of a tree, within the drip line, approximately 1.5 m above ground. An hour was considered wet when there was a 50% or greater deflection in the recording pen from the dry to wet position. Fruit on unsprayed trees of the cultivars 'Golden Delicious,' 'Liberty,' and 'Cortland' in the Mark, M.9, and abandoned orchards, respectively, were examined every other day for symptoms of SB and FS beginning at 10 days after petal fall.

During the 1993 and 1994 growing seasons, fungicide applications were made in the Mark orchard only for SB and FS control in response to various numbers of accumulated wetness hours. In 1993, two treatments in the annual fungicide evaluation trial received applications of Captan 50WP at 4 lb/A at inch green, followed by Nova 40WP at 5 oz. per acre on a 10-day schedule, from tight cluster to second cover for control of apple scab. Nova is known to have little efficacy for control of SB and FS. Treatments consisted of four, single-tree replications of 'Golden Delicious' arranged in a randomized complete block design. Fungicides were applied dilute (300 gal/A) with a handgun at 450 PSI. Petal fall occurred on May 13, and second cover occurred on May 27.

Accumulation of wetness hours was initiated at 10 days after petal fall on May 23. Fungicide applications in these plots were suspended after second cover until wetness hours reached 200 and 250 hours, respectively. Foliar applications of Benlate 50W 12 oz. per acre plus Captan 50W 4 lb. per acre were applied to each plot when the designated number of hours were reached. Additional cover sprays were then maintained on a 14-day schedule until harvest. Percentage of fruit infected by SB and FS was determined on 25 fruits per tree (replication) for each treatment (200 and 250 accumulated wetness hours) and an untreated control at harvest.

In 1994, two treatments were repeated as previously described except that 300 and 325 wetness hours were used to initiate cover sprays after second cover. Petal fall occurred on May 18, and accumulation of wetness hours was initiated on May 28 (10 days after petal fall). Second cover was made on June 2.

Results

During all three years of testing, the number of wetness hours required until the first symptoms of SB and FS were visible exceeded the 200- to 225-hour threshold in the Mark and M.9 orchards (Table 1). In 1993, conditions were very dry, and a total of only 277 hours of wetness was accumulated for the entire season. Although the authors initiated fungicide treatments at 200 (Aug. 3) and 250 (Sept. 8) hours of wetness, no SB or FS developed. By initiating

Table 1. Number of Accumulated Hours of Wetness Greater Than Four Hours Duration When First Symptoms of Sooty Blotch and Flyspeck Appeared in Three Apple Orchards During Three Years of Testing.

	Accumulated Number of Hours of Wetness Prior to Symptom Development					
	1993		1994		1995	
Orchard	SB[z]	FS	SB	FS	SB	FS
Mark	ND[y]	ND	392	392	489	489
M.9	ND	ND	392	392	489	489
Abandoned	225	240	231	244	241	241

[z] SB = sooty blotch and FS = flyspeck.
[y] ND = no disease developed.

cover sprays at 200 and 250 hours, a total of four and six sprays were saved, respectively (Table 2). For the 250-hour treatment, no additional sprays were made after second cover. In the abandoned orchard, symptoms of SB were observed at 225 hours and FS at 240 hours. Although disease incidence in the abandoned orchard was 100%, disease severity was low (less than 5%).

In 1994, similar results were observed. Due to the lack of symptom development in 1993, the authors extended the threshold period to 300 and 325 hours. First symptoms of both diseases were observed at 392 hours on July 25 in the Mark and M.9 orchards. A total of 657 hours accumulated for the total season (ending Aug. 30). At harvest, the incidence of SB and FS was 100% and 79%, respectively, on unsprayed 'Golden Delicious' fruit in the Mark orchard; however, severity was less than 2% for each disease. By initiating fungicide sprays at 300 hours (July 9) and 325 hours (July 12), two fungicide applications were saved and disease control was still 100%. In the abandoned orchard, first symptoms of SB and FS were observed after 230 hours (June 30) and 244 hours (July 2), respectively. At harvest, disease incidence and severity were 100% and 85%, respectively.

In 1995, SB and FS first appeared in the Mark and M.9 orchards after 489 hours of wetness on July 28. Symptoms of both diseases first appeared after 241 hours of wetness in the abandoned orchard.

Discussion

Conditions for SB and FS development in the Mark and M.9 orchards were not highly conducive. Both orchards have well-pruned (3) dwarf trees and are in an open area that promotes good air movement. In addition, the orchards are approximately 500 m from the nearest woods. There were no wild brambles within the orchard to serve as a source of inoculum. In contrast, the abandoned orchard, which has not been pruned for more than 25 years, contains a large population of wild blackberries and raspberries (alternate hosts) and consists of very large trees on seedling rootstock. The authors believe that the differences in orchard management and inoculum level for both diseases account for the large differences in the number of accumulated wetness hours required for first symptom development in these tests.

In the well-managed orchards with very low inoculum levels, the number of accumulated wetness hours greatly exceeded the 200- to 225-hour threshold suggested by Brown and Sutton

Table 2. Timing of Fungicide Applications in a Standard 14-Day Protectant Schedule in Response to Accumulated Hours of Wetness of Four Hours Duration or Greater for Control of Sooty Blotch and Flyspeck in 1993 and 1994.

	1993 Program[z]			1994 Program[y]		
Application Timing	Standard	200 Hr	250 Hr	Standard	300 Hr	350 Hr
Petal Fall	May 13	May 13	May 13	May 18	May 18	May 18
First Cover	May 20	May 20	May 20	May 24	May 24	May 24
Second Cover	May 27	May 27	May 27	June 2	June 2	June 2
Third Cover	June 10	—[c]	—	June 15	—	—
Fourth Cover	June 24	—	—	June 28	—	—
Fifth Cover	July 8	—	—	July 12	July 12	July 12
Sixth Cover	July 22	—	—	July 27	July 27	July 27
Seventh Cover	Aug. 5	Aug. 5	—	Aug. 10	Aug. 10	Aug. 10
Eighth Cover	Aug. 19	Aug. 19	—	Aug. 24	Aug. 24	Aug. 24

[z] 200 Cumulative wetness hours were reached on Aug. 3; 250 cumulative wetness hours were reached on Sept. 8.
[y] 300 Cumulative wetness hours were reached on July 9; 325 cumulative wetness hours were reached on July 12.
[c] No spray made due to lack of threshold wetness hours.

(2). However, in the abandoned orchard, first symptoms always appeared in less than 250 hours over three years of testing. Thus, under conditions that are highly conducive for disease development, a threshold of 200 to 250 hours may be satisfactory for use within Ohio. In orchards where conditions are not highly conducive for disease development, a much higher threshold may be required.

In order to determine a precise threshold for well-managed orchards with low inoculum levels in Ohio, a great deal of research is required; however, use of a conservative threshold such as 225 to 250 wetness hours could be valuable. Use of a threshold of 250 wetness hours for well-managed, low-inoculum orchards, especially during dry growing seasons, could allow growers to adjust the summer disease-spray program. Growers may wish to cut sprays completely until the threshold is reached, increase spray intervals to 21 days instead of 14, or use only a protectant fungicide such as Captan in cover sprays, and include a benzimidazole fungicide such as Benlate or Topsin-M only when the 250-hour threshold is reached.

Acknowledgment

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Influence of Pesticides and Water Stress on Photosynthesis and Transpiration of Apple

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Introduction

Chemical pesticides are frequently applied to crop plants that are already under environmental stress. In fact, the pesticide application process itself may be the cause of additional plant stress. Thus, crop plants are often subjected to two or more stress factors simultaneously, the combination of which may result in a different level of physiological response than that caused by individual stress factors alone. The effects of these combined stresses are often subtle in nature and may go unobserved until visual symptoms appear. Consequently, the direct measurement of some sensitive physiological processes such as photosynthesis (Pn) may be the best and earliest means of detecting potential plant injury.

Many of the early pesticides used in agriculture reduced growth and yield of the very crop plants they were designed to protect. These effects have been reviewed for many of the older sulfur, copper, and oil formulations as well as some of the newer organic materials (2, 8, 9). Other chemicals such as antitranspirants (29), growth regulators (11, 24), and spray adjuvants (15) can also influence Pn and transpiration (E). Insects and mites (16), foliar and vascular diseases (7, 20, 25, 28), air pollutants (3, 19, 22, 23), and foliar injury (16) as well as physical stress (13) have been shown to cause changes in Pn and E of numerous woody species.

Ferree and Hall (12) looked at the interactions of water stress and mites on potted apple trees and found that both mites and moisture stress reduced Pn and leaf water potential. Soil moisture stress reduced E, while mites increased it. There was no information between changed physiology of the leaf due to soil water stress and mite feeding as reflected in Pn and E measurements. Data from other studies (14), involving the interaction of mites with either scoring or shade, indicated that the influence of mites on Pn was independent of other stress factors, while the effect on E varied. In studies with containerized sweetgum seedlings, Roberts (21) reported no significant interaction between air pollution (sulfur dioxide) and drought on either Pn or stomatal conductance. But in similar experiments with potted red spruce, Roberts and Cannon (23) noted a greater impact of the combination of air pollution and drought on water relations (xylem water potential) than when either stress factor occurred singly. Cannon and Roberts (3) reported an important interaction involving the stomatal physiology of young yellow-poplar seedlings exposed to low levels of ozone and short periods of plant-moisture stress.

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Very few studies have evaluated the impact of the new, more refined protective chemical formulations on host-plant physiology. The present series of nine studies was designed to evaluate some of the newer sulfur compounds and oil formulations that are proposed for use in the production of organic produce.

Materials and Methods

Common Procedures

MM.106 and MM.111 (Study IV) apple rootstocks were planted in a medium containing equal volumes of Wooster silt loam soil, peat, and perlite and grown in a greenhouse. Trees were cut off 10 cm above the soil line, trained to a single shoot, and fertilized every three weeks with a liquid fertilizer (20-20-20) in place of the normal watering. When the trees reached a height of 40–50 cm, the chemical treatments described with each experiment were applied using either a CO_2-pressurized sprayer (Study I, II, III, V, VI) or a hand atomizer (Study IV, VII, VIII, IX) to thoroughly wet all the leaves on each plant. When systemic pesticides were used, the pots were covered with a plastic bag to avoid possible absorption by the roots.

Measurements of Pn and E were made using a portable gas analyzer (Analytical Development Corp., LCA-2) with an air supply unit and a Parkinson leaf chamber (6.25 cm^2). The inlet to supply air to the analyzer originated outside the greenhouse to avoid uneven CO_2 levels in the compartment, and air flow was maintained at 300 ml/min. Trees were placed under a 400 W metal arc lamp suspended above the greenhouse bench to ensure saturating light levels above 800 μmol/m/s. When whole seedlings were treated, measurements of Pn and E were made on a recently fully expanded leaf, usually the sixth to eighth from the terminal end of the shoot at the time of treatment. Normally six single-tree replications were used in a randomized block design. Deviations from this protocol are mentioned in the description of each individual study.

Study I

On June 1, 1990, the materials and rates shown in Table 1 were applied. Pn and E were measured the day of application and 4, 11, 20, 27, and 45 days following application. Phytotoxicity appeared as translucent areas on the leaves and was rated visually on July 17, 1990, using a scale of 1 = no injury to 10 = severe injury. In addition to the degree of injury, the number of leaves showing symptoms and the number of leaves that had abscised were counted. The sixth leaf from the terminal end appeared fully expanded at the time of treat-

Table 1. Influence of Sprays of Oil and Sulfur Formulations and Adjuvants on Leaf Injury and Leaf Expansion of MM.106 Apple Trees. Study I.

		Leaf Injury		Leaf Area $(cm)^2$		
Treatment	Rate/L	Leaves with Symptoms	Severity[z]	Test Leaf	Average Leaf 1-6	Ratio
Control	—	0.0 b[y]	1.0 c	42.7 a	44.8 a	1.1 a
Safer Soap	20.0 ml	0.1 b	1.1 c	47.6 a	46.3 a	0.9 ab
70 Sec Oil	2.5 ml	6.0 a	6.0 a	45.7 a	24.8 c	0.6 c
6E Oil	2.5 ml	5.6 a	4.5 b	42.3 a	31.0 b	0.8 bc
Sulfur 96WP	4.8 g	0.3 b	1.1 c	43.1 a	46.7 a	1.1 a
MicroSulfur	6.0 g	0.0 b	1.0 c	31.5 b	34.1 bc	1.1 a
X100	1.3 ml	0.8 b	1.5 c	36.7 a	40.7 ab	1.5 a
AG98	2.5 ml	0.6 b	1.1 c	43.0 a	38.6 ab	0.9 ab

[z] Rating scale: 1 = no injury to 10 = severe injury.
[y] Mean separation by Duncan's multiple range test ($P = 0.05$).

ment and was used to measure Pn and E. At the conclusion of the study, the average leaf area of the six leaves above the measurement leaf was determined to evaluate the effect of treatment on developing leaf area expansion.

Study II

The pesticide treatments listed here were applied on June 21, 1990: (1) Control, sprayed with distilled water; (2) Microsulfur 80%, 6 g/l.; (3) Safer soap, 2 ml/l.; (4) Combination of 2 and 3; (5) Omite 6E, 0.8 ml/l.; (6) Combination of 3 and 5; (7) Vendex, 0.62 ml/l.; (8) Combination of 3 and 7. The carrier for all sprays was distilled water, and combination sprays were tank-mixed before application.

Study III

The miticides listed here were applied three times to the same trees on June 22, June 29, and July 6, 1990: Control, sprayed with water; Omite WP, 1.5 g/l.; Omite 6E, 0.8 ml/l.; Kelthane 35 WP, 1.3 g/l.; Kelthane 50WP, 0.9 g/l.; Vendex 4L, 0.62 ml/l.; Guthion 3E, 0.9 ml/l.; and Guthion WP, 0.85 g/l.

Study IV

'Red Prince Delicious' apple trees on MM.111 rootstocks were trained to single shoots as previously described. In each of three experiments, six leaves in the center of a 20-leaf plant were randomly assigned a pesticide treatment applied to wetness with a hand atomizer. The leaf receiving the spray was shielded from other leaves on the same plant. The materials used and the application dates are shown in Table 2. Each treatment was replicated six times.

Study V

Fruiting 'Starkrimson Delicious'/MM.106 apple trees in containers were sprayed to wetness with a CO_2- pressurized sprayer on May 15, 1991. Prime oil at 300 ml/l was combined with either 2.4, 4.8, or 7.2 g/l of microsulfur and treated plants were compared with untreated controls. Fruit size and shape were measured on each of 10 fruits per tree. Pn and E were also measured. Each treatment was replicated six times.

Study VI

Fruiting trees of 'Golden Delicious'/MM.106 in containers were sprayed weekly beginning May 15, 1991, with three applications of Safer soap, 20 ml/l; microsulfur, 6.0 g/l; or a combination of the two materials. Treated trees were compared to untreated controls. The diameter of 10 fruits on each tree was measured weekly. Pn and E were measured on a spur leaf of a fruiting spur beginning after the three applications had been made.

Study VII

In 1993, a number of fungicides (see Table 5 for materials and rates) and insecticides (see Table 6 for materials and rates) were evaluated for their effects on Pn and E with the intent of selecting a material to interact with water-stressed and unstressed (control) plants (see Table 7 for materials and rates). All plants were well watered until July 8, 1993, when pesticides were applied with a hand atomizer to thoroughly wet the leaves of whole trees. Trees were not watered following treatment, and Pn and E were measured two hours, one day, and six days after pesticide application. Xylem water potential was measured six days after treatment (26). Treatments were arranged in a split-plot design with water stress as the whole plot and pesticide treatment as the split-plot with eight single-tree replications.

Study VIII

Pesticide sprays (materials listed in Table 8) were applied April 11 and again on April 18, 1994. Following the April 18 application, water was withheld from half the seedlings, while the other half were watered as needed. As soon as some of the trees in the water-stressed treatment exhibited slight wilting, all trees in this treatment received 100 ml of water. This sequence was repeated until the study ended. Measurements of Pn and E began April 12, one day after the initial pesticide treatment, and were repeated 8, 10, 15, and 22 days after the initial treatment. The latter three treatments (10, 15, and 22 days) were made after initiation of water stress. Treatments were arranged as a 2 x 5 factorial in a randomized complete block design with six single-tree replications.

Study IX

In a second 1994 study, water was withheld from half the plants beginning April 11, with the remaining plants well watered. On April 16 several of the stressed seedlings exhibited wilted foliage, and all stressed plants received

Table 2. Influence of Pesticides Applied to Single Leaves on 'Red Prince Delicious'/MM.111 Greenhouse-Grown Apple Trees. Study IV.

Trial	Rate (ml/L)	May 29		June 13		July 12		July 27	
		Pn	E	Pn	E	Pn	E	Pn	E
Experiment 1[w]									
Control	—	16.5 a[v]	8.2 a	7.5 a	4.6 a	3.2	4.4 a	10.0	7.4 a
Prime Oil	5.0	14.4 b	7.5 bc	5.7 b	3.2 cd	3.5	4.1 a	10.1	7.2 a
Prime Oil II	12.5	11.9 c	7.0 c	4.3 c	2.4 d	3.3	3.1 b	8.0	5.8 b
Plex	5.0	14.8 b	7.7 ab	7.4 a	4.4 ab	3.5	3.7 ab	9.4	7.3 a
Activate Plus	5.0	14.3 b	7.4 bc	6.9 a	3.8 bc	3.6	3.8 ab	9.5	6.8 ab
Omite 6E	1.6	15.8 ab	8.2 a	5.4 b	3.1 cd	3.9	4.1 a	9.3	6.3 ab
Experiment 2[u]									
Control	—	16.4 a	9.6	10.9 a	7.3 a	4.2 ab	5.0 a	10.7 ab	9.3 a
Kinetic	5.0	14.5 b	8.9	6.8 b	5.0 d	3.3 b	4.1 b	8.9 c	8.0 b
Triton CS-7	2.5	15.2 ab	9.2	9.4 a	6.4 ab	4.6 ab	5.0 a	11.9 a	9.7 a
X-77	5.0	14.3 b	9.1	9.3 a	6.2 bc	4.4 ab	4.8 ab	10.7 ab	8.9 a
Bond	1.2	15.4 ab	9.1	10.0 a	7.1 a	3.6 b	4.9 a	9.9 bc	9.2 a
Omite 6E	1.6	14.9 b	9.0	7.8 b	5.4 cd	5.4 a	5.2 a	9.1 c	7.8 b
Experiment 3[t]									
Control	—	11.6 c	8.3 a	11.1 a	6.6 a	4.0 ab	4.4	7.5	7.8 a
Nufilm 17	0.6	13.5 a	8.7 a	11.0 a	6.4 a	4.0 ab	4.5	7.0	6.8 ab
Penetraber	0.3	11.9 bc	8.5 a	10.2 a	6.1 a	4.5 ab	4.4	8.0	7.5 a
Induce	2.5	9.7 d	7.3 b	10.7 b	6.6 a	3.8 b	4.3	8.5	7.6 a
Nufilm P	0.3	13.2 ab	8.8 b	10.8 a	6.5 a	4.9 ab	4.7	8.7	7.5 a
Omite 6E	1.6	11.0 cd	8.2 a	7.8 b	4.7 b	5.2 a	4.6	7.5	6.4 b

[z] Treatments applied three times to six replicate trees with all treatments randomized on leaves of each tree (1991).
[y] Pn = μmol CO_2 $m^{-2}s^{-1}$
[x] E = μg H_2O $m^{-2}s^{-1}$
[w] Experiment I application dates: 5/15, 5/29, 6/13.
[v] Mean separation by Duncan's multiple range test ($P = 0.05$). Within experiments, values without letters are not significantly different.
[u] Experiment 2 application dates: 5/15, 5/29, 6/13.
[t] Experiment 3 application dates: 5/21, 5/30, 6/11.

100 ml water per pot. This procedure was repeated over the duration of the experiment as the stressed plants exhibited wilting. On April 18 most of the water-stressed plants exhibited signs of wilt, and the same pesticides used in Study VIII were applied again. Pesticide treatment was repeated a second time seven days later. Xylem water potential was measured as previously described. Treatments were arranged in a 2 x 5 factorial, randomized block design with six single-tree replications.

Results

Study I

Superior (70 sec) oil caused an immediate reduction in both Pn and E. The effect lasted for 11 days with E and for the entire 45 days with Pn (Figure 1). The 6E formulation of oil first reduced Pn four days after application and the effect persisted. Safer soap and the two formulations of sulfur first caused a reduction in Pn and E 11 days after application, and the effect persisted for the duration of the study. Leaf injury symptoms were apparent 11 days after application for both oil formulations, and these materials, along with microsulfur, resulted in a reduction in size of newly formed leaves (Table 1). The surfactants X100 and AG98 had no effect on Pn or E.

Study II

Promoted as an acceptable "organic" insecticidal material, Safer soap had no effect alone on Pn and E, but it appeared to interact with other materials (Figure 2). A foliar spray of microsulfur reduced Pn and E, but a greater reduc-

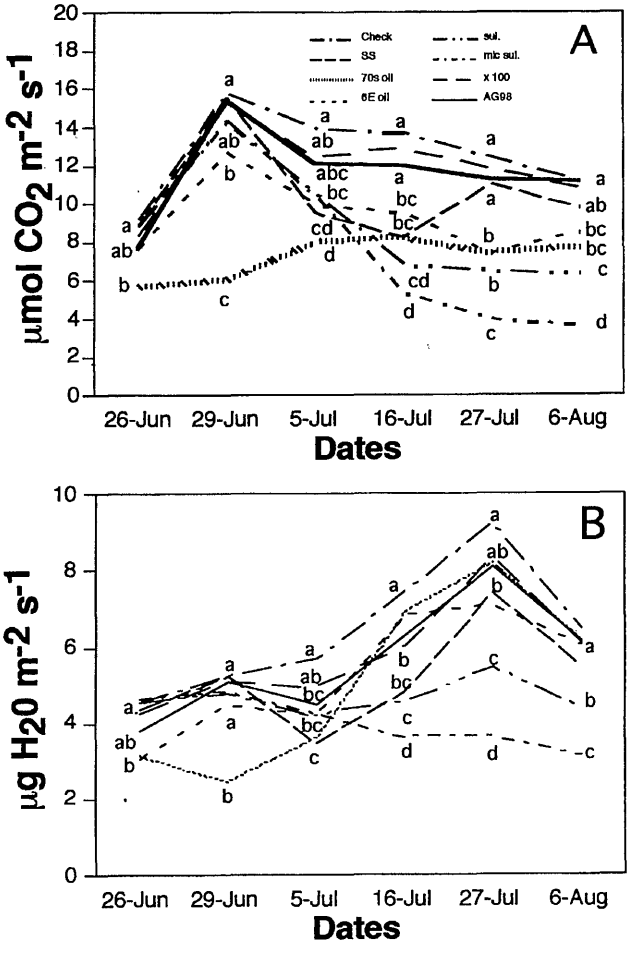

Figure 1. Influence of oil and sulfur formulations and adjuvants on net photosynthesis (A) and transpiration (B) of greenhouse-grown MM.106 apple trees. Each value is the average of six observations. Study I.

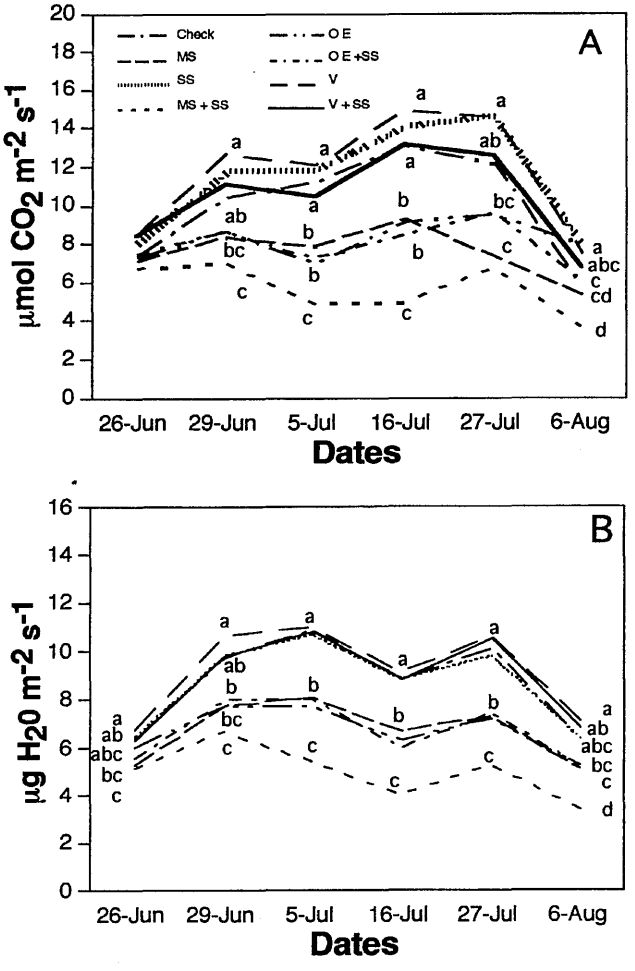

Figure 2. Influence of various pesticides combined with Safer soap on net photosynthesis (A) and transpiration (B) of leaves of greenhouse-grown MM.106 apple trees. Each value is average of six observations. Study II.

tion occurred when it was combined with Safer soap. Omite 6E reduced Pn and E on two of the six measurement dates and combining with Safer soap made no difference in performance. Vendex had no effect on Pn or E when applied alone or when combined with Safer soap.

Study III

Pn and E were not affected by three weekly applications of miticides except for Omite 6E, which reduced both (Figure 3). The wettable powder formulation of Omite reduced Pn when measured immediately after the second application (seven days), but neither material had an influence at subsequent dates.

Study IV

The three experiments using three applications to single leaves of 'Delicious' trees confirmed that oil, this time as two formulations of Prime Oil, caused a reduction in Pn and E (Table 2). Omite 6E also generally caused reductions in Pn and E. Of the wide range of surfactants tested, Plex, Activate Plus, X-77, and Induce caused slight short-term reductions, while Nufilm 17 and Nufilm P caused short-term increases in Pn and E. The effect of Activate Plus on E persisted for the duration of the study.

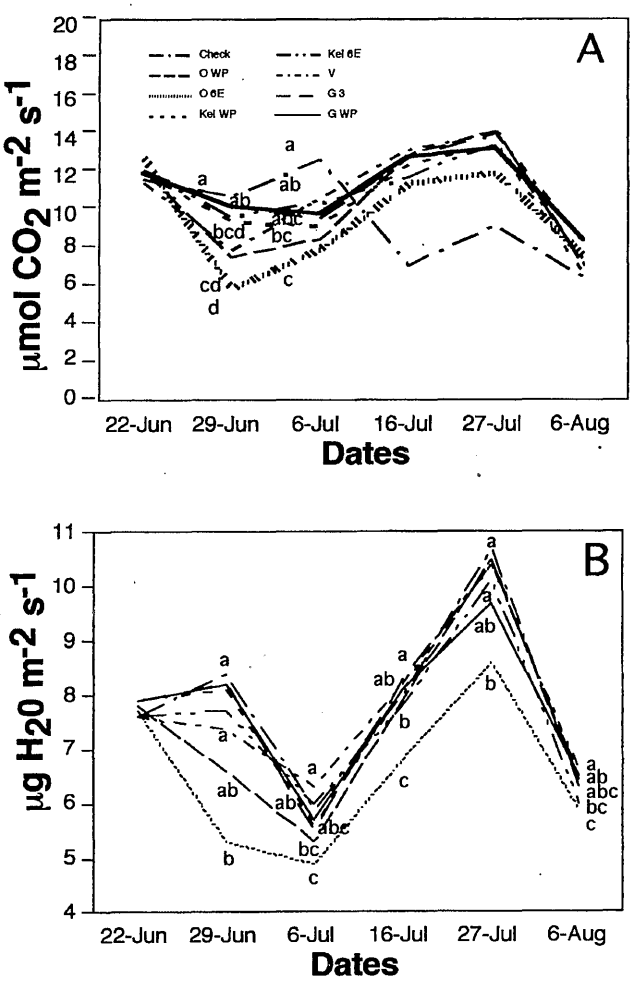

Figure 3. Influence of miticide formulations on net photosynthesis (A) and transpiration (B) of MM.106 apple trees. Each value is an average of six observations. Study III.

Study V

Since it is often necessary to apply both a fungicide and an insecticide to produce quality fruit, the combination of microsulfur and Prime oil II was repeated three times, as might be required in an "organic" regime (Table 3). The low rate (2.4 g/l) of microsulfur combined with Prime oil II had no effect on Pn or E; however, the high rates of microsulfur (4.8 and 7.2 g/l) consistently reduced Pn and E. Very low rates of Pn were measured on June 13, and results appeared abnormal, while results of E were consistent with the other measurement dates. The highest rate of microsulfur and Prime oil II reduced early season fruit growth.

Study VI

Measurement of Pn on the spur leaf following three applications shows that the combination of Safer soap and microsulfur reduced Pn and E with no effect of either material alone (Table 4). Pn was still affected two weeks later with Safer soap alone also causing a reduction. Six weeks after the last spray no effect on Pn or E was noted, and no significant effect of fruit growth was observed.

Study VII

Two applications of various fungicides had little effect on Pn, but Rovral tended to decrease E. Banner and Benomyl had some effect on single dates (Table 5). Although a single spray of various oil formulations had no effect on Pn, two applications of superior oil, Safer soap, CS-7, or Prime oil reduced Pn for four days following the second application (Table 6). Well-watered trees were sprayed with superior oil or Alliette, and then soil moisture was withheld from half of the trees. Water stress was observed by a reduction in Pn and xylem water potential six days after withholding water (Table 7). Two hours after pesticide application,

Table 3. Influence of Microsulfur and Prime Oil II on Net Photosynthesis and Transpiration of 'Starkrimson Delicious' Greenhouse-Grown Apple Trees. Study V.

		May 29		June 13		July 11		Δ Fruit Diameter (cm)			
Treatment[z]	Rate (g/L)	Pn[y]	E[x]	Pn	E	Pn	E	May-June	June-July	L/D	Wt. Fruit (g)
Control	—	8.3 a[w]	8.5 ab	1.5 b	8.1 a	8.8 a	8.6 a	1.9 a	1.5	0.83 ab	173
Microsulfur	2.4	7.7 a	9.6 a	5.3 a	4.6 b	5.9 ab	6.1 ab	1.6 ab	1.2	0.84 ab	138
Microsulfur	4.8	3.7 b	6.6 bc	2.7 a	2.9 b	2.6 b	2.9 b	1.6 ab	1.1	0.82 b	131
Microsulfur	7.2	3.8 b	5.9 c	3.3 a	3.5 b	3.3 b	3.9 b	1.5 b	1.2	0.86 a	139

[z] Prime Oil, 300 ml/l combined with each microsulfur treatment applied weekly beginning May 15, for three applications.
[y] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[x] E = μg H_2O $m^{-2}s^{-1}$.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Values within columns without letters are not significantly different.

Table 4. Influence of Three Weekly Whole-Tree Pesticide Sprays on Net Photosynthesis and Transpiration of 'Golden Delicious' Greenhouse-Grown Apple Trees. Study VI.

		May 29		June 13		July 11		Δ Fruit Diameter (cm)		
Treatment[z]	Rate/L	Pn[y]	E[x]	Pn	E	Pn	E	May-June	June-July	Wt. Fruit (g)
Control	—	15.3 a[w]	11.1 a	11.7 a	9.1	13.9	9.8	2.18	1.74	201
Safer Soap (SS)	20 ml	14.8 a	10.6 a	8.3 c	8.1	12.6	9.8	2.13	1.70	209
Microsulfur (MS)	6 g	15.8 a	11.3 a	11.1 a	9.3	12.6	9.4	2.05	1.66	195
SS + MS	20 ml + 6 g	12.2 b	9.7 b	10.0 b	8.2	11.7	9.0	2.04	1.59	181

[z] Treatments applied weekly beginning May 15, for three applications.
[y] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[x] E = μg H_2O $m^{-2}s^{-1}$.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Values within columns without letters are not significantly different.

Table 5. Influence of Various Fungicides Applied as Two Foliar Sprays on Net Photosynthesis and Transpiration of Potted MM.106 Apple Trees. Study VII.

		Pn[y]				E[x]			
Treatment[z]	Rate/L	6/22	6/26	6/28	7/2	6/22	6/26	6/28	7/2
Control	—	10.9	9.4	9.0	10.8	8.6 ab[w]	8.5 ab	5.1 ab	8.7
Benomyl	3.4 g	12.1	9.7	8.5	11.4	8.9 a	8.4 ab	4.2 c	8.5
Banner	0.6 ml	11.1	8.8	8.2	12.5	8.9 a	7.8 b	4.6 abc	9.0
Alliette	11.2 g	11.9	8.6	8.5	11.9	9.4 a	8.1 ab	4.9 abc	9.5
Alliette	22.4 g	10.6	9.9	8.0	12.5	8.9 a	8.9 a	4.5 abc	9.6
Rovral	2.6 ml	10.0	10.2	7.9	11.4	7.9 b	8.5ab	4.4 bc	8.8
Ridomil	0.5 ml	11.2	8.9	8.3	1.9	9.0 a	8.3ab	5.3 a	9.2

[z] Sprays applied with hand atomizer to drip on six replicate trees each on June 22 (measurement two hours after spray) and repeated on June 28.
[y] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[x] E = μg H_2O $m^{-2}s^{-1}$.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Values within columns without letters are not significantly different.

Table 6. Influence of Various Insecticides Applied as Two Foliar Sprays on Net Photosynthesis and Transpiration of Potted Apple Trees. Study VIII.

		Pn[y]			E[x]		
Treatment[z]	Rate (ml/L)	6/22	6/26	7/2	6/22	6/26	7/2
Control	—	11.5	12.9	11.4 a[w]	9.0 b	8.8	8.0
Superior 6E Oil	1.2	11.8	12.4	8.5 b	9.2 ab	8.9	7.0
Superior 6E Oil	2.4	11.7	12.9	9.8 ab	9.6 ab	8.9	7.8
Superior 6E Oil	5.0	11.1	11.5	8.2 b	9.2 ab	8.6	7.1
Safer Soap	1.2	12.1	11.8	8.7 b	9.7 ab	8.4	6.9
CS-7	2.4	11.7	12.9	8.3 b	9.3 ab	9.2	7.1
Prime Oil	2.4	12.6	13.1	8.7 b	9.9 a	8.9	7.0

[z] Sprays applied with hand atomizer to drip on six replicate trees each on June 21 and repeated on June 28.
[y] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[x] E = μg H_2O $m^{-2}s^{-1}$.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Values within columns without letters are not significantly different.

Table 7. Influence of Soil-Moisture Stress and Foliar Pesticide Sprays on Net Photosynthesis, Transpiration, and Water Potential of Potted MM.106 Apple Trees. Study VII.

Effect	Rate/L	Pn[z] 6/22	Pn[z] 6/26	Pn[z] 7/2	E[y] 6/22	E[y] 6/26	E[y] 7/2	Xylem Water Potential (Mpa)
Moisture Stress[x]								
Control	—	—	13.3	11.4	—	10.6	8.7	- 0.56
Stress	—	—	10.1	6.4	—	7.2	4.5	-1.65
Pesticide								
Control	—	14.1 a[w]	12.3	9.3	15.6 a[w]	9.3	6.7	-1.00 a
Superior Oil	2.5 ml	12.0 ab	12.0	9.0	13.1 b	8.7	6.6	-1.22 b
Alliette	22.4 g	9.7 b	10.9	8.4	12.3 b	8.7	6.5	-1.10 ab
F Significance								
Stress		—	**[v]	**	—	NS	NS	**
Pesticide		**	NS	NS	*	NS	NS	NS
Stress x Pesticide		—	NS	**	NS	NS	NS	NS

[z] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[y] E = μg H_2O $m^{-2}s^{-1}$.
[x] Well watered until day of pesticide treatment.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Values within columns without letters are not significantly different.
[v] NS,*,** = nonsignificant, or significant at $P \geq 0.05$ or 0.01, respectively.

