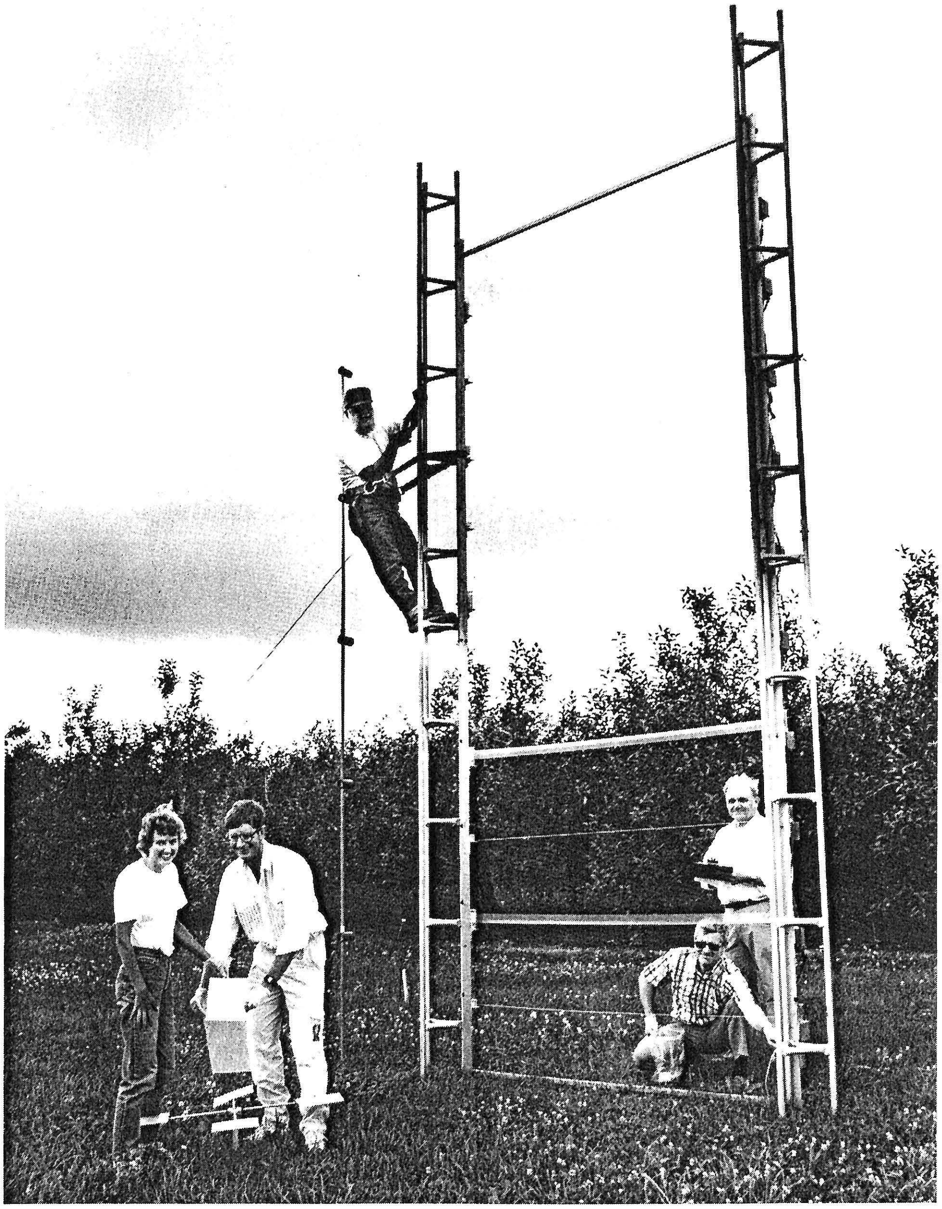
Research Circular 297 July 1990

Fruit Crops 1990: A Summary of Research



The Ohio State University
Ohio Agricultural Research and Development Center
Wooster, Ohio

Contents

Orchard Temperature Profiles in Spring Frost Conditions 1

Orchard Sprayers: How Much Spray Moves Out of the Orchard? 9

Influence of Pruning Treatments on Mature Spur-Bound 'Starkrimson Delicious' Apple Trees . . . 16

The Winter of 1983-84: A Test Winter for Ohio's Fruit Crops 23

Performance of Apple Roostock, Cultivars and Cultural Treatments Under the Stress of the 1988 Drought 25

Performance of a Spur and Standard Delicious Strain in a Slender Spindle System 37

Survey of Ohio Strawberry Growers: Present Practice and Future Directions 39

Orchard Crop Loss Assessments: A Precondition for Improved Crop Protection Decisions 50

Evaluation of Compounds for Control of Foliar Grape Phylloxera, *Daktulosphaira vitifoliae* (Fitch) in Ohio 60

Marketing Ohio Strawberries 63

On the Cover: Interdisciplinary team of agricultural engineers and plant pathologists from the Agricultural Research Services of the USDA and entomologists from the OARDC Laboratory for Pest Control Application Technology are joined in a cooperative project measuring drift of pesticide application from orchard sprayers. Research is showing that downwind ground deposits decrease rapidly from the point of application and are extremely low beyond 500 feet. Pictured clockwise, beginning at the top: Allan Swank, Robert Fox, Ross Brazee, Roger Downer and Jane Cooper.

7-90-1.5M

Orchard Temperature Profiles in Spring Frost Conditions

R.D. Brazee and R.D. Fox, USDA, Agricultural Research Service,
Department of Agricultural Engineering
D.C. Ferree, Department of Horticulture

Introduction

Air temperature distribution in orchards is an important factor in fruit crop development and protection. In the latter case, temperature is the grower's prime index for anticipating onset of conditions that may result in cold damage to fruit crops. Furthermore, temperature profiles, rather than spot readings of temperature, are regarded as critical data in efforts to improve orchard management systems, including the tasks of pruning, pest management and cold protection.

While air temperature is only one of several microclimatic state variables, the interactions of heat energy with airflow, radiation and humidity makes temperature a key measurement for understanding orchard microclimate. Therefore, the specific objectives of this work were: (1) To measure and compare orchard temperature profiles under various synoptic weather conditions accompanying spring frosts; (2) to compare temperature profiles within and outside an orchard; and (3) to determine the rate of temperature drop close to the soil surface.

The forms of temperature profiles in some plant canopies have been fairly well established (2,3,4,5,6). Factors that cause variations in temperature profiles are wind, soil temperature, solar and long-wave radiation exchange interacting with cloud cover, and plant canopy structure. In particular, the concept of atmospheric stability is critically important in delineating the strong interaction between air movement and heat transfer, and ultimately temperature.

Stability

Orchard microclimates can be classified in part by their stability, which is in turn related to change in temperature with elevation above the ground surface. Neutral stability implies that air temperature decreases with elevation at the adiabatic temperature lapse rate. When temperature decreases at a rate greater than the neutral rate, the atmospheric condition is unstable. Unstable conditions usually occur on sunny days that produce warm air near the surface, stimulating vertical convection and promoting air mixing in the surface layer. Stable conditions occur when temperature either decreases at a rate less than the neutral rate or increases with elevation, as with inversions where vertical mixing is inhibited. Cool air remains near the surface and can flow into low-lying areas. Stable conditions can also occur when the ground surface is cooled by radiation during clear nights, as in radiation frosts.

The dimensionless gradient Richardson number (Ri) (8) can be used as an index of stability. The gradient Richardson number is generally defined as

$$Ri = \frac{g \cdot (\Delta T / \Delta Z_T)}{T_o \cdot (\Delta U / \Delta Z_U)}$$

where g is the acceleration due to gravity (0.98 meters/sec^2 (m/s^2)); T_o is the local absolute air temperature; ΔT is the mean air temperature difference over the vertical distance ΔZ_T; and ΔU is the mean air velocity difference over the vertical distance ΔZ_U Values of Ri less than 0.2 usually indicate that pre-existing turbulence and the accompanying atmospheric mixing effects will be sustained (7). Values of Ri greater than 0.2 usually indicate that pre-existing turbulence will tend to be suppressed, as in stratified, stable conditions. Fox and Brazee, 1988, discussed the nature of stability with respect to orchards for warm weather conditions.

Experimental Conditions and Methods

Reported temperature profiles were obtained during experiments on frost control with irrigation in a peach orchard (1) conducted in spring 1983 at the Ohio Agricultural Research and Development Center, Wooster, Ohio. This work centers on cold-weather vertical temperature profiles observed during the 1983 irrigation studies under various weather conditions. Trees were spaced 3 m (10 ft) apart within rows, with rows spaced 4.5 m (15 ft) apart. Tree width of 2.1 m (7 ft) was maintained by summer mechanical hedging, with trees topped at 2.4 m (8 ft) in mid-July of the preceding year. Tree foliation was limited at the time of the experiments, as can be seen in photographs shown by Brazee *et al.*, 1984. Experiments were performed when frost conditions either threatened or occurred.

Temperatures were measured with aspirated, radiation-shielded copper-constantan thermocouples, sequentially sampled once per minute for each level in a profile, and with each sample an average of 1000 individual temperature observations taken over the sample interval in order to eliminate possible system noise. Each temperature profile reported was in turn based on the means of temperature samples over a 15-minute interval. The lowest level for temperature measurement was about 0.1 cm (0.3 ft).

Two instrument towers were used for obtaining microclimate and temperature-profile data: Tower 1, in an open area just outside the orchard with grassy surface cover similar to the orchard, and Tower 2, located within the orchard. In temperature profile plots, open triangles are for temperature observations from Tower 1, and open circles correspond to observations obtained at Tower 2. Some gaps appear in the plots due to occasional instrumentation problems. Data for Richardson number determinations were obtained at Tower 1. Mean temperature and velocity differences over vertical distances of 3.6 and 4.4 m (11.8 and 14.4 ft), respectively, were used to estimate the values of Ri. Wind velocities for the Richardson number measurements were taken at levels of 0.9 meter (3.0 ft) with a small, precision cup anemometer and at 5.3 m (17.4 ft) with a 3-component propeller anemometer. Mean wind velocity values for a particular experiment are shown for the 5.3 m level.

The Experiments and Results

Experiments during the period April 17-19 were carried out under advective-freeze conditions. Experiments in the period May 8-10 occurred under radiation-frost conditions commonly affecting Ohio in middle to late spring.

Temperature profiles shown in Figures 1(a)-5(b) are identified according to a particular experiment. Times indicated are Eastern Standard, with 15-minute average profiles being shown at approximately hourly intervals over the course of an experiment. Mean wind and wind azimuth values are indicated on the plots for each 15-minute period and Richardson number values for each experiment are given in the figure captions when available. Wind azimuth values are measured in degrees clockwise from north. Barometric pressures given are local and not corrected to sea level.

Experiment 83-01 was conducted on the night of April 15-16. Although frost occurred, there was no irrigation since air temperature did not fall to the critical bud temperature of -6.1^0 to -3.9^0 C (21^0 to 25^0 F). The sky was clear except for a slight overcast appearing near daybreak, and local barometric pressure was at 74.0 cm Hg (29.1 in Hg). Richardson number values were not considered reliable for this particular experiment due to instrumentation problems. Mean wind velocity was 4.42 m/sec (9.9 mph). Figures 1(a) and 1(b) show consecutive temperature profiles from 0300 to 0804 on April 16. The temperature profiles show a characteristic drop in temperature of about 1^0 C (1.8^0 F) within the surface air layer, the first 2 m (6.6 ft) above ground level, which implies nighttime cooling at least in part by radiation as is well known. The profile in Figure 1(b) shows a warming trend up to 2 m (6.6 ft) in the surface layer near daybreak. Profiles inside and outside the orchard are similar except for an apparent canopy shielding effect evident in the lags in cooling or warming of the canopy surface layer up to about 1.0 m (3.3 ft) compared with surface-layer temperatures outside the orchard.

Experiment 83-02 was conducted on the night of April 17-18. Irrigation was necessary since the temperature reached an overnight low of -7.2^0 C (19^0 F). Sprinklers were started at about 2204 hours on April 17. Neither tower was in a sprinkled area, except Tower 2 was downwind of a sprinkled area of the orchard. Advective freeze conditions prevailed under a large cold air mass with daytime wind velocities of 3.1 to 8.7 m/sec (7 to 15 mph). Skies were lightly overcast and local barometric pressure was at 71.2 cm Hg (28.05 in Hg). Richardson number values were also suspect in this experiment, due to the continuing instrumentation problem which there had not been time to correct. Therefore, unfortunately, Richardson number values are again omitted. Mean wind velocity was 3.1 m/sec (6.9 mph). Figures 2(a) and 2(b) show consecutive temperature profiles from 2339 on 17 April to 0416 on April 18. The temperature profiles are fairly uniform in this case except for profiles at 0144, 0245 and 0416, which indicate a gradual increase in temperature with elevation for a total of about 2^0 C (3.6^0 F) up to about 4 m (13.1 ft). Profiles inside and outside the orchard are similar.

Experiment 83-03 was conducted on the night of April 18-19. Irrigation was continued with air temperature reaching an overnight low of −3.7° C (25° F). Sprinklers were started at about 1923 hours on April 18. Neither tower was in a sprinkled area, except Tower 2 was again downwind of a sprinkled orchard block. Advective freeze conditions continued under the same cold air mass as for Experiment 83-02 with daytime wind velocities of 3.1 to 8.7 m/sec (7 to 15 mph). Skies were lightly overcast and mean local barometric pressure was 71.3 cm Hg (28.07 in Hg). The mean Richardson number value for the duration of the experiment was −0.008±−0.03, which indicates sustained turbulence and air mixing. Mean wind velocity was 2.4 m/sec (5.4 mph). Figures 3(a) through 3(d) show consecutive temperature profiles from 2022 on April 18 to 0733 on April 19. The temperature profiles in this case exhibit the surface layer cooling effect in the first 1 to 2 m (3.3 to 6.6 ft) beginning at 2022 hours on April 18, with warming becoming apparent at about 0733 hours on April 19, about daybreak. The greatest temperature difference is about 1° C (1.8° F). Profiles inside and outside the orchard are separated by as much as 0.5° C (0.9° F) in some cases, with the in-canopy temperatures tending to be higher. It is possible that the overall temperature elevation at Tower 2 in the orchard may reflect latent heat release from the irrigation operation. The lag of the in-canopy temperatures in cooling and warming near the ground surface is again apparent.

Experiment 83-04 was conducted on the night of May 8-9. Air temperature dropped rapidly on May 8

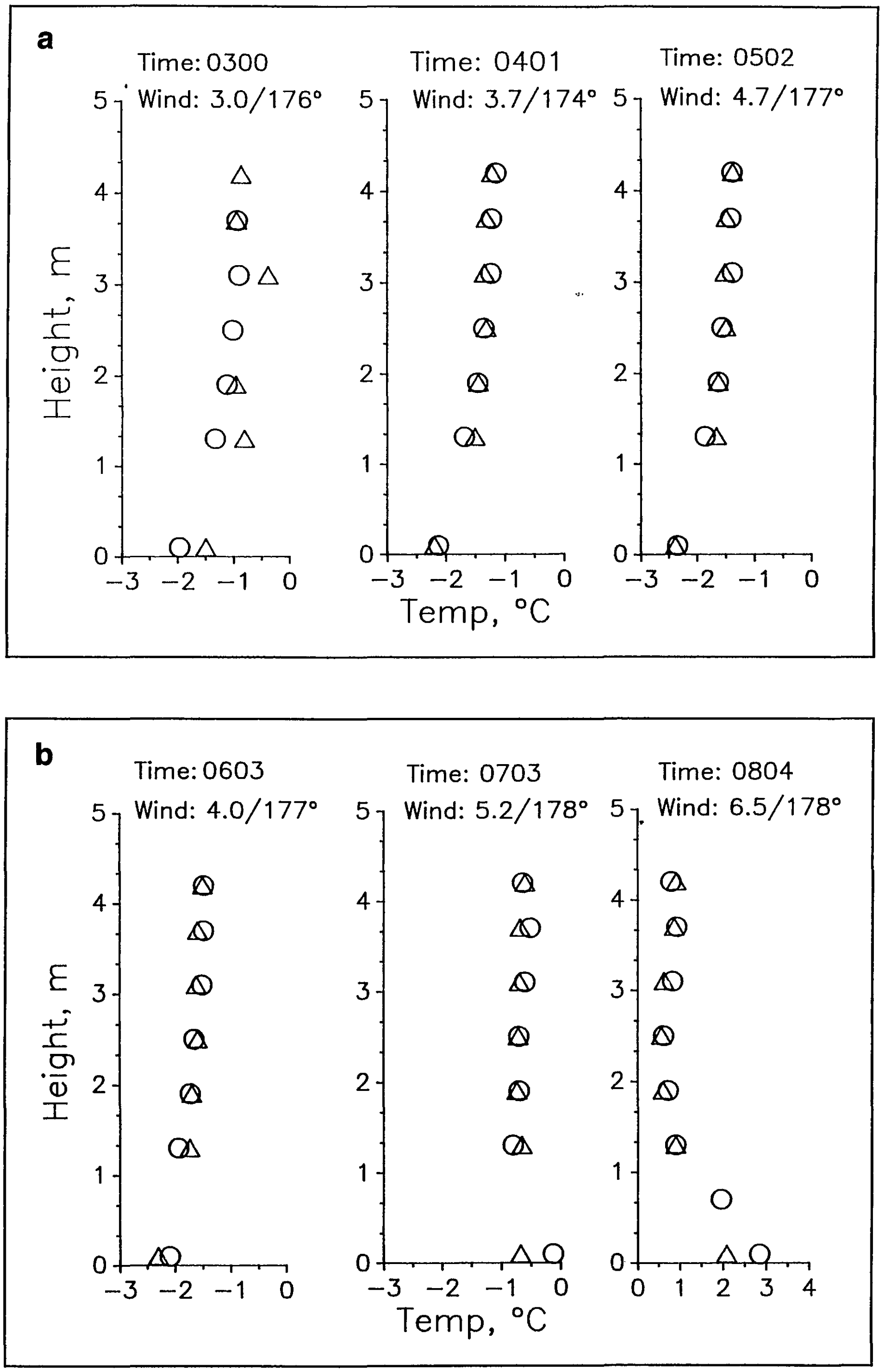


Figure 1(a,b). Temperature profiles within ○ and outside △ a peach orchard at pink bud stage, Experiment 83-01, night of April 15-16, advective freeze conditions approaching. Richardson number values for the experiment were suspect due to an instrumentation problem and therefore are not given.

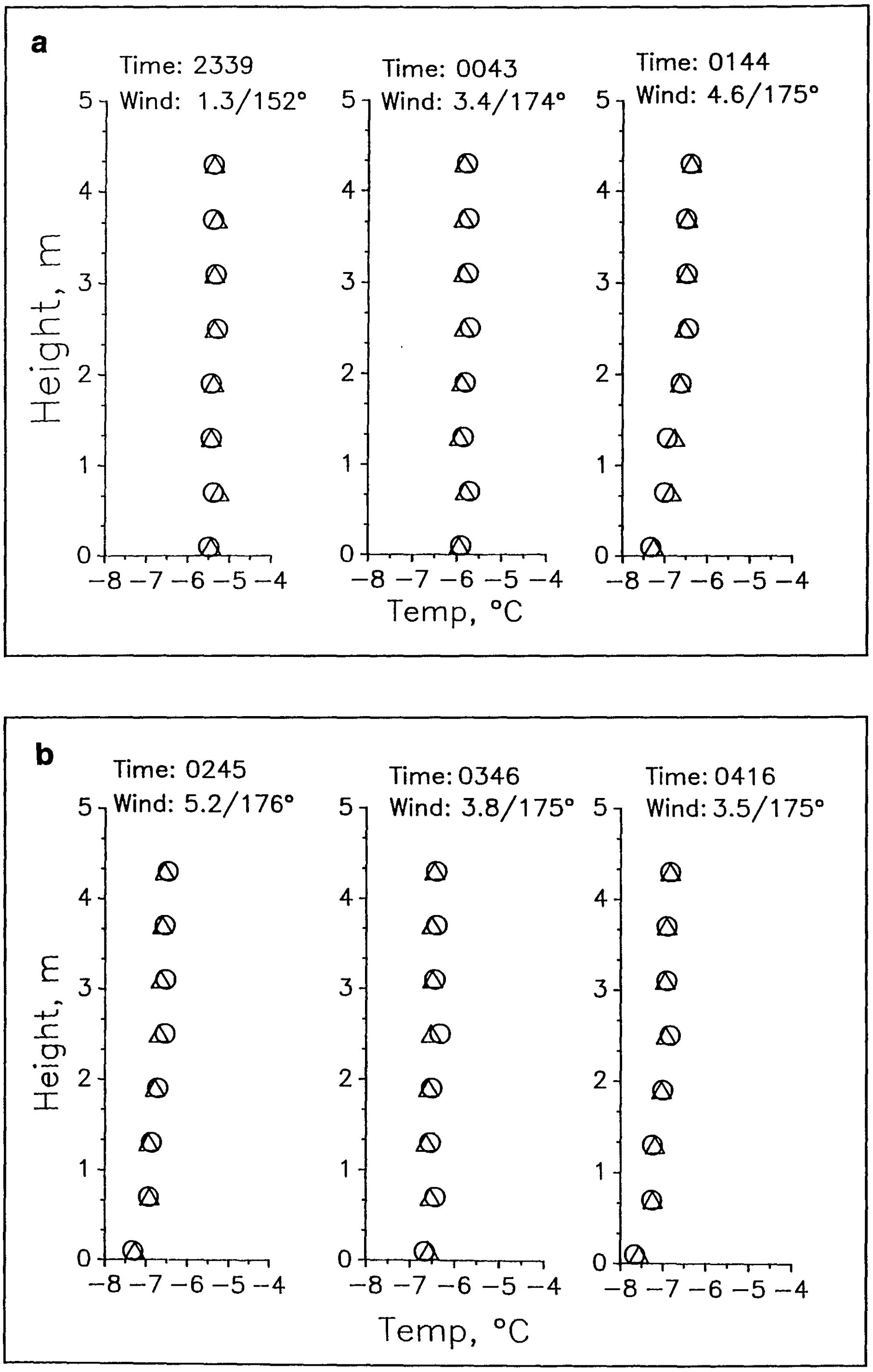


Figure 2(a,b). Temperature profiles within ○ and outside △ a peach orchard at pink bud stage, Experiment 83-02, night of April 17-18, advective freeze conditions. Richardson number values for the experiment were suspect due to an instrumentation problem and therefore are not given.

and reached a low of -2.4^{0} C (27.7^{0} F) early on May 9. Irrigation was necessary as a safeguard, since the critical temperature tolerance at this late bloom and small fruit stage was judged to be about -3.9^{0} C (25^{0} F). Due to the prevailing wind direction, neither tower was in, nor downwind of, a sprinkled area. Skies were clear, with mean local barometric pressure of 72.29 cm Hg (28.46 in Hg) and mean wind velocity at 1.2 m/sec (2.7 mph), conditions favoring radiation frost. The mean Richardson number value for the duration of the experiment was $+0.128 \pm 0.04$, which approaches the upper limit for sustaining pre-existing turbulence and mixing. Figures 4(a) and 4(b) show consecutive temperature profiles from 0123 to 0628 hours on May 9. The temperature profiles exhibit definite cold air stratification in the first 2 m (6.6 ft), with a total temperature drop of about 1.5^{0} to 2^{0} C (2.7^{0} to 3.6^{0} F) near the ground compared with temperatures at one meter (3.28 ft) and beyond in elevation. Profiles inside and outside the orchard are essentially identical.

Experiment 83-05 was conducted on the night of May 9-10. Irrigation was again required, with temperature reaching an overnight low of -2.0^{0} C (28.4^{0} F). Again due to prevailing wind direction, neither tower was in, nor downwind of, a sprinkled area. Skies were clear, with local barometric pressure at 72.47 cm Hg (28.53 in Hg) and mean wind velocity at 0.77 m/s (1.8 mph), conditions again favoring radiation frost. The mean Richardson number value for the duration of the experiment was $+0.477 \pm 0.18$, which indicates that pre-existing turbulence and mixing would tend to be suppressed. Figures 5(a) and 5(b) show consecutive temperature profiles from 0213 to 0718 hours on May 10. Although there are some irregularities, the temperature profiles exhibit cold air stratification, with a typical overall decrease in temperature near the ground of as much as 2^0 to 3^0 C (3.6^0 to 5.4^0 F) in the surface layer up to about 4 m (13.1 ft). There are only small differences in profiles inside and outside the orchard except for lags.

Summary

The objective of this study was to measure and compare temperature profiles under various cold-weather stability conditions typical of Ohio for a peach orchard maintained under summer mechanical pruning and optimum management programs. Vertical temperature distributions (profiles) were obtained in conjunction with experiments on irrigation frost control in the orchard (1) conducted in the spring of 1983 at the Ohio Agricultural Research and Development Center. Temperature profiles were observed both with and without irrigation under conditions of limited tree foliation. Experiments were performed either when frost damage conditions threatened or actually occurred. Experiments during the period April 17-19 were carried out under advective-freeze conditions. Experiments in the period May 8-10 occurred under radiation-frost conditions commonly affecting Ohio in middle to late spring. Where

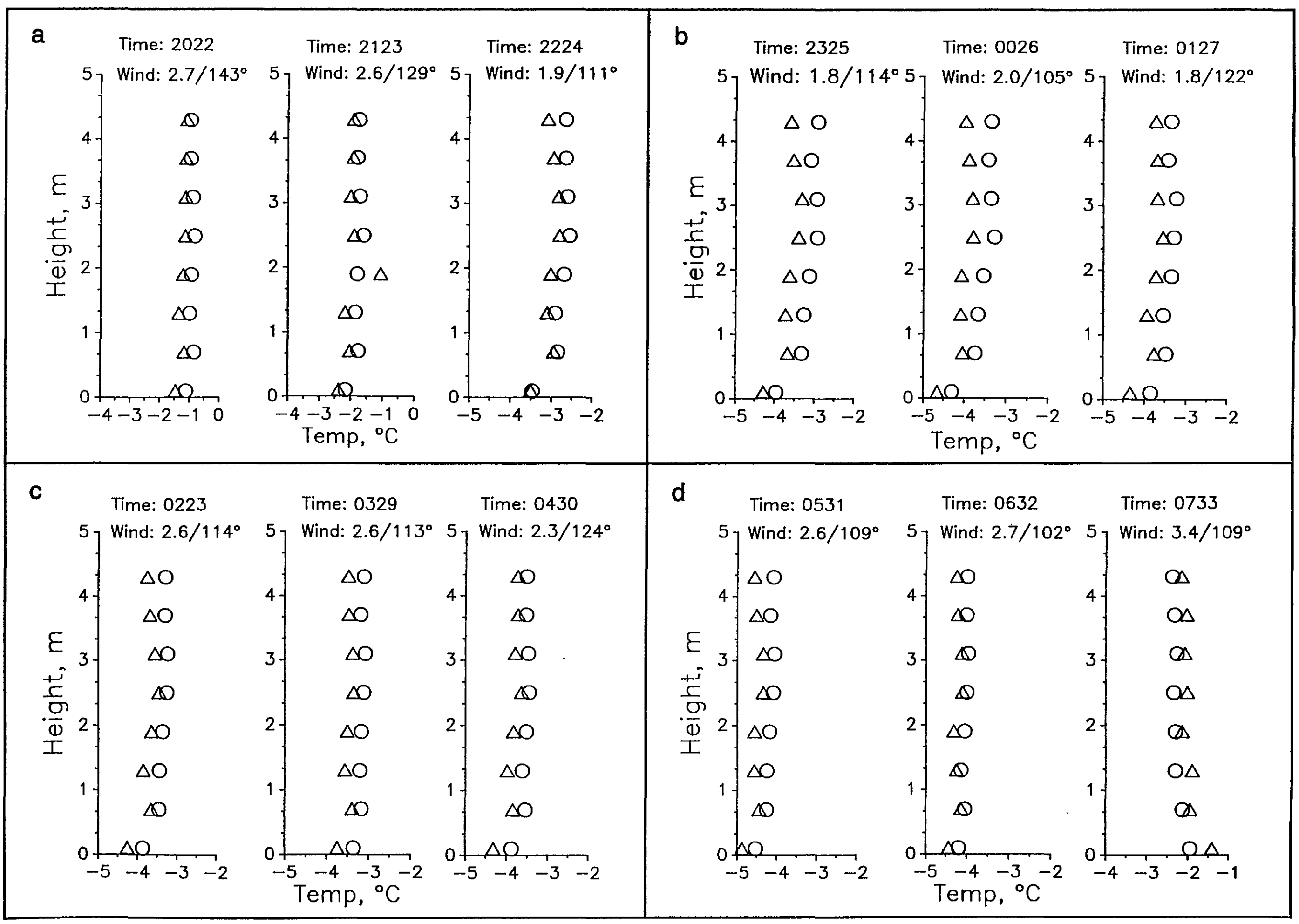


Figure 3(a-d). Temperature profiles within ○ and outside △ a peach orchard at pink bud stage, Experiment 83-03, night of April 18-19, advective freeze conditions. The mean Richardson number for the experiment was -0.008 ± 0.03.

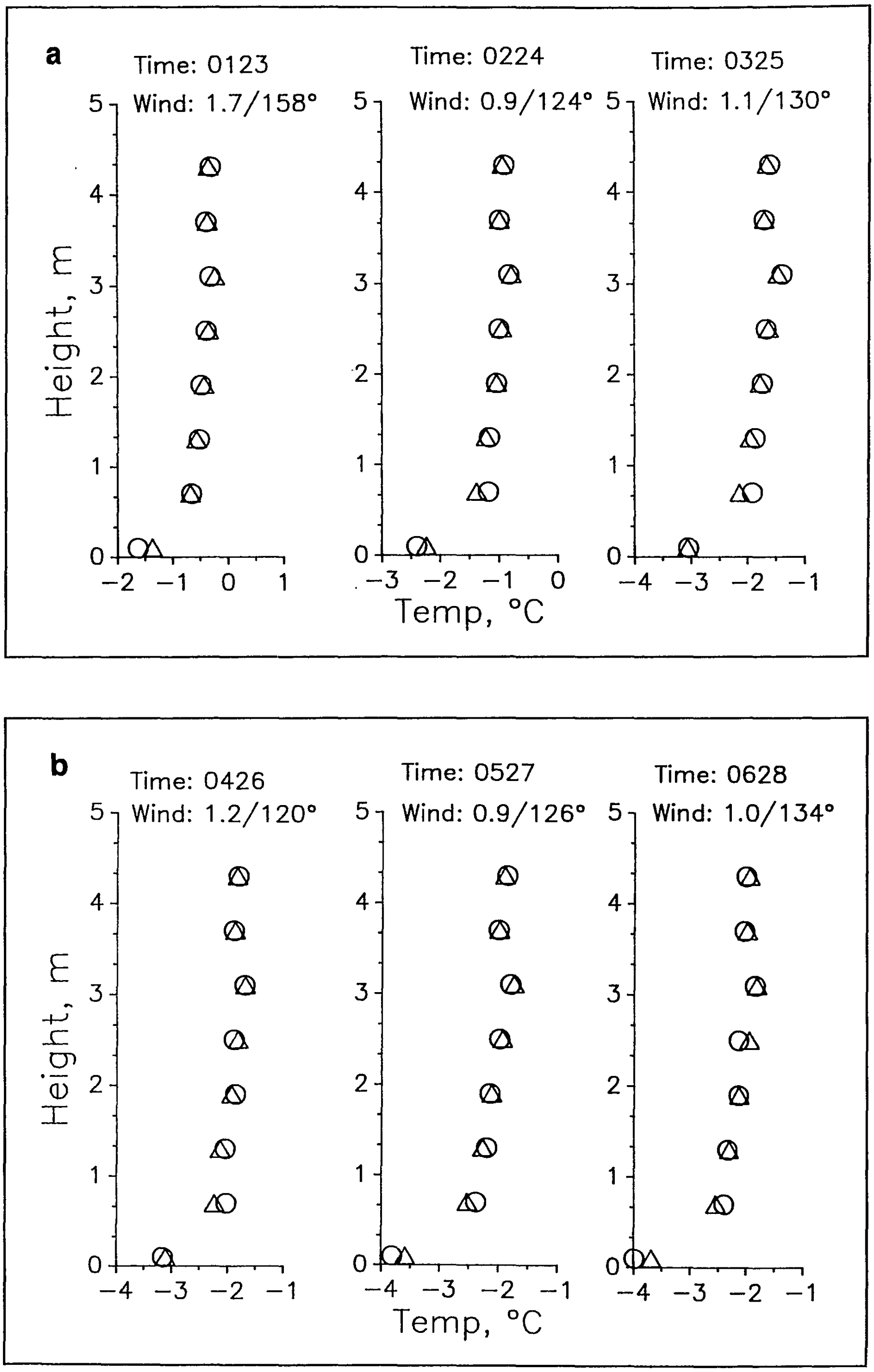


Figure 4(a,b). Temperature profiles within ○ and outside △ a peach orchard at full bloom stage with some small fruit, Experiment 83-04, night of May 9 radiative frost conditions. The mean Richardson number for the experiment was +0.128±0.04.

appropriate data were available, Richardson number (Ri) was used as the index of stability. Temperature profiles were similar for either advective or radiation-frost conditions, with a surface layer found to vary from 2 to 4 meters thick depending on the strength of stratification. The thicker surface layer situations tended to show some degree of irregularity in the profiles. There was generally a lag in cooling or warming near the ground surface within the orchard as compared with temperature profiles outside the orchard. The temperature difference between upper and lower levels in the profiles was typically from 2° to 3° C depending on the strength of stratification. It can generally be expected...and not surprisingly...that radiation-frost conditions will produce the greater thickness of the surface layer and temperature decrease toward the ground surface. Generally, temperature profiles within and outside the orchard were nearly identical under these light foliage conditions.

Aside from the value of temperature profile data in research on orchard microclimate and management, such information is of concern to the grower in gaining an overall, practical understanding orchard environment. The fruit production industry of Ohio is often subject to cold weather extremes when the crop is most vulnerable, generally more so than fruit producing regions further north. In fact, wide fluctuations between cold and warm conditions may induce that vulnerability. Also, the frequent lack of strong inversions tends to limit frost control that are practicable, especially wind machines or helicopters. Thus, it is important for growers operating under such restrictions to have a good practical understanding of cold weather systems and the accompanying orchard microclimates. In the case of temperature distribution, growers need to know how choice of a location to monitor orchard temperature can affect management decisions on whether to undertake a possibly expensive protection operation and, if so, what the temperature extremes may be in the orchard depending upon that decision.

Acknowledgement

The authors are grateful for the assistance of W.R. Alvey, D.L. Collins, J.Y. Elliott, J.C. Schmid and A.W. Swank in conduct of experiments and in analysis of data.

References

1. Brazee, R.D., R.D. Fox, D.C. Ferree and G.A. Cahoon. 1984. Advective and radiative frost control with irrigation in peaches. Fruit Crops 1984: A Summary of Research, OSU/OARDC Research Circular No. 283: 54-62.
2. Fox, R.D., R.D. Brazee and D.C. Ferree. 1980a. Effect of orchard heaters on vertical temperature profiles. Fruit Crops 1980: A Summary of Research, OSU/OARDC Research Circular No. 259: 16-19.
3. Fox, R.D., R.D. Brazee and D.C. Ferree. 1980b. The effect of orchard heaters on air movement and temperature. Fruit Crops 1980: A Summary of Research, OSU/OARDC Research Circular No. 259: 20-24.
4. Fox, R.D., and R.D. Brazee. 1988. Air temperature interactions with microclimate in an orchard canopy. Fruit Crops 1987: A Summary of Research, OSU/OARDC Research Circular No. 295: 28-31.

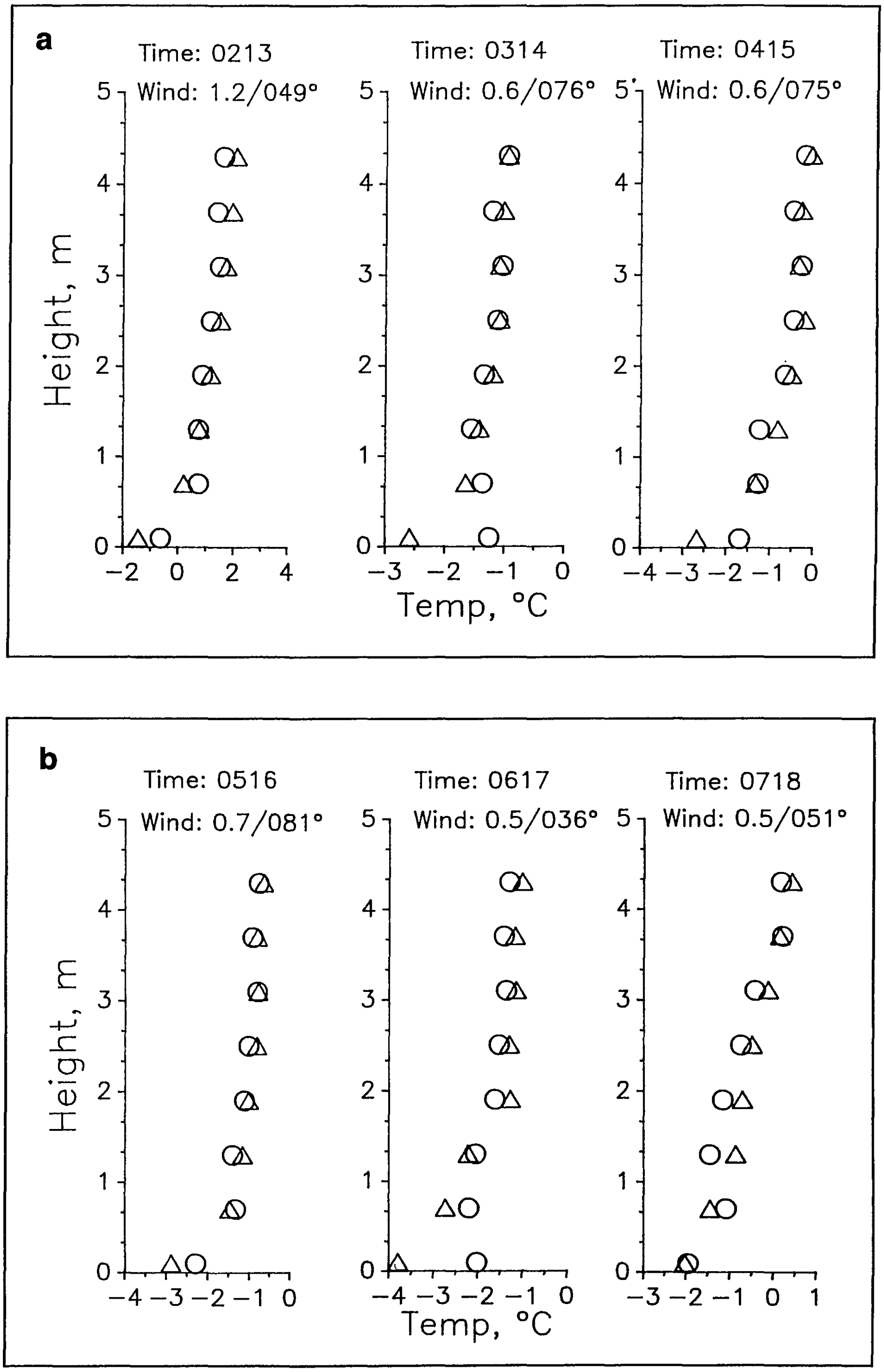


Figure 5(a,b). Temperature profiles within ○ and outside △ a peach orchard at full bloom stage with some small fruit, Experiment 83-05, night of May 10, radiative frost conditions. The mean Richardson number for the experiment was +0.477±0.18.

5. Lang, A.R.G., K.G. MacNaughton, C. Fazu, E.F. Bradley and E. Ohtaki. 1983. Inequality of eddy transfer coefficients for vertical transport of sensible and latent heats during advective inversions. Boundary Layer Meteorology. 25(1):25-41.
6. Lemon, E.R., D.W. Stewart and R.W. Shawcroft. 1971. The sun's work in a cornfield. Science 174:371-378.
7. Lumley, J.L. and H. Panofsky. 1964. The Structure of Atmospheric Turbulence. Interscience Publishers, New York.
8. Sutton, O.G. 1958. Micrometeorology. McGraw-Hill Book Co. Inc., New York.

Orchard Sprayers: How Much Spray Moves Out of the Orchard?

R.D. Fox, D.L. Reichard and R.D. Brazee, USDA, Agricultural Research Service, Department of Agricultural Engineering
F.R. Hall, Department of Entomology

Introduction

In the United States, most pesticides and plant growth regulators are applied to fruit trees and grapes with air blast sprayers. Many fruit crops are sprayed several times during the growing season to protect trees and their fruit from pest damage. Some spray never reaches fruit or foliage and falls to the ground or is carried out of the orchard by the wind, as drift. Spray missing the trees is not only wasted expense for growers, but is also a possible source of environmental pollution including ground water contamination.