Alliette caused a reduction in Pn, and both pesticides reduced E. Pesticides had no effect one or six days following application. Application of superior oil caused a greater reduction in Pn than Alliette six days after application (Figure 4).

Study VIII

As a follow up to the pesticide-water stress interaction in Study VII, a similar study was conducted in 1994 using several rates of Alliette (Table 8). The plants were stressed from lack of soil moisture 10 days after withholding water, as indicated by reductions in both Pn and E. Pesticide treatment had little effect on Pn, E, or xylem water potential.

Study IX

In order to evaluate the influence of time of pesticide application to the development of water stress, a second study was conducted in

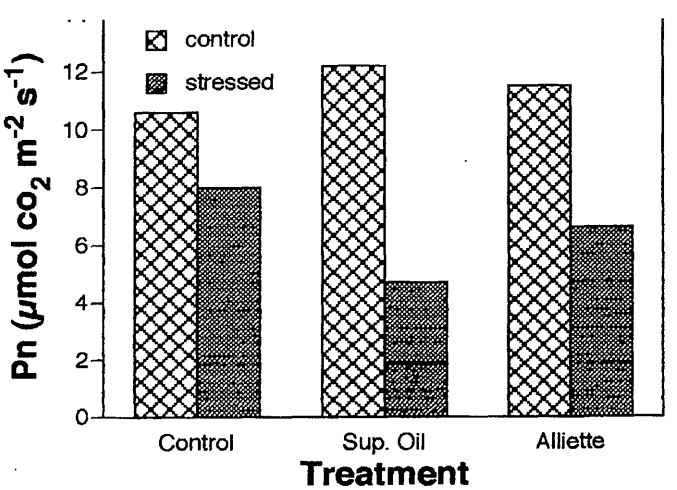

Figure 4. Interaction of soil-moisture stress and pesticide application six days after treatment on net photosynthesis of MM.106 apple trees. Study VII.

Table 8. Influence of Selected Pesticides on Net Photosynthesis, Transpiration, and Water Potential on MM.106 Apple Trees Subjected to a Soil Moisture Stress Following Pesticide Applications. Study VIII.

Effect	Rate/L	Xylem Water Potential (MPa)[x]	Pn[z] on Days Following Treatment					E[y] on Days Following Treatment				
			1	8	10	15	22	1	8	10	15	22
Moisture Stress Level												
Nonstress	—	-1.25 b[w]	10.6	12.9	10.7 a	12.8 a	9.8 a	4.6	6.2	4.1 a	7.6 a	4.9a
Stress	—	-2.12 a	10.6	12.8	6.2 b	10.9 b	7.0 b	4.6	6.3	2.9 b	6.3 b	3.0b
Treatments												
Control	—	-1.67 ab	10.6	12.9	8.8	12.4	8.2	4.5 ab	6.1	4.0	7.0	3.9
Alliette	5.6 g	-1.62 a	10.9	12.2	8.5	11.4	8.7	4.8 a	6.2	4.0	6.8	4.0
Alliette	11.2 g	-1.77 b	10.8	13.7	8.4	11.8	8.4	4.6 ab	6.3	4.0	6.7	3.9
Alliette	22.4 g	-1.73 ab	10.6	13.2	8.3	11.7	7.8	4.7 ab	6.3	3.9	6.9	3.9
Superior Oil	1.2 ml	-1.65 ab	10.2	12.4	8.1	12.0	9.0	4.3 b	6.3	3.9	7.2	4.0
F Significance												
Stress		**[v]	NS	NS	**	**	**	NS	NS	**	**	**
Treatment		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stress x Treatment		NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS

[z] Pn= μmol CO_2 $m^{-2}s^{-1}$.
[y] E = μg H_2O $m^{-2}s^{-1}$.
[x] Measured 22 days following treatment.
[w] Mean separation by Duncan's multiple range test ($P = 0.05$). Each mean contains 12 observations. Values within columns without letters are not significantly different.
[v] NS,*,** = nonsignificant, or significant at $P \geq 0.05$ or 0.01, respectively.

1994 where pesticides were applied to plants already showing signs of water stress (Table 9). Following two applications of the pesticide (15 days after initial treatment), all rates of Alliette and superior oil reduced both Pn and E and increased xylem water potential. The interaction of pesticide and water stress (Figure 5) show a similar increase in stress with both Alliette and superior oil treatment; however, the concentration of Alliette had no appreciable effect.

Discussion

As was true in past studies (2, 9, 10, 27), applications of oil to apple foliage generally caused persistent reductions in Pn and E. The formulations of oil used in these studies made little difference (Figure 1, Tables 2, 3, and 6). Formulation did affect the response from some compounds (e.g., Omite). The emulsifiable formulation appeared to cause a greater decrease than the wettable powder formulation. Newer materials such as Safer soap, often advocated as "soft" materials for organic production

Table 9. Influence of Selected Pesticides on Net Photosynthesis, Transpiration, and Water Potential on MM.106 Apple Trees Subjected to Soil-Moisture Stress Preceeding Pesticide Applications. Study IX.

Effect	Rate/L	Xylem Water Potential (MPa)	Pn[z] on Days Following Treatment 1	3	8	15	E[y] on Days Following Treatment 1	3	8	15
Moisture Stress Level										
Nonstress	—	-1.27 b[x]	8.9 a	13.9 a	10.9 a	12.0 a	4.7 a	5.9 a	5.7 a	5.2 a
Stress	—	-2.33 a	6.0 b	5.9 b	9.1 b	7.5 b	3.1 b	3.0 b	5.0 b	3.2 b
Treatments										
Control	—	-1.74	8.7 a	10.8 a	9.6	11.1 a	4.4 a	4.6	5.3	4.6 a
Alliette	5.6 g	-1.77	6.6 b	8.6 b	9.7	9.4 b	3.5 b	4.4	5.2	4.0 b
Alliette	11.2 g	-1.80	7.7 ab	10.2 a	9.7	9.2 b	4.3 a	4.6	5.5	4.1 b
Alliette	22.4 g	-1.83	7.9 b	10.3 a	9.3	9.6 b	3.8 ab	4.5	5.4	4.2 b
Superior Oil	1.2 ml	-1.87	7.0 b	9.6 ab	9.6	9.5 b	3.5 b	4.3	5.3	4.1 b
F Significance										
Stress		**[w]	**	**	*	**	**	**	**	**
Treatment		NS	**	**	NS	**	*	NS	NS	*
Stress x Treatment		*	NS	NS	NS	NS	NS	NS	NS	NS

[z] Pn = μmol CO_2 $m^{-2}s^{-1}$.
[y] E = μg H_2O $m^{-2}s^{-1}$.
[x] Mean separation by Duncan's multiple range test ($P = 0.05$). Each mean contains 12 observations. Values within columns without letters are not significantly different.
[w] NS,*,** = nonsignificant, or significant at $P \geq 0.05$ or 0.01, respectively.

tended to reduce Pn, particularly when combined with fungicides such as microsulfur. A number of earlier studies reported a marked reduction in Pn of apple leaves due to lime sulfur and other forms of sulfur (1, 5, 17, 18). Newer formulations of sulfur used in the authors' studies (Figures 1 and 2, Tables 3 and 4) also generally caused a reduction in Pn, particularly when combined with Safer soap or oil.

There was no strong interaction between pesticide application and water stress in the current series of studies. It appeared that the pesticide effect was greater when applied to plants already under water stress (Table 9) than when applied to well-watered plants that subsequently developed water stress (Tables 7 and 8). However, this cannot be definitely concluded since separate studies are reported, and a combined study was not conducted. The lack of a strong interaction may have been due to the smaller effect of pesticide on Pn compared to a greater effect due to water stress. Reports in the literature regarding the significance of interactions involving two or more stress factors on physiological activity tend to be somewhat contradictory. While interactions between mites and a series of other stress factors were not significant for apple leaf Pn or E (12, 14), other studies with air pollutants suggest that certain stress combinations may significantly interact to affect overall growth and physiological activity of other important woody species

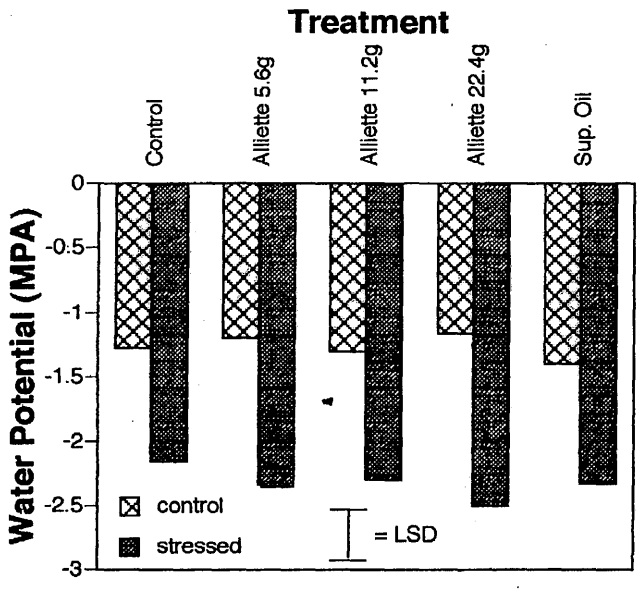

Figure 5. Interaction of soil-moisture stress and pesticides on water potential of MM.106 apple trees 15 days after pesticide application. Study IX.

(3, 4, 6, 22). Without question, factors such as type/duration of stress, plant species, cultural conditions/practices, etc., all influence the degree to which interactions may impact growth and development.

In summary, some newer pesticide formulations of oils and sulfur or Safer soap may be deleterious to Pn of apple leaves. The majority of pesticides tested had little effect on Pn and E of apple trees. There did not appear to be strong interactions between the pesticide influence on Pn and the effect of water stress on Pn.

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Influence of Temporary Bending and Heading on Branch Development and Flowering of Vigorous Young Apple Trees

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Summary

Vigorous one-year-old upper limbs on the central leader of young 'Gala' and 'Red Cort' apple trees on M.7 rootstocks were subjected to bending at different times to determine the effect on growth and flowering. Bending vigorous laterals resulted in more flowering spurs than heading for both cultivars, but neither treatment differed from the control. Generally, bending and heading reduced terminal shoot growth on the laterals of both cultivars, and the combination of the two treatments had a greater effect than either alone. All treatments on the laterals of 'Gala' decreased flowering, but only treatments including heading reduced the total flowering of 'Red Cort.' Significant reductions in growth of the terminal shoots occurred from May 23 through June 20 for laterals headed or headed and bent. Bending on or before May 9 caused a reduction in terminal growth of 'Gala,' but none of the treatments affected terminal growth of 'Red Cort' during this time. Bending in the spring had no effect on total shoot growth of 'Red Cort,' but with 'Gala,' bending early in the spring caused a greater reduction in total shoot growth than bending later in the spring (June).

In a second study, central leaders on vigorous trees were bent first to the north for 15, 30, or 45 days and then to the south for the same time period at three different times during spring. No interaction occurred between time of season and length of bending time for the central leader or between treatments and cultivars. Scoring or heading the leader had no significant effect on number or length of laterals formed on the leader or flowering the following year. Contrast analysis indicated average lateral shoot length was greater on leaders bent April 11 than when bent May 9. Numbers of lateral flowers were generally greater on leaders bent 15 days than when bent 30 days.

Introduction

In modern high-density systems, achieving early production is critical to assist in maintaining an optimum balance of growth and fruiting. Often techniques such as bending and scoring are used to reduce growth and induce flowering. Bending branches has been a common practice to reduce shoot extension (6, 7, 8, 12, 14, 17, 18) and promote flowering (7, 8, 12, 14, 17). However, increased flowering and fruiting have not been consistently found in studies utilizing bending (6, 10). Bending the leader is often recommended for slender spindle or HYTEC training systems to encourage growth in the lower scaffolds and to weaken the leader on vigorous cultivars or sites (1, 6, 13, 14). Although bending the leader in one direction and reversing it is often recommended on vigorous sites to control growth, Parker and Young (13) found they got asymmetrical growth and considered the treatment a failure.

Bending scaffolds increased flowering of 'Smoothee Golden Delicious,' and trees of 'Lawspur Rome Beauty' had increased flower density (6). Cumulative yields were increased

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on trees on Mark rootstock (11%), while having no yield influence on more vigorous trees on M.7 rootstock (6). A heading pruning cut is often used as a quick replacement for bending to induce branching on vigorous trees. Elfving (3, 4) has shown that annual dormant heading of 'Delicious' and 'Empire' reduced yield. Ferree and Schmid (7) reported that heading young 'Fuji' trees increased growth, but the increase did not result in increased flowering.

The present study was initiated to examine differences in the time of bending on growth and flowering of two apple cultivars vigorously growing on M.7 rootstock. Trees of 'Regal Gala,' a cultivar prone to producing flowers laterally on one-year wood, were compared to 'Red Cort' which is generally a terminal bearing cultivar.

Materials and Methods

Leader Bending

At the beginning of the third growing season, leaders of free-standing central-leader trees of 'Red Cort'/M.7 (second-year leader length 87 cm) and 'Regal Gala'/M.7 (second-year leader length 89 cm) were given one of the following 12 treatments: 1. Control; 2. Headed — removal of 30% of terminal; 3. Score — cut through bark with a knife encircling the leader just above the bud-scale scars at the base on April 11; 4–12. Bending at various developmental stages and for various time periods — leader bend approximately 70° off vertical by tying it to a lower branch.

Bending was performed April 11 when terminals were just showing green, April 25, or May 9, which was one week past bloom on older trees in this orchard. Bending was first to the north for 15, 30, or 45 days and then reversed to the south for the same amount of time. When the treatment time was complete, the string used for bending was removed. The treatments were arranged as a randomized block with six single tree replications of each treatment. Cultivars were in adjacent rows in a commercial orchard at Pataskala, Ohio. In addition to analysis of variance, single degree of freedom contrasts were made to evaluate dates during the season, length of bending time, and interaction between these factors.

Bending Upper Limbs

Trees in a second group in this same orchard were selected so that each tree had four vigorous laterals of approximately equal length on the upper portion of last year's central leader. The following treatments were applied to the laterals at random: 1. Control; 2. Bend — lateral bent to approximately 50° to 60° from vertical; 3. Head — 25% of the lateral removed by a heading cut; 4. Bend and head — a combination of the latter two treatments.

These treatments were applied at the following times — April 16 (half-inch green stage), April 25, May 9 (one week past bloom), May 23, June 6, and June 20. The treatments were arranged as a randomized complete block with 10 single-tree replicates for 'Red Cort' and nine for 'Regal Gala.'

For both studies, at the end of the growing season, lateral growth and terminal growth were measured and the following spring, terminal, lateral, and spur flowers were counted.

Results

Leader Bending

One of the purposes of this study was to determine if an interaction existed between the time of season the leader was treated by bending and the length of time it was held in the bent position. No interaction occurred between time of season and length of bending time or between the treatments and cultivar. Thus, only main effects are presented.

Scoring or heading the leader had no significant effect on current season shoot growth or flowering the following spring (Table 1). Bending the leader first to the north and then to the south for periods of 15 to 45 days had no effect on shoot growth or flowers produced by the leader compared to the control. Contrast analysis indicated that average lateral shoot length was greater on leaders bent April 11 than when bent May 9. Lateral and total flower numbers were greater on leaders bent 15 days than when the leaders were bent 30 days.

'Gala' was more vigorous than 'Red Cort,' having more and longer shoots. 'Red Cort' had more terminal flowers and more flowers on spurs than 'Gala.' 'Gala' had a very large num-

Table 1. Influence of Time of Season and Duration of Bending and Reverse Bending of Leaders on Growth and Flowering of Three-Year-Old 'Regal Gala' and 'Red Cort' Apple Trees on M.7 Rootstock.

	Bending Time			Lateral Shoots		Flowers			
Factor	Beginning Date	Length of Time (days)	Terminal Shoot Length (cm)	No. of Laterals	Mean Length (cm)	Terminal	Lateral	Spur	Total
Treatment									
Control	—	—	40.6 abcd[z]	12.2 a	28.5 abc	6.6	38.4 ab	4.7	49.9 ab
Score	—	—	47.8 ab	10.6 ab	30.1 abc	6.8	25.5 ab	4.7	37.1 ab
Heading	—	—	49.1 a	11.1 ab	35.2 a	7.7	41.9 a	3.0	52.7
Bending	4/11	15	43.0 abc	12.8 a	33.2 ab	9.4	37.4 ab	3.1	50.0 ab
	4/11	30	26.5 d	10.1 ab	27.8 abc	5.8	20.6 b	5.3	31.7 ab
	4/11	45	26.8 d	9.6 ab	34.8 a	6.2	24.9 ab	4.7	35.8 ab
	4/25	15	33.3 cd	10.5 ab	31.7 ab	6.5	36.1 ab	4.3	47.0 ab
	4/25	30	29.0 cd	7.9 b	32.7 ab	5.5	18.4 b	4.9	28.8 b
	4/25	45	34.8 bcd	10.8 ab	27.8 abc	7.2	26.3 ab	5.4	38.9 ab
	5/9	15	31.4 cd	9.9 ab	21.3 c	7.4	23.4 ab	3.2	34.0 ab
	5/9	30	27.7 d	12.0 a	23.8 bc	7.2	18.1 b	4.0	29.3 b
	5/9	45	41.1 abcd	10.0 ab	34.1 ab	7.6	33.7 ab	3.1	44.5 ab
Cultivar									
Red Cort	—	—	26.0 b	9.1 b	22.6 b	8.7 a	4.9 b	6.1 a	19.9 b
Regal Gala	—	—	47.1 a	12.3 a	38.1 a	5.1 b	54.7 a	2.2 b	62.1 a

[z] Means within a column are separated by Duncan's multiple range test ($P = 0.05$). Columns without letters were nonsignificant.

ber of lateral flowers on one-year wood compared to 'Red Cort.'

Upper Limb Bending or Heading

'Red Cort'

The time of treatment had no effect on the number of flowering spurs produced on last year's laterals, but treatment on June 6 resulted in more vegetative spurs than treating on May 9 or April 25 (Table 2). Bending resulted in more flowering spurs than heading, but neither treatment differed from the control. Generally, the earlier the lateral shoots were manipulated, the greater the growth of the terminal shoot on the lateral. Timing had little effect on the total length of secondary lateral shoots or on flowering. Heading the laterals decreased the length of the terminal shoot on the lateral and decreased the number and total length of secondary laterals. Bending alone had no effect on flowering, while heading decreased terminal and total number of flowers.

Significant interactions occurred between time and treatment for terminal shoot length, total shoot length, and total number of flowers. The length of the terminal shoot on each lateral for the control and bending treatments was similar over all times, while terminal length for treatments involving heading was reduced from May 23 onward (Figure 1A). This same

Table 2. Influence of Bending and Heading Times on the Growth and Flowering of One-Year-Old Lateral Limbs on the Central Leader of Three-Year-Old 'Red Cort' Apple Trees on M.7 Rootstock.

Factor	Spurs/Limb		Terminal Shoot Length (cm)	Number of Secondary Lateral Shoots	Total Secondary Lateral Length (cm)	Total Shoot Length (cm)	Flowers/Limb		
	Flowering	Vegetative					Terminal	Lateral	Total
Time									
4/16	2.5	0.42 ab[z]	35.8 a	4.0 ab	100	136	4.5	3.6	10.7
4/25	2.0	0.22 b	31.7 ab	3.6 ab	84	115	4.4	3.2	9.7
5/9	2.6	0.28 b	32.0 ab	3.6 ab	85	116	4.1	2.7	9.5
5/23	2.8	0.38 ab	25.8 bc	3.6 ab	85	112	4.3	3.4	10.6
6/6	2.9	0.83 a	23.9 c	3.0 b	88	118	3.5	2.5	9.1
6/20	2.2	0.64 ab	28.2 bc	4.4 a	108	138	4.6	2.9	9.8
Limb Treatment									
Control	2.5 ab	0.56	35.0 a	5.4 a	123 a	158 a	5.9 a	3.2 a	11.7 a
Bend	2.9 a	0.40	31.8 ab	5.1 a	111 a	143 a	5.5 a	2.6 b	11.0 a
Head	2.0 b	0.33	29.8 b	2.0 b	64 b	96 b	2.6 b	4.4 a	9.2 b
Bend + head	2.6 ab	0.52	22.0 c	2.2 b	60 b	85 b	2.9 b	2.0 b	7.6 c
F Significance									
Time	NS[y]	**	**	NS	NS	NS	NS	NS	NS
Treat	*	NS	**	**	**	**	**	**	**
Time x Treatment	NS	NS	**	NS	NS	*	NS	NS	*

[z] Means within a main effect column separated by Duncan's multiple range test, $P = 0.05$.
[y] NS, *, **, nonsignificant or significant at $P \geq 0.05$ or 0.01, respectively.

pattern was observed for total shoot length (Figure 1B). Laterals that were bent on May 23 through June 20 had more total flowers than laterals that had both heading and bending, while total flower number on laterals that were untreated or received heading only were not influenced by time of treatment (Figure 1C).

'Regal Gala'

The time of treatment had no effect on spur development, but treating on June 6 resulted in less shoot growth than some of the earlier treatments (Table 3). The number of terminal flowers formed was higher when lateral limbs were treated April 16 or in June, compared to treating on April 25. 'Gala' produced many more lateral flowers than were formed on either spurs or terminals, but timing did not influence lateral flowers.

Heading reduced both flowering and vegetative spurs. All treatments reduced terminal shoot length, lateral shoot number, and total length, and generally the combination of bending and heading caused the greatest reduction in growth. In general, lateral flowering followed the same pattern as growth being reduced by all treatments. Formation of terminal flowers was only reduced by the combination treatment.

The interaction between time of season and the limb treatments was significant for the following factors — terminal shoot length, total secondary lateral shoot length, and total secondary shoot length.

Terminal shoot length was reduced by bending consistently over the season, while heading had little effect on terminal length through May 9, but caused a reduction after that date (Figure 2A). For both total shoot length (Figure 2B) and total lateral length (Figure 2C), bending caused a significant reduction in growth early in the season, but the effect was less in June. Heading had no effect on these indices through May 9, but after that time caused a significant decrease in both total shoot length and total length of secondary laterals.

Discussion

The length of time of bending the leader had no effect on shoot growth, but 15 days appears to increase flowering and additional time had

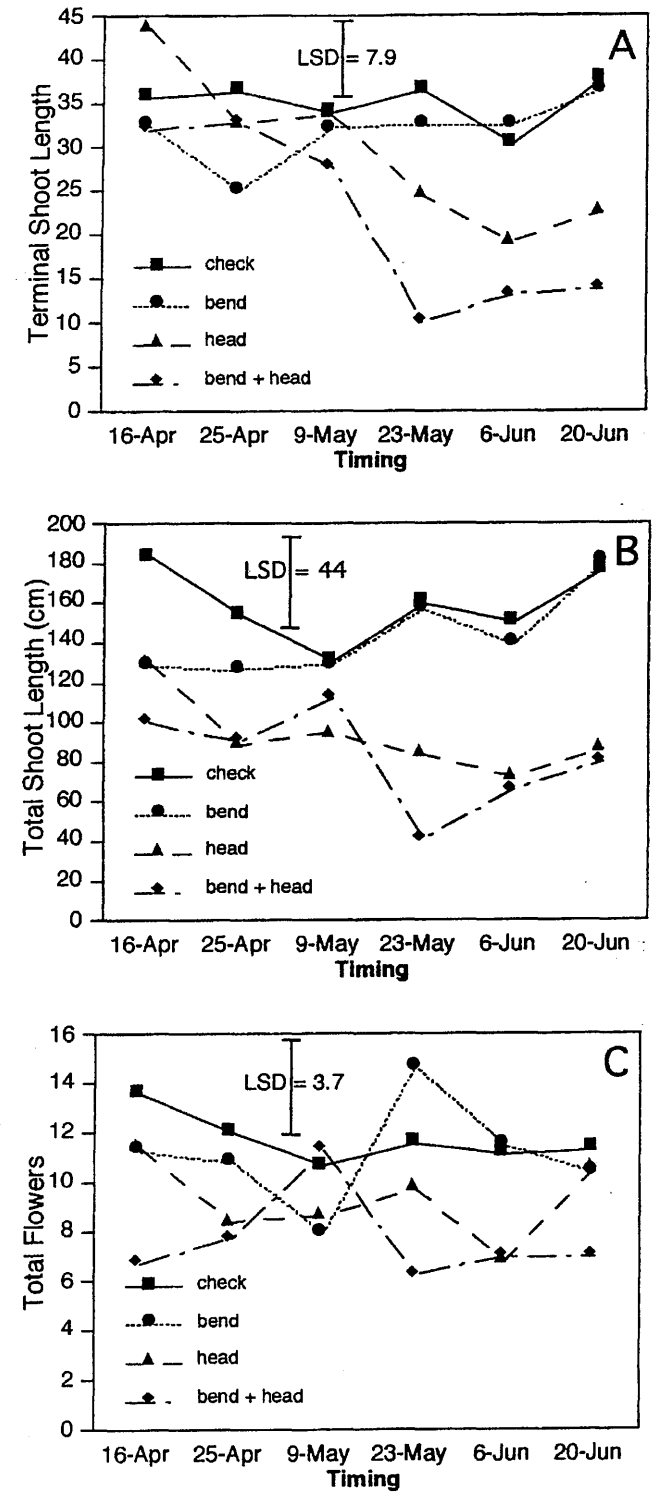

Figure 1. Interactions between time of application and bending and heading vigorous laterals on the central leader of 'Red Cort' on M.7 rootstock apple trees on terminal shoot length on the lateral (A), total shoot length (B), and total flowers (C).

Table 3. Influence of Bending and Heading Times on the Growth and Flowering of One-Year-Old Lateral Limbs on the Central Leader of Three-Year-Old 'Regal Gala' Apple Trees on M.7 Rootstock.

Factor	Spurs/Limb		Terminal Shoot Length (cm)	No. of Secondary Lateral Shoots	Total Secondary Lateral Length (cm)	Total Shoot Length (cm)	Flowers/Limb		
	Flowering	Vegetative					Terminal	Lateral	Total
Time									
4/16	0.7	8.3	42.8 ab[z]	5.3 a	130 ab	173 a	2.7 a	14.1	17.5
4/25	0.7	8.3	42.6 ab	4.9 a	123 ab	166 a	1.5 c	10.2	12.4
5/9	0.6	11.0	46.8 a	4.4 ab	134 a	181 a	1.6 bc	14.9	17.2
5/23	0.8	9.2	37.3 ab	4.1 ab	108 ab	145 ab	2.0 bc	12.5	15.3
6/6	1.5	8.3	33.0 c	3.5 b	89 b	122 b	2.6 ab	11.9	16.0
6/20	1.0	8.0	40.0 ab	4.5 ab	122 ab	163 ab	2.5 ab	13.9	17.5
Limb Treatment									
Control	1.0 a	10.6 a	55.4 a	6.1 a	155 a	210 a	2.5 a	22.7 a	26.3 a
Bend	1.3 a	10.6 a	35.3 c	4.7 b	111 bc	146 b	2.5 a	9.8 bc	13.6 bc
Head	0.5 b	6.4 c	42.7 b	4.1 b	119 b	162 b	1.9 ab	11.8 b	14.3 b
Bend + head	0.7 ab	8.4 b	28.5 d	3.0 c	87 c	115 c	1.7 b	7.2 c	9.7 c
F Significance									
Time	NS[y]	NS	**	**	*	**	**	NS	NS
Treat	*	**	**	**	**	**	**	**	**
Time x Treatment	NS	NS	**	NS	*	**	NS	NS	NS

[z] Means within a main effect column separated by Duncan's multiple range test, $P = 0.05$.
[y] NS, *, **, nonsignificant or significant at $P \geq 0.05$ or 0.01, respectively.

no benefit. Leopold (9) reported that physical bending of stems of several tree species resulted in a large increase in endogenous ethylene content. In further work, Robitaille and Leopold (15) reported the rise in ethylene content in apple stems reached a maximum two days following bending and returned to levels in control plants after three weeks. Thus, it is not surprising to see the effect on flowering being exhibited following the shortest period (15 days) in this study. It is surprising that bending the leaders on these trees had no effect on growth compared to the control trees. This may have been due to the minimal pruning of these trees as the central leader averaged approximately half the growth that occurred the previous year.

The hypothesis that the response to bending may differ at various times during the period of rapid shoot growth in the spring was refuted in this work. The bending response was similar from mid-April through mid-June for both cultivars (Figure 1A and Figure 2A). Bending had no effect on growth of 'Red Cort,' but caused a reduction at all dates with 'Gala.' The authors are unaware of other work comparing various times of bending during the period of active growth.

Heading lateral shoots on the central leader prior to May 9 had little effect on subsequent

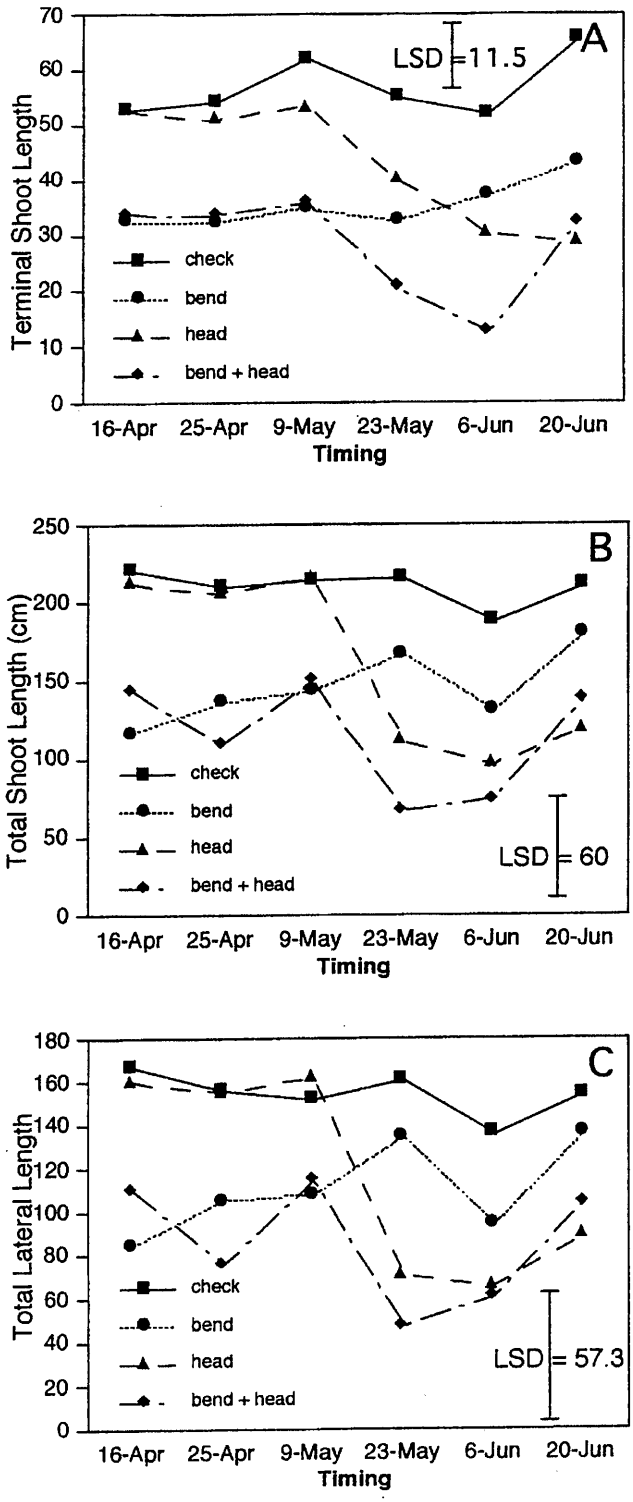

Figure 2. Interaction between time of application and bending and heading vigorous laterals on the central leader of 'Regal Gala' on M.7 rootstock apple trees on terminal shoot length on the lateral (A), total shoot length (B), and total lateral shoot length (C).

length of the terminal shoot growth on the lateral or total growth. This was probably because the early stage of development and regrowth could compensate for the growth removed; however, after May 9 regrowth from heading was unable to compensate for the growth removed. Results of summer pruning trials indicate that the earlier in the season pruning is accomplished, the greater the regrowth that occurs (11, 16).

Time during the spring when laterals were manipulated had no effect on flowering the following season. Heading consistently decreased flowering of both apple cultivars. This is consistent with previous findings showing the negative effect of heading on flowering and fruiting (2, 3). Bending did not increase flowers in this study no matter when it was performed during the early spring period of active growth, as has been found in other studies (6, 10), although many studies report increased flowering (7, 8, 12, 14, 17). In fact, lateral flowering of 'Gala' was decreased with bending and when combined with heading, both terminal flowering and total flowering of 'Red Cort' were decreased. Some studies (5, 7, 8) show that flowering on young trees is related to total growth which could possibly explain the results in this study since growth was reduced by these treatments.

In summary, the length of time the bend was in place or the time during early spring (mid-April through mid-June) had little effect on the response to bending leaders or branches of young vigorous apple trees. Heading laterals reduced flowering the following year. The effect of heading on regrowth of the leader and total lateral growth was greatest from mid-May through mid-June with much less effect earlier in the season.

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The Effect of Apple Fruit Bruising on Total Returns

Richard C. Funt, Ewen A. Cameron, and Nigel H. Banks

Introduction

Apple growers produce and market a crop that requires a large investment in labor, equipment, and chemicals. Success in the orchard is a combination of good management and sound business practices. Depending on farm size, many apple growers are able to perform most of the labor requirements, except for harvesting and packing. Many growers hire labor at harvest time and transport the harvested fruit to a packing house. Prior to harvest, the grower has some control over the condition of the fruit including color, size, firmness, and freedom from pest and disease damage. At harvest, the hired labor plays an important economic role in the total returns that the grower receives. Apples at harvest can be bruised by labor, transport to the packing house, and the grading and packing operation.

Apples for the fresh export market in New Zealand (NZ) provide the greatest sales volume and highest returns for the grower. The fruit is required to be free of blemishes (maximum 6%), diseases, disorders, insects, bruises, and other spoiled characteristics. In 1991, bruising cost growers of export apples 25 million New Zealand dollars (2). In a competitive world market, bruising can affect future sales if strict marketing standards do not eliminate bruised apples at the packing house. Therefore, the future of the New Zealand apple industry is dependent on a quality product, which results from excellent marketing standards in addition to growers who can achieve profitable pack out of exported fruit.

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Objectives

The objectives of this study were to:

- Determine the average loss in revenue from the bruising of six apple cultivars that have field inspections or no field inspections during harvest.
- Determine the loss in revenue from bruising in low- and high-priced apples.
- Make recommendations for reducing apple fruit bruising and lowering harvest costs.

Orchard and Labor Descriptions

A farm size of 10.6 hectares (ha) was chosen to demonstrate the effect of bruising. This is the same farm size used by the Ministry of Agriculture and Fisheries (MAF) to develop an estimate of costs and returns (9). In the Hawkes Bay fruit region there are 861 orchards with a total of 6,600 ha for an average acreage of 7.7 ha of apples and pears (10). Orchard size does vary among the fruit-producing regions in New Zealand, but Hawkes Bay produces more than 50% of all apples (1).

'Braeburn,' 'Fuji,' and 'Royal Gala' apple cultivars were selected as high-priced cultivars. Harvesters of 'Royal Gala' and 'Fuji' were considered to be paid an hourly rate (NZ $8.00/hr)[1] since these fruits have four to five pickings

per season (13). Because of multiple pickings per season, it was estimated that a harvester could average two to three bins (24 cartons, 18.5 kg/carton) per day at an average cost of $0.98 to $1.33 per carton (Table 1). Therefore, at 2.5 bins per day an average cost is $1.11 per carton (Table 2). For Braeburn, the harvesting cost was considered to have 50% of the fruit harvested at the hourly rate (similar to 'Royal Gala' and 'Fuji') and 50% at a contract rate of $22 per bin (13) (Table 2). Therefore, Braeburn's cost is $1.10 per carton.

'Red Delicious,' 'Premier Red Delicious,' and 'Granny Smith' apple cultivars were selected as low-priced cultivars. Harvesters of 'Red Delicious,' 'Premier Red Delicious,' and 'Granny Smith' could pick an average of three bins per day at $20 per bin for a cost of $0.83 per carton (Table 2). Generally, these apples had fewer pickings per season, and more fruit were harvested at each picking.

The cost of field supervision (inspection) of bruised apples was calculated to be $10.00/hour for an eight-hour day (Table 2). It was estimated that the inspector would average 32 bins per day.

The cost of grading apples used in this analysis was reported by one packer (3). Another packer had a flat fee of $0.13/kg. As the percent of total apples packed decreases, the cost of grading increases as calculated (Table 3). It is assumed that as the number of bruised or defective fruit increases, additional labor is hired or the speed of the grader is reduced to accommodate a low packout. Therefore, total grading costs increased as bruising and other defects increased. The unit cost of packaging is the same regardless of the percent packout.

Apple prices received by growers were obtained from reports of the MAF Monitoring Reports and Financial Budget Manuals for 1990 to 1994 (7, 8, 9). Apple prices for processing were estimated from the Financial Budget Manuals (4). Prices received over a four-year period were averaged. Based on MAF estimates of production, the percent of production and percent of return per cultivar were calculated for 1993 and 1994.

Table 1. Cost Per Carton and Per Bin to Harvest New Zealand Apples in 1994.

			Per Carton[z,y]	
No. Bins/Day[z]	Cost/ Bin[z]	Difference	Rate/ Hour	Difference
1	$64.00	—	$2.67	—
	—	$32.00	—	$1.34
2	32.00	—	1.33	—
	—	10.67	—	0.44
3	21.33	—	0.89	—
	—	5.33	—	0.22
4	16.00	—	0.67	—
	—	3.20	—	0.14
5	12.80	—	0.53	—

[z] 24-carton bins. Estimates in New Zealand dollars, cost rounded to the nearest cent.
[y] $8.00 per hour and an eight-hour day for $64/day.

Table 2. Cost to Harvest an 18.6 kg Carton of New Zealand Apples in 1994[z].

Cultivar	Hourly	Contract	Supervision[y]	Total Cost
Braeburn[x,w]	$1.11	$0.92	$0.10	$1.12
Fuji[w]	1.11	—	0.10	1.21
Royal Gala[w]	1.11	—	0.10	1.21
Red Delicious[v]	—	0.83	0.10	0.93
Premier Red	—	0.83	0.10	0.93
Granny Smith	—	0.83	0.10	0.93

[z] Estimates in New Zealand dollars.
[y] Supervisory labor at $10.00/hour for an eight-hour day would equal $2.50/bin or $0.10/carton.
[x] 'Braeburn' is 50% hourly and 50% contract.
[w] Average 2.5 bins/day.
[v] Rate is $20.00/bin for 'Red Delicious,' 'Premier Red,' and 'Granny Smith.'

Table 3. Contract Cost to Grade New Zealand Apples[z].

Packout (%)[y]	Cost/Bin[x]
90	$48
85 - 89	49
80 - 84	50
70 - 79	52
65 - 69	55
60 - 64	90
55 - 59	65
50 - 54	70
45 - 49	75
44	80

[z] Source: Burtt and Fleming (2). Estimates in New Zealand dollars.
[y] Percent of apples meeting New Zealand export standards.
[x] Bin capacity = 22 bushels; 1993 charges in New Zealand dollars.

Results

The actual cost to harvest an 18.5 kg. carton of apples at an hourly rate is dependent on the number of bins harvested per day (Table 1). As the number of bins harvested increased, the price per carton decreased.

It was estimated that a harvester could average two and one-half bins per day. This equals an average cost of $1.11 per carton for 'Royal Gala' and 'Fuji' (Table 2). Braeburn's cost is $1.12 per carton. 'Red Delicious,' 'Premier Red,' and 'Granny Smith' were all harvested at the $20 for 24 carton bin rate for a cost of $0.83/carton.

The cost of supervision was an additional $0.10/carton when a supervisor (inspector) was used in the comparison of supervised to nonsupervised harvesters (Table 2). The total cost to pick a carton of apples with supervision was $1.21 per carton. Further, as bruising increased, the grading cost increased $0.21 per carton for 60 from 69 percent packout and $0.42 for 50 to 60 percent packout (Table 3). For every 1% increase in bruising, grading costs increased $0.02 to $0.04 per carton.

As the number of bruised fruit increases, the total packout decreases. The average return for 'Royal Gala,' 'Fuji,' and 'Braeburn' (high-priced apples) over a four-year period from 1990–91 to 1993–94 was $22.82 per carton. The average return for 'Red Delicious,' 'Premier Red,' and 'Granny Smith' (low-priced apples) was $9.64 per carton (Table 4). The return per bin (of high-priced apples) for 50% to 70% was $274 to $383 and for low-priced apples it was $116 to $162 (Table 5). For every 1% increase in packout, there is a $5.48 increase in returns per bin of high-priced apples and $2.31 for low-priced apples. As packout increases by 1%, the amount of processed apples may decrease by 1%. However, this was not included.

The net returns (returns minus costs) for each 1% increase in packout due to reduced bruising for high-priced fruit and supervised harvest labor would be $4.31 per bin ($5.48 - 1.11 - 0.10 + 0.04 = $4.31), $4.41 nonsupervised, and $1.42 and $1.52 for low-priced fruit and supervised and nonsupervised harvest labor, respectively.

Returns per ha of land are a product of yield, packout (percent of grade and size), and price received. Based on reports and estimates for a 10.6 ha apple orchard, high-priced apples such as 'Braeburn' can produce 24 to 27% of the volume but returned 35 to 36% of the revenue (Table 6). In 1993 and 1994, the price received for 'Braeburn' was 43 and 32%, respectively, higher than the average price for all apples. 'Royal Gala' is similar to 'Braeburn' in percentage of packout but in 1993 'Fuji' had a very low packout (32%) and below-average price ($9.48) was received. Packout for Fuji in 1994 was higher than in 1993. In 1993 'Red Delicious,' 'Premier Red Delicious,' and 'Granny Smith' accounted for 4 to 20% of the production, but for only 2 to 9% of the revenue (Table 7). Similar, but lower, levels of production and revenue for these cultivars were recorded for 1994. However, 'Granny Smith' had the lowest packout and price of low-priced cultivars in 1993 and 1994. Before 1993, a higher price was received for 'Granny Smith' than for 'Red Delicious' or 'Premier Red Delicious' (Table 4).

[1] All economic data reported within are expressed as New Zealand dollars.

Table 4. Total Payment Per Average Tray Carton Export for Fancy Grade of Apples Grown in New Zealand, 1990–91 to 1993–94[z].

Cultivar	Year 1993/94	1992/93	1991/92	1990/91	Mean
Braeburn	$13.76	$27.21	$27.06	$22.62	$22.66
Fuji	13.93	20.98	31.39	22.51	22.51
Royal Gala	17.07	22.22	31.16	23.21	23.28
Mean[y]	14.92	24.80	29.87	21.68	22.82
Red Delicious	5.15	10.83	11.89	8.80	9.18
Premier Red	4.86	8.96	14.60	9.04	9.36
Granny Smith	4.64	9.76	17.18	10.02	10.40
Mean[y]	4.88	9.85	14.56	9.29	9.64
Processed[x]	0.16	0.21	0.16	0.16	0.17

[z] Source: Burtt and Fleming (2, 3). Estimates in New Zealand dollars.
[y] Average for all counts (sizes) and cultivars listed.
[x] Average price per kg sound fruit. In 1993–94, processing/standard/reject price was $0.04/kg.

Table 5. Returns Per Bin for High- and Low-Priced New Zealand Apples with 50 to 70 Percent Packout[z].

Packout (%)	No. Export Cartons/Bin[y]	Returns/Bin High[x]	Low[w]
50	12.0	$273.84	$115.68
52	12.5	285.25	120.50
54	13.0	296.66	125.32
56	13.4	305.79	129.18
58	14.0	319.66	134.96
60	14.4	328.61	138.82
62	14.8	337.74	142.67
64	15.4	351.43	148.46
66	15.8	360.56	152.31
68	16.3	371.97	157.13
70	16.8	383.38	161.95

[z] Estimates in New Zealand dollars.
[y] 24/18.5 kg cartons packed for export.
[x] High-priced cultivars 'Braeburn,' 'Fuji,' and 'Royal Gala' average $22.82 (Table 4).
[w] Low-priced cultivars 'Red Delicious,' 'Premier Red,' and 'Granny Smith' average $9.64 (Table 4).

Table 6. Percent of Total Production and Percent of Total Revenue of a Typical 10.6 ha Farm for 'Braeburn,' 'Fuji,' and 'Royal Gala' Apples Produced in New Zealand in 1993 and 1994[z]

Year and Cultivar	Total (CE)[y]	Packout (%)	Export[x]	Price (TC)[w]	Total (CE)	Percent Production	Percent Revenue
1993							
Braeburn	6,244	58	3,609	$14.34	$89,824	24	35
Fuji	1,134	32	363	9.48	10,753	4	4
Royal Gala	4,648	62	2,904	13.18	61,254	18	24
Total[v]	25,952	54	14,111	10.00	256,810	—	—
1994							
Braeburn	6,418	62	3,954	$11.27	72,317	27	36
Fuji	1,262	52	622	10.18	12,851	5	6
Royal Gala	4,768	61	2,917	10.35	49,330	20	24
Total[v]	23,648	55	12,933	8.50	201,196	—	—

[z] Source: MAF (8, 9). Estimates in New Zealand dollars.
[y] Total production is a weighted average of Hawkes Bay (54%), Nelson (34%), and Canterbury (12%) and is based on a 10.6 ha farm. CE = carton equivalent.
[x] Export tray cartons.
[w] Price received from carton equivalent (18.5 kg). Percent tray carton (TC) value plus processed value = average price received.
[v] Total = all apple cultivars.

Discussion

Apple bruising is caused by the impact of one fruit touching another fruit in the picking container, by the impact of fruit hitting the bottom of the apple bin, and by fruit to fruit impact as they roll from the top to the bottom of the pile in the bin. Apples are also bruised during transport and grading. Managers in the orchard and at the packing house can influence the occurrence and rate of bruising by controlling events and conditions in the distribution system (12). It is believed that 40% of bruising occurs in the orchard. An additional 40% is caused by the grading operation, with the remaining 20% coming from other causes from transporting apples from the field to grading operation (2). Further, Banks recommends that growers can control bruising by instructing harvesters how to place fruit into picking containers, how to release the fruit into field bins, and how to fill the bins evenly across the bin area to avoid having fruit roll from the top to the bottom of the pile of apples. Padding of the field bin can reduce bruising in the bottom layer of fruit by 30 to 60% (2). In this study, the reduction of bruising at harvest by 1% could increase the net returns by $1.42 to $4.41 per bin for low- or high-priced fruit, respectively.

Field supervision is a practice in some New Zealand orchards where each harvester's bin is checked for bruising and in some cases for fruit size and color. The supervisor can indicate to other harvesters that the amount of bruising (above 2 to 3%) is unacceptable, and the harvester can be released from work if bruising is not reduced. Some growers may pay a bonus to

Table 7. Percent of Total Production and Percent of Total Revenue of a Typical 10.6 ha Farm for 'Red Delicious,' 'Premier Red,' and 'Granny Smith' Apples Produced in New Zealand in 1993 and 1994.[z]

Year and Cultivar	Total (CE)	Packout (%)	Export[x]	Price (TC)[w]	Total (CE)[y]	Percent	
						Production	Revenue
1993							
Red Delicious	3,390	66	2,236	$6.86	$23,260	13	9
Premier Red	911	63	575	5.77	5,257	4	2
Granny Smith	5,080	36	1,810	4.17	21,179	20	8
Total[v]	25,952	54	14,111	10.00	256,810	—	—
1994							
Red Delicious	2,578	64	1,648	5.35	13,286	11	7
Premier Red	340	85	289	6.70	2,278	1	1
Granny Smith	3,692	27	991	2.97	10,969	12	5
Total[v]	23,648	55	12,933	8.50	201,196	—	—

[z] Source: MAF (8,9). Estimates in New Zealand dollars.
[y] Total production is a weighted average of Hawkes Bay (54%), Nelson (34%), and Canterbury (12%) and based on a 10.6 ha farm. CE = carton equivalent.
[x] Export tray cartons.
[w] Price received from carton equivalent (18.5 kg). Percent tray carton (TC) value plus processed value = average price received.
[v] Total = all apple cultivars.

those persons who can pick apples with low amounts of bruising.

Harvest labor accounts for 41% of total wages, and all wages account for 42% of the total costs to produce apples in New Zealand (7, 8, 9). Total wages paid to employees increased 9.7% between 1990–91 and 1992–93, but decreased in 1993–94 due to hail-damaged fruit which were not harvested. However, average yields per ha are some of the highest in the world. Due to strict export requirements, an average of 58% packout is considered to be below average, but certain cultivars such as 'Fuji' are responsible for this. In Washington State, USA, red color sports of 'Delicious' are expected to have a 76% packout and 'Golden Delicious' 62%. Sixty percent is considered to be the average packout in Washington (6). All apple growers must understand the effect of returns on packout in order to be competitive in a global economy.

In New Zealand, where the export market is of extreme importance, strict standards are paramount to maintain worldwide reputation. The Apple and Pear Marketing Board, therefore, allows no more than 6% of the final pack to have bruises or defects. As any one defect or spoilage increases, it puts the other defect under greater pressure to be reduced. Therefore, the Apple and Pear Marketing Board oversees the quality control programs of packing houses through weekly inspection. Generally, bruising is 0.6% and total defects are less than 6.5%. While packing houses are eliminating most of the bruised apples, growers and the Marketing Board need to encourage packing houses to

make adjustments (reduce height differences, provide padding, reduce collision, reduce speed, etc.) or purchase new improved equipment in the short term to decrease the amount of bruised fruit.

Also, the authors are concerned that growers may face a reduced amount of locally available and experienced harvesters in the near future. With the expansion of new orchards and vineyards and the need to pack fruit for export during the harvest season, the labor required for seasonal work will increase. Currently, non-agricultural wages are also increasing up to 20%, and therefore competition for labor may require an increase in harvesters' hourly or contract rate. However, growers are shifting from trees that require ladders to dwarf-sized trees that require no ladders for harvesting or pruning.

Dwarf trees will increase the number of bins harvested per hour. In the United States, where harvesters are paid by the piece rate, labor studies indicate that persons using ladders can harvest nine to 10 bushels (19.1 kg/bu) per hour compared to a harvest of 11.5 bushels per hour without ladders (11). Increasing the number of units per hour decreases the harvesting cost per unit when harvesters are paid by the hour. New Zealand growers also expect fewer number of pickings on dwarf trees, which will also increase efficiency (5). It is possible that, as wages increase, orchard systems, harvest supervision, and techniques to reduce bruising (such as use of padding) can hold total harvesting costs to a minimum, ensuring constant or increasing returns over the next five to 10 years.

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Yield, Berry Quality, and Economics of Mechanical Berry Harvest in Ohio

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Introduction

Mechanical harvest systems for blueberries and brambles (raspberries and blackberries) have gained wide acceptance in recent years due to the increased demand for both fresh market and processed berries, the increased acreage planted to berry crops, the scarcity of seasonal labor, and the need to reduce production costs in a competitive world market (8). Early mechanical harvest systems, widely used by the late 1950s, employed mechanical hand-held vibrators powered by compressed air or batteries to remove fruit which was then retrieved in a cloth-covered catching frame positioned at the base of the plant. Such simple systems increased harvest efficiency (time) by more than 250% and reduced harvest cost by 55% (21). Since then, advances in harvester design and technology have enhanced overall harvester performance, improved the quality of mechanically harvested fruit, and reduced the incidence of mechanical damage to fruiting plants (8). The development of cultivars and production systems optimized for mechanical harvest have also contributed to the popularity of the harvester among growers. Currently, mechanical harvesters are being sold in countries throughout the world, including the United States of America, Canada, Scotland, Russia, Chile, Argentina, and Poland (8).

Technological advances notwithstanding, the processing industry remains the primary outlet for most mechanically harvested berries. For this reason, mechanical harvest of blueberries and bramble fruit is perhaps most prevalent in the Pacific Northwest, where weather conditions are relatively dry during harvest and the processing industry infrastructure is well-developed. Oregon growers, for instance, now mechanically harvest up to 98% of their red raspberries (7). Although mechanical berry harvest has become a standard practice in the Pacific Northwest, a minor, but significant portion of the total berry crop is still hand harvested when weather conditions are favorable and then sold at premium returns through the fresh market. This ability to alternate harvesting techniques in response to markets and weather conditions has led to the continued viability of the industry.

Historically, Ohio's small-fruit industry has been based on the production of high-quality fruit for the fresh market. Although small-fruit acreage within the state is currently limited (9, 18), recent publicity regarding the health benefits of berries and the proximity of Ohio to large metropolitan areas on the East Coast suggest that Ohio's industry is positioned for expansion. During a recent strategic planning exercise, members of the Ohio Fruit Growers Society and their collaborators identified four interrelated primary components necessary for the growth and long-term stability of the small-fruit industry in Ohio:

- The expansion of small-fruit production acreage.

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- The evolution of new fresh-market strategies and options.
- The acquisition of mechanical-harvest capabilities and development of a berry-processing industry.
- The continued emphasis on production of high-quality fruit.

Undoubtedly, the design or adaptation of a mechanical harvester for Ohio will be a key element in the successful development of dual production, harvesting, and marketing systems in this region. Harvesters developed for use in the Pacific Northwest may be suitable for the Ohio industry, but data regarding their efficiency or that of other harvesters under Ohio conditions is almost nonexistent (i.e., prior to this study in 1995, blueberries had been mechanically harvested by Ohio growers on a limited basis, but brambles had not). Moreover, unlike the Pacific Northwest, wet weather conditions often prevail during the Ohio harvest season. Heavy rainfall can result in softer, more easily damaged fruit, can increase *Botrytis cinerea* (grey mold) infection rates and severity, and can reduce the number of operating days (8). Wet weather can also increase the susceptibility of bramble primocanes to mechanical damage and hasten their subsequent cane death by *Leptosphaeria coniothyrium.* Ultimately, consideration of Ohio's unique climatic conditions will most likely affect the evaluation of the mechanical efficiency and economic viability of a given harvester design.

The major objective of this study was to evaluate, under Ohio conditions, the suitability of a popular mechanical harvester designed for the Pacific Northwest (19). Target crops included black raspberries, highbush blueberries, fall-bearing red raspberries, and thornless blackberries. Yield, performance parameters, fruit quality, and costs associated with the acquisition, maintenance, and operation (harvest expenses) of the harvester were explored.

Materials and Methods

Mechanical Harvesters

A Littau (Model FR9508) self-propelled, over-the-row, "shaking drum with fingers"-type harvester (Figure 1) was leased from the Littau Berry Harvester Co. (Salem, Oreg.) through the support of growers, the Ohio Department of Agriculture, and The Ohio State University (19). In the front of the machine, vertically oriented spiked-drum shakers oscillated in a horizontal plane. As the machine moved down the row, these drums rotated freely and the oscillation caused ripe fruit to drop onto a catching surface that opened and closed around the canes. Berries rolled into cups and were conveyed vertically to a cleaning and sorting belt. Sorted fruit was collected in field containers, which were removed from the machine by hand at the end of the row.

In addition to the Littau machine, a grower-owned BEI (Model 'Little Blue,' Blueberry Equipment Inc., South Haven, Mich.) tractor-mounted, "slapper"-type mechanical harvester was used to harvest blueberries.

Trial Sites and Experimental Design

Trial sites, cultivars harvested, dates of harvest, host growers, planting descriptions, and trial experimental designs are listed in Table 1. Experiments were performed using mature plantings at all sites. Trials 1, 3, 4, and 5 were conducted concurrently with the first harvest of their respective sites during the 1995 season, whereas experimental plots used in Trial 2 had been harvested by hand three times prior to experimentation. In Trials 1 and 5, fruit removal efficiency during harvest (based on total, marketable, and cull fruit yields) was evaluated using eight uniform small-scale plots arranged in randomized complete block designs (RCBs), with two harvesting treatments (hand and Littau Harvester) and four replications per treatment. Two similar RCB designs (Tests A and B) were used for Trial 4 (highbush blueberries); Tests A and B contrasted the efficiency of fruit removal by hand picking with that of mechanical harvest using the Littau and BEI harvesters, respectively. Estimates of fruit harvest rates for the Littau harvester were determined in Trials 1, 2, and 4 using large-scale plots (60–452 ft. of row, plots not replicated). At each site, machine speed (mph) was ascertained, and fruit yields and times to harvest were recorded. Plot descriptions (i.e., plot size or composition) for each trial are listed in Table 1. No experimental parameters were measured during the harvest of Trial 3 (blackberries), as it

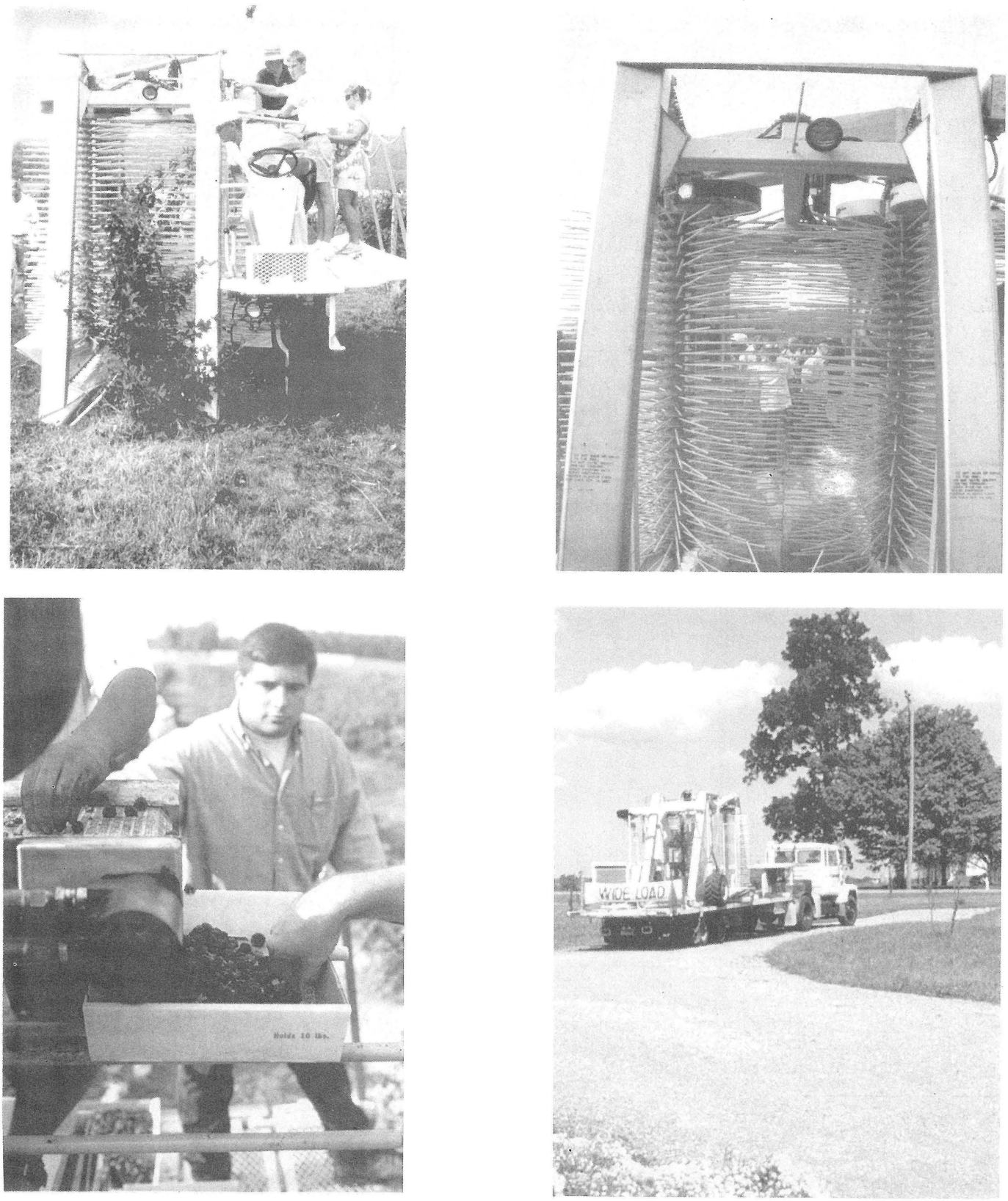

Figure 1. The Littau (Model FR9508) Harvester at Trial 3 ('Chester' thornless blackberries), Piketon, Ohio. Frontal view (top left); drum details (top right); grading belt details (bottom left); harvester transport (bottom right).

was intended only as a field demonstration of the Littau harvester for growers.

Harvesting Procedures

Members of the Ohio Small Fruit Research and Extension Team hand-harvested designated plots at each site prior to machine harvest. Ripe fruit (judged by appearance) were carefully removed from all plants within each plot, collected in containers appropriate for each crop, then placed in the shade. Machine harvest of the small- and/or large-scale plots at each site was accomplished using harvester settings that were determined during preliminary harvester runs. Machine-harvested fruit were collected in commercial lugs without hand sorting on the harvester's grading belt. Lugs were immediately placed in the shade.

Soon after harvest, berries from all harvest treatments were sorted and weighed; total weight, weight of marketable berries (whole rounded berries without grey mold, defects), culls (unripe or damaged berries, berries with stems attached), and trash (stems, leaves, and other debris, blueberries only) were recorded. Yield data were obtained in the field. In addition, blueberries (Trial 4) were sorted by machine in a standard packing shed.

Fruit-Quality Evaluations

Quality evaluations were obtained on a per-plot basis for fruit that was hand or machine harvested from small-scale plots in Trials 1 and 5 and on a per-treatment basis for those harvested in Trial 4. Black raspberry fruit were sampled directly from picking containers, whereas blueberry and red raspberry fruit were mechanically or hand sorted respectively to remove culls prior to sampling for quality analyses. Red raspberry fruit firmness (Trial 5) was evaluated on site. All other quality analyses were performed on fruit samples (500 g – 1 kg) that were randomly chosen from the total harvest of each treatment (blueberries) or plot (black raspberries and red raspberries), placed in plastic bags, and then transported in ice chests to the Crop Quality Evaluation Laboratory on the Wooster, Ohio, campus of The Ohio State University's Ohio Agricultural Research and Development Center. Laboratory measurements of each quality parameter were obtained using appropriately sized, randomly chosen subsamples.

In the laboratory, the percentage of immature black raspberry fruit (Trial 1) was determined gravimetrically; fruit with torus and pedicel attached were considered to be immature. Aliquots of the macerate from two 20-berry subsamples per plot were used to measure soluble solid levels by refractometry (Abbe, Mark II, Model 10480s/n, Keene, N.H.). Titratable acidity levels were determined on 4 g aliquots of the macerate from two 20-berry subsamples per plot using standard techniques described by Perkins-Veazie and Collins (20). Color reflectance parameters were measured on 180 ml subsamples per plot (three readings per subsample) using a Hunter Color Difference meter (Model 25, Reston, Va.). Raw reflectance values of L*, a*, and b* were transformed according to Setser (25).

Differences in blueberry fruit firmness (Trial 4) were detected using four five-berry subsamples per treatment. Individual berry firmness (the force required to penetrate the epidermis) was determined on an Instron (Model 1101, Canton, MA) firmness tester equipped with a 500 g transducer and a 3.2 mm diameter probe traveling at 50 mm/min. Blueberry soluble solid contents, titratable acidity levels, and color reflectance values were measured using techniques similar to those described earlier. Storage performance of hand- and machine-harvested blueberries (four storage trials per treatment) were evaluated by transferring a weighed quantity (≈80 g/storage trial) of intact berries to new fiberboard pint containers, then storing them in air at 3°C for five days. Containers were uncovered, but protected against air currents during storage. Percentage moisture loss was calculated from sample weights before and after storage; percentage fruit loss was determined as the ratio of the weight of damaged, shriveled, and moldy berries to after-storage weight.

Red raspberry fruit firmness (Trial 5, measured on site) was evaluated on five-berry subsamples per plot using an Ametec AccuForce II Gauge (Model ML4432-5, Largo, Fla.) equipped with a flat-surfaced probe. Individual berry firmness (the force required to close its central cavity opening) was measured with this gauge

Table 1. Blueberry and Bramble Mechanical Harvest Trial Dates, Hosts, Locations, and Field Descriptions, Trial Designs, and Plot Descriptions, 1995.

Trial	Crop, Date, Host, Location, and Field Description	Trial Design and Plot Description: Fruit Removal Efficiency	Trial Design and Plot Description: Machine Harvest Rate[z]
1[y]	Crop: 'Bristol' black raspberries Date: June 30 Host: Dale Stokes Location: Stokes Berry Farm, Wilmington, Ohio Plant spacing: 3' X 12'[x] Trellising: none	Design: RCB Treatments: Littau harvester, hand harvest Reps: 4 Plot size: 20 ft of row	Design: none Treatments: Littau harvester Reps: 1 Plot size: 60 ft of row
2[y]	Crop: 'Bristol' black raspberries Date: July 11 Host: Dale Stokes Location: Stokes Berry Farm, Wilmington, Ohio Plant spacing: 3' X 12' Trellising: none	n.d.[w].	Design: none Treatments: Littau harvester Reps: 1 Plot size: 250 ft of row
3	Crop: 'Chester' thornless blackberries Date: Aug. 17 Host: The Ohio State University Location: Piketon Research and Extension Center, Piketon, Ohio Plant spacing: 8' X 12' Trellising: 2 wire I-trellis	n.d.	n.d.
4	Crop: 'Elliott' highbush blueberries Date: Aug. 23 Host: Steven Bielstein Location: The Blueberry Patch, Mansfield, Ohio Plant spacing: 4' X 12' Trellising: none	Design: RCB Treatments Test A: Littau harvester, hand harvest Test B: BEI harvester, hand harvest Reps: 4 Plot size: 2 mature plants or 10 ft of row	Design: none Treatments: Littau harvester Reps: 1 Plot size: 452 ft of row
5	Crop: 'Heritage' red raspberries Date: Sept. 9 Host: Robert Rothchild Location: Rothchild Berry Farm, Urbana, Ohio Plant spacing: not applicable (hedgerow-planted) Trellising: none	Design: RCB Treatments: Littau harvester, hand harvest Reps: 4 Plot size: 20 ft. of row	n.d.

[z] Littau harvester (Model FR9508).
[y] Trial 1 and Trial 2 harvests of 'Bristol' black raspberries were obtained from different experimental sites on the same farm; harvest dates correspond with the first and fourth harvests (i.e., beginning and end) of the season, respectively.
[x] Spacings indicated correspond to within row x between row measurements.
[w] n.d. = not determined. Because Trial 3 was intended as a field demonstration of the Littau harvester only, no harvest parameters were measured.

following the technique described by Perkins-Veazie and Collins (20). Soluble solids, titratable acidity, and color reflectance assessments were obtained in the laboratory using techniques identical to those described previously.

Economic Evaluations

In order to compare the economic efficiency of hand and machine harvest, a detailed economic analysis was prepared as follows:

Fixed and Variable Machine Costs

Fixed and variable machine costs were calculated (Table 2) using methodology and rationale reported previously (10). Acquisition, maintenance, and operating costs for both the Littau and BEI harvesters were based upon a projected seven-year life span. Interest, depreciation, repair, insurance, housing, fuel, and operating labor costs and salvage values were determined in an identical manner for each machine.

Mechanical Harvest Costs

Expected machine harvest rates (lbs. of fruit/hr.) were determined from optimal harvester speeds and subsequent yield data from large-scale plots harvested during the 1995 field demonstrations. Machine-harvest rate calcula-

Table 2. Fixed and Variable Costs for Acquisition, Maintenance, and Operation of Mechanical Berry Harvesters.

		BEI Harvester System[z]	
Costs	**Littau Harvester[y]**	**Harvester**	**Tractor**
Acquisition Costs			
Machinery ($)	78,000	15,000	20,000
Depreciation ($/yr)[x]	10,029	1,928	2,571
Interest/yr ($/yr)[w]	4,290	825	1,100
Maintenance Costs			
Repairs ($/yr)[v]	2,786	535	714
Insurance and housing ($/yr)[u]	48	36	36
Acquisition and Maintenance Cost Total ($/yr)	17,153	3,324	4,421
Operation Costs			
Fuel/oil/lube ($/hr)[t]	1.32	2.26	
Labor ($/hr)[s]	36.74	36.74	
Operating Cost Total ($/hr)	38.06	39.00	

[z] BEI harvester (Model 'Little Blue'); pull-type, propelled by a 38-horsepower diesel tractor.
[y] Littau harvester (Model FR9508); self-propelled, equipped with a 22-horsepower diesel engine.
[x] Based on straight-line depreciation over seven years with 10% salvage value.
[w] Based on interest at 10% per year on the average balance for seven years.
[v] Based on 25% of initial machine cost.
[u] Housing costs estimated at $0.20/ft^2/yr.
[t] Fuel costs estimated at $1.10/gal and 0.045 gal/horsepower/hr of operation; oil and lubrication costs based on 20% of fuel costs.
[s] Based on the salaries of one operator (driver) at $14.30/hr and three fruit handlers at $7.48/hr.

tions assumed harvester speeds of 0.57 mph and 0.25 mph for the Littau and BEI machines, respectively. These values were based on actual recorded maximum speeds in the field. A six-min/hr (10%) turn around and down time was added for expected shifts of containers and harvest-crew breaks.

Harvest rates and fixed and variable machine cost statistics were then used to calculate the following: cost per hour of operation; cost per acre at 12- or 10-ft.-row spacings; and cost per harvested pound at fixed harvest rates of 1,000, 500, and 250 pounds of fruit per hour for the Littau harvester and 500, 250, and 125 pounds of fruit per hour for the BEI harvester, targeted to represent expected rates for first and subsequent harvests of the same field, respectively (Table 3). All costs were calculated for 40, 80, or 120 hours of estimated seasonal usage (i.e., conservative estimates based upon the modest berry acreage in Ohio and an anticipated limited initial acceptance of the harvester by growers).

Current and Projected Hand-Harvest Costs

A range of hand-harvest costs per pound of fruit was estimated based on three wage rates and four picking rates for bramble and blueberry fruit (Table 4). The lowest wage rate ($5.92/hr) used reflected the current minimum wage ($5.15) plus 15% benefits; the two additional wage rates ($7.07 and $8.22) were included to compare current hand-labor costs with projected increases in wages and benefits over the next seven years. The standard picking rate (64 pts/day or 6 lbs/hr) for red raspberry and highbush blueberry was derived from grower records for an average picker's performance over the entire season. Similar records were used to calculate the standard picking rate (64 qts/day or 12 lbs/hr) for black raspberries. Additional picking rates were included to reflect poor and superior picker performance.