Most spray drift research has centered on aircraft or ground operated, boom sprayer applications. Few studies of drift from orchard air sprayers have been reported. Herrington, *et al.* (1981), Randall (1971) and Whitney, *et al.* (1989) all reported studies of spray deposition on trees. MacCollom, *et al.* (1986) compared drift from an orchard sprayer with drift from fixed wing aircraft. They reported that in most trials, drift from the air sprayer was less than from an aircraft sprayer. However, in one trial, a temperature inversion resulted in significantly greater drift at 50 m downwind from the orchard with the air sprayer.

Tracers used for measuring spray deposit include copper, salts, color and fluorescent dyes, and active pesticides. Spray deposits have been collected on foliage, cards, plastic sheets, paper tape, string, bottles and other targets.

Whitney and Roth (1985) compared string collectors with paper tape as a technique for measuring spray deposits containing fluorescent. They found that strings produced greater fluorometer readings than paper tape. Carpenter, *et al.* (1983) used bottles to collect airborne spray from a row-crop air sprayer.

Riley and Wiesner (1989) measured drift from an orchard sprayer using water sensitive cards, stainless steel plates, rotorod samplers, and arrays of horizontal wires. They used delta methrin as the trace material. Both sides of the downwind row were sprayed in four trials and the outside four rows were sprayed in a 5th trial. They found that ground deposits decreased rapidly with increased distance from the sprayer; no ground deposits were measured beyond 325 ft (100 m). About 0.32 percent of the spray was still airborne at 165 ft (50 m) downwind.

Fox, *et al.* (1990) attempted to collect all of the spray from an orchard sprayer. They measured ground deposits from the sprayer to a vertical collection rack 15 ft away from the sprayer; and airborne spray with the collection rack. The rack, with no obstruction between it and the sprayer, contained 6.6 ft (2 m) long strings at 3.3, 6.6, 9.8, 13.1, and 16.4 ft (1, 2, 3, 4, and 5 m) levels. By summing total deposit on the ground collectors and airborne spray deposited on the strings, they accounted for about 75 percent of the total spray material.

The objective of this study was to measure the deposition pattern of spray material produced by an orchard sprayer and to compare several types of spray collectors. Only spray material deposited on the ground and that remaining airborne in the test area downwind from the orchard was measured; no attempt was made to measure deposit on trees.

Materials and Methods

These experiments were conducted in a plot of dwarf apple trees at Wooster, OH. Figure 1 is a drawing of the orchard and surrounding region including locations of sample collectors that were used for the 1988 experiments. The same site was used for the 1986 and 1987 experiments, however, some sample collectors were placed in different locations and not all of the collectors used in 1988 were used in 1986 and 1987. The orchard site was on the crest of a low ridge, with a downward of slope about 3 percent both upwind and downwind from the spray site. The upwind fetch included short grass for 440 yards then there was a road with widely scattered trees.

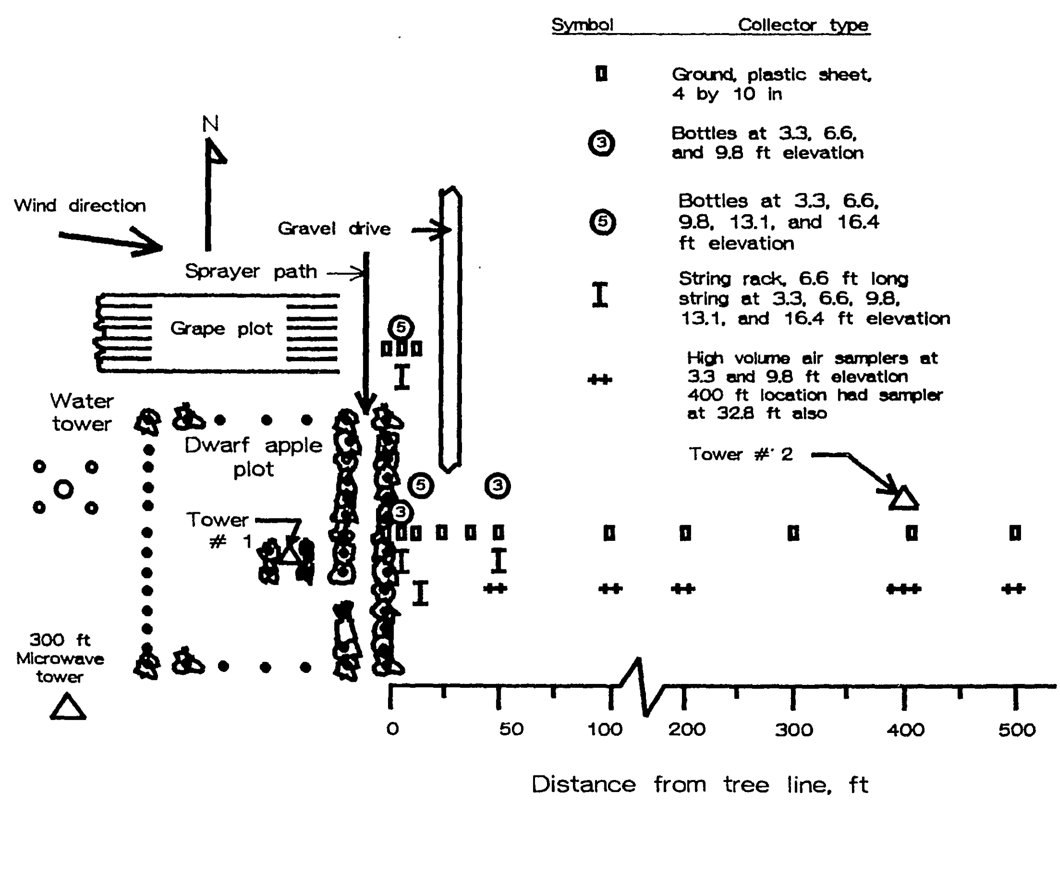
The apple trees were small with thin foliage at the time of these experiments. Plot size restricted the spray-line length, and therefore experiments could be conducted only when winds were nearly westerly (270° ± 20°). To simulate the worst case for drift, only the outside (downwind) row was sprayed using the left side of a Myers A36[1] orchard air sprayer traveling from north to south at 3 mph. The sprayer used six Spraying Systems D2-25 nozzles (operated at 130 psi) that applied 50 gal/a if both sides of the trees were sprayed.

Fluorescent tracer was used to measure spray deposit. In 1986 and 1987, Rhodamine B was mixed with water at a rate of 7.5 g of dye to 75 gallons of water; in 1988, Uvitex (Ciba-Geigy) was mixed at a rate of 38 g of dye to 50 gallons of water. The sprayer applied 79, 79 and 600 mg of dye per ft travel in 1986, 1987, and 1988, respectively.

Table 1 is a list of the dates, times and weather conditions during the experiments. The instrument trailer, microclimate instrument towers, and collector supports were in place approximately six weeks each year but only one working day each year had suitable wind conditions. The 1987 and 1988 locations of the microclimatic instrument towers are shown in Figure 1. Instruments on Tower 1 were: a 3-propeller anemometer at 18.7 ft elevation, eight shielded thermocouples between 0.3 ft and 14 ft, and a dew-point hygrometer and aneroid barometer at 5 ft. Instruments on Tower 2 were: a bivane anemometer

[1]Reference to a proprietary product or company is for specific information only and not to imply approval or recommendation of the product by the U.S. Department of Agriculture or The Ohio State University to the exclusion of others that may be suitable.

Figure 1. 1988 spray drift experimental site.



and miniature thermocouple at 33 ft, and eight shielded thermocouples between .3 and 14 ft. Microclimate data at each tower were sampled at 10-second intervals, averaged over one minute, and recorded on the Campbell Scientific Model 21X datalogger located at each tower.

Locations of spray drift collectors used in the 1988 experiment are shown in Figure 1. Ground collectors were 10 mil plastic sheets, 4 x 10 in; most locations were used all three years. In all three years, glass microscope slides were mounted at 3.3 ft (1 m) above the ground at 10 and 15 ft from the center of the tree row. Three slides were mounted vertically with about six-inch horizontal separation.

Bottles and string collectors were used to sample airborne spray. Bottles were mounted horizontally with the open end toward the sprayer at elevations of 3.3, 6.6, and 9.8 ft (1, 2 and 3 m) at some locations and at 3.3, 6.6, 9.8, 13.1 and 16.4 ft (1, 2, 3, 4, and 5 m) at other locations. In 1986 and 1987 bottles were placed at only 1, 2, and 3 m elevations.

In 1988 strings were mounted horizontally on four frames designed to hold 6.6 ft (2 m) long collectors at elevations of 3.3, 6.6, 9.8, 13.1, and 16.4 ft (1, 2, 3, 4, and 5 m). The string was undyed, six strand floss with a diameter of approximately 0.04 in. In 1986 and 1987 only two short samples of string were used.

In all three years, Staplex high-volume samplers with 4 in diameter, cellulose filters were used to collect spray samples at greater distances from the spray line, cf. Figure 1. Staplex samplers were positioned at 3.3 and 9.8 ft (1 and 3 m) elevations at all locations, except for the 400 ft location, (700 ft in 1986), where an additional sampler was mounted at 32.8 ft (10 m) elevation. Assuming slug flow, air velocity through these filters was about 3.5 mph.

Deposit samples were collected after each sprayer pass. Experimental procedure was as follows: collectors were placed, sampling blowers started, and the row of trees sprayed. After a 5-minute delay to allow spray material not collected to move out of the area, sampling blowers were stopped, the exposed collectors removed and placed in bottles, and clean collectors mounted. Meteorological data were collected during the entire experiment. Four sprayer passes were made in 1986, two passes in 1987 and six passes in 1988.

After exposure in the field, collectors were placed in glass bottles and stored in a cool, dark place until analyzed. Samples were prepared for analysis by adding distilled water to a bottle containing the collector and shaking the bottle. Then a 5 cc sample of the wash water was placed in a Turner model 112 fluorometer and the fluorescent intensity measured.

Results

Weather: Synoptic weather data for the time period of each sprayer pass are summarized in Table 1 for all three years. Wind direction at the spray line was $270^{\circ} \pm 20^{\circ}$, which was acceptable for the experimental deployment. Mean windspeed for the experiments was generally between 5 to 10 mph. Relative humidity varied from year to year, but was typical for Ohio; ambient temperature was about 50°F for most of the spray passes.

Deposits on glass slides, in bottles, and on strings: Between each experimental season, we improved procedures and techniques and modified collectors; however, glass slides and bottles were used all three years. Table 2 shows the amount of fluorescent tracer deposited on the slides and in bottles for 1986, 1987, and 1988. Because less fluorescent material per gallon of spray was applied in 1986 and 1987, measured deposits for these years were multiplied by 296/25, the ratio of the application rates. In 1986 some slides were also mounted horizontally, however, these slides collected only about one-third as much tracer as slides mounted vertically.

In nearly all measurements, year-to-year variation was about as expected. We have frequently found large differences between deposits on closely spaced collectors sprayed by orchard sprayers. For example, consider deposit data on slides in Table 2: the slides at both 10 feet and 15 feet from the tree row were about 6 inches apart. Therefore, the 1986 line 1 value of $1790 \mu g/m^2$ was the mean deposit collected on these slides for three sprayer passes; the line 2 value of 2230 was the mean deposit collected on three slides about 6 inches south of the slides of 1 for the same three sprayer passes. There was a difference of 20 percent in spray deposited on two slides 6 inches apart. Year-to-year differences shown in the table are only slightly greater than this.

Bottle deposits for 1986 and 1987 seemed to indicate that the most spray was collected at the 3.3 ft (1 meter) elevation and that deposit steadily decreased as height increased. This result was true for all three locations in both years. This was also true for the 15 and 50 foot locations in 1988, but at 10 feet location, deposit at the 9.8 ft (3 meter) elevation was greater than deposit

Table 1. Weather during drift experiments.

Day	Time	Air temperature ^{0}F	^{0}C	Wind mph(m/s)/ direction	Relative humidity %	Cloud cover
1986/NOV/17	1400-1600	50	(10)	6-8 (2.5-4)/258^0	68	Hazy, mostly cloudy
1987/OCT/29	1400-1500	50	(10)	6 (2.5)/260^0	45	Mostly cloudy to overcast
1988/OCT/13	1000-1600	37-46	(3-8)	4-9 (2-4)/280^0	50	Mostly cloudy to overcast

Table 2. Spray deposit on glass slides, glass bottles and on 6.6 ft long strings, μg/m^2.

Distance from tree ft	Position No.	Height ft	Slides 1986[1]	Slides 1987[1]	Slides 1988	Height ft	Bottles 1986[1]	Bottles 1987[1]	Bottles 1988	Bottles 1988	Height ft	String 1988	String 1988
10	1	3.3	1790	2620	2270	3.3	5200	3140	3,470		3.3	10,040	
	2	3.3	2230	3070	2050	6.6	3150	2980	2,940		6.6	13,420	
	3	3.3	2740	3070	2476	9.8	2940	2090	4,230		9.8	7,690	
											13.1	3,340	
											16.4	1,800	
15	1	3.3	2600	3270	3010	3.3	4660	2740	11,690	5940	3.3	9,880	4560
	2	3.3	2830	3760	2450	6.6	2370	2400	7,490	3580	6.6	5,170	3920
	3	3.3	1260	3470	2810	9.8	2170	1830	2,980	2240	9.8	4,060	2640
						13.1			1,540	2010	13.1	2,770	1160
						16.4			960	720	16.4	1,960	1560
50						3.3	620	460	960		3.3	1,200	
						6.6	580	460	890		6.6	1,090	
						9.8	480	300	810		9.8	820	
											13.1	530	
											16.4	370	

[1]1986 and 1987 measured values multiplied by 11.4 to adjust for amount of fluorescent dye used in spray tank mix.

These collectors were not behind trees.

1986 results were mean of 4 measurements;
1987 results were mean of 2 measurements;
1988 results were mean of 6 measurements.

at either 3.3 or 6.6 ft (1 or 2 meter) elevations. This irregular result was caused by two of the six passes where deposit was 2 and 3 times the deposit on the other four passes. The standard deviation of bottle deposits was greater than other collectors, this may be due to the small size of the bottle opening.

The amount of fluorescent dye deposited on the string collectors (only used in 1988) at 10 feet from the trees was much greater than the amount deposited on bottles at that distance. However, at the other three locations, similar amounts of dye were deposited on string and bottles.

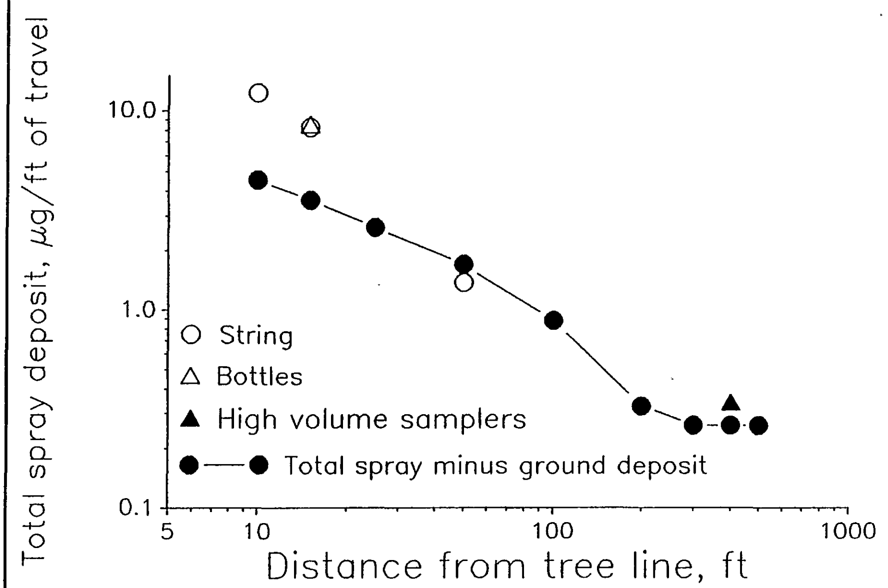
For both bottles and strings at 15 feet from the tree line, more dye was found on collectors behind the tree row than on collectors in the open. Because the results persisted for six passes, it is difficult to dismiss these results as experimental variation. One explanation might be that the air jet from the sprayer interacted with the tree to produce turbulent flow that transported spray particles past the collectors several times before the spray was carried away from the collectors by the wind. If we could understand what happened and incorporate that action within a tree, perhaps deposit could be increased.

Airborne spray: In Figure 2, we have plotted results that attempt to account for spray as it is carried downwind in the 1988 experiments. Starting at the sprayer, deposit on each ground collector was multiplied by the ground surface area it represented to calculate total spray falling on the ground. This total ground deposit was subtracted from the total spray produced by the orchard sprayer; these values should be the amount of spray still airborne beyond each ground collector. These values are plotted on Figure 2 as the filled circles connected with a line.

Past studies (Harrington *et al*, 1981) have measured tree deposits on dwarf hedgerow apple trees sprayed with an air-blast sprayer at 60 gal/a. This study reports that about 60 percent of the spray was retained on the trunk, branches, shoots and leaves. On other tree-types, they found about 22 percent of the spray was retained on the total tree. Of course, the amount retained is affected by the sprayer, tree size and shape, wind, and other factors. For purposes of Figure 2, we assumed 40 percent of the spray was deposited on the trees. Considering the large sprayer used in these experiments and the small trees, this estimate may be high.

Total airborne spray collected on strings (circles) and bottles (triangle) were summed from the ground to 19.7 ft (6 m) elevation; high volume sampler deposits (filled triangle) were summed from the ground to 65.6 ft (20 m) elevation. As mentioned in the section on slides, bottles and string, collectors at 10 and 15 ft from the spray line collected samples that indicated more total spray than the sprayer produced. At the 50 ft location, total deposit was 20 percent less than expected while

Figure 2. Effect of distance from sprayed tree row on expected airborne spray compared to measured spray in vertical planes, 1988. String and bottle deposits were summed from 0-20 ft elevation; high volume samplers were summed from 0 to 66 ft elevation. We assumed 40 percent the of spray was deposited on trees.



at the 400 ft location about 50 percent more spray was collected than was expected. Part of this difference may be due to the height over which the deposit was summed. At 50 ft, we measured deposits at 3.3, 6.6, 9.8, 13.1, and 16.4 ft (1, 2, 3, 4, and 5 m) elevations and summed from 0 to 19.7 ft (0 to 6 m); at 400 ft, we measured deposit at 3.3. 9.8 amd 30.5 ft (1, 3, and 10 m) elevations and summed from 0 to 65.6 ft (0 to 20 m). Spray still airborne at 400 feet from the tree row was estimated to be about 3.6 percent of the total amount sprayed.

Ground deposits: Figure 3 is a plot of deposit on ground collectors as a function of distance from the sprayer for the 1986, 1987, and 1988 experiments. The measured deposits for 1986 and 1987 were corrected for the increased fluorescent dye concentration in the tank mix used in the 1988 experiments. Less deposit was collected in 1986 and 1987 at all distances less than 300 ft. There is no obvious reason for this difference. However, our analysis procedures were better in 1988, so that data should be more reliable. At distances greater than 300 ft, deposit in 1986 and 1987 was near the minimum detectable values for measuring fluorescence. However, when these small values were multiplied by 11.4 to correct for 1988 spray concentration, they appeared greater than values measured in 1988. The 1988 results were somewhat above minimum detectable levels and should be more accurate. The R^2 value for the linear regression in log-log coordinates is 0.92.

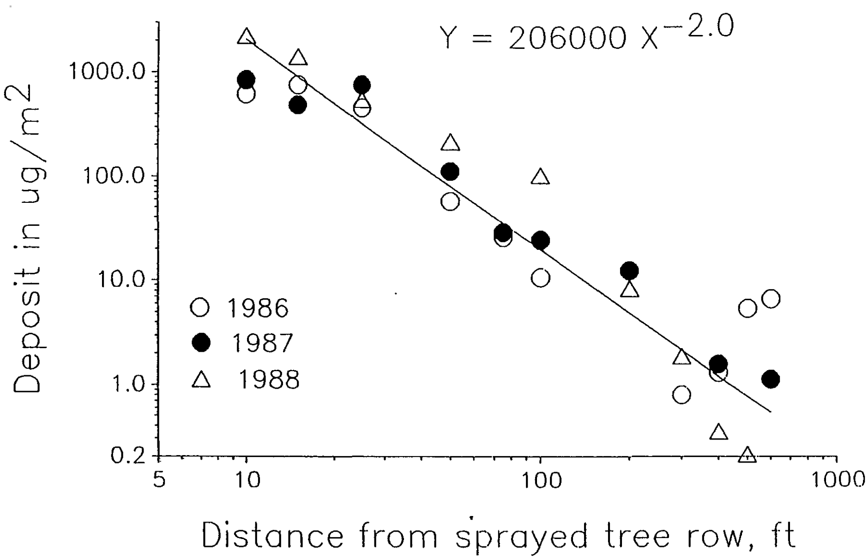


Figure 3. Effect of distance from sprayed tree row on deposits on ground in 1986, 1987, and 1988. The solid line is a linear regression in log-log coordinates with an R value of 0.92.