Sensitivity Analysis of Hand- vs. Mechanical-Harvest Costs

To delineate the conditions under which fruit harvest using the Littau harvester would be more economically viable than hand harvesting, a sensitivity analysis diagram was prepared from data presented in Tables 3 and 4. The diagram relates hand vs. machine costs per pound of harvested fruit using projected hand-harvest costs per pound of fruit and costs per pound of machine-harvested fruit at the three estimated levels of seasonal machine use (40, 80, and 120 hrs/yr) and three estimated harvest rates (250, 500, and 1,000 lbs/hr).

Statistical Analyses

All yield and fruit-quality data from small-scale plots were subjected to analyses of variance using the SAS statistical package (24) and procedures (i.e., PROC ANOVA, GLM). Parameter means were compared using the LSD statistic ($P \leq 0.05$).

Results and Discussion

Harvester Performance

Because Ohio's current bramble and blueberry production acreages are relatively limited, mechanical harvesters that are not suited to the harvest of several crops will not likely be adopted by the industry. Even if the industry realizes its goals for expansion and the development of a processing industry, growers are likely to continue to base their operations on the culture of several crops rather than to rely upon the harvest of a single commodity to generate total farm income. For these reasons, it was important to evaluate the harvester under consideration (i.e., the Littau Berry Harvester, Model FR9508) using a variety of crop species.

Fortunately, the Littau harvester design did allow for the effective harvest of all crops tested. The harvester seemed to be especially suited for the harvest of 'Chester' thornless blackberries and, perhaps, provided fruit that were superior to those obtained from a typical hand harvest of this crop. Nearly all machine-harvested blackberries in Trial 3 were mature, firm, and intact, with little or no bruising, epidermal tearing, or juice loss to the container. Moreover, the Littau harvester was able to negotiate the blackberry trellis, easily maneuvering around five- and six-inch posts and the double-strand trellis wire.

Harvester Design and Operating Parameters

The maximum recorded operating speed for the Littau harvester was 0.57 mph (3,010 ft/hr) for all trials. Assuming a 10% correction for

Table 3. Variable Costs of Mechanical Harvester Operation Per Hour, Per Pound, and Per Acre of Harvested Fruit at Three Levels of Seasonal Harvester Use.

	Seasonal Harvester Use (hrs/yr)		
Harvester and Cost Variable	**40**	**80**	**120**
Littau Harvester[z]			
Cost/hr of operation ($)[y]	466.89	252.47	181.00
Cost/acre harvested ($)[x]			
12 ft row spacings	625.86	338.43	242.63
10 ft row spacings	750.63	405.90	291.00
Cost/lb fruit harvested ($)[w]			
250 lbs/hr	1.81	1.01	0.72
500 lbs/hr	0.93	0.50	0.36
1,000 lbs/hr	0.47	0.25	0.18
BEI Harvester[v]			
Cost/hr of operation ($)[u]	177.36	117.39	94.33
Cost/acre harvested ($)[t]			
12 ft row spacings	542.39	359.00	288.47
10 ft row spacings	649.67	430.00	345.53
Cost/lb fruit harvested ($)[s]			
125 lbs/hr	1.41	0.93	0.75
250 lbs/hr	0.71	0.47	0.38
500 lbs/hr	0.35	0.23	0.19

[z] Littau harvester (Model FR9508).
[y] Estimates based on fixed and variable costs for the Littau harvester (Table 2). Estimates do not include costs for machinery or personnel transport from farm to farm.
[x] Estimates calculated from cost per hour estimates and machine-harvest rates of 0.746 and 0.622 acres per hour for 12 ft. and 10 ft. between row spacings, respectively; machine-harvest rates based upon a machine speed of 2,709 ft/hr [0.57 mph (or 3,010 ft/hr) - 10% turn around and down time] and 3,630 and 4,356 linear ft. of row/acre for 12 ft. and 10 ft. between row spacings, respectively.
[w] Estimates calculated from cost per hour of operation for the Littau harvester.
[v] BEI harvester (Model 'Little Blue').
[u] Estimates based on fixed and variable costs for the BEI harvester (Table 2). Acquisition and maintenance costs for the tractor were reduced to reflect a presumed additional use of 40 hours per year on cultural tasks not related to harvest (i.e., tractor cost per hour of operation calculated at 80, 120, and 160 hours use); harvest estimates do not include costs for machinery or personnel transport from farm to farm.
[t] Estimates calculated from cost-per-hour estimates and machine-harvest rates of 0.327 and 0.273 acres per hour for 12 ft. and 10 ft. between row spacings, respectively; machine-harvest rates based upon a machine speed of 1,188 ft/hr [0.25 mph (or 1,320 ft/hr) - 10% turn around and down time] and 3,630 and 4,356 linear ft. of row/acre for 12 ft. and 10 ft. between row spacings, respectively.
[s] Estimates calculated from cost per hour of operation for the BEI harvester.

Table 4. Projected Labor Costs for Hand Harvested Red Raspberries, Black Raspberries, and Blueberries at Three Wage Rates and Four Picking Rates[z].

	Picking Rate (lbs/hr)[y]			
Wage Rate[x]	6	7.5	12	15
	Labor cost ($/lb of fruit harvested)			
$5.92/hr	0.83	0.66	0.42	0.33
$7.07/hr	1.02	0.82	0.51	0.41
$8.22/hr	1.21	0.97	0.61	0.49

[z] Standard picking rates (lbs/hr) were determined using grower records for the average daily volumes harvested by an average picker over the entire season. Daily volumes were converted to hourly weights as follows: for red raspberry and highbush blueberry — 64 pts/day ÷ 8 hr/day = 8 pts/hr, 8 pts/hr X 0.75 lbs/pt = 6 lbs/hr; for black raspberry — 64 qts/day ÷ 8 hr/day = 8 qts/hr, 8 qts/hr X 1.5 lbs/qt = 12 lbs/hr.

[y] For red raspberry and blueberry, hourly rates of 6 and 7.5 lbs/hr correspond to 8 and 10 pts/hr, respectively; for black raspberry, hourly rates of 6, 12, and 15 correspond to 4, 8, and 10 qts/hr, respectively.

[x] Wage rates are based on base pay rates of $5.15/hr, $6.15/hr, or $7.15/hr plus 15% benefits, respectively.

turn around and down time (mechanical adjustments, crew breaks, etc.), the overall harvester speed was considered to be 0.51 mph (2,709 ft/hr). At the corrected harvester speed, the Littau harvester would require 1.34 and 1.61 hours to harvest an acre planted at 12 ft. (3,630 linear ft. row/acre) and 10 ft. (4,356 linear ft. row/acre) between row spacings, respectively. When a large number of berries were ripe, such as during the first harvest of 'Bristol' black raspberries (Trial 1) and 'Elliott' blueberries (Trial 4), the Littau machine traveling at 0.57 mph within the row (0.51 mph, overall) was capable of harvesting more than 1,000 pounds of fruit per hour. However, when harvesting blueberries (Trial 4) at this speed, the machine reached its full capacity (the point at which its rotating cups were overflowing and berries fell to the ground). The Littau harvester would need to be refitted with larger cups in order to increase operating speed without loss of crop, especially in first-harvest situations where yields have been optimized by the planting of high-yielding cultivars or the use of superior cultural techniques.

In comparison, the BEI harvester used in Trial 4 traveled at an average rate of 0.25 mph (1,320 ft/hr). When BEI harvester speeds were corrected similarly for turn around and down time (i.e., 0.22 mph or 1,188 ft/hr), it was estimated that this machine would need 3.05 and 3.66 hours to harvest an acre planted at 12 ft. and 10 ft. between row plantings, respectively.

Obviously, the actual maximum harvester speed during the harvest of a given planting would be determined primarily by field conditions and the number of ripe berries present at the time of harvest. The relative skill of the machine operator and crew would also affect harvest rates. In our studies, the operator and crew were relatively unfamiliar with operating the Littau harvester, and thus data reported herein may represent the minimum level of its performance. An experienced operator and crew may be able to adjust operating parameters (e.g., drum rotation speed) in order to maximize yields, minimize the time required for harvest of a given field or crop, and thus improve the cost efficiency of mechanical harvest.

Small-Scale Plot Yield and Fruit-Removal Efficiency

Total yields (g/plot) from hand- or machine-harvested 'Bristol' black raspberries (Trial 1) or for 'Heritage' red raspberries (Trial 5) were not statistically different (Table 5), suggesting that the Littau harvester was efficient at removing

Table 5. Comparison of Fruit Removal Efficiency During Hand and Mechanical Harvest of 'Bristol' Black Raspberries and 'Heritage' Red Raspberries, 1995.

Trial	Crops, Harvest Dates, and Harvest Methods	Total Yield (g/plot)[y]	Marketable Yield (g/plot)	Marketable Yield (%)	Cull Wt.[z] (g/plot)	Cull Wt.[z] (%)
1	'Bristol' Black Raspberries (June 30)					
	Hand	3851	3537	92 a[x]	314 b	8 b
	Littau harvester[w]	3356	2664	79 b	692 a	21 a
5	'Heritage' Red Raspberries (Sept. 9)					
	Hand	331	316	95	15 b	5 b
	Littau harvester	322	281	87	41 a	13 a

[z] Culls consisted of unripe or over-ripe berries.
[y] Plot size = 20 ft. of row; Trial 1 and 5 plots had not been harvested previously.
[x] Mean separation within trials by the LSD statistic ($P \leq 0.05$).
[w] Littau harvester (Model FR9508).

ripe berries from raspberry canes. A similar statistical pattern was uncovered for hand- and machine-harvested 'Elliott' blueberries in Trial 4 (Table 6), although plots harvested with the BEI harvester tended to yield substantially less than their hand-harvested counterparts. Machine-harvested lots of all three crops contained significantly greater cull weights and/or cull percentages than lots harvested by hand. In Trial 1, increased cull percentages resulted predominantly from the mechanical harvest of unripe berries; the dislodging and collection of immature fruit has been reported to be a disadvantage of many cane fruit and blueberry mechanical harvest systems (12, 15, 21, 27). In contrast, increased fruit bruising associated with mechanical harvest of blueberries most likely affected the increased cull percentages reported for Trial 4.

Yield figures for the harvest of 'Heritage' red raspberries (Trial 5, Table 5) were extremely low, presumably due to poor plant performance following extremely wet spring weather. Therefore, the data reported do not reflect the true potential of mechanical harvest for this crop. Additional trials re-examining the suitability of mechanical harvesting for 'Heritage' red raspberry are planned for a later date.

Large-Scale Plot Yields and Harvest Rates

The Littau harvester, designed for the commercial harvest of berry crops, is not scaled properly for small-plot research. Therefore, to more closely resemble typical machine operating conditions, within-row yields, projected per-acre yields, and fruit-harvest rates were based on the yield (pounds/plot) and harvest time (min/plot) associated with harvester runs through large-scale plots. Within-row yields for mechanically harvested 'Bristol' black raspberry (Trials 1 and 2) and 'Elliott' blueberry (Trial 4) ranged from 0.12–0.42 lbs. per linear ft., corresponding to projected per-acre yields of 436–1,525 lbs. and 523–1,830 lbs. for fields with between row spacings of 12 ft. and 10 ft., respectively (Table 7). Although the use of large-

Table 6. Comparison of Fruit Removal Efficiency During Hand and Mechanical Harvest of 'Elliott' Blueberries (Trial 4), Aug. 23, 1995.

Test and Harvest Methods	Total Yield (g/plot)[x]	Marketable Yield (g/plot)	Marketable Yield (%)	Cull Wt.[z] (g/plot)	Cull Wt.[z] (%)	Trash[y] (g/plot)[x]
A Hand	3,768	3,305 a[w]	88	463 b	12 b	n.a.[v]
Littau harvester[u]	3,450	2,602 b	75	744 a	22 a	104
B Hand	4,404	3,959	90	445	10 b	n.a.
BEI harvester[t]	2,679	2,061	77	536	20 a	82

[z] Culls consisted of unripe or over-ripe berries.
[y] Trash consisted of stems or other debris.
[x] Plot size = 2 bushes (≈ 10 ft. of row); berries had not been previously harvested.
[w] Mean separation within tests by the LSD statistic ($P \leq 0.05$).
[v] n.a. = not applicable.
[u] Littau harvester (Model FR9508).
[t] BEI harvester (Model 'Little Blue').

Table 7. Within-Row Yields, Projected Yields Per Acre, and Fruit Harvest Rates Associated with Mechanical Harvest of Blueberries and Brambles, 1995[z].

Trial	Crops, Harvest Dates	Plot Size (ft of row)	Harvest Duration (min/plot)	Total Yield (lbs/plot)	Within Row Yield (lbs/ft)	Projected Yield: 12 Ft. Between Rows (lbs/acre)[y]	Projected Yield: 10 Ft. Between Rows (lbs/acre)[x]	Fruit Harvest Rate (lbs/hr)[w]
1[v]	'Bristol' Black Raspberries (June 30)	60	1.33	23.35	0.40	1452	1742	1084
2[v]	'Bristol' Black Raspberries (July 11)	250	5.54	29.11	0.12	436	523	325
4	'Elliott' Highbush Blueberries (Aug. 23)	452	10.00	189.06	0.42	1525	1830	1138

[z] All data and calculations based upon performance of the Littau harvester (Model FR9508).
[y] Calculated from within-row yields based on a conversion factor of 3,630 linear ft. of row/acre.
[x] Calculated from within-row yields based on a conversion factor of 4,356 linear ft. of row/acre.
[w] Fruit harvest rates from within-row yields based on a machine speed of 2,709 ft/hr [0.57 mph (or 3,010 ft/hr) -10% turn around and down time].
[v] Trial 1 and Trial 2 harvests of 'Bristol' black raspberries were obtained from different experimental sites on the same farm; harvest dates correspond with the first and fourth harvests (i.e., beginning and end) of the season, respectively.

scale plots for determination of yield and harvest rate parameters was considered to improve the accuracy of these measurements, estimates of the within-row yields of 'Bristol' black raspberry (Trial 1) based upon small plot yields (Table 5) and large plot data (Table 7) were similar (i.e., 0.37 and 0.40 lbs/ft, respectively). In contrast, within-row yield estimates for 'Elliott' blueberry (Trial 4) based on small plots (0.83 lbs/ft) were almost double those calculated from the large plot data (0.42 lbs/ft) reported in Table 7. Small-scale plots for fruit removal efficiency studies in Trial 4 were chosen in row segments that contained fully shaped, uniform blueberry plants, whereas there was considerable variation in bush volume and fruit load within plant population in the field. In cases such as this, plant to plant variation validates the necessity of using large-scale plot data for reliable yield-potential and harvest-rate estimates.

Fruit-harvest rates (lbs/hr) for the Littau harvester, based on average within-row yields and an in-row machine speed of 0.57 mph, are also presented in Table 7. Machine-harvest rates ranged from 325–1,138 lbs/hr for the Littau harvester which corresponded well with the projected range of harvest rates (250–1,000 lbs/hr) used for economic analyses (Table 3). Since machine harvest may be employed in a given field repeatedly throughout the harvest season, it was important for our study to examine the performance of the mechanical harvester at first and subsequent harvests. A comparison of yield data and fruit-harvest rate calculations for Trials 1 and 2 illustrates expected differences associated with the first and fourth (last) harvest of a 'Bristol' black raspberry planting. By the fourth harvest cycle, both within-row yield and fruit harvest rates were reduced to approximately 30% of those obtained during the initial harvest of the season. Although it may be possible to increase harvester speeds during late harvests, it is not likely that they could be successfully trebled or quadrupled (due to inefficient fruit removal and increased damage to both fruit and plants). Therefore, later mechanical harvests are likely to yield less return on invested harvest costs, and at some point during the harvest cycle, use of the mechanical harvester will not be economically feasible. Likewise, hand-harvest systems are also subject to "the law of diminishing returns." Hand-harvest rates vary among workers and with respect to berry size and yield per acre. Generally, the first berries harvested are larger than those present after several pickings. When berries are large, hand-harvest rates tend to be optimal; when berries are small and scattered, workers are unable to pick at optimal rates.

During this study, hand-harvest rates were determined only in Trial 4. Seven members of the Ohio Small Fruit Research and Extension Team were able to hand harvest eight plots of 'Elliott' blueberries yielding 9.3±1.2 lbs/plot in an average of 80.5±9.7 min/plot which corresponded to a hand harvest rate of 7.0±0.3 lbs/hr. This figure agreed well with the historically determined rate of 6 lbs/hr reported for blueberries in Table 4. When compared with actual or historically determined hand-harvest rates, harvests by machine in Trials 1, 2, and 4 were found to be 181, 54, and 163 times more efficient than harvesting by hand, respectively, on the basis of harvest time alone. Admittedly, this overwhelming machine advantage must be considered within the context of expected yields at initial and subsequent harvests, harvest costs, and expected returns for fruit harvested when evaluating the overall efficiency of either harvest system.

Fruit Quality

The continued viability of the Ohio fresh-market berry industry depends upon the production and marketing of high-quality fruit. Fruit quality at harvest will likely be of equal importance to the development of an Ohio-based processing industry as it affects, to a substantial degree, the state's potential to offer a superior product to the marketplace (9). For this reason, the quality of machine-harvested fruit was compared to that of its hand-harvested counterparts in Trials 1, 4, and 5.

Black Raspberries, Trial 1

In Trial 1, a small but significant number of immature 'Bristol' black raspberries were removed by the mechanical harvester, whereas hand-harvested fruit was uniformly mature (Table 8). Moreover, a comparison of laboratory and field data (Tables 5 and 8) suggests that approximately 90% of the machine-harvested

cull berry weight per plots resulted from immature berry collection, whereas culls from hand-harvested plots were more likely to have been over-ripe or mechanically damaged (bruised or torn) during the harvesting process. As might be expected, the conspicuous presence of red, pink-tinged, and even white immature berries in machine-harvested lots had a significant effect on the color reflectance values of their respective laboratory samples (i.e., mechanically harvested samples were lighter, substantially more red/orange, and more vivid overall).

The presence of markedly immature berries in mechanically harvested lots may have resulted from suboptimal harvester settings; that is, the machine moved too slowly down the row or the drums oscillated too vigorously, removing fruit which should have been left on the canes for subsequent harvests (B. Strik, Oregon State University, personal communication). Moreover, the appearance of immature fruit in mechanically harvested lots suggested the simultaneous harvest of "almost-ripe" fruit in even greater proportions. A high proportion of almost-ripe fruit may have resulted in low soluble solid and high titratable acidity values in the machine-harvested fruit samples reported in Table 8. Morris (15) reported that mechanically harvested lots of cane fruits usually exhibited increased soluble solid contents and reduced titratable acidity levels when compared to their hand-harvested counterparts, a trend that was reversed in this study.

Although the presence of immature berries may render machine-harvested lots unsuitable for certain processing procedures [e.g., individually quick frozen (IQF) fruit packs], their use in more thermally processed products (preserves, juice concentrates, etc.) may have minimal impact on product quality (17). Moreover, since they are highly visible, immature berries are easily removed by hand or machine sorting after harvest. Finally, the percentage of immature berries in a given harvest lot may be highly dependent on cultivar, minimized by improved cultural practices, and, most prominently, affected by the skill of the harvester operator (12, 27).

Blueberries, Trial 4

"Perhaps the most serious limitation to current mechanical harvesting technology is the

Table 8. Quality Differences in Hand- and Mechanically Harvested 'Bristol' Black Raspberry Fruit (Trial 1), June 30, 1995[z].

Harvest Method	Immature Fruit[y] (%)	Soluble Solids[x] (%)	Titratable Acidity[w] (%)	Color Reflectance Values[v]		
				L	Θ	Chroma
Hand	0.0 b[u]	8.0	0.82	10.3 b	355.7 a	1.9 b
Littau Harvester[t]	18.5 a	7.6	0.90	12.8 a	26.7 b	5.8 a

[z] Quality differences were ascertained using 500 g samples randomly chosen from the total fruit harvest of each plot. Subsamples were chosen randomly for the measurement of each parameter.
[y] Fruit with torus and pedicel attached were considered to be immature; values represent percentage of immature fruit by weight.
[x] Aliquots of the macerate from two 20-berry subsamples/plot were used to measure soluble solid levels by refractometry.
[w] Aliquots (4 g) of the macerate from two 20-berry subsamples/plot were used to determine titratable acidity levels.
[v] Color reflectance parameters were measured on four 180 cc subsamples/plot (3 readings/subsample) using a Hunter Color Difference meter (Model 25). Values indicate the following: L indicates lightness/darkness (0 = pure black, 100 = pure white); Θ (hue angle) indicates hue as depicted by the degrees within a circle (0° = pure red, 90° = pure yellow, 180° = pure green, 270° = pure blue, 360° = pure red); chroma depicts relative color intensity (high values indicate vivid colors).
[u] Mean separation determined by LSD statistic ($P \leq 0.05$).
[t] Littau harvester (Model FR9508).

damage caused to fruit" (8). Blueberries can be easily bruised during any stage of mechanical harvesting and sorting that results in impact after a vertical fall. Brown *et al.* (4) reported extensive bruising in ripe blueberries when the drop height to a hard surface exceeded six inches. The extent of damage is proportional to the distance the fruit fall, and bruised fruit are more subject to decay during postharvest storage (1, 3, 8, 13). In addition, the bruising process often results in a loss of fruit surface wax (bloom) and thus results in darker-appearing fruit (8).

The effects of bruising associated with mechanical harvest of blueberries was readily evident in Trial 4 (Table 9). Harvesting with either mechanical harvester resulted in berries that were significantly softer than hand-harvested fruit. Moreover, the storage performance of both mechanically harvested fruit lots was extremely poor. Moisture loss during storage was greatest in fruit harvested with the BEI machine, but Littau-harvested berries exhibited the greatest overall fruit loss. These results suggest that the mechanically harvested blueberry fruit in Trial 4 would have been suitable only for immediate processing.

However, mechanical harvest procedures were not solely responsible for the poor storage performance of blueberries in Trial 4, as the hand-harvested controls in this storage study also exhibited relatively high levels of postharvest deterioration. Due to logistical constraints, Trial 4 was performed two to three days after much of the crop had reached optimum ripeness (i.e., harvested fruit tended to be

Table 9. Quality Differences in Hand- and Mechanically Harvested 'Elliott' Blueberry Fruit (Trial 4), Aug. 23, 1995[z].

				Color Reflectance Values[v]			Storage Performance[u]	
Harvest Method	Fruit Firmness[y] (g)	Soluble Solids[x] (%)	Titratable Acidity[w] (%)	L	Θ	Chroma	Moisture Loss (%)	Fruit Loss (%)
Hand	203 a[t]	9.9 a	1.26 a	16.2 ab	269.0	1.9 b	9.5 c	56.9 c
Littau Harvester[s]	148 b	9.7 a	1.24 a	15.5 b	273.6	1.8 b	10.3 b	95.8 a
BEI Harvester[r]	152 b	9.9 a	1.16 b	16.8 a	271.7	2.3 a	11.2 a	83.7 b

[z] Quality differences were ascertained using 1 kg samples randomly chosen from the total fruit harvest of each treatment after mechanical sorting. Subsamples were chosen randomly for the measurement of each parameter.
[y] Differences in firmness were detected using four five-berry subsamples/treatment. Individual berry firmness (the force in grams required to penetrate the epidermis) was determined on an Instron (Model 1101) equipped with a 3.2 mm diameter probe.
[x] Aliquots of the macerate of four 20-berry subsamples/treatment were used to measure soluble solid levels by refractometry.
[w] Aliquots (10g) of the macerate of two 10 g subsamples/treatment were used to determine titratable acidity levels.
[v] Color reflectance parameters were measured on 180 cc subsamples/treatment (four readings/subsample) using a Hunter Color Difference meter (Model 25). Values indicate the following: L indicates lightness/darkness (0 = pure black, 100 = pure white); Θ (hue angle) indicates hue as depicted by the degrees within a circle (0 = pure red, 90 = pure yellow, 180 = pure green, 270 = pure blue, 360 = pure red); chroma depicts relative color intensity (high values indicate vivid colors).
[u] Storage performance was measured by storing four 80 g subsamples/treatment in air at 3ºC for five days. Percentage moisture loss was calculated from sample weight before and after storage. Percentage fruit loss was determined as the ratio of the weight of damaged, shriveled, and moldy berries to that of after-storage weight.
[t] Means separation determined by the LSD statistic ($P \leq 0.05$).
[s] Littau harvester (Model FR9508).
[r] BEI harvester (Model 'Little Blue').

over-ripe) which may have exacerbated fruit bruising in all treatments. In addition, because of the mechanical sorting process and a delay in transport to Wooster, fruit lots used for storage studies were perhaps exposed to ambient temperatures longer than desirable. The positive effects of rapid cooling to remove field heat and continued low-temperature storage on stored blueberry firmness and quality are well documented (1, 2, 3, 5, 6, 13, 15, 23, 26).

The 'Elliott' blueberry is generally considered to be firm and to exhibit excellent storage characteristics (22). Supporting this contention, the ratio of soluble solids to titratable acids in hand and machine-harvested fruit varied from 7.8 – 8.3 (Table 9), well within the range of the values indicated by Galletta and coworkers (11) to be optimal for good keeping quality. In previous, more stringent OARDC storage trials (i.e., storage for eight days at 3°C followed by a shelf-life treatment at 20°C for an additional nine days), 'Elliott' rated highest among 60 blueberry cultivars and breeding lines for storability; at the end of the treatment period, berries had lost only 14.5% moisture; 85.4% of the berries were considered to be salable; and when subjectively scored for edibility, berries were uniformly given the highest possible rating (i.e., 5 = fruit still firm, with flavor good to excellent) (J. C. S., unpublished data).

In summary, the quantitative effects of mechanical harvesting on blueberry quality in Trial 4 could not be clearly delineated due to extraneous factors such as the harvest of over-ripe berries and the prolonged postharvest exposure to ambient conditions. However, use of either the Littau or BEI harvesters presently available will most likely damage fruit to some degree, rendering the crop suitable for processing only. If Ohio growers desire the ability to mechanically harvest fresh-market blueberries, other harvester designs will have to be considered. For instance, in a prototype harvester recently developed through the cooperative efforts of USDA and BEI personnel, design advancements in both fruit removal and catchment systems (e.g., shorter drops, specially padded surfaces, etc.) have resulted in the mechanical harvest of 'Bluecrop' blueberry where 68% of the berries were of fresh-market quality (21). In contrast, conventional mechanical-harvest and the hand-harvest tests in their study yielded 22% and 77% fresh-market quality fruit, respectively.

Red Raspberries, Trial 5

Hand- and machine-harvested 'Heritage' red raspberry fruit quality was assessed using marketable berries only (i.e., cull berries had been removed prior to analysis). Consequently, few differences in quality were uncovered (Table 10). Morris (14, 15, 16) observed machine-harvested cane fruit (especially blackberry) to be more fully ripe than their hand-harvested counterparts, due primarily to the difficulty in visually distinguishing between blackberries that were ripe from those that were merely black. 'Heritage' color reflectance values (specifically L and chroma) tended to support Morris' contention, but in contrast to his experience, fruit firmness, soluble solid contents, and acidity levels were similar in hand- and machine-harvested fruit in this study (Table 10). Unfortunately, the postharvest longevity of machine-harvested red raspberries was not explored herein. However, even though harvesting techniques appeared to produce similar quality products in Trial 5, the processing market will remain the most likely outlet for mechanically harvested Ohio red raspberries (8).

Economic Assessment

Most raspberries, blueberries, and blackberries grown in Ohio are currently harvested by hand for fresh-market sales, and growers are well aware of the economic advantages and disadvantages of current cultural, harvesting, and marketing systems. However, whenever new markets or new technologies are developed (such as those which might serve an emerging processing industry), growers must rely on accurate economic analyses in order to make rational decisions concerning the cultural and marketing alternatives available to them. Therefore, the authors have endeavored to present herein a detailed economic assessment of harvest costs based on field performance for the use of the Littau harvester for bramble and blueberry harvest and have included comparative data for the BEI harvester, which is suitable for mechanically harvesting blueberries.

Fixed and variable costs for the acquisition, maintenance, and operation of the mechanical

Table 10. Quality Differences in Hand- and Mechanically Harvested 'Heritage' Red Raspberry Fruit (Trial 5), Sept. 9, 1995.[z]

Harvest Method	Fruit Firmness[y] (N)	Soluble Solids[x] (%)	Titratable Acidity[w] (%)	Color Reflectance Values[v]		
				L	Θ	Chroma
Hand	1.14	11.3	0.74	16.2 a[u]	12.1	15.8
Littau Harvester[t]	1.25	11.5	0.71	15.9 b	12.1	14.5

[z] Quality differences were ascertained using 500 g samples randomly chosen from the total fruit harvest of each plot. Subsamples were chosen randomly for the measurement of each parameter.
[y] Differences in firmness were measured on site using five-berry subsamples per plot. Individual berry firmness (the force in Newtons required to close the central cavity opening) was determined on an Ametec AccuForce II Gauge (Model ML-4432-5) equipped with a flat-surfaced probe.
[x] Aliquots of the macerate from two 20-berry subsamples per plot were used to measure soluble solid levels by refractometry.
[w] Aliquots (10 g) of the macerate from two 20-berry subsamples per plot were used to determine titratable acidity levels.
[v] Color reflectance parameters were measured on 180 cc subsamples per plot (four readings per subsample) using a Hunter Color Difference meter (Model 25). Values indicate the following: L indicates lightness/darkness (0= pure black, 100 = pure white); Θ (hue angle) indicates hue as depicted by the degrees within a circle (0 = pure red, 90 = pure yellow, 180 = pure green, 270 = pure blue, 360 = pure red); chroma depicts relative color intensity (high values indicate vivid colors).
[u] Means separation determined by the LSD statistic ($P \leq 0.05$).
[t] Littau harvester (Model FR9508).

berry harvesters are listed in Table 2. Projected acquisition and maintenance costs for the self-propelled Littau harvester ($17,153/year over seven years) were approximately 2.2 times higher than those calculated for the BEI machine and tractor combination ($7,747/year over seven years), whereas operational costs were nearly identical for the two machines. Admittedly, the BEI system is attractive, considering its low acquisition and maintenance costs and the advantage of employing an independent power source which can be used to perform cultural tasks other than harvesting. However, it is not nearly so versatile as the Littau machine which can effectively harvest a number of small fruit crops. As stated earlier, limited small-fruit acreages in Ohio coupled with the industry growers' tendency to base their operations on the culture of several crops make harvester versatility a consideration of paramount importance.

The cost per hour of machine operation (based directly on fixed and variable costs) varied among harvesters and among projected seasonal usages of 40, 80, and 120 hrs (Table 3). Obviously, the cost of operation diminishes greatly as seasonal usage is increased. Seasonal use of a mechanical harvester on an average berry farm in Ohio (approximate size equals two acres) would be insufficient to support the purchase and maintenance of such expensive equipment. Therefore, for economic viability, it will be important for growers to maximize machine usage through cooperative ownership or through the contracted harvest of several farms within a region. Multiple machine harvests of a given field will also need to be considered. Likewise, harvester versatility will increase the likelihood for maximum use of a single machine. In such situations, actual machine use (hours per year) is likely to exceed by two- to threefold the maximum usage level (120 hrs/yr) projected herein.

Costs per acre harvested at 12 ft. and 10 ft. between row spacings (based on costs per hour

and field-determined optimal machine speeds) and costs per pound of harvested fruit were also determined at various levels of season harvester use (Table 3). Costs per pound of fruit harvested varied greatly for both machines with respect to target harvest rate (based on field data for first and subsequent harvests) and seasonal use estimates. The target harvest rates for the Littau harvester used in these calculations were twice those used for the BEI harvester based on optimal machine speeds. At a given target harvest rate, costs per pound of fruit harvested were generally lower for the BEI machine at 40 and 80 hours of seasonal use. However, apparently, this cost advantage per pound of harvested fruit is nearly lost as seasonal harvester use approaches 120 hours of operation.

Although our economic projections do not directly consider optimal machine speed as a variable, it will undoubtedly affect the overall profitability of a given mechanical harvester. For instance, even though costs per pound of harvested fruit may be similar between the two harvesters, the Littau machine will be able to more than double the total amount of blueberries harvested over a season by covering more than twice as many acres. In other words, to harvest a similar amount of blueberries, the BEI machine must be operated 2.28 times longer than the Littau harvester, thus incurring 2.28 times the operating costs.

Projected labor costs per pound of hand-harvested red raspberries, black raspberries, and blueberries are listed in Table 4. At current minimum wage/benefit rates ($5.92/hour), a pound of red raspberries or blueberries harvested by an average laborer picking at the rate of 6 lbs/hr would cost $0.83, well within the range of costs per pound calculated for the target harvest rates of the Littau harvester (i.e., $0.17/lb – $1.81/lb) and the BEI harvester ($0.15 – $1.30). Likewise, the current hand harvest cost for black raspberries ($0.42, 12 lbs/hr average picking rate) is also within the cost per pound ranges of both harvesters. Both of these relationships suggest that at some combination of harvest rate and total seasonal use, mechanical harvest costs will be below those of hand harvest.

In order to explore these relationships, a sensitivity analysis was performed; it is represented graphically in Figure 2. The shaded area of the diagram represents current and projected costs over the next several years of hand-harvest at average picker rates. Current harvest costs calculated for the Littau harvester are superimposed on hand-harvest costs for target harvest rates of 250, 500, and 1,000 lbs/hr at seasonal usage rates of 40, 80, and 120 hrs/yr. The examples presented here serve to illustrate the use of Figure 2. At low harvest rates (250 lbs/hr, representing harvester use late in the season) and low levels of seasonal usage (40 hrs/yr), machine-harvest costs per pound exceed current and projected hand-harvest costs for all three fruit crops and thus may never be profitable. Likewise, mechanical harvest at the middle harvest rate (500 lbs/hr, representing a mixture of first and subsequent harvests) and a seasonal usage of 40 hrs also exceeds current average hand-harvest costs ($0.42/lb – $0.83/lb), but may be economically viable for the harvest of red raspberries and blueberries in the future as hand-harvest costs increase over time. Mechanical-harvest costs at the middle-harvest rate and a seasonal usage of 80 hours are currently lower than those associated with the hand harvest of red raspberries and blueberries, but not black raspberries; however, the mechanical harvest of black raspberries will be economically more feasible as hand-harvest costs rise. Mechanical-harvest costs at the middle-harvest rate and a seasonal usage of 120 hours are well below hand-harvest costs for red raspberries and blueberries and slightly below those for black raspberries. Similarly, at high mechanical-harvest rates (1,000 lbs/hr, representing first harvests) and seasonal harvester usages of 80 and 120 hours, hand-harvest costs exceed those incurred by machine harvest.

In short, growers who have the management skills to produce high yields and can use a machine 80 or more hours per year are likely to lower their harvest costs using a mechanical harvester. Berry quality, the development of suitable markets for mechanically harvested fruit, and rates of return per pound of fruit sold to fresh or processing markets, respectively, must also be considered before growers can make informed decisions concerning the suitability of mechanical berry harvest for their own operations.

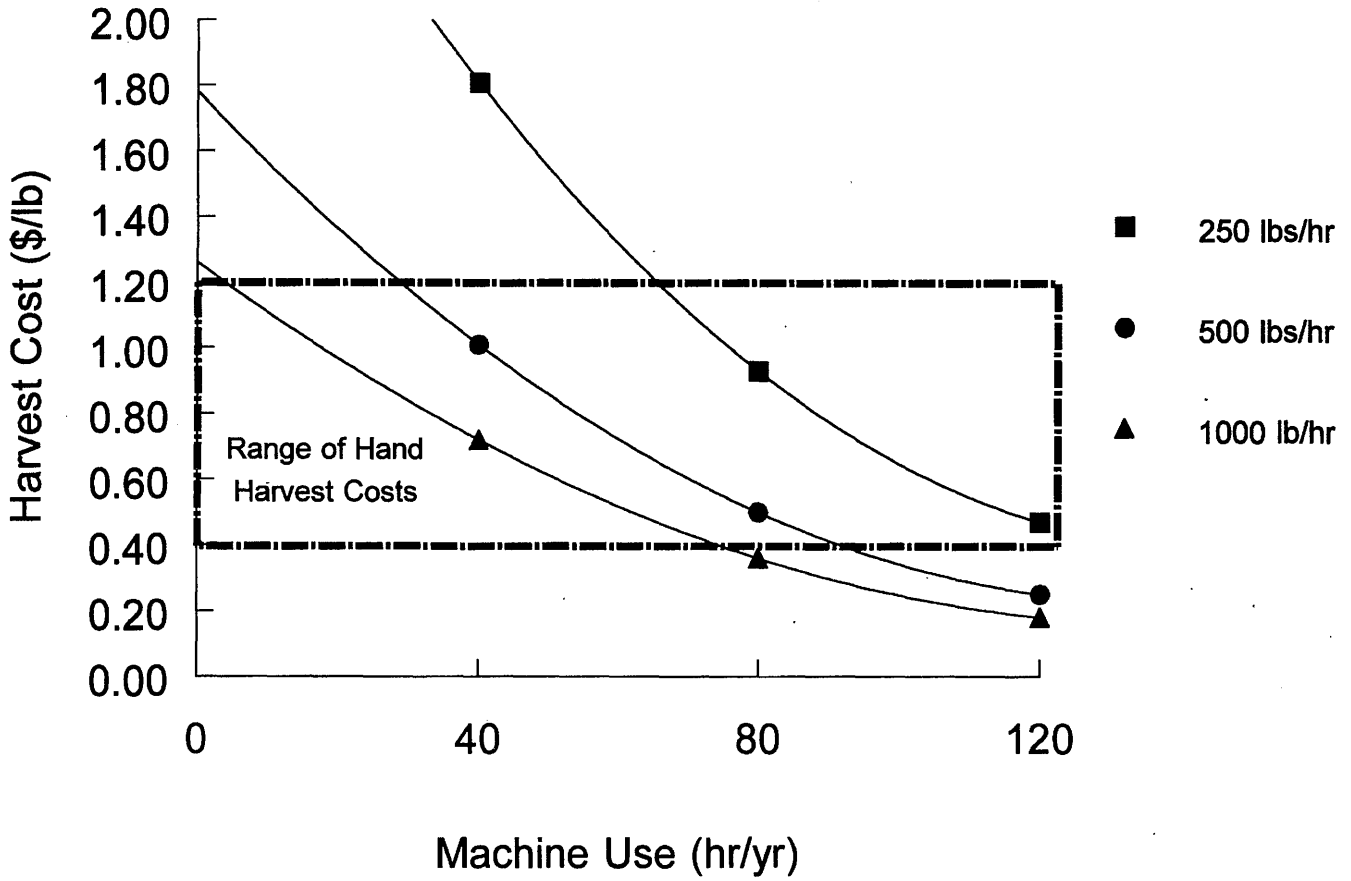

Figure 2. Sensitivity analysis of hand- vs. mechanical-harvest costs based on target harvest rates and hours of seasonal usage.

A Mechanical-Harvester Use Scenario for Ohio Growers

Although Ohio acreages might be exclusively harvested by machine in the future, it is more likely that the industry will adopt a harvest system similar to that used in the Pacific Northwest which includes alternate use of hand labor for fresh-market harvest and mechanical harvesters to harvest berries for processing. A decision by Ohio growers to use the mechanical harvester for any given harvest will likely be based on a number of considerations, including the current-market returns for fresh or processed fruit, the harvest-ready acreage (i.e., the number of acres waiting to be harvested), the condition of the fruit in the field (i.e., degree of ripeness), weather conditions, and labor availability.

If mechanical berry harvest is to be readily adopted in Ohio, a processing-industry infrastructure will need to be developed concurrently. The nature of that industry may also affect grower enthusiasm for expanding current bramble and blueberry acreages and for adopting new production and harvesting systems. The development of cooperatively owned and managed processing facilities from which producers profit directly from the manufacture of value-added products may be far more attractive than traditional scenarios where growers sell their crops at low-profit margins to a corporate processor.

Ample evidence has been presented to indicate that the economic performance of mechanical berry harvesters depends upon relatively high overall yields, relatively concentrated fruit ripening, harvester flexibility, and extended machine use throughout the season. A machine such as the Littau harvester, which has the capability of harvesting a variety of

crops, could operate over a 12-week period, beginning with black and summer-bearing red-raspberry harvest in late June and finishing in mid-September with the harvest of blueberries and fall-bearing red raspberries. Efficient use of the machine will obviously require movement from farm to farm, as in this case, the Littau harvester was placed onto a tractor-trailer and driven with relative ease more than 100 miles from trial to trial. Multiple machine harvests of the same field are also likely. Harvester speeds used in this study indicated that the Littau harvester was capable of harvesting 6.4 acres in an eight-hour day. Therefore, 25.6 acres of blueberries or 12.8 acres of brambles could be continuously harvested on a four-day and a two-day pick cycle, respectively, using a single machine.

Summary

The results of this preliminary study show that there is a potential to mechanically harvest berries in Ohio. However, further experimentation and experience with mechanical berry harvesting will be necessary before accurate economic assessments of harvester use based on the rates of return per pound of fresh market or processing fruit can be made, or the most economic scenario for the mixed hand/machine-harvest systems can be determined. Moreover, many improvements within the industry, such as controlled growth in the total number of acres planted to berry crops, market expansion, optimization of berry yields and quality through improved and standardized cultural practices, and efficient industry organization, must be realized if mechanical berry harvesting is to reach its full potential. Likewise, our knowledge of the relationships among berry production systems, berry quality, and mechanical harvesting must be expanded through additional research efforts by university personnel and cooperating growers. Admittedly, our preliminary survey of harvester capabilities was limited to the thorough testing of only one harvester design. The merits of newer mechanical harvesters and mechanical harvesting technology should also be explored, especially if the mechanical harvest of fresh-market berries becomes an industry goal.

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Monitoring Flower Thrips Activities in Strawberry Fields at Two Ohio Locations

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Introduction

A major outbreak of flower thrips, *Frankliniella tritici* (Fitch), in 1994 in northeastern North America caused extensive damage in commercial strawberries in several states including Indiana, Ohio, Pennsylvania, and Maryland (3, 7). Infestations were first observed in late May just prior to the beginning of harvest. Losses ranged from 0 to 75 percent, with significant losses in pick-your-own operations in which insecticides were discontinued early or not applied at all to allay concerns about pesticide residues as compared to conventionally treated fields.

Flower thrips invade annually from the South and are carried northward on frontal systems in early spring (5). This pest was formerly known as the strawberry thrips and was reported to have caused destructive outbreaks from Florida to Illinois (6). There was great concern by growers and crop consultants that the flower thrips might return again in high numbers in 1995 and 1996. This speculation was strengthened by the fact that in the Canadian Maritime Province of New Brunswick the flower thrips has been a major concern annually since the mid-1980s (4).

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Materials and Methods

Three sites in two Ohio counties were monitored for the flower thrips, *Franklinella tritici* (Fitch), in 1995 and 1996.

1995

In order to monitor the occurrence of flower thrips in Ohio and determine the best trapping method to achieve this goal, two different trapping regimes were employed in 1995, water traps and yellow sticky traps. The water traps consisted of rectangular, clear plastic containers (32 x 25 x 10 cm) filled with a solution of surfactant, glycerin, salt, and water in a ratio of 1:2:3:220. These traps were placed within the strawberry canopy (matted rows) allowing the foliage to eventually envelop the sides of the traps.

On May 2, 1995, six water traps were employed at two Wayne County sites, Moreland Fruit Farm and Snyder Farm, and one Warren County site, Valley Vineyard. The Moreland Fruit Farm is a commercial fruit and vegetable farm approximately 12.9 km south of Wooster, Ohio. Snyder Farm lies approximately 3.2 km south of Wooster, Ohio, and is the primary research farm for The Ohio State University's Ohio Agricultural Research and Development Center. However, the latter site differed from the others in that strawberries were not being grown in the immediate vicinity of the traps. The Warren County site is approximately 1.6 km south of Morrow, Ohio, and produces many types of fruits and vegetables for commercial sales. Water traps were collected and refilled weekly for the duration of the trial which

ended on July 11. Specimens were removed from the aqueous solution by straining with a fine, organdy material in the field, then separated and stored in hexane in the lab until they were mounted on slides for identification.

The second trap employed was an unbaited yellow sticky trap, Pherocon® AM, manufactured by Sandoz Ltd., Basel, Switzerland. These traps measure 23 x 28 cm when fully open, and when employed, are folded over backwards, exposing two opposite yellow, sticky surfaces each measuring 23 x 14 cm. Yellow has been shown to be significantly better than other colors in attracting *Frankliniella tritici* (2). Traps were fastened to the tops of 51 cm metal plot stakes with large paper clamps. The stakes were driven into the ground approximately 10 cm prior to attaching the trap. This arrangement placed the bottoms of the traps about 30 cm above the soil level.

On May 4, 1995, four yellow sticky traps were set out at Valley Vineyards in Warren County, Ohio. These traps were placed in the center of the four perimeter borders of a 15 m x 91 m section of a 0.4 ha 'Earliglow' strawberry planting. They were oriented parallel to the borders with two traps facing north-south and two facing east-west. Traps were collected and replaced weekly until they were removed on July 12. Immediately upon returning from each collection trip, all traps were refrigerated until the thrips could be extracted. Upon careful extraction with an insect pin the following day, thrips specimens were placed directly in hexane to remove the adhesive and stored until slide preparation.

All thrips specimens collected in the water and sticky traps were mounted on slides for identification and counting. Specimens were taken out of hexane storage with a fine paint brush and placed in 5% lactic acid (Janusz Piatkowski, personal communication) for approximately one hour for clearing. Thrips were then removed from the lactic acid and placed directly on the slide and then covered with two drops of Permount (Fisher Scientific) and a cover slip. No more than 200 thrips were placed on a single slide.

1996

Only the yellow sticky traps were employed in 1996. The 1995 data had indicated that these traps were superior in collection and much easier in maintenance than the water traps. On April 23, 1996, five Pherocon® AM (no-bait) traps were set out in a new 1 hectare (2.5 acre) strawberry field at the Warren County site. This new planting was established in 1995 and consists of several varieties including 'Earliglow,' 'Red Chief,' and 'Allstar.' A 30 m x 91 m portion of the field was utilized for our trials. The five traps were placed across this area on a northeast-southwest diagonal. The first trap in the series was set with an east-west orientation. Each successive trap was oriented perpendicular to the one that preceded it (three traps faced E-W, two traps faced N-S) to evaluate the effect of trap orientation on collections. Traps were collected on a weekly basis, at which time each trap was replaced with a new one. The exposed traps were returned to the lab for processing in the same manner as in 1995. Trap location and orientation were recorded along with numbers collected on each respective trap. Slides were also prepared in a similar manner as described previously.

On April 26, 1996, another series of five sticky traps was set out on the southwest-northeast diagonal of a 15 m x 182 m field of 'Earliglow' strawberries at the Moreland Fruit Farm site. Trap direction and orientation were similar to those at Valley Vineyard (three traps faced E-W, two traps faced N-S). Traps were collected weekly in the same fashion as in 1995 until they were removed on July 19, 1996. The Snyder Farm site was not surveyed in 1996.

Results and Discussion

Both collection methods utilized in 1995 were successful in sampling for flower thrips. However, sticky traps were preferred because they required less maintenance and were equal to or better than the water traps at trapping thrips. Monitoring indicated the presence of flower thrips by mid to late May at all locations prior to full bloom (Figures 1 and 2). Numbers were extremely low and did not reach their peaks until early July in northern Ohio and late

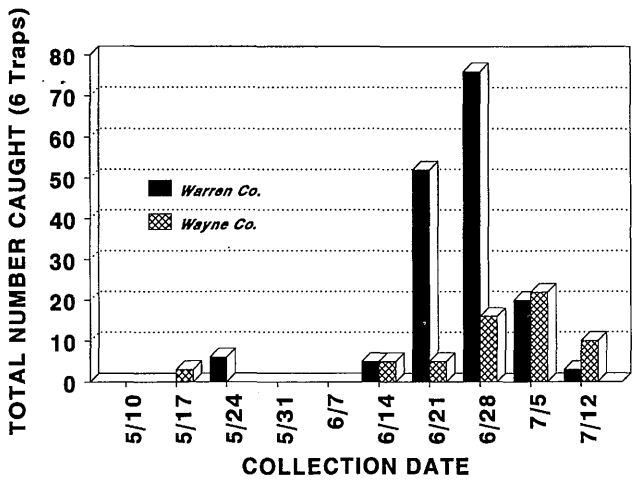

Figure 1. Flower Thrips: Water Traps, Ohio, 1995.

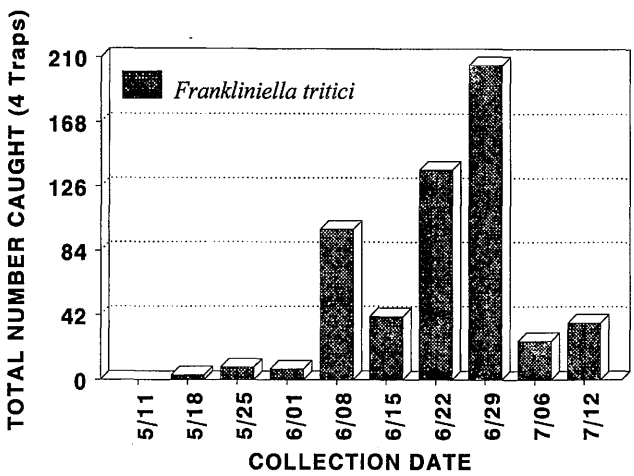

Figure 2. Thrips Data (Sticky Traps): Warren County, Ohio, 1995.

June in southern Ohio. This was late enough to avoid inflicting any serious economic injury to the strawberry crop. Monitoring of the flower thrips in 1996 again indicated their presence within the northern and southern Ohio plantings prior to and during bloom (Figure 3), but numbers were once again not sufficient to inflict significant crop loss. However, damage to fruit set and development was more prevalent in the northern Ohio planting, which had experienced higher thrips numbers prior to fruit set.

It is interesting to note that population trends were inverse in 1996 from 1995. The flower thrips population was greater in south-

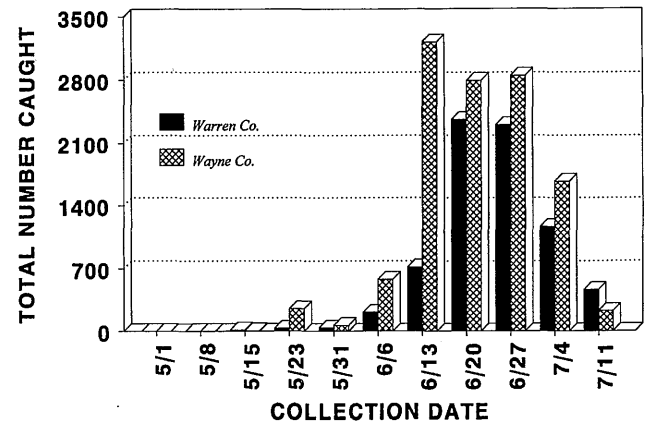

Figure 3. Flower Thrips: Sticky Traps, Ohio, 1996.

ern Ohio during 1995, while in 1996 greater numbers were collected at the northern Ohio site. Environmental conditions such as temperature, precipitation, and wind currents along with host plant development play an important role in the early season evolution of the flower thrips population. One such condition, rainfall, in Wayne County, was significant during the month of May in 1995 (avg. 115.4 mm) and 1996 (114.6 mm) as compared with 1994 (46.7 mm) in Wayne County, and a similar pattern was recorded for Warren County. The long-term average is 99 mm. Drought conditions are favorable to allowing a rapid build-up in thrips populations and may have played an important role in the elevated population in 1994 and not in subsequent years which yielded above average rainfall and were unfavorable to thrips reproduction conditions (6). This trend was also true for the three-year period at our Warren County site.

In conclusion, a total of 19,546 flower thrips were collected in 1996, 12,228 at Moreland and 7,318 at Valley. Other thrips were collected in our sampling, but only the *F. tritici* flower thrips was identified by species and counted. Populations peaked at both sites in mid-June with the Valley peak occurring one week after the Moreland peak on June 14. A relatively steady decline in the population occurs after the last week in June through renovation in mid-July.

Trap orientation (N, S, E, W) was analyzed for both sites and found not to play a significant role in the thrips collections. However,

when weekly collections for each trap were analyzed, an interesting trend was indicated. Trap No. 2 collected the greater number of thrips at both sites (Table 1). This was the second trap deployed in the plantings from the northeast corner of the field. At the Valley site this trap was statistically separable from Trap Nos. 4 and 5, and at both sites there was a trend for the first three traps (1, 2, and 3) to capture more thrips than the last two traps (4 and 5), which were in the southwest corner of the plantings.

Although numbers appeared high throughout June and early July in the traps, blossom and fruit samples never reached the level of 10 thrips per blossom which may cause significant crop loss (1). A threshold for the flower thrips has not been firmly established; however, in the New Brunswick area of Canada it has been estimated that as few as two thrips per berry in the early maturity stage may cause damage to 20% of the crop (4). It appears that in 1996, as in 1995, conditions were not conducive to a build-up in the thrips population prior to and during the vulnerable bloom and fruit-development growth stage. The population peaks in mid-June clearly occurred when most plantings were approaching harvest.

In the future, growers who are not using any chemicals for control of the tarnish plant bug or meadow spittle bug, prior to berry set, should be alert as to weather conditions during the pre-bloom period. Dry and warm conditions may be the precursor to a build up in the flower thrips population, which in turn may cause a consequential crop failure. Growers who utilized Thiodan (endosulfan) for insect control in their spray program experienced less crop loss than those who used no insecticide.

Table 1. Comparison of Flower Thrips Collections on Sticky Traps in Two Ohio Strawberry Fields, 1996.

	Mean No. Thrips	
Trap No.	Wayne Co.	Warren Co.
5	157.75 a[z]	53.09 b
4	158.00 a	55.36 b
3	199.58 a	122.36 ab
2	240.92 a	150.55 ab
1	262.50 a	283.91 a

[z] Means followed by the same letter do not differ significantly according to Duncan's multiple range test ($P = 0.05$).

Map of sticky trap deployment

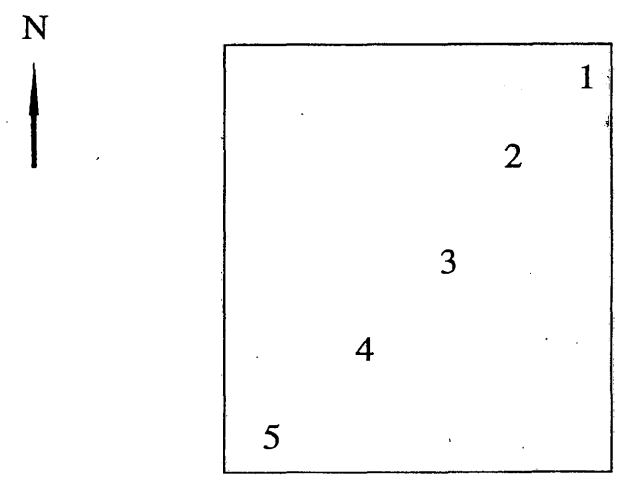

Figure 4. Map of sticky-trap deployment.

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Cluster Thinning Effects on Fruit Weight, Juice Quality, and Fruit Skin Characteristics in 'Reliance' Grapes

Yu Gao and Garth A. Cahoon

Abstract

Fruit weight, juice quality, fruit skin color, the concentration of total anthocyanin and individual anthocyanins in fruit skin, and the percentage of individual anthocyanins in 'Reliance' grape (*Vitis* hybrid) were investigated after cluster-thinning treatments were imposed. Cluster-thinning treatments were 60 (control), 40, and 20 clusters per vine, and applied when the berries were 2–3 mm in diameter. Twenty clusters per vine produced fruits of the best weight, juice quality, and color among three cluster-thinning treatments. Fruit cluster thinning decreased vine yield significantly, following a quadratic relationship. Juice soluble solids concentration (SSC) was increased significantly by cluster thinning treatments. Individual berries were heavier with 20 clusters per vine than with 60. Juice pH was not affected by cluster thinning. Juice titratable acid concentration was lower at 20 clusters per vine than with 60 clusters per vine. Twenty clusters per vine produced fruits darker and less yellow than 60 clusters per vine. Fruit red pigmentation was increased quadratically by cluster thinning. Total anthocyanin concentration in berry skin was increased linearly by cluster thinning. The concentration of individual anthocyanins, including cyanidin-3-glucoside, peonidin-3-glucoside, and acylated cyanidin derivative, was increased linearly by cluster thinning. However, the concentration of delphinidin-3-glucoside, or petunidin-3-glucoside, or malvidin-3-glucoside, was not significantly affected. Cluster thinning linearly increased the percentage of cyanidin-3-glucoside and decreased the percentage of the acylated cyanidin derivative. The percentages of delphinidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, and malvidin-3-glucoside were not affected by cluster thinning.

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Introduction

Fruit color is an important quality attribute in table grapes. The pigments responsible for the attractive red, blue, purple, and black color are anthocyanins, a class of water-soluble flavonoid pigments. Fruit color development in grapes has been studied extensively due to its importance in the table and wine-grape industry. Fruit-cluster thinning has been shown to improve pigmentation of certain grape cultivars (4, 8, 10).

The detailed study of individual anthocyanins is essential to the understanding of anthocyanin metabolism and fruit-color improvement. Most published studies on fruit coloration in grapes have dealt with changes in total anthocyanin content (7, 12, 14). Anthocyanin profiles of most pigmented grape cultivars are known to be very complex. 'Cabernet Sauvignon' (*Vitis vinifera* L.) and 'Concord' (*Vitis labruscana* L.) have potentially up to 20 different kinds of anthocyanins (6, 16, 17). Advances in instrumental analysis have made the simultaneous investigation of all anthocyanins in a grape cultivar possible.

C_{18} reverse-phase high-performance liquid chromatography (HPLC) has been the method of choice in simultaneous separation, identification, and quantification of anthocyanins in grapes and other colored fruits (5, 11, 17). HPLC studies of cultivars and the effects of climatological factors on changes in individual anthocyanins during fruit ripening (2, 11) have produced results significant to our understanding of anthocyanin metabolism in field-grown pigmented grapes.

'Reliance' (*Vitis* hybrid), a red seedless table grape, was used in this study because of its fruit-color variation at maturity, economical importance in Ohio, and simple anthocyanin profile (3). C_{18} reverse-phase HPLC analysis of anthocyanins from 'Reliance' revealed seven components. With the joint use of HPLC, paper chromatography, thin-layer chromatography, and spectral measurement, three components were identified as delphinidin-3-glucoside, cyanidin-3-glucoside, and peonidin-3-glucoside. Four other anthocyanin components were tentatively identified as cyanidin-3,5-diglucoside, petunidin-3-glucoside, malvidin-3-glucoside, and an acylated cyanidin derivative. The authors' preliminary studies on fruit-color development in 'Reliance' showed that it was enhanced by cluster thinning, or the application of chelated nutrients, or ethephon.

The objective of this study was to investigate the effects of fruit-cluster thinning on 'Reliance' grape berry weight, color, juice quality, the concentration of total anthocyanin and individual anthocyanins in the berry skin, and the percentages of individual anthocyanins.

Materials and Methods

Grapevines, Treatments, and Statistics

'Reliance' grapevines were planted in 1985 at The Ohio State University/Ohio Agricultural Research and Development Center's Wooster campus. Grapevines were trained to the single-curtain high-cordon system. Row and vine spacings were 3.1 m x 2.4 m. In 1991, grapevines were pruned to 60 buds per vine. Shoot count was adjusted to 50 per vine one week after full bloom. Cluster-thinning treatments were applied when berries were about 2–3 mm in diameter. Treatments were 60 (control), 40, and 20 clusters per vine. The design was a randomized complete block where a whole vine served as an experimental unit. Treatments were replicated eight times. Mean separation was conducted by orthogonal contrasts at $P \leq 0.05$ or 0.01.

Fruit Juice Quality and Color

Fruit juice was obtained by pressing 100 berries per sample through a Garden-Way Squeezo strainer (Lemra Products, Boca Raton, Florida). Soluble solids concentration (SSC) of the fruit juice was measured with an ABBE-3L Refractometer (Baush & Lomb, Inc., Rochester, New York). Juice pH was measured with a Beckman pH meter (Model PHI 45, Beckman Instruments Inc., Fullerton, California). Titratable acidity (TA%) was measured by titration of 5 ml of juice with 0.1 N NaOH to a pH of 8.2 (1). Fruit skin color was measured with a Minolta Chroma Meter (Model CR-100, Minolta Camera Co., Ltd., Higashi-Ku, Osaka, Japan) as CIE (Commission Internationale de I'Eclairage, translated as the International Commission of Illumination) 1976 L*, a*, and b*. L* represents bright to dark as L* values increase from negative to positive; a* represents green to red as a* values increase from negative to positive; b* represents blue to yellow as b* values increase from negative to positive. Fruit skin color measurements were taken on six clusters per vine, from the top, middle, and bottom portion of the east-facing side of each cluster. The mean of readings from these six clusters was used.

Sample Preparation for Anthocyanin Analysis

Six fruit clusters per vine were collected on August 18, 1991, when SSC in most fruits reached 18–20%. The clusters were immediately stored at 4°C. They then were weighed and berries per fruit cluster were counted the following day. Clusters were then frozen and stored at -20°C for future analyses. Berry skins were removed and collected by first thawing the frozen berries in a refrigerator at 4°C for 20 min. The berry skins were then peeled with tweezers and kept in an ice-chilled beaker. Finally, the berry skins were freeze-dried and ground with a coffee mill (Oster Model 663-06, Sunbeam Corporation, Milwaukee, Wisconsin).

Anthocyanin Extraction and Concentration

One g of ground berry skin was placed in 100 ml of 1% 12 N HCl in methanol. The anthocyanin extraction was carried out overnight in a refrigerator at 4°C. Extracts were then filtered through Whatman No. 1 filter paper in a Buchner funnel. Twenty ml of deionized distilled water were added to each anthocyanin extract. The extracts were concentrated with a rotary evaporator under vacuum at 30°C. Concentrates were transferred to a 25 ml volumetric flask and then brought to volume with deionized distilled water. Five ml of each anthocyanin concentrate was then passed through a 0.2 µm syringe membrane filter that had been equilibrated with 1 ml of the respective anthocyanin concentrate to avoid anthocyanin dilution by syringe membrane filters. Each filtrate was stored at room temperature for less than 20 min in a screw-capped sample vial before HPLC analysis.

HPLC Analyses

HPLC analyses were performed on a Model SP4000 pump (Spectra-Physics, San Jose, California) equipped with a 20 µl Rheodyne sample loop. The analytical column was a pH stable RP-18 Spherisorb (Merck, Darmstadt, Germany) (150 mm x 4.6 mm I.D.) packed with 5 µm particles by Alltech (Deerfield, Illinois). A Spectra-Physics UV1000 variable wavelength detector and Spectra-Physics Model 4600 integrator were used.

The following conditions were used for the analyses of anthocyanins: Solvent A was 10% formic acid in water; solvent B was high-purity acetonitrile. These solvents were filtered through 0.2 µm membrane filters and sparged with helium. Solvent flow rate was 1 ml/min. The solvent program used for anthocyanins was 95% A initially, decreased from 95% A to 72% A in 20 min. following a linear slope. Detection was carried out at 520 nm. The detector was set at one absorption unit full scale.

Determination of Anthocyanin Concentration

To convert the peak areas into pigment concentration per gram of dry berry skin, a solution of cyanidin-3-glucoside (a generous gift from Dr. Geza, Hrazdina, NYSAES, Geneva, New York) in 0.1 N HCl was prepared to establish a standard curve. The solution was filtered through a 0.2 µm membrane filter and absorbance determined at 520 nm. The concentration (g/100 ml) of this solution was calculated based on the extinction coefficient of cyanidin-3-glucoside in 0.1 N HCl. A dilution series was then made. Twenty µl of samples were injected into HPLC under identical analytical conditions as for the samples.

A standard curve was established between the concentration of diluted cyanidin-3-glucoside solutions and their peak areas. The concentration of cyanidin-3-glucoside was calculated based on the following equation where the correlation coefficient was 0.998:

Equation 1. mg/100 ml = (peak area) * (0.00000391)

Since one g of dried berry skin was dissolved in a final volume of 25 ml, the concentration of cyanidin-3-glucoside was calculated as:

Equation 2. mg/g dried berry skin = (peak area) * (0.00000391) * (25ml)/100ml

The concentration of each individual anthocyanin was expressed as cyanidin-3-glucoside equivalent based on their respective peak area, since cyanidin-3-glucoside was present at the highest concentration in the 'Reliance' anthocyanin profile (3). Total anthocyanin concentration was calculated as the sum of the concentration of all the individual anthocyanins. The percentage of each individual anthocyanin was calculated as:

Equation 3. percentage = (conc. of individual anthocyanin x 100)/total anthocyanin conc.

Results and Discussion

Fruit Characteristics

Yield and SSC increased quadratically following fruit-cluster thinning (Table 1). The juice pH value was higher for the 40 clusters per vine treatment than 20 or 60 clusters per vine. Juice titratable acidity (TA) was decreased by 20 clusters per vine in comparison with 40 and

Table 1. Effects of Cluster Thinning on Grape Yield, Quality, and Fruit Skin Color (CIE 1976 L*, a* and b*).

Treatment (cluster number/ vine)	Yield (kg/vine)	Soluble Solids (°Brix)	pH	Titratable Acidity (%)	Berry Weight (g)	Cluster Weight (g)	Color Reflectance Parameters[z]		
							L*	a*	b*
60	12.7 a[y]	18.5 c	3.25 a	0.50 a	2.0 b	269.3 a	32.6 a	6.2 a	4.5 a
40	8.9 b	20.0 b	3.35 a	0.49 ab	2.1 b	294.4 a	31.3 ab	7.0 a	3.2 b
20	5.4 c	21.6 a	3.29 a	0.48 b	2.2 a	277.2 a	30.0 b	7.2 a	2.5 b
LSD	1.7	0.7	0.23	0.02	0.1	39.7	1.7	1.1	0.9
Linear Contrast	**[x]	**	NS	**	NS	NS	*	NS	**
Quadratic Contrast	**	**	**	**	**	**	**	**	**

[z] L* represents light color to dark color; a* represents red color to green color; b* represents yellow color to blue color.
[y] Mean separation by least significant difference (LSD) at $P = 0.05$ level.
[x] Orthogonal contrast at $P = 0.05$ or 0.01 level; *, **, NS = significant at 0.05 or 0.01 level, and not significant, respectively.

60. Berry weight was increased by cluster thinning following a quadratic relationship. Cluster weight was higher with 40 clusters per vine in comparison with 20 or 60. This nonsignificant difference in cluster weight might have been partially caused by variation in berry counts which the authors did not adjust. The authors hypothesized that the drought during veraison may have stopped the berries from reaching their potential maximum weight. The effect of cluster thinning on cluster weight might also have been reduced by a drought during veraison in 1991. Van Zyl and Webber (13) found that berry growth is most sensitive to water stress at veraison, followed by the period just after flowering.

Cluster-thinning treatments produced darker L* berries following a quadratic relationship (Table 1). Forty clusters per vine increased fruit red color characterized as a* compared to 60. Cluster-thinning treatments produced less yellow berries (Table 1). Differences in fruit color density were also shown in L* and b*. This lack of linear relationship in fruit red color among three cluster-thinning levels might be due to that fact that 'Reliance' is a purplish red grape instead of a true red. Furthermore, the difference in fruit color may have also been partially reduced by the variation in berry count and/or the drought.

Anthocyanins

'Reliance' berries contain anthocyanins only in their berry skins. As measured with HPLC, total anthocyanin concentration of the berry skin was increased linearly by cluster-thinning treatments (Table 2). Similar results were found in other pigmented table and wine grapes. Kliewer and Weaver (8) showed that 18.7 clusters per vine (pruned and thinned) increased the percentage of coloration by 57% in comparison with 31.8 clusters per vine, and by 85% in comparison with 120 clusters per vine. Light crop loads in several red wine grape cultivars ('Alicante Bouschet,' 'Carignane,' 'Petite Sirah,' 'Pinot Pernand,' and 'Zinfandel'), were shown to produce more highly colored fruits than heavy crop loads (15).

Table 2. Effect of Cluster Thinning on Individual Anthocyanins and Total Anthocyanin Content in Fruit Berry Skin.

Treatment (cluster number/vine)	Total Anthocyanin Content (mg/g)	Dp-3-g[z] (mg/g)	Cy-3-g (mg/g)	Pt-3-g (mg/g)	Pn-3-g (mg/g)	Mv-3-g (mg/g)	Acylated Cy Derivative (mg/g)
60	3.83 b[y]	0.59 a	2.64 b	0.06 a	0.15 b	0.03 b	0.50 b
40	4.60 ab	0.61 a	3.29 ab	0.06 a	0.17 b	0.03 b	0.58 b
20	5.99 a	0.76 a	4.35 a	0.08 a	0.22 a	0.04 a	0.71 a
LSD	1.65	0.27	1.30	0.03	0.07	0.01	0.12
Linear Contrast	**[x]	NS	**	NS	*	NS	**
Quadratic Contrast	NS	NS	NS	NS	NS	NS	NS

[z] Abbreviations for individual anthocyanins: Dp-3-g = delphinidin-3-glucoside; Cy-3-g = cyanidin-3-glucoside; Pt-3-g = petunidin-3-glucoside; Pn-3-g = peonidin-3-glucoside; Mv-3-g = malvidin-3-glucoside; acylated Cy derivative = acylated cyanidin-glycoside.
[y] Mean separation by least significant difference (LSD) at $P = 0.05$ level.
[x] Orthogonal contrast at $P = 0.05$ or 0.01 level; *, **, NS = significant at 0.05 or 0.01 level, and not significant, respectively.

Cluster thinning affected the concentration of individual anthocyanins in 'Reliance' grape unequally. The concentration of cyanidin-3-glucoside, peonidin-3-glucoside, and the acylated cyanidin derivative were all increased linearly by cluster thinning (Table 2). However, the concentration of delphinidin-3-glucoside, petunidin-3-glucoside, and malvidin-3-glucoside, was not significantly affected. There was no quadratic relationship between cluster thinning and the concentration of individual anthocyanins. Cacho *et al.* (2) reported that the concentration of all five anthocyanidins in such grape cultivars as 'Tempranillo,' 'Moristel,' and 'Garnacha' increases similarly as total anthocyanin from veraison to full maturity. Without conducting a developmental study of the concentration of individual anthocyanins in 'Reliance,' it is hard to know why the synthesis of only cyanidin-3-glucoside, peonidin-3-glucoside, and acylated cyanidin-glycoside were increased by cluster thinning. The authors hypothesized that carbohydrate allocation and complexicity of individual anthocyanins may have something to do with this phenomena.