From the slope of the data points, we can see that ground deposit decreased rapidly and that beyond 400 ft, little spray was being deposited on the ground. Fox, *et al.* (1990) reported that less than 0.03 percent of the total amount sprayed was deposited between 400 and 500 ft. If the ground deposit decreased at this same rate at greater distances, we would expect less than 0.1 percent of the total amount sprayed to be deposited on the ground between 500 and 1000 ft.

Discussion

Spray deposit on the ground is likely to decrease significantly beyond 100 ft from the spray line. Most drops larger than 150 μm in diameter will fall to the ground from a 20 ft height within about 10 seconds. In this time, at, e.g., 60 percent relative humidity (RH), evaporation will reduce drop diameters from 150 μm to about 100 μm diameter. But with a wind velocity of 10 mph, in 10 seconds, 150 μm drops will be transported about 150 ft. So most drops larger than 150 μm diameter will fall to the ground within 200 ft of the spray line.

Water in the spray mix will evaporate from most drops less than 50 μm diameter before these drops reach 400 ft downwind. For example, 50 μm diameter drops fall at a rate of 0.25 ft/sec. From a 10 ft height (and with no evaporation), 50 μm drops will reach the ground in 40 seconds. But, with 60 percent RH, in about 6 seconds they will evaporate to only involatile residue.

Water will evaporate from drops between 50 and 150 μm diameter, reducing their size, but, depending on the RH, some of these drops will still retain water at 100 ft from the spray line. These drops, greatly reduced in size, are the portion of the spray cloud most likely to be deposited on the ground between 100 and 400 ft. Unless relative humidity is above 80 percent, most drops in the 50 to 150 μm size range are likely to evaporate to a small residue particle by 400 ft downwind.

Summary

1. Under the conditions of this experiment, it is estimated that spray deposited on the ground between 500 and 1000 ft is less than 0.1 percent of the material released.
2. About 3.5 percent of the released spray was still airborne at 400 ft from the spray line.

References

1. Carpenter, T.G., D.L. Reichard, and A.S. Khan. 1983. Spray deposition from a row-crop airblast sprayer. Transactions of the ASAE 26(2)338-342,348.
2. Fox, R.D., R.D. Brazee, D.L. Reichard, and F.R. Hall. 1990. Drift from an orchard air sprayer. Accepted for publication in Transactions of the ASAE.
3. Herrington, P.J. H.R. Mapother and A. Stringer. 1981. Spray retention and distribution on apple trees. Pesticide Science 12:515-520.
4. MacCollom, G.B., W.W. Currier, and G.L. Baumann. 1986. Drift comparisons between aerial and ground orchard application. J of Econ Entomology 79(2)459-464.

5. Randall, J.M. 1971. Relationships between air volume and pressure on spray distribution in fruit trees. J of Agri Engr Research 16(1)1-31.
6. Riley, D.M., and C.J. Wiesner. 1989. Off-target pesticide losses resulting from the use of an air-assisted orchard sprayer. Proc. Tenth Symposium on Pesticide Formulations and Application Systems, Denver, CO, ASTM, Philadelphia, PA 19103-1187.
7. Whitney, J.D., M. Salyani, D.B. Churchill, J.L. Knapp, J.O. Whiteside, and R.C. Littell. 1989. A field investigation to examine the effects of sprayer type, ground speed and volume rate on spray deposition in Florida citrus. J Agric. Engineering Research. 42:275-283.
8. Whitney, R.W. and L.O. Roth. 1985. String collectors for spray pattern analysis. Transactions of the ASAE 28(6):1749-1753.

Influence of Pruning Treatments on Mature Spur-Bound 'Starkrimson Delicious' Apple Trees

D.C. Ferree, J.C. Schmid, J.R. Schupp and I.J. Warrington
Department of Horticulture

Introduction

Since the discovery of a spur-type mutation of 'Delicious' apple in 1951, and numerous additional ones since that time, most plantings of 'Delicious' have been spur-type strains. In the most recent survey (8) 'Delicious' accounts for more than 30 percent of Ohio's apple trees and in recent years nearly all the 'Delicious' planted were spur types. As spur-type 'Delicious' trees age, heavy crops or environmental conditions, such as winter injury, influence growth. Many of the trees nearly cease producing extension shoots, and spurs proliferate and become smaller and weaker (spur-bound condition). The trees develop characteristics of senescent trees, often becoming spur-bound at a relatively young age. Spur-bound trees tend to have small fruit, and this condition may be compounded because the trees often overcrop and are difficult to thin chemically.

Recent work has shown the localized importance, particularly early in the season during fruit cell division, of strong, high-quality spurs. Spurs with large leaf areas, large buds result in good fruit set, satisfactory fruit size and high fruit Ca levels (3,4). Later in the season, following cell division and during the cell expansion phase of fruit growth, shading (9) and summer pruning studies (7,10) indicate that shoot leaves are important contributors to fruit size and quality. In mature spur-bound 'Starkrimson Delicious' trees, fruit size declined from the top to the bottom of the canopy and the characteristics of spur quality followed the same pattern (2). Spur pruning of these 25-year-old trees was not sufficient to increase shoot growth or improve spur quality, but heading back into 2-year-old wood plus spur pruning increased the number of shoots and total shoot leaf area of 13-year-old 'Red Chief Delicious' trees (2). Heading of the younger trees increased leaf area of both shoots and spurs and spur pruning also increased leaf area/spur. Heading pruning increased average fruit weight, and the increase was positively correlated with total leaf area, shoot leaf area, and number of shoot leaves/cm branch circumference.

Using the above as background, a series of whole tree treatments was initiated on 25-year-old spur-bound 'Starkrimson Delicious' trees. The main objective was to determine if pruning could be an effective and economical correction of the spur bound condition.

Materials and Methods

The study was conducted on three east-west rows of 25-year-old 'Starkrimson Delicious'/seedling rootstock trees planted 10 x 30 feet in a large commercial orchard near Pataskala, Ohio. Prior to application of the treatments all trees in this block had been unformily pruned every other year. The following six treatments were applied in March of 1986: 1) unpruned—the trees were not pruned except to remove broken limbs; 2) minimal pruning—watersprouts, broken limbs and minor thinning out cuts were made to remove hanging limbs or complex spur systems; 3) heading—numerous heading cuts were made in the spur complexes on each scaffold limb, particularly in the lower two-thirds of the tree in addition to the minimal pruning described above; 4) chain saw—three to four large chain saw cuts per tree were made in an effort to open the tree, particularly in the upper portion of the canopy; 5) heading and chain saw combination; 6) spur pruning—consisted of removing 30 percent of each spur complex over the entire tree; 7) palmette leader—in the following year this treatment was added and consisted of removing by chain saw all the upper tier of scaffold limbs on either side of a N-S palmette in the top of each tree following the guidelines proposed by the originators of this pruning concept (1,5,6). In 1987 and 1988 all trees except the unpruned received a very minimal pruning, removing only broken branches and interior watersprouts. Due to the natural variability of trees of this age, 15 replicate trees were selected for uniformity received each pruning treatment, randomized over the three rows.

In 1986, representative limbs in the lower third of the canopy were tagged and bloom counted. In early September well after terminal buds had formed, shoot leaves and spur leaves were counted on these limbs to determine if the treatments had affected the relative distribution of leaf type. On June 19, a 1 m line quantum sensor (LiCOR) was used to measure light transmission on six representative trees of each system on the North and South sides of the canopy. The sensor was placed at the mid-point in the upper and lower half of the canopy. Within each canopy level, three readings were taken at the mid-point in the canopy thirds beginning at the trunk and proceeding to the outer edge. In 1987 and 1988, light readings were taken several times over the season on sunny days with the line sensor centered on the trunk at a height of 1.2 meters at the mid-point between the trunk and canopy edge on the north, south, east, and west sides of all 15 trees of each system. The readings were taken between 10:00 a.m.-12:00 p.m.

Annual yield per tree was estimated from the portion of an 18 bu bin filled by each tree. The combined yield from each treatment was stored and size distribution determined by grading each treatment separately. The size distribution classes differed slightly each year, but are similar enough to assess the overall influence of the treatments.

Results and Discussion

There was no statistical separation among treatments on fruit set or distribution of leaf types within the canopy (Table 1). There appeared to be a trend for heading to reduce fruit set slightly, but the other factors measured did not show significant trends. This confirms findings from an earlier study (2) that demonstrated that pruning caused a greater change in production of shoot growth and spur quality of 13-year-old compared to 25-year old spur bound 'Delicious' trees.

In June 1986, light transmission within the canopy was higher on the south side and top of the canopy compared to the north side and bottom half of the canopy. Generally, light increased from the inside toward the outside of the canopy at both levels (Table 2). Except for the chain saw treatment measured in the top, the inside of the canopy close to the trunk had very low light levels that were well below the 30 percent transmission threshold desirable for flower initiation and photosynthesis.

In subsequent years when light measurements were taken several times over the season, it was clear that the treatments caused greater differences in light transmission in May compared to later in the season (Figure la). In May of 1987, spur pruning and unpruned trees had the lowest light values, as expected, while trees pruned as palmette leaders in 1987 had relatively high light transmission that persisted over the season. Using the chain saw at random rather than purposely

Table 1. Influence of 1986 pruning treatments on fruit set and canopy development[1] of mature 'Starkrimson Delicious'/ seedling trees.

Pruning treatment	Fruit set %	Distribution/cm^2 limb area: spurs	shoots	fruit	Leaf area (cm^2): spur	shoot	Leaf Ratio spurs/shoot
Unpruned	17.1	.17	.326	1.9	10.8	16.8	9.8
Minimal Pruned	17.6	.15	.004	1.7	14.5	17.7	11.7
Heading	13.7	.11	.011	1.0	12.1	18.0	6.2
Chain saw & Heading	14.4	.16	.003	1.7	12.2	15.7	12.8
Spur pruning	16.2	.18	.005	2.3	10.4	22.1	3.7
Chain saw	16.5	.17	.010	1.8	12.0	21.4	4.6
LSD 0.05	8.3	.04	.252	0.9	2.3	4.5	8.4

[1]Data collected from representative limb in lower canopy of each of 15 trees/treatment.

Table 2. Influence of 1986 pruning treatments on light transmission on June 19, 1986 in mature 'Starkrimson Delicious' trees.

Pruning Treatment	Top: inside	mid	outside	Bottom: inside	mid	outside
Unpruned	8.2	20.1	42.5	6.7	9.7	18.9
Minimal pruning	7.4	13.7	30.4	3.9	13.8	21.3
Heading	13.7	20.7	28.9	3.6	12.1	26.1
Chain saw + heading	9.1	23.6	47.7	5.4	12.1	18.3
Spur pruning	10.3	21.2	30.7	5.1	7.8	17.1
Chain saw	23.8	18.0	33.8	10.1	11.1	26.7
LSD .05			10.5			

removing two sides of the tree as in the palmette leader, resulted in a much smaller improvement in light transmission even though approximately the same amount of wood was removed. In 1988 with little additional pruning and an added year of growth the effect of pruning treatments on light transmission was much smaller (Figure 1b). The palmette leader treatment again looked good having higher transmission values in May and September than most of the other treatments. In observing the trees, it appeared that the chain saw and heading treatment resulted in increased shoot and watersprout growth which caused some reduction in light transmission.

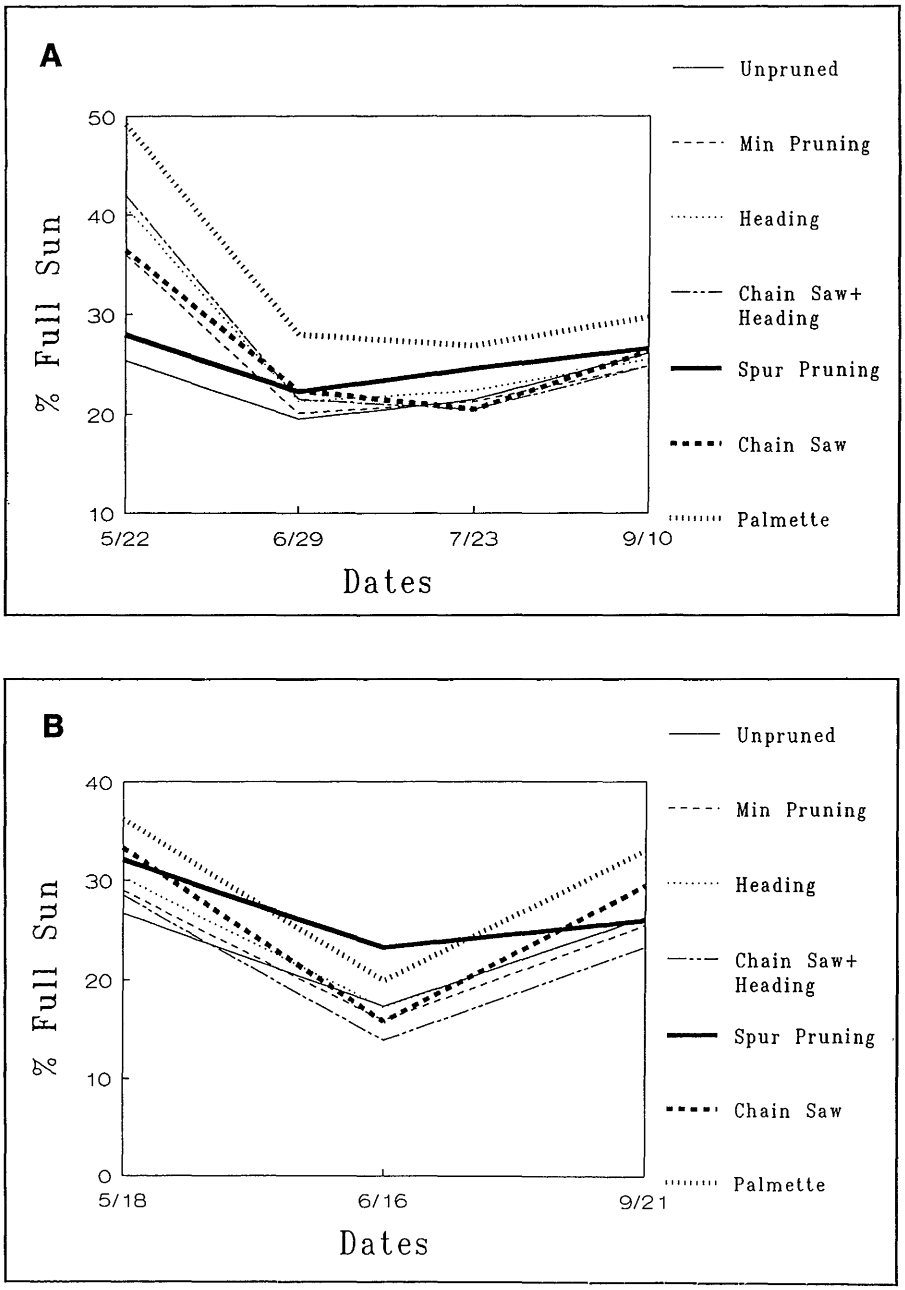


Figure 1. Influence of 1986 pruning treatments on % light transmission over the season in mature spur-bound 'Starkrimson Delicious' in 1987 (A) and 1988 (B). (Values are an average of 4 readings/tree on 15 replicate trees).

The trees were planted in east-west rows with only 10 feet between trees on seedling rootstock, and it was obvious that tree to tree competition was causing a reduction in light transmission (Figure 2a,b). In 1987, the east side of the tree had higher light transmission than the west (Figure 2a), while this effect was not as visible in 1988 (Figure 2b). Normally light measurements were made in the late morning and this could have partially explained this response. Light transmission on the North and South sides of the canopy were very similar except in September of both years.

In 1986, yields were low on the unpruned trees and those pruned with a chain saw, while in 1987 and 1988 the unpruned trees had higher yields than those in any of the other treatments (Table 3). Trees with a significant amount of their canopy removed in the chain saw and palmette leader treatments tended to have low yields in both 1987 and 1988. All pruning reduced cumulative yield and the more severe the pruning, the greater the reduction.

Since the purpose of this study was to improve fruit size on spur-bound trees, the weight of fruit in the largest size class each year was added together. A 30 to 89 percent increase in large size fruit resulted from these pruning treatments (Table 3). Heading and palmette leader pruning resulted in the largest increase in large fruit and spur pruning resulted in the smallest benefit. The beneficial effect of heading on fruit size in spur-bound trees was shown previously (2) to be related to an increase in shoots in proximity to fruit which produced an increase in size during the cell expansion phase of growth. The contribution of shoot leaves to fruit growth has been shown in several studies (7,9,10,11). Heading did require considerable time and thus pruning to palmette leaders would be more efficient. In this study the increase in fruit size was also likely attributed to the yield reduction.

The pack-out data from each treatment are shown in Tables 4, 5, and 6 and it should be noted that different size classifications were used each year depending on market demands. In an attempt to summarize the effect of the treatments, fruit smaller than 2¼ and culls were added in one class and called juice and fruit in between this class and the largest class were added and referred to as medium (Table 3). Unpruned, minimal pruned and spur pruned trees have the largest amount of medium sized fruit and juice apples. It is interesting that chain saw and palmette leader pruning had the greatest effect on reducing the amount of juice apples which bring the smallest returns.

An estimation of the overall effect of each pruning treatment can be determined by calculating the cumulative value of the yield based on the following values established for these three size classes, the cumulative value might give some estimation of overall treatment effect: Large $14.00 (42 lb. tray pack); Medium $8.00 (40 lb. bags); Juice $.045/lb. Using these figures to determine overall effect, cumulative yield is the most important factor and the unpruned, minimal pruning and spur pruning were the most profitable. The reduction in yield caused by the other treatments was not compensated for by the increase in larger higher priced apples. However, these figures may be over estimates if the cost of producing a pound of fruit is considered. If one assigns a reasonable cost of $5.50/box, then large fruit paid the grower $.17, medium $.06 and ciders lost him $.09/lb. In today's market small apples close to 2¼ may only be salable as juice. In the unpruned treatment for example, for every 10 percent of the medium-sized fruit that would be removed and sold as juice, you would remove $182.24

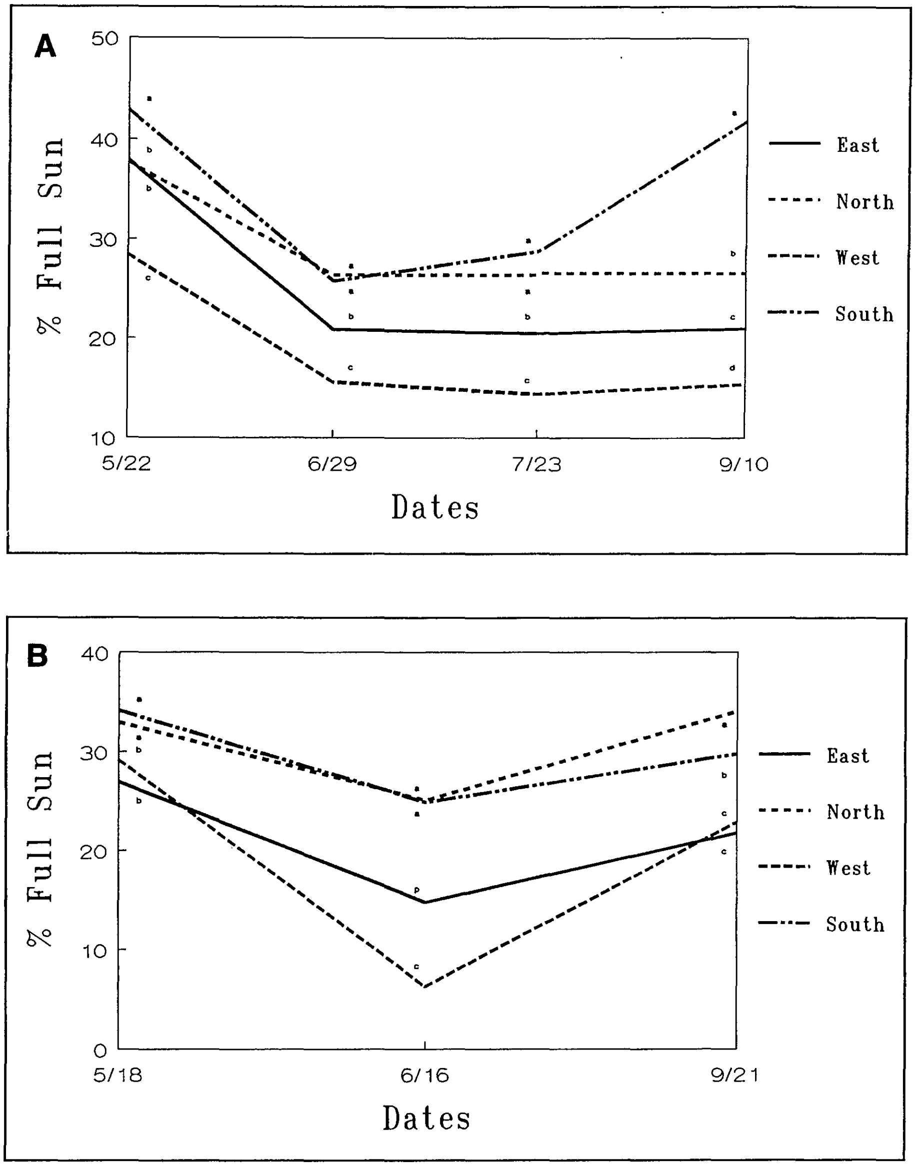


Figure 2. Distribution of % light transmission on four sides of the canopy of mature spur-bound 'Starkrimson Delicious' in east-west rows in 1987 (A) and 1988 (B). (Each value is an average from 15 replicate trees).

Table 3. Influence of 1986 pruning treatments on average yield/tree of mature 'Starkrimson Delicious' trees.

Pruning treatment	Yield (lbs/tree) 1986	1987	1988	cum.	Average pruning time/tree (min)	Cumulative Fruit Weight (lbs/15 trees) largest species	medium size class	juice fruit	Relative%[3] Large size	Med. size	Juice size	Value $[2]
Unpruned	186bc	398a	531a	1115	0	1954	11796	2623	100	100	100	3085.14
Minimal pruned	—	317b	408b	1087[1]	8.3	3219	9734	2986	164	82	113	3082.63
Heading	203abc	262bcd	398b	863	13.5	3696	7494	1947	189	63	74	2736.27
Chain saw & heading	207ab	272bc	267c	746	17.30	2773	8531	1690	142	72	64	2644.96
Spur pruning	256a	287bc	393b	936	26.5	2552	11643	2522	130	98	96	3236.04
Chain saw	138c	242cd	274c	654	2.7	3286	7094	1203	168	60	45	2495.24
Palmette leader	—	196d	264c	690[1]	3.0	3526[1]	7314[1]	1320[1]	180	62	50	2619.17

Means separated by Duncan's Multiple Range, P=.05.
[1]Calculated using the average of 2 years for the missing value.
[2]Value=large $14.00 tray ($.31/lb); medium=$8.00 bag ($.20/lb); juice=$.045/lb.
[3]Fruit size values for the unpruned treated as 100% and the relative percentage calculated for other treatments.

Table 4. Influence of 1986 pruning treatments on fruit size distribution of mature 'Starkrimson Delicious' trees in 1986.

Treatment	Total Weight for 15 Trees (lbs) >3"	2 5/8-3"	2 1/4-2 5/8"	Under 2 1/4"	culls	total	% Distribution >3"	2 5/8-3"	2 1/4-2 5/8"	Under 2 1/4"	Culls
Unpruned	184	1320	900	76	227	2707	6.7	48.7	33.2	2.8	8.3
Minimal pruning	200	1240	1086	92	454	3072	6.5	40.3	35.2	2.9	14.7
Heading	240	1200	1068	160	227	2895	8.2	41.4	36.8	5.5	7.8
Chain saw & heading	184	1320	765	68	302	2639	6.9	50.0	28.9	2.5	11.4
Spur pruning	320	2080	1787	224	378	4789	6.6	43.4	37.3	4.6	7.9
Chain saw	272	1040	678	52	151	2193	12.4	47.4	30.9	2.3	6.9

Table 5. Influence of 1986 pruning treatments on the fruit size distribution of mature 'Starkrimson Delicious' trees in 1987.

	Total Fruit Weight for 15 Trees (lbs)						% Distribution				
Treatment	$>2\frac{3}{4}+$	$2\frac{3}{4}$	Bags	Under $2\frac{1}{4}$"	culls	total	$>2\frac{3}{4}+$	$2\frac{3}{4}$	Bags	Under $2\frac{1}{4}$"	Culls
Unpruned	720	1360	3600	360	240	6280	11.4	21.6	51.3	5.7	3.8
Minimal pruning	1540	1600	3000	160	480	6780	22.7	23.5	44.2	2.3	7.0
Heading	1320	1400	1010	120	320	4170	31.6	33.5	24.2	2.8	7.6
Chain saw+heading	1380	1660	3150	80	320	6590	20.9	25.1	47.7	1.2	4.8
Spur pruning	960	1440	3400	240	720[1]	6760	14.2	21.3	50.2	3.5	10.6
Chain saw	560	880	2840	120	80	4480	12.5	19.6	63.3	2.6	1.7
Palmette Leader	860	1120	2180	80	160	4400	19.5	25.4	49.5	1.8	3.6

[1]Most cullage attributed to picker bruising.

Table 6. Influence of 1986 pruning treatments on fruit size distribution of mature 'Starkrimson Delicious' trees in 1988.

	Total Fruit Weight for 15 Trees (lbs)					% Distribution			
Treatment	$>2\frac{3}{4}$"	$2\frac{1}{4}$-$2\frac{3}{4}$"	Under $2\frac{1}{4}$"	culls	total	$>2\frac{3}{4}$"	$2\frac{1}{4}$-$2\frac{3}{4}$"	Under $2\frac{1}{4}$"	Culls
Unpruned	1050	4616	840	880	7386	14.2	62.4	11.3	11.9
Minimal Pruning	1479	2806	520	680	5487	26.9	51.1	9.4	12.3
Heading	2136	2816	400	720	6072	35.1	46.3	6.5	11.8
Chain saw & heading	1209	1636	160	760	3765	32.1	43.4	4.2	20.1
Spur Pruning	1272	2936	240	720	5168	24.6	56.8	4.6	13.9
Chain saw	2454	1656	160	640	4910	49.9	33.7	3.2	13.0
Palmette Leader	1491	1576	160	480	3707	40.0	42.5	4.3	12.9

from the figure. A 20 percent shift would result in the value of fruit from the unpruned 15 trees being $2,720.16 which is very close to the value of the heading or palmette leader treatments. These manipulations do not account for the difference in time required for these two pruning treatments.

In summary, this series of pruning treatments demonstrate that fruit size on old spur-bound 'Starkrimson Delicious' trees can be improved but significant reductions in yield occur. These reductions may be justified if the bag market for very small fruit disappears. The grower with trees of this age and condition should also consider the option of replanting a portion with a modern intensive orchard with a superior coloring strain and potential for long-term fruit size improvement. Considering the time investment the palmette leader shows much promise in maintaining the economic viability of trees in this condition. The trees in this study did not usually have a strong central leader framework, but more likely were closer to a multiple leader or open center tree which are much more difficult to convert to a palmette leader. The type of tree in this study requires removal of much more wood to achieve the desired shape then converting a well structured central leader tree.

Literature Cited

1. Belmont, G. 1988. Putting palmette to the test. Grower. Feb. 46-56.
2. Ferree, D.C. and C.G. Forshey. 1988. Influence of pruning and urea sprays on growth and fruiting of spur-bound 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 113(5):699-703.
3. Ferree, D.C. and J.W. Palmer. 1982. Effect of spur defoliation and ringing during bloom on fruiting, fruit mineral level and net photosynthesis of 'Golden Delicious' apple. J. Amer. Soc. Hort. Sci. 107:1182-1186.
4. Jones, H.G. and T.J. Samuelson. 1983. Calcium uptake by developing apple fruits. II. The role of spur leaves. J. Hort. Sci. 58:103-190.
5. Lakso, A.N., T.L. Robinson and S.G. Carpenter. 1989. The palmette leader: a tree design for improved light distribution. HortScience 24:271-275.
6. Lakso, A.N. and T.L. Robinson. 1987. Tree training system improves yields. Amer. Fruit Grower 107(11):6-7.
7. Myers, S.C. and D.C. Ferree. 1983. Influence of time of summer pruning and limb orientation of vigorous 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 108:630-633.
8. Ramy, J.E. and W.F. Matthews. 1988. Ohio 1987 commercial fruit tree survey. Ohio Agric. Stat. Serv. pp. 11.
9. Rom, C.R. and D.C. Ferree. 1986. The influence of fruiting and shading of spurs and shoots on spur performance. J. Amer. Soc. Hort. Sci. 11:352-356.
10. Van der Boon, J. 1980. Prediction and control of bitter pit in apple: II. Control by summer pruning, fruit thinning, delayed harvesting and soil calcium dressings. J. Hort. Sci. 55:313-321.
11. Watson, R.L., J.J. Landsberg, and M.R. Thorpe. 1978. Photosynthetic characteristics of the leaves of 'Golden Delicious' apple trees. Plant, Cell & Env. 1:51-58.

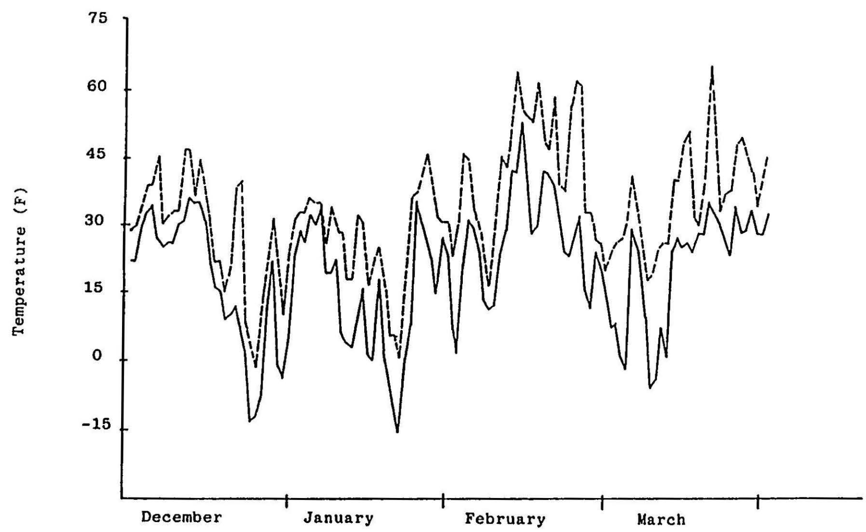
The Winter of 1983-84: A Test Winter for Ohio's Fruit Crops

Craig K. Chandler and David C. Ferree
Department of Horticulture

Introduction

The winter of 1983-84 caused significant damage to Ohio fruit crops. There were some near record-breaking low temperatures around Christmas and again during the second half of January. February was unusually warm, followed by subzero temperatures in early March (Figure 1). Winter injury symptoms in the apple, pear, peach, grape and blackberry plantings at the OARDC, Wooster, varied from misshapened fruit to death of whole plants. Considering the injury that had occurred in research plantings, the pomology faculty within the Department of Horticulture agreed that it would be useful to know the extent of injury in commercial plantings throughout the state. A survey of Ohio fruit growers was conducted during the fall of 1984. This article summarizes that survey and results of trial plantings at the OARDC at Wooster.

Figure 1. Daily minimum (———) and maximum (------------) air temperatures at the OARDC, Wooster during the winter of 1983-84



Materials and Methods

A questionnaire was sent in the fall of 1984 to each person whose name appeared on a mailing list of 1150 Ohio fruit growers. One hundred thirty-one questionnaires were completed and returned. Growers were asked to list the apple, peach, or pear scion/rootstock combinations or grape, bramble, and strawberry varieties on their farm that had been injured, in order of severity, starting with the variety combination they thought had suffered the most winter injury. Growers were also asked to indicate, beside each entry, the type of injury observed. A numbered key[1] was provided for grower convenience. Room for additional comments was provided on the questionnaire. Growers were asked to note if injury (or lack of injury) seemed to be associated with one or more of the following factors: wet or dry spots, tile drainage, light or heavy soil, raised or flat beds, or the presence or absence of mulch.

Results

Apples: Injury occurred in every region of the state, and on trees of all ages. 'Delicious', 'Golden Delicious', 'Jonathan', and 'Grimes Golden' were the cultivars most often listed as having been injured, and most suceptible to cold damage but significant injury also occurred on 'Cortland', 'Gravenstein', 'Idared', 'Melrose', 'McIntosh', 'Mutsu', 'Paulared', 'Rome', and 'Stayman'. The entire range of injury symptoms, from misshapened fruit to tree death, was reported.

From the comments written on the questionnaires, it seems that wind was a significant factor contributing to injury. Damage generally was

[1]Types of winter injury: 1) misshapened fruit; 2) poor to light crop; 3) lack of vigor; 4) unusually small leaves; 5) yellowish (chlorotic) leaves; 6) twig or branch die-back; 7) bark splitting; 8) death of whole plant (growers were asked to indicate the percentage of plants killed).

worse on north slpes, outside rows, outer (exposed) parts of trees, and on hilltops. It should be noted that the low temperatures that occurred on December 24 were accompanied by wind velocities of 30 mph or more.

Malling 7 was the rootstock most often listed as having been injured, although significant injury also occurred on trees with M.9, M.26, MM.106, MM.111, M.9/MM.106, and M.9/MM.111, and seedling rootstocks. Some growers reported that water stressed trees—either too wet or too dry—sustained the most damage. The absence of ground cover (mulch, grass, weeds, or snow) under the trees was also reported as a factor associated with winter injury. Ground covers apparently improved tree survival by slowing down the loss of heat from the upper layers of soil.

Pears: The entire range of injury symptoms was also observed on pears. Damage to spurs, resulting in light cropping, was the most common type of damage reported. In a cultivar planting at the OARDC, Wooster, trees of 'Seckel' and 'Tyson' had the best crops.

Peach: As with apples, injury occurred on peach trees in every region of the state. "No crop" was the most common questionnaire response, followed by bark splitting, lack of vigor, and tree death. In an OARDC, Wooster planting, 'Redhaven' showed less damage than the nectarine 'Redgold'. At Ohio State University's Overlook Farm near Columbus, trees on Siberian C rootstock were damaged less than trees on Lovell or Halford stocks.

Grapes: Questionnaire responses indicated tremendous damage to grapes. More damage occurred on *Vitis vinifera* and French-American hybrids than on American (*V. labrusca*) varieties, although injury and loss of plants did occur with cultivars such as 'Concord', 'Niagara', and 'Fredonia'. Injury to American types was confined primarily to young plants or weak plants growing in stressful situations (e.g., wet spots). The greatest plant loss reported occurred in 1-year-old plantings of 'Canadice' (70 percent loss), 'Reliance' (70 percent loss), and 'Himrod' (50 percent loss).

Brambles: Most blackberry plants were killed back to the ground throughout the state. The most common injury reported on raspberries was shoot and branch die-back and reduced crop.

Blueberries: Blueberry plants were reported to have come through the winter without significant damage—probably because they were heavily mulched.

Strawberries: Mulch appeared to be the key factor in plant survival. Reports were that if straw or snow was covering the plants on Christmas eve, the plants survived. If plants were not covered, then severe injury occurred.

Discussion

The exact combination of climatological events and plant physiological status that caused such severe injury to Ohio's fruit crops during the winter of 1983-84 is unknown. But, we can speculate that many plants had not attained their maximum hardiness level by December 24, when temperatures of -12 to -16°F were accompanied by high winds. Then during the unusually warm February weather, hardiness levels were probably lost, to some degree, making additional injury in March possible. (Damage that occurred in December could have also predisposed plants to damage in March.) Temperatures around the state on March 9 ranged from -1°F at Jackson to -14°F at Canfield. Domoto (1), working with apples in Iowa, determined that the December cold snap injured buds, while the March cold snap injured bark.

Conclusions

What can Ohio fruit growers do to reduce winter injury in future years? Several general recommendations are supported by the survey:

1) Avoid planting on marginal (stressful) sites.
2) Follow a cultural and pest management program that will ensure healthy plants going into the winter months.
3) Consider a ground cover (espe-cially if you are unlikely to have a natural snow cover). Allowing some weed growth under trees in late summer or early fall might be a practical solution.
4) Plant wind breaks.
5) Mulch young plants.
6) Plant hardy cultivars when possible.

Literature Cited

1. Domoto, Paul A. 1986. Winter injury effects on M.9 interstem apple trees. Compact Fruit Tree. 19:119-127.

Performance of Apple Rootstock, Cultivars and Cultural Treatments Under the Stress of the 1988 Drought

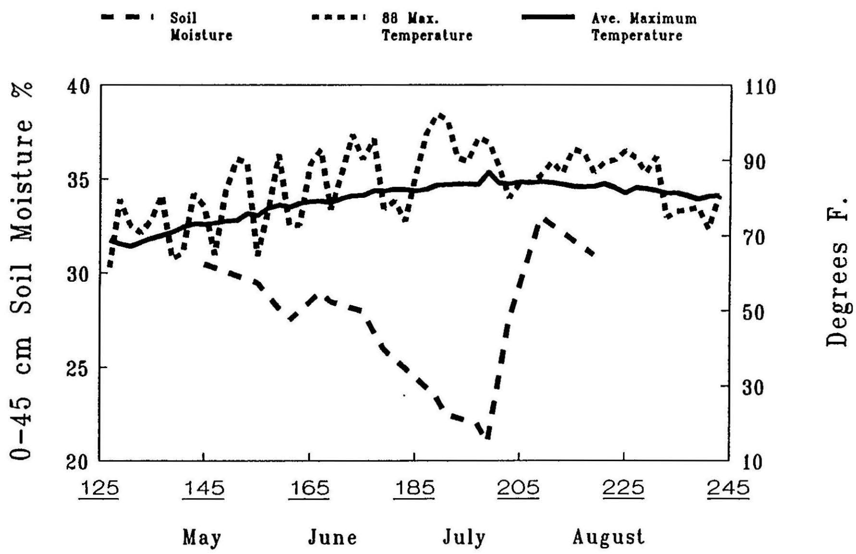
D.C. Ferree and J.C. Schmid
Department of Horticulture

Introduction

In 1988 Ohio experienced the driest spring on record with accumulated rainfall from April through June only 44 percent of normal (15). The dry conditions actually began during the first half of 1987, which had rainfall only 79 percent of normal. From September 1987 through June 1988 monthly rainfall was subnormal except in December and February when most rain would run off due to frozen soil. The 1988 planting season was particularly dry. April rainfall totaled 2.33 inches (66 percent of normal), May totaled 1.78 inches (47 percent of normal) and June had .85 inches (21 percent of normal). The drought conditions resulted in the following reductions in yields for various Ohio crops compared to the previous year: corn 30 percent, soybeans 32 percent, hay 20 percent (1).

Soil moisture measured at Wooster (14) in a conventionally tilled corn planting in a Canfield and Riddles soil series shows the continuous drying from late May until July 18 when the first significant rains fell (Figure 1). The rootstock plantings described in Experiments 2 and 3 were planted in a Canfield series soil. As is typical, the effects of the drought on plants were magnified because of the above normal temperatures that occurred (Figure 1).

Figure 1. Development of the soil moisture deficit in a Canfield soil (14) and long-term and 1988 maximum air temperature at Wooster, Ohio.



Typically, apple orchards in Ohio are not irrigated and long-term studies (3,4) have shown little benefit of irrigation under normal rainfall conditions. Thus, when severe drought conditions occur, growers are not equipped to respond. As it became evident in 1988 that a severe drought was developing, it seemed prudent to evaluate our extensive rootstock plantings to determine if some responded better than others to this stress and also to evaluate cultural techniques that might alleviate the stress. The data have been divided into seven experiments for ease of presentation.

Experiment 1: Rootstock Influence on Leaf Moisture—Ripley.

In the spring of 1986, two large rootstock plantings were established at the Ripley Branch of the Ohio Agricultural Research and Development Center. In the first planting, 20 rootstocks thought to produce semi-dwarf to semi-standard sized trees were set 9′×18′ and in the second planting, 25 rootstocks that would be more dwarfing were set 6′×16′. Trees in both studies were established in randomized blocks with the cultivars 'Lawspur Rome Beauty' and 'Macspur McIntosh' planted in rows with 10 single tree replications. Five replications of 'Redchief Delicious' were also included in both plantings. Soil management was herbicide strip with sod middles, and no irrigation was applied. On July 12, 1988, a sunny, hot day, a Li-Cor 1600 steady state porometer was used to measure stomatal conductance and transpiraton of a well exposed mid-terminal shoot leaf of each tree.

Experiment 2: Seasonal Leaf Moisture Status of 9-Year-Old Delicious Trees in the NC-140—1980 Trial.

Leaves on 'Starkspur Supreme Delicious' on nine rootstocks established in 1980 at Wooster in a randomized complete block design with 10 single-tree replications were measured with a porometer as described above on the following six dates: July 5, July 21, July 26, August 16, September 8, September 26.