The percentages of two anthocyanins, in relation to total anthocyanin content, were also affected by cluster-thinning treatments (Table 3). The percentages of cyanidin-3-glucoside and the acylated cyanidin derivative were increased linearly by cluster thinning. The percentages of delphinidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, and malvidin-3-glucoside were not affected by cluster thinning. There was no quadratic relation between the percentages of individual anthocyanins and cluster thinning.

Cluster thinning had the opposite effect on the percentage of cyanidin-3-glucoside as for the percentage of acylated cyanidin derivative. The same relationship exists between the per-

Table 3. Effect of Cluster Thinning on the Percentages of Individual Anthocyanins.

Treatment (cluster number/vine)	Dp-3-g[z] (%)	Cy-3-g (%)	Pt-3-g (%)	Pn-3-g (%)	Mv-3-g (%)	Acylated Cy Derivative (%)
60	12.5 a[y]	67.3 b	1.4 a	4.4 a	0.8 a	13.6 a
40	12.0 a	68.6 b	1.3 a	4.4 a	0.6 b	13.2 a
20	12.2 a	71.4 a	1.3 a	3.7 a	0.6 b	10.8 b
LSD	3.6	4.1	0.4	0.9	0.2	2.9
Linear Contrast	NS[x]	*	NS	NS	NS	*
Quadratic Contrast	NS	NS	NS	NS	NS	NS

[z] Abbreviations for individual anthocyanins: Dp-3-g = delphinidin-3-glucoside; Cy-3-g = cyanidin-3-glucoside; Pt-3-g = petunidin-3-glucoside; Pn-3-g = peonidin-3-glucoside; Mv-3-g = malvidin-3-glucoside; acylated Cy derivative = acylated cyanidin-glycoside.
[y] Mean separation by least significant difference (LSD) at $P = 0.05$ level.
[x] Orthogonal contrast at $P = 0.05$ or 0.01 level; *, **, NS = significant at 0.05 or 0.01 level, and not significant, respectively.

centages of cyanidin-3-glucoside and malvidin-3-glucoside. The effect of cluster-thinning treatments on the percentage of individual anthocyanins does not appear to be only related to berry ripening. Roggero *et al.* (11) reports that anthocyanin composition in 'Syrah' is quickly set after veraison and remains nearly stable until the grapes mature except for the cyanidin derivative, which is the precursor of other pigments. Based on a calculation of ratios of individual anthocyanins presented by Cacho *et al.* (2), it seems that percentages of anthocyanins also remain stable after veraison. However, ethephon, a growth regulator that is well known to promote fruit ripening, altered the pigment makeup, characterized as percentages of individual anthocyanins, in 'Pinot noir' when applied at 500 ppm at veraison (9).

Cluster-thinning treatments seem to shift the balance among cyanidin-3-glucoside and acylated cyanidin derivative without significantly affecting the percentages of other anthocyanins. Cacho *et al.* (2) found that cyanidin-3-glucoside content naturally varies very little from ripening to maturity in 'Tempranillo,' 'Moristel,' and 'Garnacha.' The authors do not know whether cluster-thinning effects on the percentages of individual anthocyanins are related to the ethylene production in berries. It is still very interesting that both cluster thinning and ethephon could alter the percentages of anthocyanins in a grape cultivar. Measurements of ethelene production in berries after imposing cluster thinning, at different developmental stages, could help shed some light on the mechanism of anthocyanin metabolism.

The manipulation of fruit color in a grape cultivar can be achieved by alteration of anthocyanin composition alone without affecting total anthocyanin. Fruit-color improvement by cluster thinning could be attributed to increased total anthocyanin and change in anthocyanin composition. Increase in cyanidin-3-glucoside must have contributed to increased red color in 'Reliance.' However, it is very difficult to increase composition of an anthocyanin

without affecting total anthocyanin content of field-grown grapes. How much of a change in anthocyanin composition is needed to significantly alter the color of a grape cultivar is still unknown.

Twenty clusters per vine were shown to be the best in improving fruit quality and color under single-curtain and high-cordon systems in northeastern Ohio. Grapevines thinned to 20 clusters per vine produced grapes of larger berry size, higher soluble solids, and better fruit color than those thinned to 40 or 60 clusters per vine. This study was an attempt to investigate the effects of cluster thinning on both total and individual anthocyanins of 'Reliance.' In the future, such crop levels, ranging from 20 to 80 clusters per vine, alone and in combination with other variables such as temperature, growth regulators, or fertilization, should be used to investigate change in individual anthocyanins from veraison to maturity by progressive sampling. More research is needed to understand anthocyanin metabolism in pigmented grapes and to achieve effective manipulation of fruit color.

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Effects of Various Fungicide Programs on Powdery Mildew Control, Percent Berry Sugar, Yield, and Vine Vigor of 'Concord' Grapes in Ohio

Michael A. Ellis, Laurence V. Madden, L. Lee Wilson, and Gregory R. Johns

Introduction

Powdery mildew, caused by the fungus *Uncinula necator* (Schwein.) Burrill, is the most widespread and destructive disease of grapevines in the United States (6). In Ohio, the disease can cause serious losses of yield and fruit quality on susceptible cultivars. Although none of the grape cultivars currently grown in Ohio are completely resistant to powdery mildew, cultivars do vary in their degree of susceptibility (2, 11). Most cultivars of *Vitis vinifera* L. and many *Vitis* interspecific hybrid cultivars are highly susceptible to powdery mildew. In general, cultivars of *Vitis labruscana* L. H. Bailey tend to be more resistant to powdery mildew. The *V. labruscana* cultivar 'Concord' is one of the least susceptible and most widely planted cultivars in Ohio and throughout the Great Lakes region. Although 'Concord' grapes are relatively resistant, powdery mildew incidence and severity can be quite high in some growing seasons if the disease is not effectively controlled with fungicides. Although the disease can appear to be quite severe, effects of powdery mildew on yield and fruit quality of 'Concord' grapes is not well documented, and many Ohio growers feel that the disease is not a serious problem on 'Concord' grapes.

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Control of grape powdery mildew largely depends on the use of effective fungicides. Depending upon susceptibility of the cultivar, three to 12 applications of fungicide may be required for powdery mildew control (9). Due to the relatively low value of 'Concord' grapes (as compared to *V. vinifera* wine grapes), many 'Concord' growers have expressed concerns about the cost of fungicides for disease control. In Ohio, most 'Concord' growers make three to five fungicide applications per season, starting when new shoots are 4- to 10-inches long, with repeated applications at 10- to 14-day intervals. Generally, the fungicide program is terminated two to three weeks after bloom.

Diseases of primary concern during this period are black rot caused by *Guignardia bidwellii* (Ellis) Viala and Ravaz, downy mildew caused by *Plasmopara viticola* (Berk. and Cont.) Berl. and deToni, Phomopsis cane and leaf spot caused by *Phomopsis viticola* (Sacc.) Sacc., and powdery mildew. Ideally, each fungicide application should contain fungicides with efficacy for controlling all of these diseases simultaneously. However, fungicides with efficacy for powdery mildew are often omitted. Traditionally, many growers apply a mid- to late-season copper fungicide if supplemental control of powdery or downy mildew is required. However, many growers avoid copper fungicides due to potential damage (phytotoxicity) to grape vines (3, 10). This presents an additional problem for growers of 'Concord' grapes in relation to late-season control of powdery mildew with fungicides. Sulfur is an effective and relatively inexpensive fungicide for powdery mildew control and is commonly used for late-season control on varieties that are not sulfur

sensitive. Unfortunately, 'Concord' grapes are extremely sensitive to sulfur. If growers choose not to use copper fungicides, the only alternatives are ergosterol biosynthesis-inhibiting fungicides such as myclobutanil or fenarimol, JMS-stylet oil, or the newly registered azoxystrobin fungicide, Abound. All of these fungicides are highly effective for powdery mildew control; however, they are expensive and many 'Concord' growers are reluctant to use them for late-season control of powdery mildew. Whereas post-bloom (late season) development of powdery mildew is common on 'Concord' grapes, it is often disregarded by growers as having no perceived effects on yield or fruit quality (percent sugar).

The purposes of this study were to evaluate the efficacy of various fungicide programs for control of powdery mildew and determine the effects of powdery mildew on yield, vine vigor, and fruit quality (percent sugar) of 'Concord' grapes in Ohio.

Materials and Methods

Field trials were conducted during 1994, 1995, and 1996 in a block of 'Concord' grapes at The Ohio State University/Ohio Agricultural Research and Development Center's Grape Research Branch at Kingsville. Vines were planted in 1985 and were spaced with eight feet between vines and nine feet between rows. The vineyard consisted of 15 rows with nine vines per row. Vines were trained to a bilateral cordon system (no tie) and were pruned to a maximum of 60 buds per vine, regardless of pruning weights. The experimental vineyard was divided into three blocks of five rows each, and treatments were applied to the center three rows of each block. Each of the center three rows was considered as a sample for purposes of data analysis. In order to achieve large enough plots for airblast spraying, each block consisted of a single treatment. Fungicide treatments were applied to both sides of the three center rows using an FMC model 1229 FTM airblast spray in 100 gallons of water per acre at a pressure of 250 psi. In order to prevent drift, there were two nontreated rows between each treated block. Data was collected from each of the center three rows (replications). Powdery mildew disease incidence and severity for leaves and cluster stems were taken approximately two weeks prior to harvest during each year of the study. Foliar disease incidence was based on the number of leaves infected for 10 randomly selected leaves from each of nine vines per replication and treatment. Disease incidence for cluster stems was based on the number of infected cluster stems on 10 randomly selected clusters from each of nine vines per replication and treatment. Disease severity for leaves and cluster stems was based on the area of the same leaves and cluster stems covered by powdery mildew using the Horsfall-Barratt scale, and converting values to percent using Elanco conversion tables (1). Percent sugar content was measured at harvest from a 100-berry composite sample from each replication per treatment. Yield (total berry weight) was recorded for each vine at harvest. Pruning weights for each vine were recorded as a measure of vine vigor for each vine during the dormant season following each harvest.

Fungicide treatments were designed to evaluate a four-spray program of mancozeb plus an ergosterol biosynthesis-inhibiting fungicide (either myclobutanil or fenarimol) applied on a 10- to 14-day schedule from approximately six-inch new shoot growth through two weeks after bloom. This represents the currently recommended fungicide program for 'Concord' grapes in Ohio (2). This four-spray program (standard program) was the foundation for all fungicide treatments during all years of testing. Fungicides, rates, and application dates are presented in Tables 1, 2, and 3. In 1994, additional treatments consisted of one additional post-bloom application of metalaxyl plus copper 70W or two additional post-bloom applications of JMS-Stylet oil (Table 1). In 1994, an untreated control was not included in the trial. In 1995, treatments consisted of the standard program alone, the standard program plus two additional post-bloom applications of JMS-Stylet oil, and an untreated control (Table 2). In 1996, treatments consisted of the standard program alone, and the standard program plus one additional application of JMS-Stylet oil, and an untreated control (Table 3).

For data analysis, the standard error of the difference (SED) between means was calculated for each variable (e.g., disease incidence). An

Table 1. Effects of Various Fungicide Programs on Powdery Mildew Control, Sugar Content of Berries, Yield, and Vine Vigor of 'Concord' Grapes in 1994.

Treatment Compounds, Rates per Acre, and Timing	Powdery Mildew				Sugar Content (%)	Mean Total Yield Per Vine[w] (lbs)	Mean Pruning Weight Per Vine[v] (lbs)
	Leaves		Cluster Stems				
	Incidence[z]	Severity[y]	Incidence[z]	Severity[y]			
1. **Standard Program** Myclobutanil 40W, 4 oz Mancozeb 75DF, 3 lb June 1, 3-6" shoot June 14, pre-bloom June 28, bloom July 11, post bloom	100.0	37.5	100.0	41.5	15.9	29.8	3.6
2. **Standard Program Plus** See Treatment 1 then Metalaxyl + Copper 70W, 2 lb July 22, cluster closing	100.0	13.6	100.0	21.9	16.3	29.0	3.5
3. **Standard Program Plus** See Treatment 1 then JMS STYLET-Oil, 1.5% July 22 August 9	44.8	1.0	50.8	1.6	16.0	30.2	3.6
LSD[u]	5.3	1.7	5.4	1.9	0.6	3.7	0.5
SED[t]	3.0	1.0	3.1	1.1	0.2	1.5	0.2

[z] Disease incidence based on the number of leaves/clusters infected for 10 randomly selected leaves/clusters from each of nine vines per replication and treatment.
[y] Disease severity based on percent area of leaf/cluster covered with mildew on the same leaves/clusters used for incidence (Horsfall-Barratt scale) and converted to percent using the Elanco conversion table.
[x] Based on mean % sugar of one 100-berry composite sample for each row (replication) per treatment.
[w] Mean total yield per vine. Based on three rows (replications) of nine vines each per treatment.
[v] Mean pruning weight per vine in 1995. Based on three rows (replications) of nine vines each per treatment.
[u] LSD = least significant difference ($P = 0.05$).
[t] SED = standard error of the difference between two means.

approximate least significant difference (LSD) was calculated based on the SED.

Results and Discussion

In 1994, powdery mildew incidence was 100% on leaves and cluster stems for the standard program and one additional application of metalaxyl plus copper. Although there was no significant difference in disease incidence between these treatments, the additional application of metalaxyl plus copper resulted in significantly less disease severity on both leaves and cluster stems (Table 1). Two additional applications of JMS-Stylet oil resulted in significantly less powdery mildew incidence and severity on leaves and cluster stems than any other treatment. JMS-Stylet oil reduced disease severity from 38% and 42% to 1% and 1.6% for leaves and cluster stems, respectively. JMS-

Table 2. Effects of Various Fungicide Programs on Powdery Mildew Control, Sugar Content of Berries, Yield, and Vine Vigor of 'Concord' Grapes in 1995.

Treatment Compounds, Rates Per Acre, and Timing	Powdery Mildew				Sugar Content (%)	Mean Total Yield Per Vine[w] (lbs)	Mean Pruning Weight Per Vine[v] (lbs)
	Leaves		Cluster Stems				
	Incidence[z]	Severity[y]	Incidence[z]	Severity[y]			
1. **Standard Program** Myclobutanil 40W, 4 oz Mancozeb 75DF, 3 lb May 23, 6" shoot June 15, pre-bloom June 21, bloom July 10, post bloom	89.2	15.2	70.2	2.1	14.9	28.1	3.0
2. **Standard Program Plus** See Treatment 1 then JMS STYLET-Oil, 1.5% July 24 August 18	20.3	5.4	30.1	1.8	15.1	27.6	3.1
3. **Untreated Control**	100.0	21.6	81.3	17.5	15.0	27.9	3.3
LSD[u]	14.8	5.1	14.0	10.3	0.3	2.9	0.4
SED[t]	7.0	3.1	6.9	5.9	1.2	1.3	0.2

[z] Disease incidence based on the number of leaves/clusters infected for 10 randomly selected leaves/clusters from each of nine vines per replication and treatment.
[y] Disease severity based on percent area of leaf/cluster covered with mildew on the same leaves/clusters used for incidence (Horsfall-Barratt scale) and converted to percent using the Elanco conversion table.
[x] Based on mean % sugar of one 100-berry composite sample for each row (replication) per treatment.
[w] Mean total yield per vine. Based on three rows (replications) of nine vines each per treatment.
[v] Mean pruning weight per vine in 1996. Based on three rows (replications) of nine vines each per treatment.
[u] LSD = least significant difference ($P = 0.05$).
[t] SED = standard error of the difference between two means.

Stylet oil has been reported to be highly effective for control of powdery mildew of grape (4, 5, 7, 8). Although disease incidence and severity was high on vines in the standard program and was significantly reduced by two additional applications of JMS-Stylet oil, there were no significant differences in percent sugar of berries, total yield, and vine pruning weights between any of the treatments (Table 1).

In 1995 and 1996, a nontreated control was included for comparison. In both years, there were no significant differences in disease incidence on leaves or cluster stems between the standard program and the untreated control. However, disease severity for both leaves and cluster stems was significantly less for the standard program than the untreated control during both years. Two additional applications of JMS-Stylet oil in 1995 resulted in significantly less disease incidence and severity on leaves than the standard program. On cluster stems, two additional applications of Stylet oil resulted in significantly less disease incidence than the standard program; however, there were no significant differences between the treatments in disease severity (Table 2). In 1996, one additional application of JMS-Stylet oil

Table 3. Effects of Various Fungicide Programs on Powdery Mildew Control, Sugar Content of Berries, Yield, and Vine Vigor of 'Concord' Grapes in 1996.

Treatment Compounds, Rates Per Acre, and Timing	Powdery Mildew: Leaves Incidence[z]	Powdery Mildew: Leaves Severity[y]	Powdery Mildew: Cluster Stems Incidence[z]	Powdery Mildew: Cluster Stems Severity[y]	Sugar Content (%)	Mean Total Yield Per Vine[w] (lbs)	Mean Pruning Weight Per Vine[v] (lbs)
1. **Standard Program** Mancozeb 75DF, 3 lb Fenarimol May 22, 3-6" shoot June 10, pre-bloom June 24, bloom July 12, post bloom	100.0	15.5	100.0	17.6	14.3	27.5	3.7
2. **Standard Program Plus** See Treatment 1 then JMS STYLET-Oil, 1.5% Aug. 4, veraison	36.9	4.5	41.3	5.6	14.4	26.7	3.3
3. **Untreated Control**	100.0	35.5	100.0	39.6	14.3	28.6	3.5
LSD[u]	14.9	6.5	15.1	8.9	0.2	2.1	0.5
SED[t]	8.1	4.3	7.9	4.2	0.1	0.9	0.2

[z] Disease incidence based on the number of leaves/clusters infected for 10 randomly selected leaves/clusters from each of nine vines per replication and treatment.
[y] Disease severity based on percent area of leaf/cluster covered with mildew on the same leaves/clusters used for incidence (Horsfall-Barratt scale) and converted to percent using the Elanco conversion table.
[x] Based on mean % sugar of one 100-berry composite sample for each row (replication) per treatment.
[w] Mean total yield per vine. Based on three rows (replications) of nine vines each per treatment.
[v] Mean pruning weight per vine in 1997. Based on three rows (replications) of nine vines each per treatment.
[u] LSD = least significant difference ($P = 0.05$).
[t] SED = standard error of the difference between two means.

resulted in significantly less disease incidence and severity on both leaves and cluster stems than the standard program (Table 3). As in 1994, there were no significant differences in percent sugar content of berries, total yield, and pruning weight per vine between any of the treatments in 1995 or 1996.

The results of this study indicate that the standard four-spray program for grape disease control is not highly effective for providing season-long control of powdery mildew on 'Concord' grapes. It should be noted that in all years of testing, no powdery mildew was observed in any of the test plots at the time when the standard program was terminated (approximately two weeks after bloom). Therefore, all visible powdery mildew in the plots developed relatively late in the season. Although disease incidence and severity were high in the standard program and unsprayed plots, the disease appeared to have no effect on fruit sugar content, yield, or vine vigor over the three-year period that tests were conducted. In all years of testing, late-season applications of JMS-Stylet oil resulted in significantly less disease incidence and severity (Tables 1–3). In some years, especially 1994 and 1996, these differences were quite large regardless of de-

gree of significance; however, they did not result in significant differences in fruit quality, yield, or vine vigor.

Based on the results of this study, it appears difficult to economically justify late-season fungicide applications for control of powdery mildew on 'Concord' grapes. The authors are not suggesting that growers ignore powdery mildew on 'Concord' grapes. However, the authors believe that additional information is needed to demonstrate the need for, and benefits of, additional fungicide applications for powdery mildew control beyond the traditional four-spray program on 'Concord' grapes.

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Influence of Growth Regulators, Cropping, and Number on Replacement Trunks of Winter-Injured 'Vidal Blanc' Grapes

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A low temperature of -26°F in January of 1994 resulted in significant injury to grapevines in Ohio and other Midwestern states (1, 4). Of the two most important white French-American hybrids grown in Ohio, 'Vidal blanc' was more severely injured by the low winter temperature than was 'Seyval blanc.' Early spring growth on mature 'Vidal' vines was sparse and weak with some arms showing no growth at all. Some trunks developed longitudinal splits.

In climates where serious injury to trunks can occur, several references suggest leaving multiple trunks (2, 6, 7), but the subject of the best procedure to produce hardy replacement trunks is not addressed. Conventional wisdom suggests allowing several new shoots to develop from the base to avoid the production of very vigorous "bull" canes that lack hardiness. Others suggested allowing everything to grow and then ultimately selecting canes with modest growth characteristics as the replacement trunks.

A series of studies was conducted following the January 1994 freeze episode to evaluate several practices that might moderate growth and result in new trunks that would be hardy. Growth regulators that moderate growth through interruption of gibberellin biosynthesis were tested in the first trial. In the second, different numbers of replacement shoots were retained to determine the effect on growth of replacement trunks. In the third trial, the influence of retaining the top and adjusting it to different crop levels along with growth retardant chemicals was tested. A fourth study evaluating growth-retarding chemicals was conducted in a grower vineyard, near Conneaut, that had significant injury in the vinifera cultivar 'Chardonnay.'

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Materials and Methods

'Vidal' Growth Regulator Trial

Injured trunks along with the entire vine top were removed in mid-May 1994 at a height of approximately 50 cm (approximate snow level when cold event occurred). On June 22, 1995, vines with one to four shoots, approximately 50 cm long and arising from the lower 30 cm of the trunk, were selected and sprayed to drip with a hand-held CO_2 pressurized sprayer with the compounds and rates shown in Table 1. Treatments with an x3 designation were repeated on July 22, 1994, and August 22, 1994. The growth-retarding chemicals used were Alar [daminozide (2,2-dimethyl hydrazide)], Ponnax [mepiquat chloride (N,N-dimethyl piperidinium chloride)], and Primo [(4-cyclopropyl-α-hydroxy-ethylene)-5,5-dioxo-cyclohexanecarboxylic acid ethyl)]. BAS 125 (prohexadione calcium) was an experimental gibberellin biosynthesis inhibitor from BASF which was compared with the commercial gibberellin biosynthesis inhibitors Ponnax from BASF and Primo from Ciba-Geigy. Basal shoots were tied up periodically over the summer, first to the cut-off trunk and subsequently to the existing trellis wires. The length of the basal shoots was

Table 1. Influence of Foliar Growth Regulator Applications on 1994 Growth of Replacement Trunks of 'Vidal' Grapevines Following January 1994 Injury and Removal of the Top of the Vine.

		Change in Shoot Length (cm)		Sixth Internode				1995			
Treatment	Rate[z] (ppm)	7/25–8/23	8/23–7/25	Length (cm)	Diameter (mm)	Basal Internode Diameter (mm)	Pruning Weight (lbs/vine)	Shoot Length[y] (cm)	Flower Clusters/ Vine	Harvest Clusters/ Vine	Yield (lbs/vine)
Control	—	56.8 c-e	66.9 b-d	9.6 a-b	9.9 a-b	12.4	2.20 a	18.8 c-d	56.0 a-c	34.5 a-b	14.2 a
Alar	1000	32.3 e	90.8 a-d	7.5 a-c	9.3 b-c	10.6	1.51 b-d	22.3 a-c	29.1 c-f	22.4 b-c	6.6 b-d
Alar	2000	98.4 a-e	88.7 a-d	7.8 a-c	8.7 a-c	10.4	1.71 a-d	21.5 a-c	38.5 a-e	26.4 b-c	9.3 a-c
Primo	250	43.3 d-e	83.1 a-d	7.1 b-c	8.5 a-c	10.2	1.94 a-c	20.7 b-d	59.1 a	28.2 b-c	11.6 a-b
Primo	500	58.8 b-e	127.9 a-b	6.0 c	7.6 b-c	9.9	1.42 c-d	19.8 b-d	25.0 e-f	22.8 b-c	7.9 b-c
Primo	750	80.5 a-e	68.0 b-d	6.6 b-c	8.5 a-c	11.0	1.97 a-c	19.5 b-d	57.7 a-b	34.7 a-b	10.9 a-c
Primo	250 x 3	35.5 e	24.3 d	7.9 a-c	6.9 c	10.0	1.40 c-d	25.4 a	28.5 d-f	17.7 c-d	5.2 c-d
Ponnax	250	86.7 a-e	111.9 a-c	7.8 a-c	9.1 a-c	10.3	1.74 a-d	23.4 a-b	44.4 a-e	44.0 a	14.2 a
Ponnax	500	112.1 a-c	141.5 a	9.1 a-c	10.0 a-b	11.6	1.64 a-d	20.6 b-d	31.7 b-e	26.5 b-c	10.9 a-c
Ponnax	750	110.0 a-c	144.8 a	5.8 c	10.4 a	12.3	2.04 a-b	21.1 a-c	43.2 a-e	29.2 b-c	10.9 a-c
Ponnax	250 x 3	131.9 a	86.7 a-d	8.3 a-c	10.3 a	10.8	1.81 a-d	22.4 a-c	44.4 a-e	36.0 a-b	14.0 a
BAS 125	250	94.2 a-e	94.9 a-c	9.5 a-b	9.2 a-c	11.0	1.62 a-d	20.1 b-d	38.4 a-e	27.8 b-c	9.2 a-c
BAS 125	500	124.3 a-b	108.7 a-c	8.6 a-c	8.4 a-c	10.7	1.28 d	19.7 b-d	34.8 a-e	31.5 a-c	9.7 a-c
BAS 125	750	83.9 a-e	99.6 a-c	7.5 a-c	8.4 a-c	11.5	1.81 a-d	23.3 a-b	55.5 a-d	25.5 b-c	9.5 a-c
BAS 125	250 x 3	69.8 a-e	53.0 c-d	8.3 a-c	9.1 a-c	11.2	1.65 a-d	21.1 a-c	60.0 a	30.1 a-c	10.5 a-c
GA3	100 x 3	86.1 a-e	65.0 b-d	10.6 a	9.2 a-c	10.7	1.21 d	16.6 d	5.7 f	7.7 d	2.3 d
GA4+7	100 x 3	106.1 a-d	123.4 a-b	10.8 a	10.2 a	12.2	1.74 a-d	20.8 b-d	26.8 e-f	27.5 b-c	9.3 a-c

[z] Single applications June 22 except x3 where sprays were repeated at monthly intervals.

Table 2. Influence of Different Number of Replacement Trunks on Growth of Replacement Trunks on Winter-Injured 'Vidal' Grapevines with the Tops Removed.

No. of Replacement Trunks	Average Replacement Trunk Length (cm)			Basal Diameter (mm)	Sixth Internode		Pruning Weight (lbs/vine)	1995[z]		Yield	
	6/24	7/25	10/27		Length (cm)	Diameter (mm)		Avg. Shoot Length (cm)	Flower (clusters/ vine)	(clusters/ vine)	(lbs/vine)
1	188.4 a[y]	214.6 a-b	321.2 a	11.1	9.5 a-b	11.5 a	1.38 b	21.0 a-b	35.7 b	17.4 c	8.0 b
2	153.8 a-b	244.7 a	297.7 a-b	15.9	10.5 a	10.9 a	2.37 a	20.0 b	70.5 a	30.6 a-b	15.1 a
4	141.8 a-b	189.9 b-c	240.5 b-c	10.3	9.1 a-b	9.0 b	2.10 a	20.4 b	57.4-a-b	39.4 a	14.4 a
6	143.4 a-b	187.5 b-c	268.7 a-c	10.7	8.9 a-b	8.8 b	1.99 a	22.1 a-b	62.8 a-b	29.5 b	11.6 a-b
8	132.9 a-b	156.1 c	197.6 c-d	10.6	8.8 a-b	7.8 b	2.05 a	22.7 a-b	54.8 a-b	32.9 a-b	13.2 a-b
10	115.3 b	166.9 b-c	184.4 d	10.3	8.0 b	7.6 b	2.02 a	23.6 a	62.3 a-b	36.1 a-b	14.2 a
Linear	**[x]	**	**	*	NS	**				**	NS
Quadratic	NS	NS	NS	NS	NS	NS				*	NS

[z] Measurements in June 1995 at full bloom.
[y] Mean separation by Duncan's multiple range test, $P = 0.05$.
[x] NS, *, **, nonsignificant or significant at $P \geq 0.05$ or 0.01, respectively.

measured at monthly intervals. Laterals were removed on all replacement trunks until primary shoots reached the top wire, at which time the laterals were allowed to grow. At the end of the season, the diameter and length of the sixth internode, which had formed after treatments began, was measured. Two of the canes were selected as trunks and established as a bilateral cordon in the following spring.

The following spring (1995) when growth had started and cluster development was obvious just prior to bloom, the length of five shoots per vine and all the clusters per vine were counted. The 1995 harvest season was recorded and the studies terminated. Treatments were arranged as a randomized complete block with seven single-vine replications.

'Vidal' Number of Replacement Trunks Trial

Trunks were handled as described previously except that vines were selected that had five or more shoots arising from the lower 30 cm of trunk on June 20, 1994. The number of shoots was reduced to either 1, 2, 4, 6, 8, or 10. Care and data collection were the same as described previously. Treatments were arranged as a randomized complete block with six single-vine replications.

Retaining the Top and Adjusting Crop Level on 'Vidal'

Vines either had the top removed (0 crop load) or the top retained and a crop load of approximately 20 or 30 clusters retained July 5, 1994. On some vines too few clusters were available to achieve the desired level. Retention of 48 shoots was attempted on all vines, but again this was not always possible. Replacement trunks were limited to four per vine and given one of the following treatments applied on June 22, 1994:

1. Untreated control.
2. Pinched — terminal removed June 20 and July 20 when laterals were also removed.
3. Alar at 2000 ppm.
4. Ponnax at 500 ppm.

In 1995, where possible, all vines retained 48 shoots per vine and were cluster-thinned to 30 clusters per vine. Data, as previously described, was collected with the addition of yield data on the vines with tops retained. Treatments were arranged in a factorial design of 0, 20, 30 clusters per vine and four treatments (Table 3) with six single-vine replications.

Growth Retarding Chemicals on 'Chardonnay' Replacement Trunks

Mature 'Chardonnay' vines on 18815 rootstock that had severe winter injury in the Markko Vineyard near Conneaut had their tops removed as previously described. Growth-retarding chemicals were applied to replacement trunk shoots on June 24, 1994, with a high-pressure hand-gun sprayer until drip. These shoots averaged 40–50 cm in length. The chemicals and rates used are shown in Table 4. Four replacement trunk shoots per vine were labeled and measured at monthly intervals. At the end of the season, the length and diameter of the sixth internode as well as the basal diameter of each replacement shoot was measured. The treatments were arranged as a randomized complete block with six individual vine replications.

Results

'Vidal' Growth Regulator Trial

Only Ponnax applied three times and BAS 125 at the 500 ppm rate significantly increased growth in the first month after application (Table 1). In the second month, Ponnax-treated vines, at 500 ppm and 750 ppm, grew more than the control, with no differences among the other treatments. Primo at 500 ppm and Ponnax at 750 ppm reduced the length of the sixth internode, which formed shortly after the initial treatment was made, while Primo at 250 ppm applied three times reduced diameter growth of this internode. These treatments reduced pruning weight per vine: Alar, 1,000 ppm; Primo, 500 ppm; Primo, 250 ppm applied three times; BAS 125 at 500 ppm; and GA3. Early-season shoot growth the following season was enhanced by Primo at 250 ppm applied three times, Ponnax at 250 ppm, and BAS 125 at 750 ppm. Flower clusters per vine were reduced by these treatments: Primo at 500 ppm and at 250 ppm applied 3 times, GA 4+7, and GA3. Yield per vine in 1995, the year following

Table 3. Interaction of Removing the Vine Top or Leaving the Top with Two Crop Loads and Applying Growth Regulators on Growth of Replacement Trunks and Vine Performance of Winter-Injured 'Vidal' Vines.

									1995			
	Change in Growth (cm)			Sixth Internode			Yield				Yield	
Factor	7/25–6/24	8/23–7/25	Basal Diam. (mm)	Length (cm)	Diam. (mm)	Pruning Weight (lbs/vine)	(clusters/ vine)	(lbs/ vine)	Avg. Shoot Length[z] (cm)	Flower (clusters/ vine	(clusters/ vine	(lbs/ vine)
Clusters/Vine												
0	105.3 a[y]	33.5	10.4 a	9.0	8.7 a	1.51 b	2.7 b	0.8 b	20.6	30.9 c	20.0 b	6.9 b
20	80.8 b	31.4	9.1 b	7.5	6.6 b	2.54 a	23.2 a	8.4 a	20.1	129.2 b	38.6 a	16.2 a
30	68.7 b	20.5	9.2 b	8.1	6.6 b	2.60 a	28.2 a	9.6 a	19.5	164.7 a	41.8 a	16.3 a
Treatment												
Control-Top Removed	88.8	43.3 a	9.6	9.1a-b	8.0	2.32	21.7	7.0	20.3 a	106.5	36.1	14.4
Pinched top	97.1	7.2 b	9.7	9.5 a	7.2	2.01	16.1	6.1	21.1 a	113.4	30.7	12.6
Alar 2,000 ppm spray	82.4	33.4	9.2	7.5 b-c	7.0	2.25	17.3	6.1	20.6 a	100.0	33.9	13.3
Ponnax 500 ppm spray	70.4	34.4	9.6	6.8 c	7.0	2.25	17.0	5.8	18.1 b	114.5	33.2	12.4

[z] Measured at bloom (June)
[y] Mean separation by Duncan's multiple range test, $P = 0.05$.

the treatments, was reduced by these treatments: Alar, 1,000 ppm; Primo, 500 ppm; Primo 250 x 3; and GA3. Interestingly, three applications of GA 4+7 had little effect on yield, while similar treatment with GA3 resulted in the lowest yield of all treatments, showing the sensitivity of grape-flower initiation to GA3.

A separate analysis (data not shown), comparing the three antigibberellin materials, indicated that Primo caused slightly more growth reduction than the others. None of the materials demonstrated a significant sensitivity to rate of application, and there was no interaction for any factor measured between chemical and rate of application.

'Vidal' Number of Replacement Trunks

Replacement trunk length declined as expected as the number of retained shoots increased. Growth failed to reach the top wire when eight or more shoots were retained (Table 2). Average basal diameter of all shoots and the diameter of the sixth internode followed a similar linear decline as number of replacement shoots increased. Pruning weight in 1995 was reduced when a single replacement shoot was retained in 1994. Shoot growth and cluster number in 1995 were generally increased as replacement shoot number increased even though only two replacement trunks of modest growth were retained. Although not significantly different from vines with greater number of replacement trunks, vines with two replacement shoots retained in 1994 had the largest sixth internode, the greatest pruning weight, and most flower clusters.

Retaining the Top and Adjusting Crop Load on 'Vidal'

Cutting off the top resulted in the greatest length of replacement trunk, the most growth late in the season, and the largest sixth internode (Table 3). The two crop levels did not differ in their effect on growth or pruning weight. Growth the following season was not affected, but clusters per vine were least where the top had been reduced and new cordons laid down, and highest where a six-ton crop was carried the previous year.

'Chardonnay' Growth-Regulating Chemicals

BAS 125 reduced early growth of replacement trunks on winter injured 'Chardonnay' vines at concentrations > 500 ppm (Table 4). A single application of 750 ppm resulted in greater control of growth than did three applications of 250 ppm. The treatments had no significant effect on growth after July. A comparison of effects on the sixth internode, which formed shortly after the initial application, indicated that all treatments except Ponnax at 250 ppm and BAS 125 at 250 ppm applied three times reduced internode length. Internode diameter was reduced by BAS 125 at either 500 or 750 ppm.