Experiment 3: Seasonal Leaf Moisture Status of 5-Year-Old Delicious Trees in the NC-140 1984 Trial.

Leaves on 'Starkspur Supreme Delicious' on 17 rootstocks established in 1984 at Wooster in a randomized complete block design with 10 single-tree replications were measured with the porometer described above on the following seven dates: July 5, July 14, July 21, July 26, August 16, September 9 and September 26.

Experiment 4: Cultivar Response to Drought Stress.

In 1985, 11 apple cultivars either on their own roots or on MM.111 were established at the Jackson Branch in a split plot design with rootstock as the whole plot and cultivars as the split plot with five single-tree replications. Leaf moisture status was measured on July 13, a hot, sunny day using the porometer as described previously.

Experiment 5: Influence of Root Pruning and Added Water on Transpiration, Growth, Fruit Size and Yield of 'Jonathan' apples.

'Jonathan' apple trees planted 12′× 20′ in 1968 were root pruned 60 cm from the trunk on two sides to a depth of 35 cm during late dormancy (mid-March), at full bloom or in mid-June annually beginning in 1985. Since previous work (9) had indicated that moisture stress was the most likely reason for the growth reduction caused by root pruning, half of the trees had a small soil dike (100 × 100 cm) created around them and 15 gallons of water per week were placed inside the dike unless an inch of rain per week occurred. In 1988 this treatment began at full bloom (May 9) and continued weekly through July 11. Photosynthesis and transpiration were measured on a mid-terminal leaf with an Analytical Development Co. Model LCA-2 portable infrared gas analyzer equipped with a 6.25 cm^2 Parkinson leaf chamber on June 24, July 1, July 8, and July 22. Length of 10 terminal shoots/tree was measured after leaf fall and fruit size distribution determined on an FMC weight sizer. Treatments were arranged as a split plot with water added as the whole plot and timing as the split with seven single-tree replications.

Experiment 6: Influence of Foliar Vapor Gard Sprays on Leaf Moisture Status, Yield and Fruit Quality of 'Redchief Delicious' Apples.

'Redchief Delicious' trees planted in 1985 on MM.111 rootstock were sprayed to drip with a 2 percent spray of Vapor Guard on July 6 or July 29 or on both dates. The treatments were applied in a randomized complete block design with six single-tree replications. Net photosynthesis and transpiration were determined with the ADC unit as described above. Total yield was recorded and the following measurements made on a sample of 15 fruit from each tree: average size, soluble solids, firmness, and length to diameter ratio.

Experiment 7: Assessment of Commercial Techniques of Hauling Water to Trees in Drought Stress.

Lynd Fruit Farm personnel began hauling water to trees beginning in early July and in each orchard they left a group of representative trees untreated. Using the ADC portable unit described previously, we measured 10-15 trees treated in each of the following ways or untreated on July 18:

1. 'Law Rome Beauty' trees with 30-40 gallons of water applied to the soil surface in the herbicide strip every two to three days.
2. 'Law Rome Beauty' trees with a single 12-inch diameter hole augured 15 inches deep at the edge of the herbicide strip 10-15 gallons of water placed in the hole every three days.
3. 'Smoothee Golden Delicious' with and without approximately a bushel of comptil mulch applied to the soil surface the previous year.

Results

Experiment 1: Rootstock influence on leaf moisture—Ripley.

The readings at Ripley were made on July 12, just prior to the first significant rains and would likely represent the most severe drought effects. 'Redchief' had lower stomatal conductance and transpiration values than either 'MacSpur' or 'Lawspur' which were similar. It is recognized that a single reading cannot be definitive in determining the tolerance of rootstocks to this type of stress condition, but it may provide some indication. It is interesting that trees on the very dwarfing P-16 had a higher stomatal conductance and transpiration level than any of the rootstocks producing much larger trees (Table 1). The following rootstocks appeared to have relatively high rates of stomatal conductance and transpiration indicating more tolerance of drought conditions: Ant 313, MM.106 EMLA, MM.111 EMLA, M.4, M.7A, MM.104 EMLA, MM.106, P-18, and B490. The following had lower rates of transpiration and may have been more stressed by the drought conditions: Ant. 306 and B.118.

In the second planting at Ripley containing rootstocks that supposedly produce smaller trees, rates of transpiration tended to be higher (Table 2). Trees on M.9, C 6 and M.7 EMLA tended to have high values for stomatal conductance and transpiration, while trees on M.9 EMLA tended to have low values. However, there was considerable similarity and not any striking differences among rootstocks. Interestingly, while taking the measurements, trees on either MARK or MAC 9 appeared to have a yellowish coloration to the leaves and possibly the beginning signs of wilting. However, measurement of leaf stomatal conductance and transpiration showed no difference compared to M.9 or others of similar size that had no visible symptoms. Interestingly in this planting 'Macspur' had low values of conductance and transpiration compared to the other cultivars.

Table 1. Influence of rootstock on stomatal conductance, and transpiration of 3-year-old apple trees on July 12 during the 1988 drought (Ripley, Ohio). Experiment 1.

Rootstock[1]	Stomatal conductance cms^{-1}	Transpiration $\mu g\ H_2O\ cm^{-2}s^{-1}$
Cultivar		
Macspur	3.31a	24.7a
Lawspur	3.27a	22.9a
Red Chief	2.15b	20.0a
Very dwarfing		
P-16	2.81a	22.0a
Semi-dwarfing		
M.7A	2.37b	18.0bc
M.7EMLA	2.38bc	17.5bcd
MM.106EMLA	2.50b	19.2b
M.2EMLA	2.36bcd	18.1bcd
MM.106	2.40bc	18.8bc
MAC 1	2.37bc	17.7bcd
Dwarfing		
Seedling	2.29bcd	17.9bcd
Ant 313	2.40bc	19.5b
Ant 306	2.21bcd	15.3cd
M.4	2.23bcd	18.4bc
MM.111EMLA	2.46b	19.3b
MM.104EMLA	2.34bcd	18.7bc
MAC 4	1.90d	16.5bcd
MAC 16	2.27cd	19.1bcd
MAC 24	2.19bcd	17.4bcd
P-13	2.03bcd	16.8bcd
P-18	2.35bcd	18.7bc
B 118	2.28bcd	15.0d
B 490	2.28bcd	18.8bc

[1]Since the cultivar x rootstock interaction was not significant, the 2 cultivars ('Lawspur' and 'Macspur') were averaged.

Experiment 2: Seasonal Leaf Moisture Status of 9-year-old Delicious Trees in the NC-140—1980 Trial.

As indicated previously, the drought at Wooster began early and continued until July 18 when 1.54 inches of rain fell and 4.25 inches additional fell before the leaf measurements on July 26. Considering the 9-year-old 'Starkspur Supreme Delicious' trees on the dwarfing rootstocks in the NC-140 trial, trees on M.9 EMLA had higher values of conductance and transpiration than trees on M.27 EMLA (Table 3). Trees on M.7 EMLA had higher conductance

Table 2. Influence of rootstock and cultivar on stomatal conductance and transpiration of 3-year-old apple trees on July 12 during the 1988 drought (Ripley, Ohio). Experiment 1.

Rootstock[1]	Stomatal conductance cms^{-1}	Transpiration $\mu g\ H_2O\ cm^{-2}s^{-1}$
Cultivar		
Macspur	.84c	15.6b
Lawspur	1.92b	22.6a
Red Chief	2.15a	22.9a
Semi-dwarfing		
M.7EMLA	1.48ab	19.8abc
MAC 10	1.32cde	19.0abc
MAC 46	1.32cde	18.6abc
OAR 1	1.40abcd	19.4abc
CG 10	1.38abcd	19.3abc
P-1	1.41abcd	20.2ab
V605-1	1.44abc	20.3ab
V605-4	1.30de	18.7abc
V605-7	1.33cde	19.1abc
Dwarfing		
M.9	1.50a	20.6a
M.9EMLA	1.25e	18.0c
M.26EMLA	1.36bcde	19.6abc
MARK	1.40abcd	19.1abc
MAC 9	1.41abcd	19.2abc
MAC 39	1.39abcd	18.5bc
C 6	1.48ab	20.4ab

[1]The interaction between cultivar and rootstock was not significant, thus data is averaged for each.

values than trees on MAC 24. Following the first rains there was no difference among rootstocks on July 21, but on July 26, trees on M.27 EMLA tended to have low values compared to the other rootstocks. A comparision of the transpiration values of rootstocks over the season (Figures 2a & 2b) reveals that transpiration values for all rootstocks were very high in mid-August. Trees on M.9 EMLA had the highest values and those on M.27 EMLA the lowest. Differences on the other dates were much smaller.

Experiment 3: Seasonal Leaf Moisture Status of 5-year-old Delicious Trees in the NC-140—1984 Trial.

Thirteen days (July 5) before the first rain, 5-year-old 'Delicious' trees on the dwarfing stocks tended to have higher conductance and transpiration values, however, the differences were often not significant compared to rootstocks in the other size groups (Table 4). In the vigorous rootstock group, seedling stood out as having higher values and M.4 the lowest, but again the differences were not always significant. Three days after the first rain (July 21) the differences in conductance were not significant. Trees in the very dwarfing group of rootstocks tended to have low transpiration values indicating that they did not respond as quickly to the improved soil moisture as the larger trees. In general, this pattern was also present on July 26 after a total of 5.77 inches of rain had fallen, since rainfall began on July 18. A comparison of transpiration values recorded seven times over the summer (Figures 3a-d) demonstrate lower values and greater separation among rootstocks in the vigorous group of rootstocks when the drought was severe on July 5 compared to rootstocks in the other size groups. The high readings recorded in August 16 generally demonstrated a greater variance in transpiration among rootstocks than occurred on the other dates. It would have been desirable to take more readings in August to see if they would also have been high. It is interesting that readings on July 14 were slightly higher than on July 5.

Experiment 4: Cultivar Response to Drought Stress.

There were no differences in leaf moisture status between these trees produced through tissue culture on their own roots and those on MM.111 rootstock (Table 5). The various strains of 'Delicious' tended to have high values of conductance and transpiration compared to 'Gala' and 'Macspur', but the differences were not always statistically significant.

Experiment 5: Influence of Root Pruning and Added Water on Transpiration Growth, Fruit Size and Yield of 'Jonathan' Apples.

Root pruning tended to reduce transpiration prior to the first rains on July 18 and following the rain there

Table 3. Influence of rootstock on stomatal conductance (cms^{-1}) and transpiration ($\mu H_2O\ cm^2s^{-1}$) of 'Starkspur Supreme Delicious' apple leaves during the drought of 1988 (NC-140, 1980-81 planting). Experiment 2.

Rootstock	July 5 Stomatal Conductance	July 5 Transpiration	July 21 Stomatal Conductance	July 21 Transpiration	July 26 Stomatal Conductance	July 26 Transpiration
Dwarfing						
M.9	.39ab	12.4ab	1.75	13.4	1.28a	17.0ab
M.9EMLA	.46a	14.5a	1.26	12.8	1.34a	17.4a
M.26EMLA	.40ab	12.4ab	1.59	14.0	1.32a	17.5a
M.27EMLA	.32bcd	9.8bc	1.62	14.0	1.15b	15.7b
MAC 9 (MARK)	.37abc	12.1ab	1.26	12.7	1.39a	18.1a
Ottawa 3	.41ab	12.9ab	1.26	12.8	1.40a	18.2ab
Semi-dwarfing						
M.7EMLA	.36abc	11.1abc	1.25	13.1	1.33a	17.7a
OAR 1	.26cd	8.5c	1.24	12.8	1.29a	17.7a
MAC 24	.24d	7.7c	1.26	13.1	1.33a	16.7ab
			NS	NS		

Figure 2a. Seasonal leaf transpiration of 9-year-old 'Starkspur Supreme Delicious' trees in the 1980-81 NC-140 trial on dwarfing rootstocks.

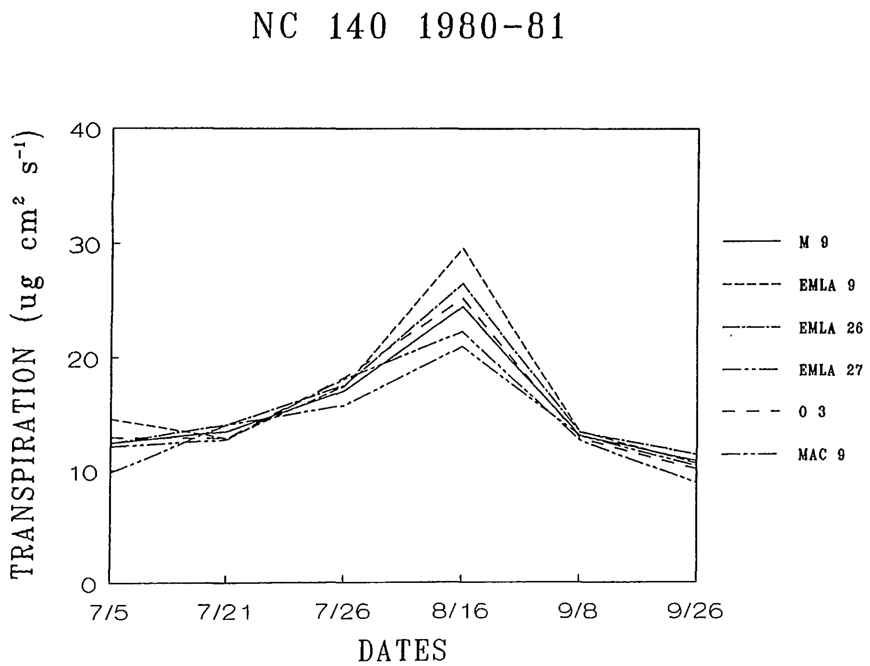


Figure 2b. Seasonal leaf transpiration of 9-year-old 'Starkspur Supreme Delicious' trees in the 1980-81 NC-140 trial on semi-standard rootstocks.

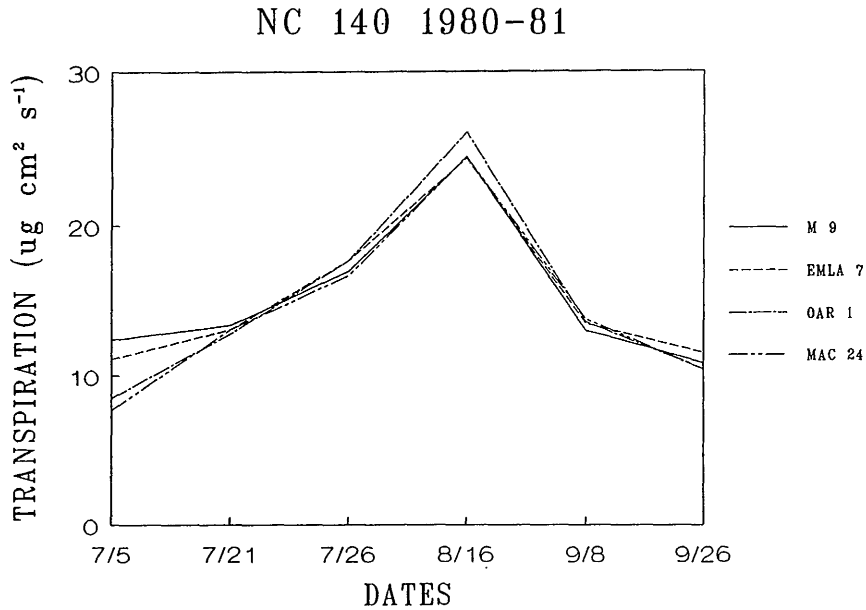


Table 4. Influence of rootstock on stomatal conductance (cms-1) and transpiration (μH_2O cm^2s^{-1}) of 'Starkspur Supreme Delicious' apple leaves during the drought of 1988 (NC-140, 1984 planting). Experiment 3.

	July 5		July 21		July 26	
Rootstock	Stomatal Conductance	Transpiration	Stomatal Conductance	Transpiration	Stomatal Conductance	Transpiration
Very Dwarfing						
P-22	.40abcd	14.3abcd	1.05	11.5de	1.18bc	14.7bc
P-16	.41abcd	14.8abcd	.79	12.5cde	1.14c	14.2c
P-2	.39bcd	13.8bcde	.75	11.0e	1.22abc	14.8bc
Dwarf						
B 9	.49a	17.2a	.78	13.2cde	1.19abc	14.6bc
CG 10	.47ab	16.5ab	.85	13.9abcd	1.25abc	15.8ab
M.26EMLA	.47ab	16.7ab	.86	14.3abcd	1.30ab	15.9ab
C 6	.46ab	16.4ab	.91	14.8abc	1.25abc	15.7abc
Semi-dwarf						
M.7EMLA	.37bcde	13.4bcde	.88	14.4abc	1.15c	14.8bc
P-1	.40abcd	14.2abcd	.84	13.8abcd	1.30ab	16.0ab
MAC 1	.38bcd	13.8bcde	.84	13.9abcd	1.22abc	15.5abc
MAC 39	.44abc	15.3abc	.88	14.5abc	1.30ab	16.0ab
CG 24	.44abc	15.6abc	1.01	16.4a	1.33a	16.3a
Vigorous						
Seedling	.44abc	15.5abc	.89	14.5abc	1.29ab	15.8ab
B 490	.33de	11.9de	.87	13.5abcde	1.24abc	15.5abc
P-18	.38bcd	13.7bcde	.96	15.4ab	1.23abc	15.5abc
Ant 313	.35cde	12.8cde	.89	14.8abc	1.26abc	15.5abc
M.4	.28e	10.7e	.91 NS	15.2abc	1.25abc	15.2abc

Figure 3a. Seasonal leaf transpiration of 5-year-old 'Starkspur Supreme Delicious' trees in the 1984 NC-140 trial on very dwarfing rootstock.

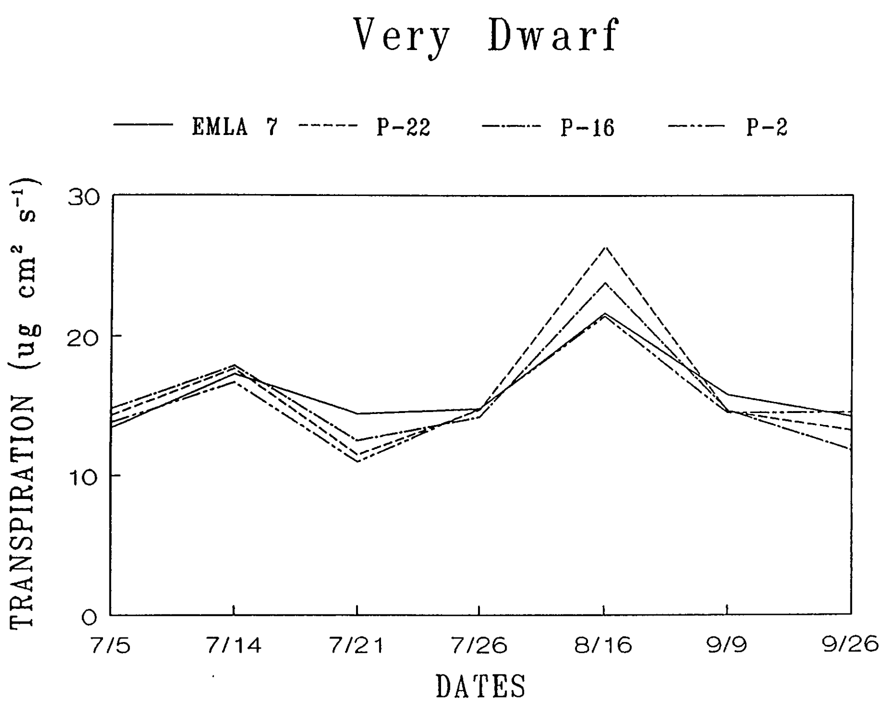


Figure 3b. Seasonal leaf transpiration of 5-year-old 'Starkspur Supreme Delicious' trees in the 1984 NC-140 trial on dwarfing rootstocks.