Discussion

The 1994–1995 winter was mild, and significant winter injury did not occur to test the survivability of the replacement trunks that developed. The effect of the gibberellin-inhibiting growth regulators was modest. Primo was the only inhibitor that tended to reduce cluster development. However, the application of gibberellins that were included in this trial to potentially enhance vigor and produce undesirable replacement trunks had minimal effect on growth, but GA3 did reduce flower clusters. It appeared that GA3 tended to cause a greater reduction in flowering than GA4+7. Studies (3, 5) have shown that grapes are very responsive to GA3.

Results of these studies suggest that "conventional wisdom" was correct that growth is moderated by leaving a greater number of replacement trunks than ultimately desired. This practice resulted in increased pruning weight, cluster number, and yield the following season, with yield peaking when originally four replacement shoots were retained. Although these replacement trunks were not tested by severe cold, a general recommendation from this work to moderate growth of these new trunks would be to retain and tie up approximately four replacements and then select two with moderate growth characteristics for retention after the first year.

Another practical outcome from these studies on 'Vidal' was that it would be wise not to be in a hurry to cut off trunks of partially in-

Table 4. Influence of Growth-Retarding Chemicals on Replacement Trunk Shoots of Winter-Injured 'Chardonnay' Vines.

Treatment	Rate (ppm)	Change in Length (cm)			Sixth Internode		Basal Node Diameter (mm)
		7/27–6/29	8/24–7/27	10/27–8/24	Length (cm)	Diameter (mm)	
Control		69.0 a[z]	26.9	1.3	5.8 a	7.8 a	11.3 a
Alar	1000	49.1 a-b	20.8	5.5	3.8 b	6.6 a-b	9.4 a-b
Ponnax	250	55.0 a-b	9.9	0.6	4.3 a-b	7.1 a	10.3 a-b
Ponnax	500	56.3 a-b	3.2	3.2	3.6 b	6.6 a-b	9.5 a-b
BAS 125	250	39.6 a-b	21.4	12.2	3.6 b	6.1 a-c	10.6 a-b
BAS 125	500	8.1 c-d	4.5	3.5	2.6 b	4.8 b-c	8.8 b
BAS 125	750	2.0 d	22.0	9.1	2.9 b	4.5 c	9.7 a-b
BAS 125	250 x 3	31.2 b-c	11.9	0.3	4.1 a-b	6.3 a-c	10.2 a-b

[z] Means separation by Duncan's multiple range test, $P = 0.05$.

jured vines. Retaining the tops resulted in a partial crop the year of the injury and a 60% larger crop the following year compared to vines from new replacement trunks laying down new cordons. The majority of the 'Vidal' vines with the top retained following injury have recovered and have remained productive. A few have lost a cordon, and the new replacement trunk was used to replace the injured portion.

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Effect of New Herbicides on Tissue-Cultured Black Raspberry Plants

Richard C. Funt, Thomas E. Wall, and B. Dale Stokes

Introduction

Controlling weeds during the first (establishment) year in raspberries is extremely important. Young, newly transplanted raspberry plants grow most rapidly in a weed-free environment. Herbicides reduce weed pressure in raspberry plantings and labor costs. When herbicides are properly selected and applied at the optimal rates, plant growth can be enhanced. However, raspberry transplants can be damaged if they are subjected to improper herbicide selection and application rates. Mechanical cultivation, which may be done several times over the season, can also cause reduced plant growth and death.

In previous studies, pre-emergent herbicides applied over the top of newly transplanted raspberries, bare root and dormant, were found to control many annual weeds and allow good plant growth (1). New technology allows tissue-cultured raspberry plants to be shipped to growers as dormant or growing plants, either as plugs or as nursery-matured plants. Tissue cultured plants are generally more vigorous than bare-rooted plants, and as plug plants, are easier to transplant mechanically. Thus, this study was designed to test currently labeled and newly released herbicides on plug or nursery-matured plants to achieve weed control over a long period of time.

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The objectives of this study using greenhouse and field trials were to determine:

- If the application of herbicides is phytotoxic to raspberry plants within 10 days of transplanting.
- If pre-emergence or systemic herbicides are phytotoxic several weeks after planting into the field.
- If certain herbicides can be mixed without phytotoxicity.
- If herbicides are mixed together, can they provide a greater level of control than if applied alone.

Materials and Methods

Experiment 1 — Indoor Study

Dormant tissue-cultured 'Jewel' black raspberry (*Rubus occidentalis*) plugs were planted into 4-inch (10 cm) peat pots containing a soilless mixture (Premier Pro-mix) of peat moss and perlite on Dec. 1, 1995. At planting, each plant received 100 ml of 100 ppm 20-20-20 (Peters) solution. Group A treatments were applied immediately after planting (Table 1). The same treatments were applied 10 days later (Group B) as a delayed application to test the effects of herbicides on newly emerged leaves. Herbicides were applied using a pressurized system at 40 psi with a set of two nozzles to equal a 20 gallon/acre rate. The following herbicides were used in this study: Surflan (Oryzalin 4AS) and Poast (Sethorydim 1.5EC), pre-emergent and post-emergent systemic grass herbicides respectively, which have been recommended for growers for several years (4); Gallery (Isoxaben 75 DF) and Prism (Clethomin 2EC), pre-emer-

Table 1. Leaf Appearance, Number of Shoots, Shoot Dimensions, and Shoot and Root Weights of Greenhouse-Grown 'Jewel' Black Raspberries Treated with Various Herbicide Regimes, 1996.

Herbicide Treatments and Application Rates (per acre)	Plant Appearance			No. of Shoots	Shoot Dimen. (mm)		Shoot Wt. (g)		Root Wt. (g)		Total Wt. (g)	
	Good	Damaged	Final Leaf[z]		Caliper	Length	Fresh	Dry	Fresh	Dry	Fresh	Dry
Group A[y]												
1. Control	1.17	0.17	2.5	2.6	2.3	11.2	3.0	0.4	19.0	3.4	22.0	3.8
2. Surflan (4 qt)	1.33	0.00	2.7	0.8	4.8	17.5	2.9	1.2	19.7	3.4	22.6	6.1
3. Surflan (4 qt) + Gallery (1.3 lb)	0.66	0.50	3.7	0.2	2.8	7.0	0.6	0.1	8.9	1.7	9.5	4.4
4. Surflan (4 qt) + Gallery (1.0 lb)	0.83	0.33	2.7	0.5	2.2	4.5	0.5	0.1	16.5	2.9	17.0	2.9
5. Prism (16 oz) + Oil (1 qt)	0.20	0.00	2.2	1.2	2.2	9.8	2.6	0.4	12.8	2.4	15.5	3.3
6. Prism (16 oz) + Dash (1 pt)	1.00	0.17	1.8	1.4	2.8	31.2	5.2	0.8	21.8	3.6	27.0	4.9
7. Poast (32 oz) + Dash (1 pt)	0.50	0.33	2.0	1.0	2.4	11.5	2.7	0.2	17.7	3.1	20.4	4.1
Significance (Spray vs. Control)[x]	NS[w]	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
Group B[v]												
1. Control	1.17	0.17	2.5	2.6	2.3	11.2	3.0	0.4	19.0	3.4	22.0	3.8
2. Surflan (4 qt)	0.33	0.17	2.5	0.8	2.4	14.0	1.4	0.6	16.0	3.5	17.4	4.0
3. Surflan (4 qt) + Gallery (1.3 lb)	0.33	0.00	2.7	1.0	3.1	7.6	1.5	0.4	21.1	4.0	22.6	4.9
4. Surflan (4 qt) + Gallery (1.0 lb)	0.17	0.00	2.2	1.0	2.8	17.0	1.5	1.4	22.2	3.0	23.7	5.6
5. Prism (16 oz) + Oil (1 qt)	0.16	0.00	1.8	1.0	1.9	10.0	0.9	0.2	17.1	3.2	18.0	3.4
6. Prism (16 oz) + Dash (1 pt)	0.50	0.17	2.0	1.1	2.4	16.0	3.0	0.8	22.2	4.2	25.2	5.5
7. Poast (32 oz) + Dash (1 pt)	0.67	0.00	2.3	0.6	2.4	15.2	2.4	0.6	20.4	3.8	22.8	5.8
Significance (Spray vs. Control)	**	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
Significance (All Trials)												
2 Avgs. 2 B	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
3 Avgs. 3 B	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4 Avgs. 4 B	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
5 Avgs. 5 B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6 Avgs. 6 B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
7 Avgs. 7 B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Average number of good and damaged leaves after first spray. Final leaf color evaluated on Feb. 26, 1996. Rating scale: 1 = good/green; 2 = light green; 3 = brown edges; 4 = brown; 5 = dead.
[y] Group A plants treated on Dec. 1, immediately after transplanting.
[x] Orthogonal contrasts from analysis of variance.
[w] NS, *, ** = nonsignificant or significant at $P = 0.05$ and 0.01 levels, respectively.
[v] Group B plants treated on Dec. 11, 10 days after transplanting.

gent and post-emergent grass herbicides respectively, which have been recently released on the market (4).

Plants were grown indoors (near Wilmington, Ohio) under fluorescent lighting with daily temperatures ranging from 60 to 80°F (16 to 27°C). Plants were evaluated for leaf damage on Dec. 11, 1995, for Group A; Dec. 21, 1995, for Group B; and Feb. 26, 1996, for both groups, by counting leaves that had light green color to dark dry brown condition with 1 = dark green, 2 = light green, 3 = brown edges, 4 = brown all over, 5 = dead. Shoots greater than 1 cm were removed, measured for length and caliper, and weighed to obtain both fresh and dry weights. Roots, which included some growing medium which would not separate from the roots after washing, were weighed both fresh and dry. Dry

weight was obtained by placing plant parts in a drying oven at 125°F (51°C) for 48 hours.

Experiment 2 — Field Study

Dormant tissue-cultured 'Jewel' black raspberry plugs and nursery-matured plants were transplanted onto a raised bed on May 20, 1996, in a field near Wilmington, Ohio. Herbicide Treatments 2, 3, 4, 5, 6, 9, and 10 were applied two days later after 0.2 inches (5 mm) of rainfall (Table 2). Straw mulch was applied to a depth of 2.5 inches (6.3 cm) to Treatments 2 and 3. Herbicides were banded over the rows with a pressurized CO_2 system at 40 psi and a set of 2 nozzles (8002) to equal a 20 gallon/acre rate. The chemicals used in the treatments were the same formulations as in Experiment 1.

On July 8, 1996, the control group was hand weeded, and Treatments 6, 7, and 8 were applied (Table 2). Where straw had been removed by wind, straw mulch was replaced. Plots were visually rated on July 8 for types of weeds, number of certain weeds, percent of soil without weed cover, and number of dead plants. Calcium nitrate [$Ca(NO_3)_2$] was applied at 6 lbs per 100 ft of row (2.7 kg per 30m). Stinger (Clopyralid 3EC), a selective post-emergent broadleaf herbicide, was applied to emerged weeds in Treatment 8.

Fall herbicide applications were applied on Oct. 2, 1996, to Treatments 2, 3, 4, 5, 9, and 10. Kamex (Diuron 80WP) was mixed with Surflan in Treatments 2 and 9. Surflan was mixed with Gallery in Treatments 3 and 10.

Statistical Design and Analysis

In Experiment 1, there were two groups (Groups A and B) of application times (10 days apart). These were arranged in a completely randomized design with border plants. Within each group there were seven treatments including a control. Within each treatment, there were six single-plant replicates. A general linear model analysis program was used to contrast differences among treatments within a group, and between treatments in groups (2A vs. 2B, etc.).

In Experiment 2, herbicide treatments were arranged in a split-plot design with plant type as subtreatments. There were four plug plants or nursery-mature plants in each sub plot. An analysis of variance was done for the depen-

Table 2. Time of Application for Various Herbicide Regimes Applied to Field-Grown 'Jewel' Black Raspberries, 1996.

Treatments and Application Rates (per acre)	Time of Application		
	May 22	July 8	October 2
1. Cultivated Control	X	X	X
2. Surflan (4 qt) + Straw Mulch	X	—	X[z]
3. Gallery (1.3 lb) + Straw Mulch	X	—	X[y]
4. Surflan (2 qt) + Straw Mulch	X	—	X
5. Surflan (2 qt)	X	—	X
6. Prism (16 oz) + Surflan (2 qt) + Gallery (1 lb)	X	X	—
7. Prism (16 oz) + Dash (16 oz) + Surflan (4 qt) + Gallery (1.3 lb)	—	X	—
8. Prism (16 oz) + Dash (16 oz) + Surflan (4 qt) + Gallery (1.3 lb) + Stinger (6 oz)	—	X	—
9. Stinger (6 oz) + Surflan (4 qt)	X	—	X[z]
10. Gallery (1.3 lb)	X	—	X[y]

[z] Karmex (2 lb) was used with Surflan (4 qt). No straw was applied in October.
[y] Surflan AS (4 qt) was used with Gallery (1.3 lb).

dent variable (2). Treatments were separated using least significant difference tests.

Results

Experiment 1 — Indoor Study

Where herbicides were applied on the day of planting (Group A), there were no significant differences between treatments and the control in all variables except for the number of shoots (Table 1). The control had more than twice the number of shoots than all treatments except for Treatment 6. There was a significant difference between herbicide treatments applied at the second spray (Group B) and the control for plant appearance. Among the herbicide treatments, Treatments 6 and 7 had a better appearance than other herbicide treatments. Further, there was a significantly better appearance in Treatment 2A than 2B. Also 2A had a significantly greater shoot caliper than Treatment 2B. In the final leaf appearance, Treatment 4A had a significantly better appearance than 4B.

Experiment 2 — Field Study

There were significant differences among treatments for percent weed-free plots in 1996 (Table 3). Treatments 2, 3, 4, 5, 6, 9, and 10 had a fewer number of weeds as compared to the control and Treatments 7 and 8. There were no differences among treatments for Canadian thistle and those for the control group. The control and Treatments 7 and 8 had the highest number of weeds. The types of grasses and

Table 3. Weed Ratings, Number of Weeds, and Crop Plant Survival in Plots of 'Jewel' Black Raspberries Treated with Various Herbicide Regimes, 1996.

Treatment	Weed Rating[z]	Weeds (No.)	Thistles (No.)	Surviving Raspberries (No.)
1.	2.3 b[y]	26.1 a	2.1	3.4 a
2.	10.0 a	5.6 b	1.1	3.3 ab
3.	9.5 a	13.2 b	4.2	2.8 abcd
4.	9.7 a	9.8 b	6.3	1.8 d
5.	9.8 a	7.8 b	1.7	2.3 bcd
6.	9.9 a	9.5 b	3.1	2.0 cd
7.[x]	1.1 b	30.0 a	4.1	2.8 abc
8.[x]	2.0 b	27.0 a	1.1	2.5 bcd
9.	9.7 a	10.0 b	2.3	2.6 abcd
10.	9.6 a	12.5 b	5.0	2.6 abcd
Significance[w]				
Treatment	*[v]	NS	NS	*
Plant Type[u]	NS	*	NS	NS
Treatment X Plant Type	NS	NS	NS	NS

[z] Visual ratings performed on June 26. Rating scale: 1 = complete weed coverage to 10 = very few weeds actively growing.
[y] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).
[x] Treatments 7 and 8 were designed to determine the effect of delayed residual plus a selective systemic herbicide. Therefore, they were not applied until after this evaluation was performed.
[w] Significance of F-values from analysis of variance.
[v] NS, *, ** = nonsignificant or significant at $P = 0.05$ and 0.01 levels, respectively.
[u] Plant type refers to original nursery stock used to establish the planting (i.e., tissue-cultured plug plants vs. nursery-matured plants).

broadleaf weeds identified among all plots are listed in Table 4. Treatment 4 had the lowest number of plants as compared to the control and Treatments 2 and 7. There was a significant interaction in the number of tissue-cultured plants (low survival) as compared to the nursery-matured plants for all treatments.

In 1997, Treatment 3 had significantly fewer weeds than the control in the percent of ground covered with weeds (Table 5). All other treatments were not significantly different than the control. However, Treatment 3 was significantly greater than the control and other treatments (except for Treatment 4) for the percent of grasses in the plot. Broadleaf weeds ranged from 62 to more than 98 percent of weeds found in this experiment. Treatment 8 had the lowest number of surviving plants and number of shoots. Treatments 3, 4, and 10 had a significantly lower number of dandelion weeds as compared to the control and Treatments 2 and 7. There were no differences among treatments for Canadian thistle. Treatment 3 had the highest vigor rating and Treatment 8 had the lowest rating (Table 6). Treatment 2 was significantly greater in fresh and dry weight than any other treatment including the control. Treatments 3, 5, and 6 were significantly greater in fresh weight than the control and Treatments 7 and 8. There were no phytotoxic symptoms observed among the treatments.

Discussion

Indoors, the application of herbicides to dormant plug plants at planting appeared not to be phytotoxic. However, the control plants had more shoots than any of the herbicide treatments. When herbicides were applied 10 days after planting, Surflan-treated plants had a lower overall leaf appearance than those without Surflan. Perhaps these plants received low amounts of light and the leaves developed thinner cuticle (wax cover). There were no differences in either plant or root growth measurements between the control and herbicide treatments at the end of the study.

In the field, the Surflan and Gallery treatments applied within several days after transplanting to weed-free soil provided good weed control and the best plant growth. The high rates of Surflan and Gallery (Treatments 2 and 3) plus straw mulch generally had the highest plant vigor and new shoots among the herbicides tested. High rates of Gallery, 1.3 lbs /acre alone (Treatments 3 and 10), had lower numbers of dandelion. Dow Elanco, the producer of Gallery, indicates that Gallery is a pre-emergent herbicide for broadleaf weeds such as dandelion, clover, and chickweed and may control them for up to eight months. Where Gallery was applied at 1.3 lbs/acre several weeks after planting (Treatment 7), dandelions were not

Table 4. List of Weeds Observed Among Plots.

Type	Common Name	Scientific Nomenclature
Grass	Crabgrass	*Digitaria sanguinalis*
	Barnyardgrass	*Eclinochloa cues-galli*
	Goosegrass	*Eleusin indica*
	Giant Foxtail	*Setaria faberi*
	Fall Panicum	*Panicum dichotomiflorum*
Broadleaf	Pennsylvania Smartweed	*Polygonum pennsylvanicum*
	Dandelion	*Taraxacum officinale*
	Canadian Thistle	*Cirsium arvense*
	Northern Yellow Nutsedge	*Cypernus esculentus*
	Lambsquarter	*Chenopodium albuina*
	Red Root Pigweed	*Amaranthus retroflexus*
	Smooth Groundcherry	*Pysalis subglabrata*
	Black Nightshade	*Solanum ptycanthum*

Table 5. Weed Infestation Severity in Field-Grown 'Jewel' Black Raspberries Treated with Various Post-Plant and Fall-Applied Herbicide Regimes, 1997.

Treatment	Weed Cover in Plots (%)	Proportion of Weed Types Present (%)		Weed Population (No.)	
		Grass	Broadleaf	Dandelion	Thistle
1.	47.1 a[z]	0.7 b	99.3 a	5.3 ab	0.4
2.	29.3 ab	8.0 b	92.0 ab	7.4 ab	2.4
3.	7.0 b	36.6 a	62.4 b	0.6 c	0.0
4.	25.0 ab	15.0 ab	85.7 ab	1.0 c	0.1
5.	36.7 a	5.8 b	94.0 ab	3.3 bc	1.0
6.	46.5 a	4.4 b	95.6 a	2.9 bc	0.0
7.	52.9 a	1.0 b	98.7 ab	10.1 a	5.0
8.	33.2 ab	0.2 b	99.4 ab	2.4 bc	0.2
9.	38.6 a	6.7 b	91.6 ab	4.7 bc	0.0
10.	25.8 ab	1.4 b	98.6 ab	1.0 c	8.4

[z] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

controlled. Post-emergent control of dandelion and thistle in Treatments 8 and 9 could have resulted from Stinger. Stinger plus Gallery, applied in July, was not different from Gallery alone when applied in late May. The application of Stinger did not improve thistle control. However, raspberries showed leaf cupping and stress several weeks after it was applied. Applying Prism several weeks after transplanting provides similar grass control as the weeded control.

When herbicide treatments were delayed for several weeks after transplanting in July, broadleaf weed populations were significantly higher in the first year, and raspberry plant growth in the second year was reduced. Fresh and dry weights of the plants treated with Stinger plus other herbicides were less than that of the weeded control. There were no phytotoxic symptoms on any treatment regardless of whether they were applied alone or in combination with each other.

Erf and Funt (1) reported the greatest weed control using high rates of Surflan with no apparent phytotoxic symptoms on standard tip-layered transplants in Ohio. When Princep (Simazine 80%) was used on newly set transplants of 'Brandywine' purple raspberry, phytotoxic symptoms were observed. Trinka and Pritts (3) tested Princep and Devrinol (Napropamide 50DF) separately and found Princep to have similar symptoms on "Heritage" raspberry as to those observed in Ohio.

In New York, Trinka and Pritts (3) used straw mulch, which enhanced plant growth on newly transplanted tissue-cultured heritage plants. In this study, when straw mulch was combined with high rates of either Surflan or Gallery alone, plant growth was enhanced and was the highest as compared to other treatments including the control. Straw mulch improved weed control and soil moisture even when rainfall was adequate and trickle irrigation was used.

Conclusions

Uncontrolled weed growth during plant establishment inhibits raspberry plant growth and production into the second and third growing seasons. Using a combination of a pre-emergent herbicide and straw mulch immediately after transplanting can reduce weed populations and enhance raspberry plant growth even with adequate rainfall.

Table 6. Growth of Field-Grown 'Jewel' Black Raspberries Treated with Various Post-Plant and Fall-Applied Herbicide Regimes, 1997.

		Plant Wt. (g)[y]		Plant Population (No.)	
Treatment	Vigor Rating[z]	Fresh	Dry	Plants	Shoots
1.	4.3 ab[x]	57.6 ef	33.4 def	3.0 a	14.7 ab
2.	4.6 ab	335.8 a	171.6 a	3.0 a	16.4 a
3.	6.5 a	182.7 b	91.0 b	2.5 ab	11.7 ab
4.	4.6 ab	80.4 de	43.7 cdef	1.7 bc	4.6 bc
5.	6.5 a	138.0 bcd	74.0 bcd	2.5 ab	11.7 ab
6.	3.8 bc	158.2 bc	81.6 bc	2.4 ab	12.8 ab
7.	4.1 b	35.2 ef	18.4 ef	2.7 ab	9.0 bc
8.	1.6 c	1.8 f	1.3 f	1.1 c	3.5 c
9.	3.8 b	91.1 cde	50.7 bcde	2.4 ab	9.7 abc
10.	3.9 b	110.4 bcde	61.2 bcde	2.1 ab	14.3 ab

[z] Vigor was determined visually from a combination of plant height, thickness of cane, and leaf color. Rating scale: 1 = lowest vigor; 10 = highest vigor.
[y] Fresh and dry weights measured on dormant canes from 1996 growing season which were harvested in March 1997. Canes were dried at 135ºF for five days.
[x] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

Surflan alone applied immediately after planting to a weed-free area at 4 qts per acre, or Gallery alone at 1.3 lbs per acre, provided good weed control and, when combined with straw mulch, enhanced plant growth. In most cases, weed control was not increased when Surflan and Gallery were combined. Nevertheless, dandelion control was improved with Gallery even though Gallery did not provide good grass control. Applying Surflan or Gallery immediately after planting, to a weed-free surface, provides better weed control than applying several weeks after planting since they are both pre-emergent herbicides. Surflan alone at 2 quarts/acre at planting, and again in early October, provides good growth and plant vigor. Prism can be mixed with Surflan plus Gallery to enhance post-emergent grass control without phytotoxicity in the raspberry plant. Nursery-mature plants had a higher survival rate than plug plants. Neither type of plant was affected adversely by any herbicide.

Acknowledgments

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Investigating the Relationship Between Vine Vigor and Berry Set of Field-Grown 'Seyval Blanc' Grapevines

Steven J. McArtney and David C. Ferree

Abstract

The number of clusters and shoots on mature field-grown grapevines was restricted soon after bud break to either 15/15, 15/30, 15/45, 30/30, 30/45 or 45/45 (cluster number/shoot number) in order to investigate the relationship between shoot vigor and berry set. There were no clear effects of shoot number per vine on either elongation rates or berry set within the range imposed in this study. Restricting the number of shoots per vine to 45 resulted in a 25 percent reduction in leaf area of individual shoots at bloom compared to vines with only 15 shoots. The reduced leaf area was related, at least in part, to a reduction in the number of leaves per shoot. Shoot elongation rates were higher for the two-week period following bloom than for either the period from bud break to bloom or from two to six weeks after bloom. Light transmission through the foliage canopy at bloom was inversely related to the number of shoots per vine. Leaf photosynthesis was the same for all treatments, suggesting that there was no compensation in photosynthesis even when the leaf area per shoot was reduced by 25 percent. Transpiration rates were positively related to the number of clusters per vine when measured under light saturation. Vine yields were positively related to cluster number whereas juice soluble solids and pH were negatively related to the number of clusters per vine. Petiole nitrogen was negatively related to the number of shoots per vine. The set of berries on the shoulder of individual clusters was a poor predictor of set on the whole cluster, accounting for only 34 percent of the total variation. These data suggest that when 45 shoots were retained per vine, which can be considered a commercial pruning intensity, the initial growth of individual shoots was limited by the supply of carbohydrates from storage reserves, as suggested by the reduction in leaf area per shoot at bloom, but this reduced leaf area was not a limiting factor for berry set.

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Introduction

The relationship between vigor and fruiting potential has been extensively reviewed for apple (8), but similar information is lacking for grapevines. The number of fruit that set on apple trees is inversely related to the rate of vegetative development, particularly in the first few weeks following flowering. Grapevine inflorescences are a weak sink (12) and, presumably, the set of flowers is related positively to the supply of newly assimilated carbon from source leaves and negatively to the relative strength of competing sinks, i.e., other clusters on the same shoot and younger leaves at the shoot tip.

In the weeks that follow bud break, growth of grapevine shoots is dependant on the supply of remobilized carbohydrate reserves in cane, trunk, and root tissues. Buttrose (2) reported that four to five weeks of shoot growth were required before any net gain in dry weight of grapevine cuttings was observed, and cuttings

made from a single node were retarded in growth rate from four to six weeks after bud break relative to cuttings grown from two-nodes. Winkler (19) demonstrated that leaf area at bloom determined the number of flowers that set and, subsequently, cluster weights at harvest. Taken together these results suggest that the growth rate of grapevine shoots is dependent on carbohydrate reserves in the cane tissues, and that shoots with a greater source leaf area at bloom will set more berries and yield higher. The situation for mature field-grown vines may be different, where the major reserve tissues for carbohydrates are the roots.

Overcropping and shading may both reduce the size of the pool of carbohydrate reserves in grapevines. Shading can also have a confounding effect on fruitfulness in the following season. May and Antcliff (13) found that when sunlight was reduced by about 70 percent for a four- to six-week period at the time of inflorescence initiation, there was a 20 to 40 percent reduction in the number of fruitful shoots in the following season. Altering the number of buds retained per vine at the time of winter pruning will alter the ratio of carbohydrate reserves relative to developing sinks (shoots), without altering the potential fruitfulness of the buds themselves. Williams (18) reported that when the number of shoots retained per vine was increased, both the leaf area per shoot and the mean size of primary shoot leaves were reduced. The growth rate of primary shoots, expressed on a growing-degree-day basis, on vines with only 52 shoots was more than double that for vines with 60 or 90 shoots.

Changes in leaf area may not result in a change in net carbon supply since rates of leaf photosynthesis can compensate for changes in leaf area. When leaf area was reduced by defoliation, photosynthesis of the remaining leaves increased (3, 11) or did not change (4). In explaining the lack of response, Candolfi-Vasconcelos *et al.* (4) proposed that a certain "degree of stress" originating from an unbalance in the source to sink ratio might be needed to trigger a compensatory response in photosynthesis

The growing shoot tip is the major sink for assimilated carbon during the period of cluster elongation on a grapevine shoot (9). In the first phase of berry growth, following cluster elongation, cells in the fruit are rapidly dividing (10) and the developing cluster becomes a major sink for assimilates relative to the shoot tip (15). There does not appear to be a clear relationship between the rate of shoot growth and berry set in the literature for the grapevine. Treatments that reduced the sink strength of developing shoots during the first growth stage, such as tipping (17), pinching and topping (6), and water stress (1), all reduced the number of berries set per cluster. However, May *et al.* (14) pruned vigorous Sultana vines to different bud numbers and found that berry number per bunch decreased as the number of buds per vine increased, suggesting the set of berries is reduced on rapidly growing shoots, and flowers are weaker sinks than the shoot tip during the period of berry set.

Low light levels can reduce the set of berries (7). Catechini and Palliotte (5) reported that PAR level in the region of the cluster was around 7 percent of ambient levels during flowering. In a growth chamber study, Roubelakis and Kliewer (16) found that percentage fruit set and ovule fertilization at 2,680 ft-c were three- and eight-fold greater, respectively, than at 750 ft-c.

The objective of this experiment was to explore the relationship between shoot growth rate and berry set on grapevines.

Materials and Methods

The number of shoots retained on mature field-grown *Vitis vinifera* L. Hybrid 'Seyval blanc' grapevines was restricted to either 15, 30, or 45 per vine when developing shoots were approximately 2 cm in length (May 20, 1996). Clusters were removed to leave the basal cluster on each shoot. There were three additional treatments (15 clusters/30 shoots; 15 clusters/45 shoots; 30 clusters/45 shoots) in order to separate the effects of shoot and cluster number per vine on shoot growth rate and berry set. Each of the six treatments was applied to six grapevines arranged in a randomized complete block design. Ten fruiting shoots per vine were selected on May 20, 1996. The length of each of these sample shoots was measured at bud break (May 20, 1996), bloom (June 18, 1996), two weeks after bloom (July 3, 1996), and six weeks after bloom (August 6, 1996), and the

growth rate (mm.day^{-1}) between each of these dates calculated. The relationships between (i) shoot diameter (at the base), (ii) shoot length, or (iii) leaf number and total leaf area were assessed on a sample of 45 shoots destructively harvested from adjacent vines. Shoot length was used to predict leaf area per shoot for each of the sample shoots at bloom. Photosynthesis and transpiration were measured under light saturation at bloom on four fruiting mid-shoot leaves per vine using a portable infrared gas analyzer equipped with a 6.25 cm^2 leaf chamber (Analytical Development Co. model LCA2, Hoddesdon, England). Air-flow rate was regulated at 300 ml·min^{-1}, and ambient CO_2 concentration was monitored periodically during each series of measurements. Light transmission (percent ambient) through the canopy was measured on June 24, 1996, by placing a 1 m line quantum sensor (LiCOR, Lincoln, Nebraska) under the foliage canopy of each vine in the north, south, east, and west quadrants. Berry set was estimated for the 10 sample clusters per vine as the number of berries, counted at harvest, per 100 flowers, counted at bloom. Flower counts were made on the shoulder of the cluster. If there were less than 60 flowers on the shoulder, then a count of flowers on the entire cluster was taken. Berry set on the shoulder was compared to that of the total cluster on a sample of 30 clusters. Yield and cluster number per vine were recorded at harvest, and fruit quality [soluble solids, pH, and titratable acidity (TA)] were measured on a random sample of 100 berries taken from the pooled fruit from the 10 sample clusters per vine. The nitrogen content of petioles was determined using the Kejldahl method on a sample taken at harvest.

Results and Discussion

Shoot growth rates were highest during the two weeks following bloom (Table 1), coincident with the period of maximum flower abscission. Slowest growth of shoots occurred in the period from two to four weeks after bloom. There were only minor effects of the treatments on shoot elongation rates during the period from bud break to bloom and from two to six weeks after bloom, but there were no effects due to treatment in the two-week period starting at bloom. Shoot elongation between bud break and bloom was less on vines with 30 clusters and 45 shoots compared with the other treatments ($P < 0.05$). Vines with 15 clusters and 45 shoots had faster shoot elongation rates during the period from two to six weeks after bloom compared to vines with 15 clusters and either 15 or 30 shoots.

Shoot length was a better predictor of leaf area per shoot than shoot diameter or leaf number. Eighty-four percent of the total variation could be explained by shoot length, compared to only 71 percent for both shoot diameter and leaf number (Figure 1). Leaf area per shoot at bloom, estimated from the regression relationship between shoot length and leaf area, was negatively related to the number of shoots per vine. Increasing the number of shoots per vine from 15 to 30 resulted in a 10 percent reduction of the leaf area per shoot, measured at bloom, whereas leaf area was reduced by an average of 25 percent when 45 shoots were retained per vine (Table 2). This reduction could be explained, at least in part, by a reduction in the number of leaves per shoot (Table 2). These data suggest that leaf appearance is more sensitive to a limitation in carbohydrate supply than shoot elongation.

There was no effect of treatment on berry set, measured as the number of berries that set per 100 flowers on the shoulder of each of 10 sample clusters per vine (Table 1). Berry set was around 50 percent for all treatments. Reducing the leaf area per shoot by 25 percent had no effect on berry set when there was only one cluster present on each shoot. The highest number of shoots per vine imposed in this study could be considered a conventional commercial treatment. Under a system of minimal pruning where greater numbers of shoots are retained per vine, one might expect to see more inhibition of growth of individual shoots and a parallel reduction in berry set. The authors observed poorer berry set on vines adjacent to those used in this study which carried as many as four clusters on a single shoot, suggesting that set may be reduced by competition between clusters on the same shoot.

Light transmission through the foliage canopy at bloom was related to shoot number per vine, transmission being higher on vines with fewer shoots (Table 2). Approximately 50

Table 1. Effects of Shoot and Cluster Number Per Vine on Shoot Elongation and Berry Set of Mature Field-Grown 'Seyval Blanc' Grapevines.

Clusters/ Shoots	Shoot Elongation Rate (mm.day $^{-1}$)			Berry Set (berries/100 flowers)
	Bud Break - Bloom	Bloom - 2 WAB[z]	2 WAB - 6 WAB	
15/15	13.98 a[y]	17.34	5.61 a	48.9
15/30	13.52 ab	17.20	5.47 a	53.6
15/45	14.61 a	18.08	9.65 b	50.1
30/30	13.65 a	15.99	7.31 ab	53.6
30/45	11.72 b	14.13	6.85 ab	49.5
45/45	14.18 a	16.28	7.53 ab	49.1

[z] WAB, weeks after bloom.
[y] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

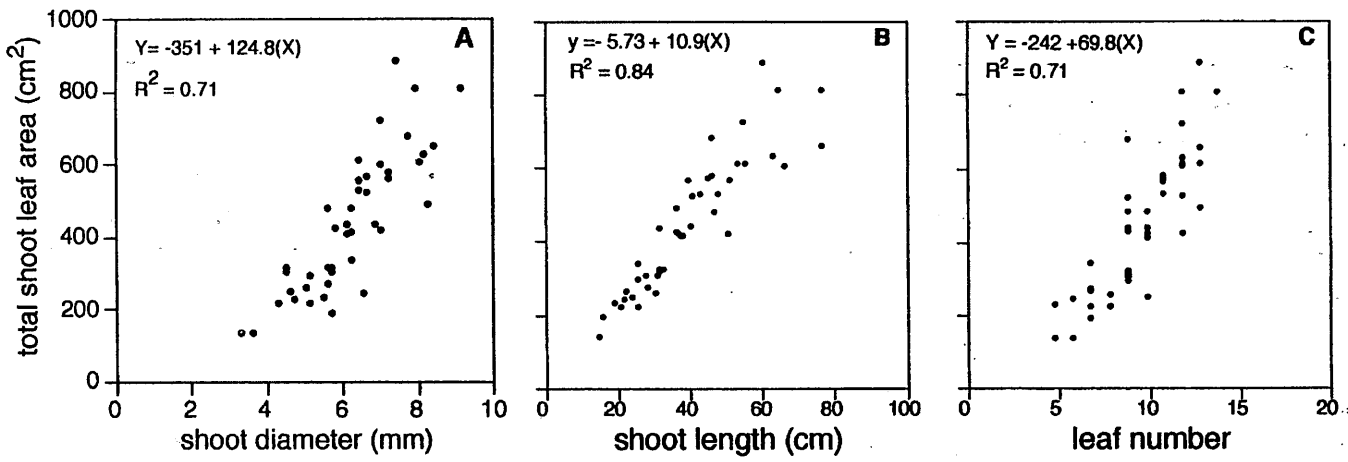

Figure 1. Relationship between the diameter of a shoot at its base (A), shoot length (B), and leaf number per shoot (C) on total leaf area of *Vitis vinifera* L. Hybrid 'Seyval' grapevines (n=45).

percent of ambient light was transmitted through the canopy on vines with 15 shoots, whereas transmission was an average of 37 and 29 percent of ambient for vines with 30 and 45 shoots respectively. Cluster number per vine had no effect on light transmission. Cartechini and Palliotti (5) reported much lower values for light transmission, finding that PAR levels measured at the cluster at bloom were only 7 percent of ambient. Considering that the authors found that 29 percent of the ambient light was transmitted beneath the foliage canopy on what they considered 'commercially' managed vines, then light levels at the cluster would have had a higher light level. Photosynthesis under light-saturated conditions (> 800 $\mu mol.m^{-2}.s^{-1}$) was not affected by either the number of clusters or shoots per vine (Table 2), suggesting there was no compensation and that perhaps even with 45 clusters and shoots, the vines were not under stress. Leaf transpiration was related to the number of clusters per vine, transpiration rates generally being lower on vines with fewer clusters.

The number of clusters per vine at harvest was fewer than was intended when the treatments were applied soon after bud break (Table

Table 2. Effects of Shoot and Cluster Number Per Vine on Light Transmission Through the Canopy, Leaf Photosynthesis and Transpiration, Leaf Number, and Area Per Shoot at Bloom of Mature Field-Grown 'Seyval Blanc' Grapevines.

Clusters/ Shoots	Light Transmission (% ambient)	Photosynthesis ($\mu mol CO_2 . m^{-2} s^{-1}$)	Transpiration ($\mu g . H_2 0 . m^{-2} s^{-1}$)	Leaf Number/ Shoot	Leaf Area/Shoot (cm^2)
15/15	49.7 a[z]	13.1	11.8 ab	12.7 a	478 a
15/30	34.1 bc	13.3	11.2 b	11.6 b	451 ab
15/45	31.1 bc	13.7	11.2 b	10.4 c	359 d
30/30	39.1 b	13.1	11.6 ab	11.6 b	437 abc
30/45	28.7 c	13.2	11.8 ab	10.8 bc	379 cd
45/45	27.6 c	13.0	12.3 a	10.9 bc	393 bcd

[z] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

Table 3. Effects of Shoot and Cluster Number Per Vine on Productivity of Mature Field-Grown 'Seyval Blanc' Grapevines.

Clusters/Shoots	Clusters/Vine	Yield (kg/vine)	Cluster Wt. (g)
15/15	8.5 a[z]	2.1 a	0.26 a
15/30	10.0 a	3.5 a	0.35 b
15/45	9.8 a	3.0 a	0.31 ab
30/30	23.2 b	6.5 b	0.28 ab
30/45	23.0 b	6.7 b	0.29 ab
45/45	37.0 c	9.3 c	0.25 a

[z] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

3). Vines that were intended to carry 15, 30, and 45 clusters in fact produced an average of 9.4, 23.1, and 37 clusters respectively. The authors believe that the major loss of clusters occurred soon after bloom as a result of damage to clusters during the counting process. Cluster number per vine was positively related to yield; however, vines with a greater leaf to fruit ratio (more shoots than clusters) did not produce larger clusters, suggesting that movement of assimilated carbon did not occur between shoots.

Fruit quality at harvest was affected by the treatments. The soluble-solids content of juice was inversely related to cluster number (Table 4). Fruit from vines with 15, 30, and 45 clusters had an average soluble-solids content of 18.0, 16.1, and 15.3 percent respectively. The ratio of clusters to shoots per vine had no effect on soluble-solids content. A similar trend was observed for juice pH; vines with only 15 clusters tended to have a higher juice pH (Table 4). There were no significant effects of the treatments on TA of juice, although the trend was for lower TAs of juice from vines with only 15 clusters. Increasing the number of vegetative shoots reduced the nitrogen content of petioles on vines with only 15 clusters. The number of

Table 4. Effects of Shoot and Cluster Number Per Vine on Juice Quality and Petiole Nitrogen Content at Harvest of Mature Field-Grown 'Seyval Blanc' Grapevines.

	Juice Quality Parameters			
Clusters/Shoots	Soluble Solids (%)	pH	TA (g/100 ml)	Petiole Nitrogen (%)
15/15	17.4 a[z]	3.02 bc	0.81	0.80 a
15/30	18.4 a	3.09 a	0.80	0.77 ab
15/45	18.1 a	3.05 ab	0.78	0.74 b
30/30	16.0 b	2.99 bcd	0.84	0.80 a
30/45	16.2 b	2.94 d	0.83	0.76 ab
45/45	15.3 b	2.96 cd	0.83	0.80 a

[z] Means with the same letter are not significantly different by LSD ($P \geq 0.05$).

clusters per vine did not affect the petiole nitrogen content (Table 4).

There was a poor relationship between the set of berries on the shoulder of individual grape clusters and the set of the entire cluster (Figure 2). Only 34 percent of the variation in total cluster berry set was explained by a linear relationship with the set of berries on the shoulder of the same cluster.

Conclusions

Increasing the number of shoots per vine did not have a clear effect on the rate of shoot elongation but did reduce the leaf area per shoot at bloom, at least in part by reducing leaf number, suggesting that the supply of carbohydrates from remobilized reserves to each shoot was limited and that leaf number was more sensitive than shoot elongation to this limitation. Despite a 25 percent reduction in the leaf area per shoot at bloom, berry set was unaffected. The data suggest that either (i) individual shoots are independent in their carbon economy and that even with a reduction of 25 percent there is still sufficient leaf area (current assimilates) to ensure optimal set of berries, or (ii) shoots are not independent in their carbon economy and the delivery of current assimilates from proximal vegetative shoots can compensate for a reduction in leaf area on flower-

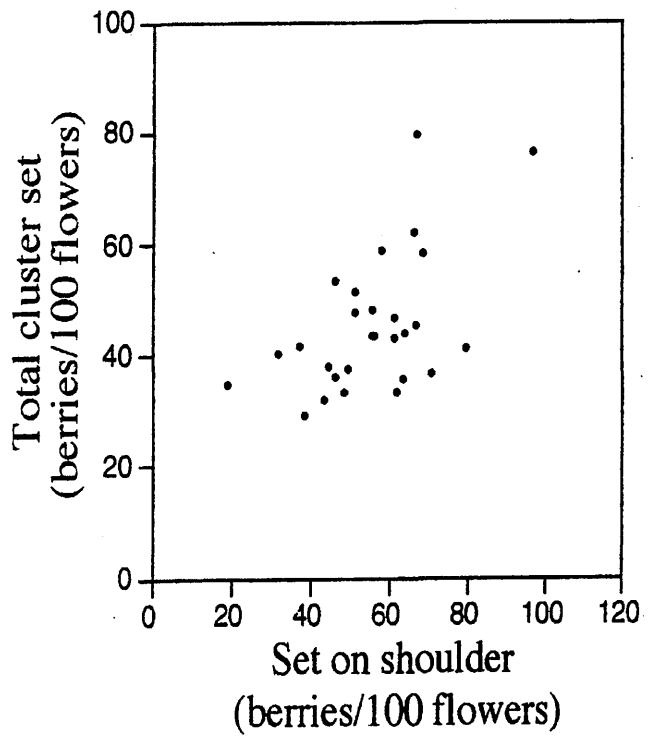

Figure 2. Relationship between set of berries on the shoulder of clusters of mature field-grown *Vitis vinifera* L. Hybrid 'Seyval' grapevines and berry set on the total cluster (n=29).

ing shoots. The authors found no evidence for compensation in the rate of photosynthesis when leaf area per shoot was reduced by 25 percent, suggesting that even with 45 clusters and shoots, vines were not under stress. In this study, the rate of shoot elongation was most rapid during the two weeks following bloom, coincident with the period of maximum flower abscission. During this period, the shoot tip is a major sink for newly assimilated carbon. This carbon is exported from the basal leaves on the shoot proximal to the developing cluster(s) (9). Set in the present study was high, with almost half of the flowers on each cluster developing into a berry. Perhaps in further studies the potential for variation in berry set due to imposed treatments can be enhanced by leaving additional clusters on each shoot so that the ratio of vegetative and reproductive sinks is reduced.

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Summary of Ohio Fruit Growers Society Apple Cider Competition, 1993–1997

Winston Bash and Diane Miller

Introduction

Cider, the fresh juice extracted from chopped, pressed apples, is an important product of the Ohio fruit industry. Of the three million bushels of apples grown annually in Ohio, up to 40% (1.2 million bushels) are used in cider production with a retail value estimated at $15 million (5). Additionally, apples from out-of-state are imported annually to Ohio for cider production, estimated at $10 million retail (5). Cider therefore ranks second economically in Ohio among fruit commodities, at roughly $25 million, behind fresh apples (estimated $30 million) (5). Ohio had 139 cider production facilities in 1996 (R. Stewart, Ohio Department of Agriculture, personal communication); most, but not all, were associated with orchards.

The Ohio apple industry is geared entirely toward apple cultivars for fresh marketing, and cider-making quality is not generally considered in the cultivar-selection process. With the many cultivars grown in Ohio, the potential exists for blends of cultivars used in cider to vary greatly. A few cultivars, however, predominate in volume. 'Delicious,' 'Golden Delicious,' 'Jonathan,' and 'Rome' account for 56% of the apple trees in Ohio (6); therefore, these cultivars would be expected to be prominent in cider blends.

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While the production steps in cider facilities are well defined and inspected by the Ohio Department of Agriculture, the selection and blending of cultivars is at the discretion of the cider maker. This results in considerable variability in taste and chemical characteristics of the ciders produced in Ohio. These cultivar/blend differences are further compounded by maturity of the apple fruits, so that even the exact same blend, made at intervals over several weeks, tastes different. The skill of the cider maker, in utilizing knowledge of the apple fruits, their maturity, and their blending, therefore greatly influences the quality of the cider.

Since 1990 the Ohio Fruit Growers Society (OFGS) has sponsored an annual cider contest, judged at the winter meetings of the association. The purpose of the contest has been to promote cider consumption (which has tripled since the mid-1980s), to attract media attention to the cider industry, and to promote improvement of cider quality among Ohio producers. The purpose of this article is to summarize characteristics of winning ciders.

Materials and Methods

The cider contest is open to all Ohio cider producers. The contest is held during the Ohio Fruit Growers Society winter meetings, normally the first week of February. Announcement of the contest is made in the December issue of *Today's Grower*, the publication of the OFGS and the Ohio Vegetable and Potato Growers Association. For each cider entered, the producer must include detailed information on production equipment, methods, sanitation,

Table 1. Entry Information Provided by Each Cider Producer for Ohio Fruit Growers Society Cider Contest, 1993-1997[z].

Raw Product Information	Processing Information
1. The percentage of cultivars used?	1. The apples were washed?
2. The number of pounds of apples pressed?	2. The apples were washed with detergent or cleaning aid?
3. The date of pressing?	3. A chemical treatment was applied during grinding but before processing?
4. The type of press used?	4. A chemical treatment was applied after grinding?
5. The majority of apples were tree run?	5. A press aid was used?
6. The majority of apples were dropped fruit?	6. The time between grinding and pressing was less than 15 minutes?
7. The fruit was graded?	7. The time between pressing and refrigeration was less than 5 minutes?
8. The fruit was refrigerated before pressing?	8. The cider was filtered?
9. The fruit was stored in CA storage?	9. A filtering aid was used?
10. Pressing occurred within three days of harvest?	10. The cider was refrigerated at 40°F or less.
11. Pressing occurred within one day of removing fruit from storage?	11. The cider was refrigerated for four hours or more after processing?
	12. The cider was given a settling treatment?
	13. The settling treatment was between pressing and bottling?
	14. The cider received a settling aid or enzyme?
	15. The settling treatment was under refrigeration?
	16. A cider preservative was added?
	17. The processing cloths were cleaned every day?
	18. The walls, equipment, and floor were cleaned every day?

[z] For raw product information, questions 5–11 were answered yes or no; all questions concerning processing methodology were answered yes or no.

and cultivar blend (Table 1) and must deliver one-half gallon of thawed or fresh cider in a plastic container (along with a $10 entry fee) to the OFGS Congress registration personnel. Beginning in 1996, cider producers also were required to provide inspection certification from the Ohio Department of Agriculture. Ciders are refrigerated at 4°C; all labeling is concealed; and ciders are given entry numbers.

Ciders are evaluated by five judges — one to two food technologists from the Ohio Agricultural Research and Development Center, one to two media representatives, and one to two industry representatives. At the time of judging, ciders are displayed side by side on tables. A single score sheet is used for each cider (Figure 1). All entries are evaluated one category at a time, *i.e.*, all are evaluated for color, then all are evaluated for flavor, then all are evaluated for defects. The judging is done by committee with each person having input and then consensus is reached on a score in each category. After judging is completed, a total score for each cider is compiled, and top-scoring ciders are selected. The superior cider group is again evaluated by the judges and ranked. First- through fifth-place winners are awarded plaques and honored at the annual OFGS banquet.

Grower entry information, focusing on comparing winning entries with other entries, for five years (1993, 1994, 1995, 1996, and 1997) has been collected, evaluated, and information presented.

OHIO FRUIT GROWERS SOCIETY
APPLE CIDER CONTEST
SCORE SHEET

ENTRY NO. _____			LIMITING RULE	SCORE
1. COLOR	A	18–20	_____	_____
	B	16–17	_____	_____
	C	0–15	_____	_____
2. FLAVOR	A	54–60	_____	_____
	B	48–53	_____	_____
	C	0–47	_____	_____
3. DEFECTS	A	18–20	_____	_____
	B	16–17	_____	_____
	C	0–15	_____	_____
1. TOTAL SCORE				
2. GRADE	A	90–100		_____
	B	80– 89		_____
	C	0– 79		_____

LIMITING RULE: Product cannot grade higher than lowest grade received.

Figure 1. Judges scoring sheet used for Ohio Fruit Growers Society Cider Contest, 1993–1997.

Chemical analysis of ciders was conducted in 1995. Samples of entries were analyzed for pH, soluble solids (SS), and titratable acidity (TA) in the Crop Quality Evaluation Laboratory at the Ohio Agricultural Research and Development Center immediately after the OFGS Congress. The pH was determined using a standard pH probe inserted into each agitating sample. Soluble solids were determined using a brix hydrometer at 20°C (3). Total acidity was determined by direct titration with a standardized sodium hydoxide solution to a phenolphthalein endpoint (3). Brix-to-acid ratio was then calculated (SS/TA).

Results and Discussion

The number of entries in the OFGS cider contest has declined over the last five years from 37 in 1993 to 26 in 1997 (Figure 2). This downward trend may reflect "dropping out" by producers whose ciders have not been successful. Judges comments and cider scores (data not presented) indicate that the overall quality of ciders entered has improved over the years.

The total number of different cultivars used in cider entries over the years 1993–97 ranged from 18 to 25 with no apparent upward or downward trend (Table 2). Over these years, use of 32 different cultivars has been reported: 'Blushing Gold,' 'Braeburn,' 'Cortland,' 'Criterion,' 'Delicious,' 'Elstar,' 'Empire,' 'Firm Gold,' 'Franklin,' 'Fuji,' 'Gala,' 'Grimes Golden,' 'Golden Delicious,' 'Gold Rush,' 'Granny Smith,' 'Holiday,' 'Honey Gold,' 'Ida Red,' 'Jonagold,' 'Jonalicious,' 'Jonathan,' 'King David,' 'Lodi,' 'McIntosh,' 'Melrose,' 'Mutsu,' 'Northern Spy,' 'Paula Red,' 'Rome,' 'Ruby,' 'Spigold,' and 'Stayman Winesap.' The number of different cultivars used in the top five rated blends has ranged from three to eight with from four to six different cultivars used in the top-rated cider (Table 2).

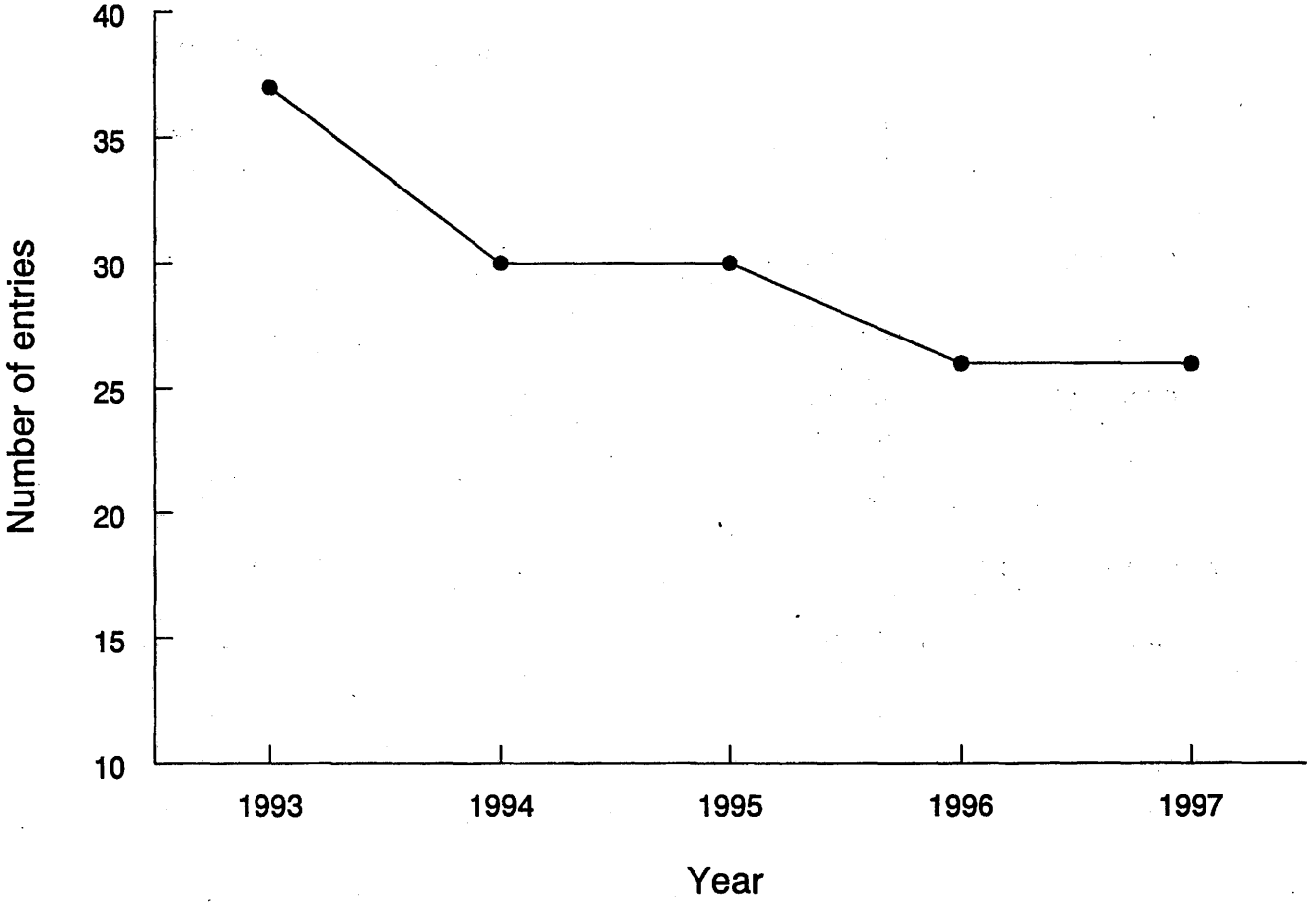

Figure 2. Number of entries, Ohio Fruit Growers Society Cider Contest, 1993–1997.

Ohio grows many different cultivars, and this is reflected in the number of different cultivars used in cider blends. The message is inherent that producers think blending is necessary for high-quality cider; single- or two-cultivar ciders have not been entered. It is interesting that no cider maker has repeatedly entered, year after year, the same blend. Perhaps similar to wine-making, cider making is an art where the growing season impacts the attributes of the cultivars selected for the blending. Cultivar strain has been reported to impart variation in sugar/acid ratios of 'Delicious,' 'Golden Delicious,' 'Jonathan,' and 'Winesap' (2).

Despite the large number of different cultivars used, 'Golden Delicious' and 'Delicious' were the cultivars used most commonly among cider blends (Figure 3). 'Jonathan,' 'Melrose,' 'McIntosh,' and 'Stayman Winesap' have also been used frequently in blends, with an increasing trend toward the use of 'Jonagold.' This reflected the apple trees in production in Ohio: 'Delicious' (25%), 'Golden Delicious' (16%), 'Jonathan' (8%), 'Law Rome' (7%), 'McIntosh' (5%), and others (39%) (6). It also compares with Ohio orchards reporting by cultivar: 'Delicious' (96%), 'Golden Delicious' (94%), 'Jonathan' (81%), 'Stayman Winesap' (66%), 'Rome' (64%), 'Cortland' (55%), 'Lodi' (55%), and 'Melrose' (48%) (6).

'Golden Delicious' and 'Delicious' have been the most commonly used cultivars in the top five cider blends during 1993–97 (Figure 4). 'Jonathan,' 'McIntosh,' and 'Melrose' have also been used commonly in winning cider blends. 'Golden Delicious' has been used in the top cider blend every year except 1995. 'Delicious' has been used in the top cider blend every year except 1997.

The authors interpret the common use of some cultivars to mean that they form a medium-acid, high-sugar "basic blend" for a good cider, not that the commonly used cultivars result in good cider individually or collectively. The authors believe the "other" cultivars used less frequently or less abundantly in a blend result in the high acid or aromatic or astringent traits which give distinctive flavors to

Table 2. Number of Cultivars Used in Cider Blends, Ohio Fruit Growers Society Cider Contest, 1993–1997.

	Year				
No. Cultivars Used	**1993**	**1994**	**1995**	**1996**	**1997**
In All Entries	18	22	25	18	25
In the Top Five Entries	4–6	3–7	3–6	3–6	3–8
In the Top Cider Blend	6	5	5	6	4

Table 3. Chemical Characteristics of Top 5 Ciders as Compared with All Entries, 1995, Ohio Fruit Growers Society Cider Contest.

Ciders Evaluated	pH	Titratable Acidity (%)	Soluble Solids (%)	Brix/Acid (SS/TA)
Range of All Entries	3.29–3.72	0.29–0.53	11.3–14.2	24.5–45.5
Range of Top Five Entries	3.41–3.70	0.33–0.47	11.9–14.2	27.6–39.4
Average of All Entries	3.49	0.38	12.6	33.2
Average of Top Five Entries	3.57	0.38	12.9	33.9

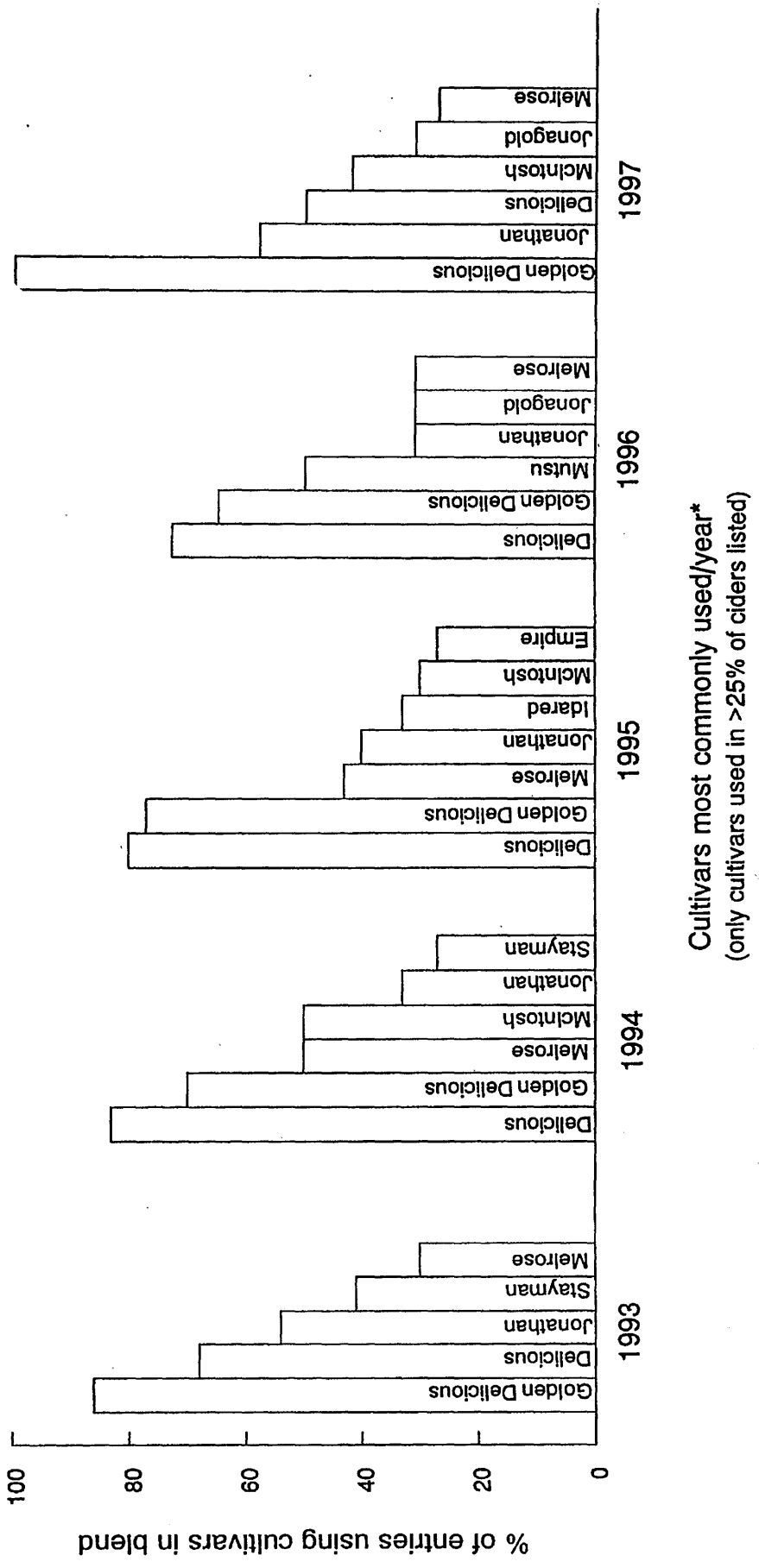

Figure 3. Most commonly used cultivars in cider blends, all entries, Ohio Fruit Growers Society Cider Contest, 1993–1997.

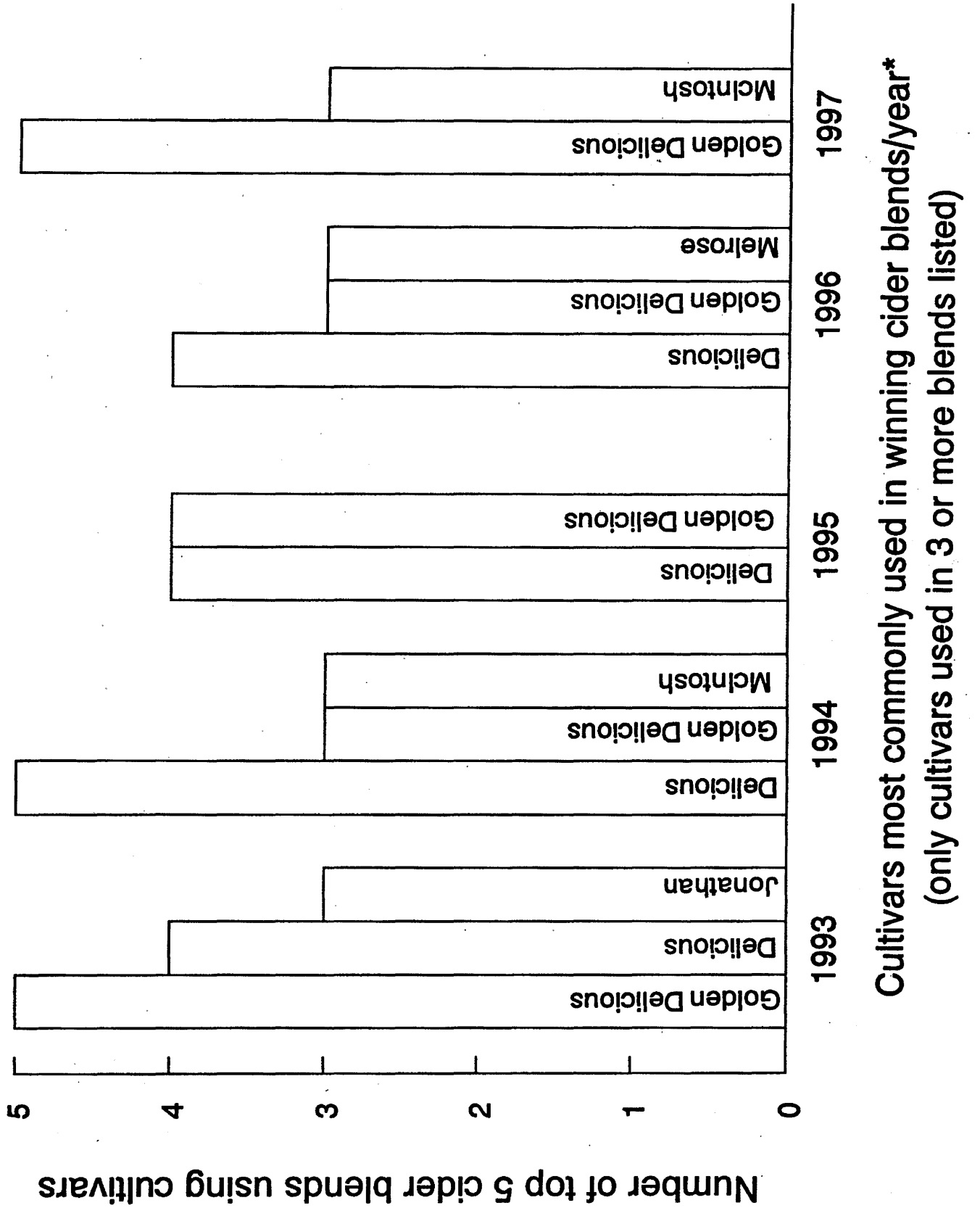

Figure 4. Most commonly used cultivars in cider blends, top five ciders, Ohio Fruit Growers Society Cider Contest, 1993–1997.

a cider. The ability to combine cultivars to achieve a sugar/acid balance with unique flavor components separates winning cider producers from those producing acceptable ciders.

The authors respect the expertise and experience of the cider producers who have entered the OFGS contest over the years and are not at liberty to reveal winning recipes by year. The authors do, however, feel it is important to give readers a randomly selected "sampling" of the top five blends:

- 'Delicious' 20%, 'Ida Red' 30%, 'Jonathan' 20%, 'Northern Spy' 20%, and 'McIntosh' 10%.
- 'Delicious' 40%, 'Golden Delicious' 40%, 'Gala' 10%, and 'Cortland' 10%.
- 'Golden Delicious' 30%, 'Melrose' 30%, 'Jonagold' 30%, and 'Granny Smith' 10%.
- 'Delicious' 35%, 'Golden Delicious' 35%, 'Jonathan' 27%, 'Winesap' 1%, 'Rome' 1%, and 'Grimes Golden' 1%.
- 'Delicious' 50%, 'Fuji' 30%, and 'Golden Delicious' 20%.

The simplest blends among the top five ciders over the period 1993–97 have combined three cultivars:

- 'Gala,' 'Delicious,' and 'Granny Smith.'
- 'Delicious,' 'Golden Delicious,' and 'Fuji.'
- 'Criterion,' 'Delicious,' and 'Golden Delicious.'

The highest percentages of one cultivar used among the top five each year (1993–97) were:

- 50% 'Delicious' (plus other cultivars to total 100%).
- 75% 'Gala' (plus other...).
- 50% 'McIntosh' (plus other...).
- 50% 'Criterion' (plus other...).
- 50% 'Golden Delicious' (plus other...).

The score sheet used for this competition places a premium on cider flavor (60 points out of 100 total), and this is where tasting and discussion among judges separates the entries. Fresh, sweet apple flavor and balance of sugars and acids are desirable traits. Samples are tasted repeatedly, but not chemically analyzed, during the judging. Color (20 points possible) evaluation includes assessing cloudiness and caramel-brown hue. In recent years, lighter golden ciders have been preferred by the judges. Evaluation for defects (20 points possible) assesses chunkiness, haziness, off-flavors due to rot or over-ripeness of fruit, or other imperfections peculiar to an entry.

To determine if there were chemical characteristics that could easily separate the top five ciders as compared with all entries, chemical analyses were conducted in 1995 (Table 2) after the competition was completed. These chemical analyses show no obvious keys to success. Winning ciders had a pH range of 3.4 – 3.7, titratable acidities of 0.33 – 0.47%, soluble solids of 11.9 – 14.2%, and brix to acid ratios of 27.6 – 39.4. These values fell within the middle of the range of all cider entries. The average values for all entries were nearly identical to the averages of the winning ciders.

Preference or acceptability has been associated with the ratio of the soluble solids to the total acid content (SS/TA) of an apple juice (1). Desirable brix/acid ratios may vary depending upon local populations (7). A brix/acid ratio of 35 has been reported as most desirable in New York state (4). No consumer preference studies with cider have been conducted in Ohio, but it is interesting that the brix/acid ratio for all entries averaged 33.2 and that winning ciders averaged 33.9 (Table 3).

Winning ciders from 1993–97 were made during October, November, December, January, and early February, showing no trends in month produced and showing no ill effect of freezing and thawing on cider acceptability. Producers used rack and cloth cider presses in the vast majority of entries and winners. Fruit of almost all entries was picked (not drops; most pronounced during 1996 and 1997), refrigerated, and graded. A small number of entries used apples from controlled-atmosphere storages. Almost all ciders were filtered although no information was collected on type or quality of filtering. No pressing aids, settling aids, or enzymes were used in cider production. Very few winning ciders used preservatives (20% of the winners from 1995–97; an occasional other). None of the ciders entered in 1993–97 was pasteurized.

The Ohio cider competition will continue, as it has resulted in good publicity for the cider industry and healthy competition within the industry. It is likely that in future years pasteurized product will be entered in the contest, and this will allow critical tasting of differences among raw and pasteurized cider. The cider contest, combined with the cider session at the OFGS Congress, has fostered good discussions among producers on aspects of cider quality and production.

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