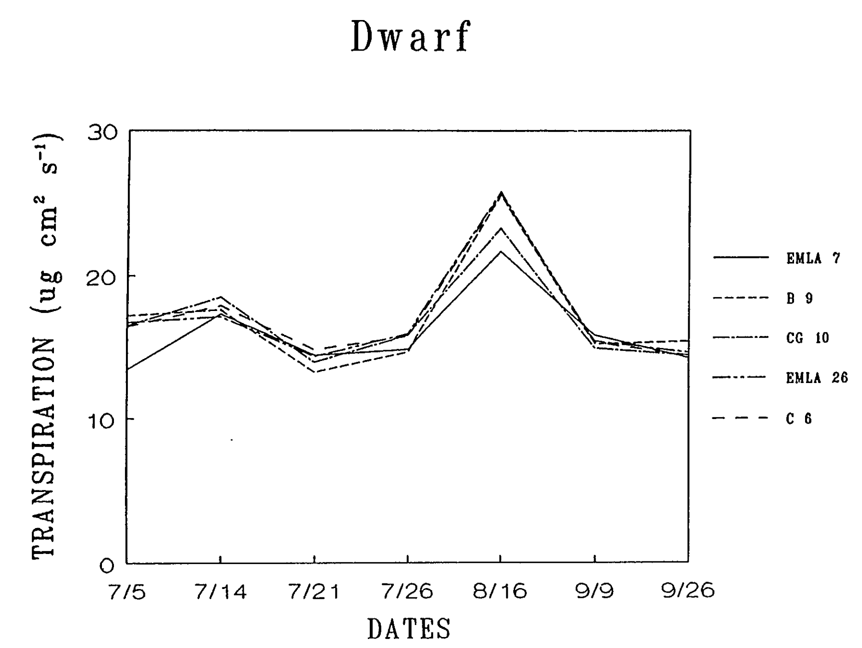


Figure 3c. Seasonal leaf transpiration of 5-year-old 'Starkspur Supreme Delicious' trees in the 1984 NC-140 trial on semi-dwarfing rootstocks.

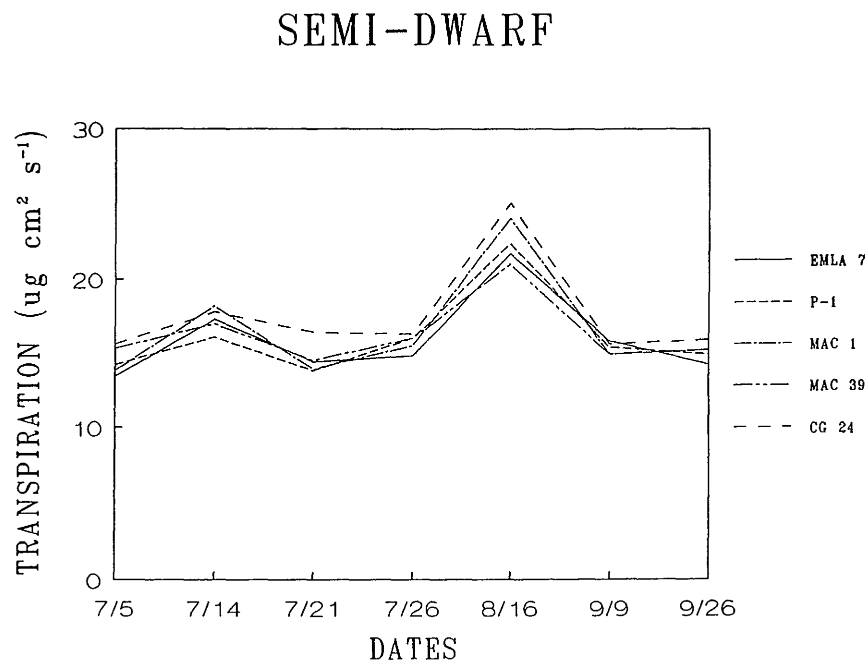
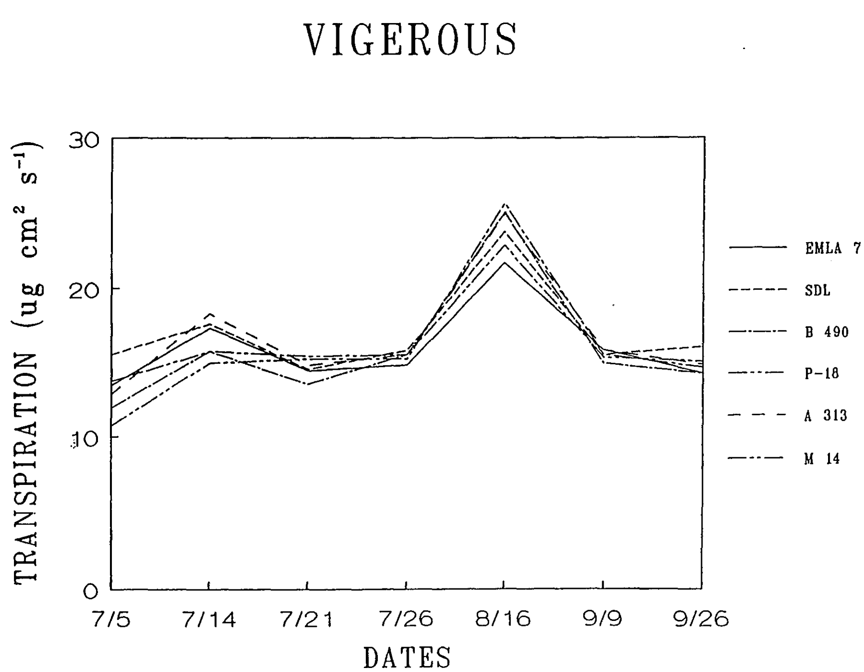


Figure 3d. Seasonal leaf transpiration of 5-year-old 'Starkspur Supreme Delicious' trees in the 1984 NC-140 trial on vigorous rootstocks.



were no differences in transpiration among pruning treatments (Table 6). Root pruning resulted in 22-30 percent reduction in shoot growth with no difference due to the time of pruning. The reduction in growth and decrease in fruit size and yield were similar to those of other years and were apparently not affected by the drought conditions.

Experiment 6: Influence of Foliar Vapor Gard Sprays on Leaf Moisture Status, Yield, and Fruit Quality of 'Red Chief' Delicious.

After it was clear that severe drought conditions were occurring, it was decided to apply the antitranspirant, Vapor Gard, to see if tree moisture status and ultimately yield and fruit quality could be improved. One day after the first application of Vapor Gard (July 6) net photosynthesis was reduced 49 percent, but transpiration was unaffected (Table 7). A second application made after the initial rains did not affect either transpiration or photosynthesis. Yield, soluble solids, firmness, or length/diameter ratio were unaffected by the Vapor Gard treatments.

Experiment 7: Assessment of Commercial Techniques of Hauling Water to Trees in Drought Stress.

When mature 'Law Rome Beauty' trees received 30-40 gal/tree of water applied to the soil surface within the herbicide strip every two to three days, the watered trees had a 30 percent higher rate of photosynthesis and 8 percent higher transpiration rate (Table 8). Applying approximately 10 gal/tree in a 15-inch deep augured hole at the edge of the herbicide strip every three days resulted in 37 percent higher photosynthesis rate and a 46 percent higher rate of transpiration.

Table 5. Influence of cultivar on stomatal conductance and transpiration of 4-year-old apple trees during the 1988 drought. (Jackson, Ohio). Experiment 4.

Cultivar[1]	Stomatal conductance $cm s^{-1}$	Transpiration $\mu g\ H_2O\ cm^{-2} s^{-1}$
Mutsu	.77abc	12.6abc
Sundale Golden Delicious	.81ab	12.9ab
Golden Delicious	.73bcde	11.6bc
Spuree Rome	.82ab	13.3ab
MacSpur	.59de	9.9c
Imperial McIntosh	.62cde	9.7c
Gala	.58e	9.9c
Delicious (Triple Red)	.79abc	12.8ab
Redchief Delicious	.87ab	14.0ab
Redspur Delicious	.76abcd	12.4abc
Vermont Spur Delicious	.91a	14.6a
Rootstock		
Own Rooted	.65a	10.6a
MM.111	.69a	11.4a

[1]Since the cultivar x rootstock interaction was not significant, the data were averaged and presented separately.

Table 6. Influence of root pruning and added water on transpiration, growth and fruit size distribution of 'Jonathan' apples during the drought of 1988. Experiment 5.

Time of Root Pruning	Transpiration ($g\ H_2O\ dm^{-1} hr^{-1}$) June 24	July 1	July 8	July 22	Shoot length cm	% Size Distribution (cm dia.) 8+	7.3–8.0	5.7–7.3	cull	Total yield lbs/tree
Unpruned	2.12c	1.68ef	2.51b	3.01a	31.6a	4.3	22.8	50.4b	21.7	319a
Dormant	2.01cd	1.54fg	2.05cd	2.87a	24.8b	3.1	18.8	61.6a	15.8	255b
Full Bloom	1.98cd	1.56fg	2.13c	2.98a	24.0b	2.3	17.0	65.6a	14.4	250b
Mid-June	1.86de	1.49g	1.98cd	2.91a	22.2b	3.2	19.5	59.2a	17.6	222b
Control	1.89d	1.55e	2.08c	2.95a	25.1a	2.5b	17.4b	62.9a	8.5	271
Water Added	2.09a	1.58e	2.26b	2.93a	21.3a	4.0a	21.7a	55.5b	8.6	252

Table 7. Influence of Vapor Gard sprays on photosynthesis, transpiration, yield and fruit quality of 4-year-old 'Redchief Delicious' on MM.111 in 1988.

	July 8		July 22		August 1		Yield	SS	Firm.	Lgth./
Treatment	Pn	E	Pn	E	Pn	E	lbs/t	(%)	(kg)	dia.
Control	12.3a	1.98a	21.9a	3.13a	24.9	3.13	19.7	15.0	6.4	.88
Spray 7/6	6.3b	1.97a	23.2a	3.04a	25.6	3.16	15.8	14.9	6.8	.88
Spray 7/29					23.6	3.01	15.8	14.3	6.7	.88
Spray 7/6 & 29					23.8	2.95	15.8	14.6	6.6	.87

Pn=mg $CO_2dm^{-2}hr^{-1}$; E=g $H_2Odm^{-2}hr^{-1}$

Table 8. Influence of hauling water on net photosynthesis (Pn) and transpiration (E) of apple trees under the 1988 drought conditions. Each value is a mean of 10-15 representative trees. Experiment 7.

		Net Photosynthesis (mg CO_2 $dm^{-2}hr^{-1}$)	Transpiration (g H_2O $dm^{-2}hr^{-1}$)
Rome	Holes for Water		
	Control	10.0	1.80
	Watered	15.9	3.36
Rome	Surface		
	Control	13.8	2.62
	Watered	17.8	2.82
Delicious	Surface		
	Control	8.2	2.02
	Watered	11.6	2.49

The effects of a small amount of mulch around young 'Smoothee' trees had no effect on photosynthesis or transpiration at this stage of the drought. Young 'Delicious'/M.7 trees watered once/week on the soil surface with 50-100 gal had increases of 30 percent in photosynthesis and 19 percent in transpiration when the water was applied no more than three days prior to the measurements.

Discussion

The most striking conclusion from the conductance and transpiration data gathered under severe drought conditions across a very wide range of apple rootstocks (Tables 1-4; Figures. 1 & 2) was the fact that the differences were relatively small. In work with peach trees in the field, Garnier and Berger (8) showed that stomatal conductance decreased linearly with decreasing soil water content under drought conditions. However, Olien and Lakso (12,13) reported no effect of five apple rootstocks on conductance or transpiration under conditions of non-limiting soil moisture. Barden and Ferree (2) also reported no differences in transpiration with younger containerized trees on a range of apple rootstocks. Olien and Lakso (12,13) reported that diurnal changes in stem water potential showed that the dwarfing rootstock M.9 and M.26 were under more stress at midday than the other stocks (M.7, MM.106 and MM.104) in their study. The trend in our measurements during the drought were for dwarfing stocks to show higher conductance and transpiration values compared to many of the more vigorous rootstocks. This finding is at odds with grower experience that trees on the dwarfing rootstocks are more negatively affected by drought than trees on the larger rootstocks, particularly MM.111. Possibly this divergence could be due to such factors as difference in root to shoot ratios among rootstocks. Another possibility is that the measurements are not good indicators of drought tolerance and other characteristics should be measured. Work by Marro and Cereghini (11) suggests that guard cells were more responsive to drought on trees on M.9 than on seedling, thus resulting in better transpiration control.

The differences in conductance and transpiration among the 11 apple cultivars were also rather small (Table 5). As in previous reports (6) under non-limiting soil moisture the'Delicious' strains tended to have high transpiration levels compared to other cultivars.

The use of a foliar antitranspirant spray applied after the conditions of the drought were obvious was not beneficial. Previous work in Ohio (16) with antitranspirants under conditions of optimum or limited soil moisture conditions also indicated limited benefit.

Funt (7) suggested that fruit trees the size of the 'Jonathan' in this study needed approximately 30 gallons of water per day to replace transpirational losses. Using another method of calculation, Kenworthy (10) suggested that 14 gal/day may be needed to replace 75 percent of the pan evaporation under normal (non-drought) conditions. In this study we only supplied 15 gallons/week or 7 percent of their estimated usage according to Funt or 14 percent using Kenworthy's method. However, this small amount of water resulted in a significant increase in transpiration on June 24 and July 8. This small amount of water applied weekly was enough to significantly increase fruit size in the greater than 8 cm and 7.3-8.0 cm diameter size classes and to decrease the percentage of small fruit. However, this small increase in size was not enough to overcome the fruit size reduction caused by root pruning.

The beneficial effects of small amounts of water hauled to trees experiencing drought stress were surprising. The consistent application of 15 gal/week from bloom until rains came on July 18 on the 20-year-old 'Jonathan'/M.26 trees increased transpiration 8-10 percent and resulted in an increase in fruit size at harvest. Thus, it appears that mature apple trees are very sensitive to even small amounts of increased moisture during the cell division stage of fruit development under conditions of critically low levels of soil moisture. Water hauling in the grower orchard was started after the drought effects were well established and a greater amount of water was applied on a more consistent basis. The physiological state of the trees was improved as indicated by the improvement in rates of photosynthesis and transpiration. It is very interesting that a greater increase in photosynthesis and transpiration was achieved with a smaller amount of water by concentrating it in a hole at the edge of the drip line. This technique may be beneficial in the future in attempts to save trees from severe drought stress with very limiting water supplies. Significant rain fell the day after the leaf measurements. Probably because the physiological condition of the trees were improved for only a short time, well after the cell division phase of fruit development, fruit size or quality at harvest was not influenced by hauling water to these trees.

The authors recognize the limitations of this collection of data and observations taken in only a single season. Generally the data collection began too late after the conditions of the drought were already affecting the trees and thus, the development of the effects cannot be illustrated. It is hoped that presentation of this collection of data may provide some starting points for future work on drought stress of apple trees and mayprove useful if another serious drought occurs.

Literature Cited

1. Anonymous. 1989. Ohio Farm Report. V. 89, No. 1.
2. Barden, J.A. and D.C. Ferree. 1979. Rootstock does not affect net photosynthesis, dark respiration, specific leaf weight and transpiration of apple leaves. J. Amer. Soc. Hort. Sci. 104(4):526-528.
3. Curry, R.B. and C.W. Donoho, Jr. 1966. Soil moisture use by apple trees. Fruit Crops Research-1966. pp. 53-56.
4. Ferree, D.C. 1976. Irrigation and nitrogen influence on growth of young apple trees. Ohio Report
5. Ferree, D.C. 1987. Apple rootstocks. IN: Rootstocks for Fruit Crops. R.C. Rom and R.F. Carlson (eds.) John Wiley & Sons, Inc.
6. Ferree, D.C., F.R. Hall, and M.A. Ellis. 1986. Influenced of mites and diseases on net photosynthesis of apple leaves. IN: The Regulation of Photosynthesis in Fruit Trees. A.N. Lakso and F. Lenz (eds.) Symp. Proc. Publ. NY St. Agr. Exp. Sta. Geneva, NY. pp. 56-62.
7. Funt, R.C. 1988. Buckeye Fruit Tips. Vol. X, No. 7. July.
8. Garnier, E. and A. Berger. 1987. The influence of drought on stomatal conductance and water potential of peach trees growing in the field. Scientia Hort. 32:249-263.
9. Geisler, D. and D.C. Ferree. 1984. The influence of root pruning on water relations, net photosynthesis, and growth of young 'Golden Delicious' apple trees. J. Amer. Soc. Hort. Sci. 109(6):827-831.
10. Kenworthy, A.L. 1972. Trickle irigation ... the concept and guidelines for use. Mich. St. Univ. Res. Rpt. 165:20.
11. Marro, M. and F. Cereghini 1977. Observations on various morphological and functional aspects

of spurs in 'Richared' apples on seedling and M.9 rootstocks. Rivista della ortoflorofruiticoltura Italian 60:1-45 (Hort. Abst. 47:1169).
12. Olien, W.C. and A.N. Lakso. 1984. A comparison of the dwarfing character and water relations of five apple rootstocks. Acta Hort. 146:151-158.
13. Olien, W.C. and A.N. Lakso. 1986. Effect of rootstocks on apple (*Malus domestica*) tree water relations. Physiol. Plant. 67:421-430.
14. Roseberg, R.J. and E.L. McCoy. 1988. Conservation tillage and corn root development. Proc. Ohio Crop Prod. Conf. Randall Reeder (ed.) OCES.
15. Stevens, Andy. 1989. Will drought hit us again? The Ohio Farmer. Mar. 4:86-87.
16. Weller, S.C. and D.C. Ferree. 1978. Effect of a pinoline-base antitranspirant on fruit growth, net photosynthesis, transpiration and shoot growth of 'Golden Delicious' apple trees. J. Amer. Soc. Hort. Sci. 103(1):17-19.

Performance of a Spur and Standard Delicious Strain in a Slender Spindle System

D.C. Ferree and J.C. Schmid
Department of Horticulture

Introduction

'Delicious' is the most widely planted apple cultivar in the United States and the most recent Ohio survey shows that more than 30 percent of the apple trees in the state are this cultivar. In recent years most plantings of 'Delicious' have been of spur type strains because of their more compact growth habit and desirable performance as central leader trees on semi-standard rootstocks. However, economic conditions have encouraged growers to look at orchard intensification to increase efficiency and many of these systems depend on dwarfing rootstocks.

The slender spindle is the most widely used intensive system in Europe, however, because 'Delicious' is not an important cultivar their experience with it in the slender spindle system is limited. Combining spur habit cultivars on fully dwarfing rootstocks such as M.9 result in very small trees and the performance of this combination as a slender spindle should be evaluated. Slender spindle with other cultivars has been a very productive system in our studies (2,4).

Materials and Methods

Trees of the standard strain 'Red Prince'/M.9 and the spur strain 'Millersturdeespur'/M.9 were planted in 1974 at a spacing of 1.52 x 3.05 m. The trees were trained as slender spindles with each tree supported by a well weathered penta-treated post (1.8 m protruding above ground) using techniques described by Wertheim (7). Rows had a N-S orientation and the trees received standard herbicide and pesticide treatments. Trees were arranged as randomized complete blocks with four replications of 17 m rows.

Results and Discussion

The trees grew well and 'Red Prince', particularly, exhibited excessive growth which exceeded their allotted space by 40 percent in 1979. A summer pruning study was imposed on these trees (5) in an attempt to control vigor and only yields from control trees are reported here. The excessive vigor and severe containment pruning required annually made the standard habit strain ('Red Prince') of 'Delicious' unacceptable for the spacing used in this study. 'Millersturdeespur' trees were not as vigorous and did not fill their allotted space. When the trees were removed, trees on 'Millersturdeespur' were 22 percent smaller in trunk cross-sectional area than trees on 'Red Prince' (Table 1).

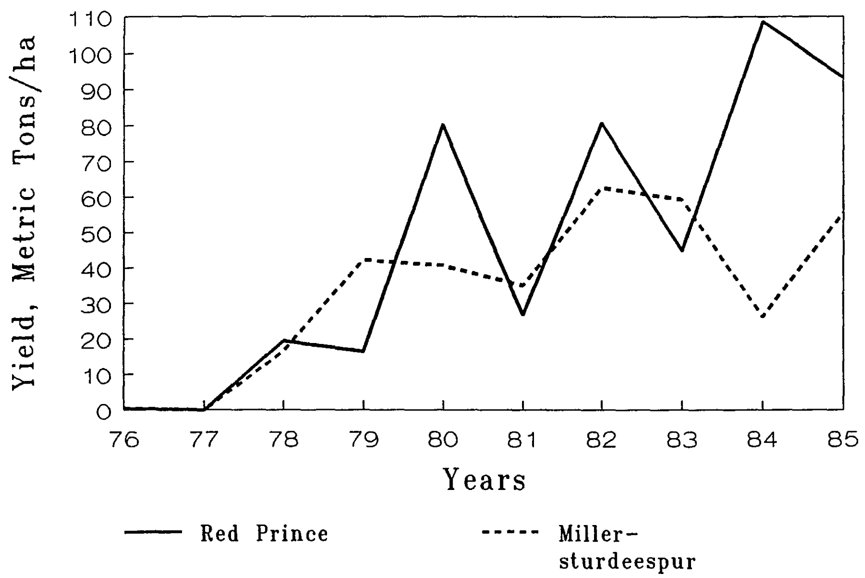
The trees produced a small crop in 1976, the third season after planting with 'Millersturdeespur' producing 33 percent more than 'Red Prince' (Figure 1). In 1977, a severe frost at bloom eliminated the crop on both strains and this added to the vigor problem with 'Red Prince'. In 1978, they had similar crops, but in 1979, 'Millersturdeespur' had 61 percent more fruit/hectare than 'Red Prince'. 'Red Prince' developed a biennial production pattern with "on" years in 1980, 1982, and 1984, while 'Millersturdeespur' had much less

Table 1. Yield per tree, tree size and efficiency of 2 strains of 'Delicious' grown as slender spindle over 12 years.

Delicious Strain	Yield/Tree (kg) 78	79	80	81	82	83	84	85	Cum.	Trunk cross-sect. cm²	Efficiency kg/cm²
Red Prince	9.0	7.6	37.4a	12.4	37.6	20.9	50.5a	43.4a	218.8a	49.3a	4.43
Millersturdeespur	7.7	19.6	18.9b	16.3	29.2	27.6	12.3b	25.8b	157.4b	38.9b	4.04

Means separated by LSD .05.

Figure 1. Yield per hectare of 'Red Prince' a standard habit and 'Millersturdeespur' a spur habit form of Delicious grown as slender spindle over 12 years.



biennial tendency. In fact, in the "off" years of 1981 and 1983 'Millersturdeespur' produced as much per hectare as 'Red Prince' and as stated above, were much smaller trees.

Cumulative yield of 'Red Prince' over the 12 years was 28 percent higher than 'Millersturdeespur'. This difference was due to the failure of 'Millersturdeespur' to fill its allotted space adequately. The combination of the dwarfing M.9 rootstock and the natural dwarfing tendency of a spur habit strain (3,6) resulted in inadequate growth to fill the 1.5 meter spacing. It is estimated that this combination could have been planted 30 percent closer and only minimal pruning would be required for containment. Even with the likely decrease in production caused by excessive containment pruning, 'Red Prince', was more productive as a slender spindle. However, the economics of this combination would be questionable since 'Golden Delicious', which required much less containment pruning in the slender spindle system and had higher yield efficiencies than 'Delicious' in other systems, was not as economically efficient as some of the less intensive systems (4). If the spacing of 'Red Prince' was increased 30-40 percent to avoid the severe, annual containment pruning, yield/hectare would also likely be reduced.

In summary, this long-term comparison provides important information on spacing and efficiency of the two growth habit forms of 'Delicious' grown as slender spindle trees under Ohio conditions. If Ohio growers follow the national trend toward increased use of the slender spindle planting system, it is important to recognize the growth potential of standard strains on M.9 and the need for very close spacing if spur strains are used on M.9.

Literature Cited

1. Ferree, D.C. 1974. Influence of freshly treated posts on growth of newly planted trees. Fruit Crops Research-1974. OARDC Res. Sum. 75:11-12, Wooster.
2. Ferree, D.C. 1989. Influence of orchard management systems on spur quality, light and fruit within the canopy of 'Golden Delicious' apple trees. J. Amer. Soc. Hort. Sci. 114(6):869-875.
3. Ferree, D.C., C.A. Morrison and L.C. Shew. 1975. Red Delicious apple—which strain is best? Ohio Rpt. 60(2):19-22.
4. Ferree, D.C., R.C. Funt, and B.L. Bishop. 1989. Yield and production efficiency of four apple cultivars in selected orchard management systems. J. Amer. Soc. Hort. Sci. 114(6):863-868.
5. Myers, S.C. and D.C. Ferree. 1983. Influence of time of summer pruning and limb orientation on yield, fruit size, and quality of vigorous 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 108(4):630-633.
6. Warrington, I.J., D.C. Ferree, J.R. Schupp, T.A.Baugher and F.R. Dennis. 1989. Spur characteristics of 'Delicious' apple strains. J. Amer. Soc. Hort. Sci. 115(3):348-356.
7. Wertheim, S.J. 1968. The training of the slender spindle. Proefstation voor de Fruitteelt Wilheminadorp. Publ. 7.

Survey of Ohio Strawberry Growers: Present Practice and Future Directions

J.C. Scheerens and G.L. Brenneman
Department of Horticulture

Introduction

Periodic surveys profiling Midwest strawberry consumers (2,3) have allowed growers to closely monitor fluctuations in consumer trends and demographics which might affect marketing decisions. Although they may also be of benefit to strawberry producers, surveys of grower opinions and practices have been conducted less frequently. The most recently published survey of Ohio growers concerning strawberry production centers, farm statistics, cultural practices, marketing potential and grower opinion was made over a decade ago (1). Up-to-date grower surveys can also aid strawberry researchers to develop new and more effective research programs by emphasizing existing and potential grower problems.

An interdisciplinary group of OARDC researchers was recently assembled to study the nature of strawberry quality and the potential for its improvement. Central to these efforts, a breeding program has been initiated wherein seedlings from more than 120 cross-pollinations will serve as the germplasm base for initial selections. Protocol for the selection process (i.e., Which characteristics are desired for the new varieties?) is still being developed. However, a strong component of the selection protocol will be based upon attributes perceived to be important in new cultivars for Ohio growers and consumers.

The development of new strawberry cultivars is a long-term, time consuming process. "Frequently, by the time the new variety is ready, the grower group which requested it has new needs. This is a source of frustration to the grower and the breeder alike"... (4). To counteract the effect of time lag, continued dialogue between the grower and breeder must be maintained.

Since research efforts benefit from an accurate and current information base, we solicited grower response to key issues by questionnaire, to provide direction for OARDC strawberry researchers, to assist the development of selection criteria for new cultivars, and to establish a dialogue between Ohio growers and OARDC's strawberry breeding program.

Materials and Methods

More than 175 self-addressed, stamped questionnaires (one standard sheet of paper printed on both sides) were distributed to interested growers in August 1988 (to Fruit Crops Day 1988 attendees), in December 1988 (to OFGA growers listed as strawberry producers) and in February 1989 (to Ohio Fruit and Vegetable Growers Congress attendees). Questionnaire recipients were not randomly chosen, but rather, an effort was made to solicit response from anyone identified as an Ohio strawberry grower.

A preamble to the questionnaire appealed for grower input and suggestions, explained for what purpose the information was to be used, invited the respondent to identify him/herself but gave them the option of anonymity, and thanked them for their time. The 10 questions on the form, chosen to provide input to the breeding program, were divided into two groups (Table 1). Responses to the first group assessed the growers' current situation whereas those from the latter group inferred the growers' vision of future possibilities for the industry.

Upon their return, questionnaires were scored for objective information such as "area under cultivation" and for response to "yes" or "no" questions. The more subjective responses to questions of opinion and reason were evaluated individually, but, if possible, were also categorized to ascertain a consensus among growers or the lack of it. Grower response to specific questions were evaluated in terms of Ohio's past and present production patterns and when possible, comparisons were made between growers' present or future outlook and past trends.

Results and Discussion

Ohio's Strawberry Production Patterns: Although worldwide production and marketing of strawberries has expanded in the last

Table 1. Questions included on questionnaire sent to Ohio strawberry growers in 1988-1989.

I. Your Present Situation

1. How many acres of strawberries do you currently have under cultivation? On a scale of 1-10 how important are strawberries to your over all production strategy?
2. What varieties do you currently produce? For your situation, what are their horticultural strengths and weaknesses?
3. If you could create the ultimate strawberry variety for you current needs, what would it be like?
4. What cultural system (i.e., matted row, ribbon row, hill, etc.) are you employing presently? Are you using drip irrigation, plastic mulches or row covers?
5. How do you currently market your strawberries (i.e., U-pick, roadside stand, farm markets, grocery chains)?

II. Your Future Situation

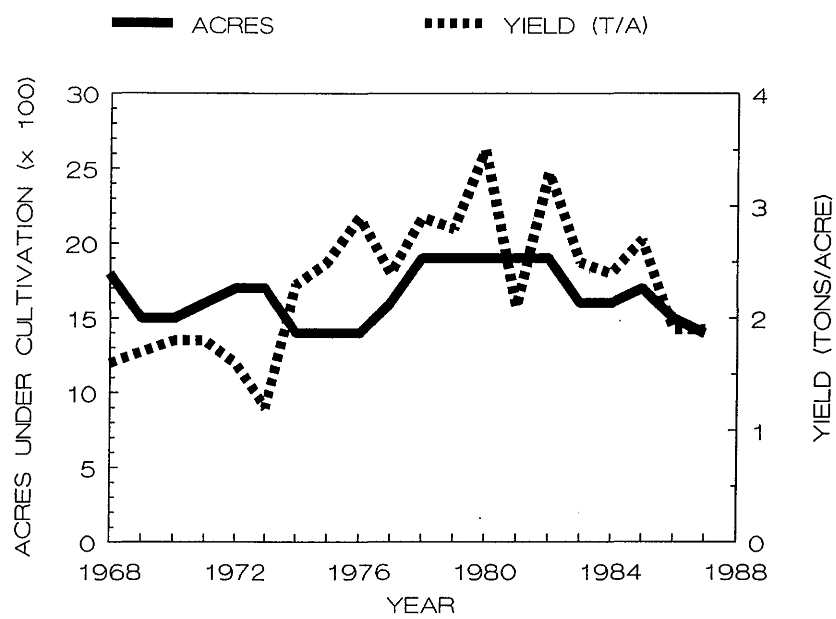
1. Would you be willing to establish a greater acreage in strawberries if you could profitably market your increased production? What (other than concern about marketing) would be the limiting factor in determining the size of your operation?
2. Would you be willing to adopt new growing practices requiring greater establishment and production costs if profit margins from increased yield were favorable?
3. If you could create the ultimate strawberry variety for your future needs, would it be like the one described previously?
4. Would you welcome day-neutral cultivars specifically suited to Ohio which would extend your harvest season?
5. Conversely, if mechanical harvesting and decapping were feasible, and processors were interested in purchasing your fruit, would you be interested in varieties with a concentrated fruit ripening habit which produced berries specifically suited to freezing and processing.
6. In your opinion, how important is the development of strawberries with improved fruit quality characteristics to the overall growth of our industry?

two decades, 20-year trends in the Ohio strawberry industry have remained comparatively static (Figure 1). During this period, the state's acreage in strawberry plantings ranged from 1400 to 1900 acres; peak acreage occurred during the late 1970's and early 1980's when interest in alternative crops stimulated an increase in the number of strawberry growers. This trend lasted until 1984 when acreage under cultivation began its decline to former levels, perhaps due to a concurrent decline in "Pick Your Own" (PYO) customers (3,6) or to the lack of marketing outlets for production levels which exceeded local demand. Even though as many as 22 new cultivars adapted to the Midwest have been released since 1979 (5), Ohio's average yield/acre (about three tons) has not increased as it is has in other production areas. The yield advantage enjoyed by California or Florida producers results from their comparatively prolonged production seasons.

Survey Response: Sixty-three responses (representing about one-third of the total questionnaires distributed) were received by May 1989 from growers scattered throughout the state (Figure 2). This level of return was substantially less in absolute numbers but similar in proportion to the 239 responses received during a 1978 survey of 699 berry growers (1). In the previous study, growers were reported to be concentrated in several distinct regions of the state, but regionality in production was not evident from survey responses reported herein (Figure 2). The higher response level from Wayne county residents may reflect their familiarity with OARDC.

The extent to which growers responded to the questions varied. Some respondents offered only single word answers to most questions, whereas others answered in far greater detail. Two concerned growers wrote letters to augment or clarify their positions as stated on the questionnaire.

Figure 1. Trends in Ohio strawberry production from 1968-1988.



Current Situation

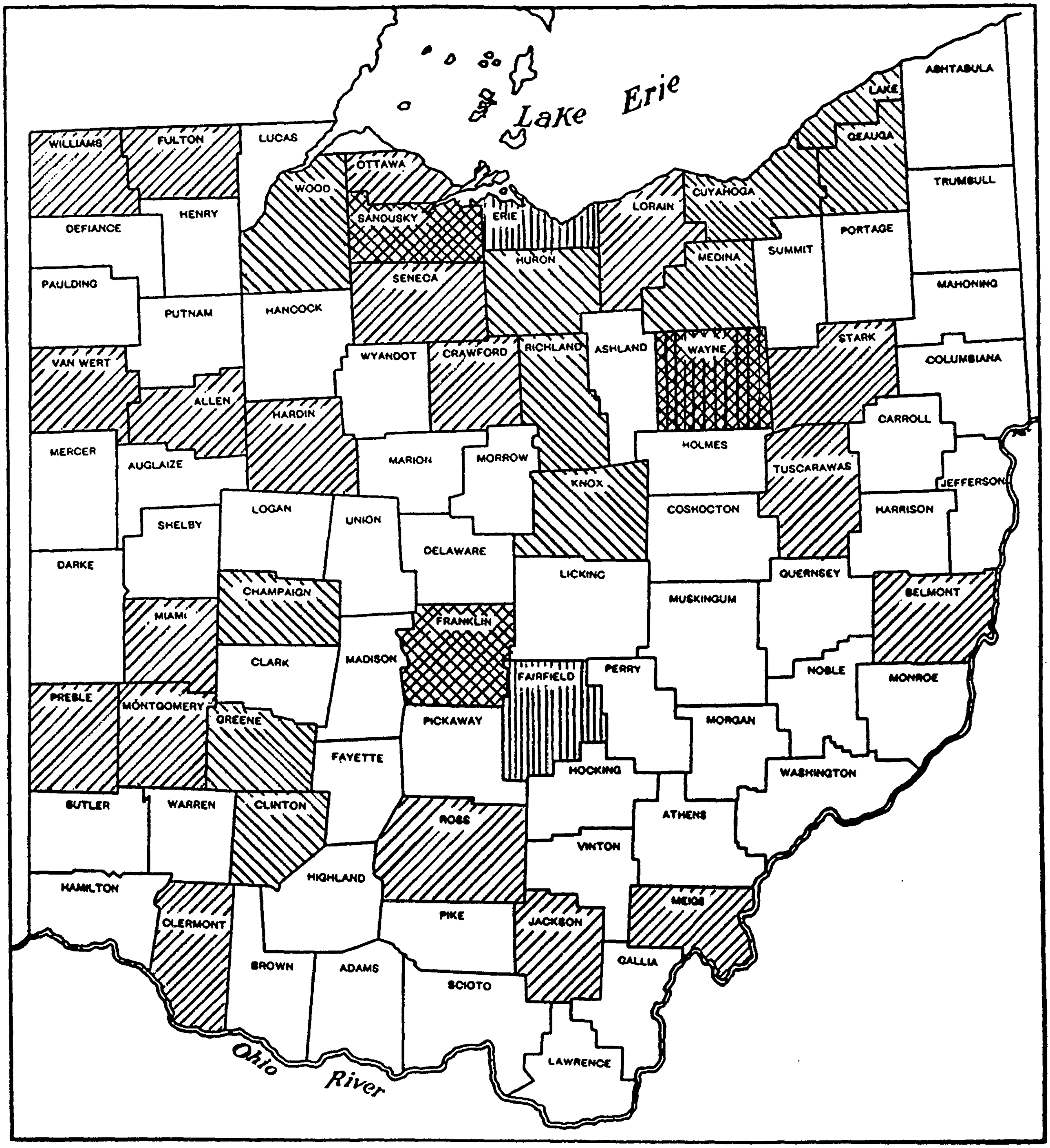
Farm Size: The size of Ohio's strawberry farms remains small, averaging about 6.55 acres/grower. However, this average is elevated by a few growers with comparatively large operations (Figure 3A). The bulk of survey respondents (over 80 percent) indicated that they currently cultivate fewer than ten acres of strawberries, with 25 growers reported having three acres or less under production. Surprisingly, 10 respondents commercially produce strawberries on less than one acre. The 1978 survey (1) revealed similar trends. A grower's production scale did not appear to be associated with his/her perception of the relative importance of strawberries to their overall production scheme, the number or identity of cultivars grown, the type of cultural regime he/she practiced, or their view of the industry's future. However, growers with the smallest acreages tended to market their berries to PYO or farm markets only.

Although their land commitment is generally small, about two-thirds of the respondents maintained that strawberry growing was of importance (response=4-10) to their overall production scheme and business. Moreover, 43 percent of those responding (including almost all individuals with greater than 10 acres under cultivation) asserted that strawberries were a very important crop (response=7-10) to them. Responses of individuals with less than 10 acres varied considerably. Comments given along with their responses ranged from— "it provides us with extra income" to "its 100 percent of our [production] income".

Cultivars: According to the survey, a great diversity of cultivars are grown in Ohio and the reasons given for growing them are almost as diverse (Table 2). Of the 27 cultivars listed, most growers cultivated at least two varieties while the average number of varieties/farm was 3.8. Although not specifically stated by respondents, the cultivars chosen for production reflected an effort to span the strawberry production season by growing a mix of early-, mid- and late-season varieties. Seven respondents grew only one variety (3-'Earliglow', 2-'Honeoye', 1-'Scott' and 1-'Redchief'), with the largest one-cultivar planting being a 15-acre planting of 'Earliglow'. The largest number of cultivars grown by a single grower was 10.

Almost two-thirds of the growers responding to the survey cultivated 'Earliglow' and over half grew 'Allstar'. The third most popular cultivar among growers was 'Honeoye'. Of these three cultivars, the latter two have been released within the last 10 years, perhaps reflecting recent success of breeding programs. That these two varieties and 10 others listed in Table 2 were recent releases (5), also indicated a

Figure 2. Counties of residence for survey respondents.



No. Respondents 1: 2: 3: 4: 5:

willingness among Ohio growers to evaluate/adopt new varieties as they are generated by breeding programs. 'Lateglow' was released as recently as 1988, but already, 15 percent of the respondents had established plantings for trial. Similarly, 'Earliglow', released in 1975, constituted about 1.4 percent of the Ohio strawberry acreage in 1976 (1).

Although new cultivar releases are soon tested, midwest varieties often enjoy commercial longevity, perhaps, due to unique and localized adaptation, to grower familiarity and/or to consumer recognition and demand. Eleven of the varieties listed in Table 2 were also grown in 1976 (1). Moreover, of the top three cultivars in the last study, 'Redchief' and 'Guardian' remain popular, as they were being cultivated by 30 percent and 27 percent, respectively, of the strawberry farmers answering the 1989 questionnaire. However, only one grower surveyed still grew 'Midway', the second most widely planted cultivar in 1976.

Grower rationale for growing specific cultivars could be deduced from comments on their relative strengths and weaknesses (Table 2). Respondents that disclosed their reasons for cultivar choice, commented on perceived strengths more often than perceived weaknesses to characterize cultivars they grew. Occasionally, two growers would report conflicting experiences with respect to a cultivar characteristic (e.g., 'Allstar' fruit color was described as both good and poor, 'Redchief' was found to offer both consistent and erratic performance from year to year). Differences in soil type, local environment, cultural treatment and grower expectation may account for these differences in performance evaluation. However, despite the diversity in response, overall patterns concerning grower preference did emerge from the data.

'Earliglow' was often described as a high yielding, early-fruiting variety with excellent quality (appearance, color and especially flavor), almost as frequently, it was criticized for its tendency to produce small, less pickable/marketable, secondary and tertiary berries late in its season. The earliness of 'Earliglow' was perceived as beneficial for generating early market profits and because it brought customers into the marketplace early in the season, providing the opportunity for the producer to entice them into return visits as other fruit became available. It was the only cultivar in this survey said to be recognized and demanded by consumers. 'Allstar' was praised for its yield and disease resistance, and for the size, firmness and prolonged shelf-life of its fruit. Many of the 'Allstar' growers indicated that it was the best berry developed to date, but others complained of erratic performance and poor fruit color. 'Honeoye' was consistently admired for yielding ability and for the size and color of its fruit; the fruit was consistently faulted for having a poor or tart flavor and because it darkens and softens excessively when over-ripe or under environmental stress. 'Redchief' and 'Lester' were praised for their good flavor and 'Guardian' for its firmness and keeping qualities. One grower commenting on 'Lateglow' fruit said it possessed good size, appearance and flavor.

The two positive plant characteristics most frequently mentioned were high-yielding and early bearing (Table 3). High yields were attributed to each of five most popular cultivars listed in Table 2 as well as to at least six others which were not as widely grown. Yield is a primary consideration in determining profit margin, and therefore, its improvement per unit of input cost is an important goal of most breeding programs. The focus on early bearing, reflecting

Figure 3. Frequency of responses among Ohio strawberry growers depicting their current situation: (A) acres cultivated; (B) production systems employed; (C) marketing strategies used.

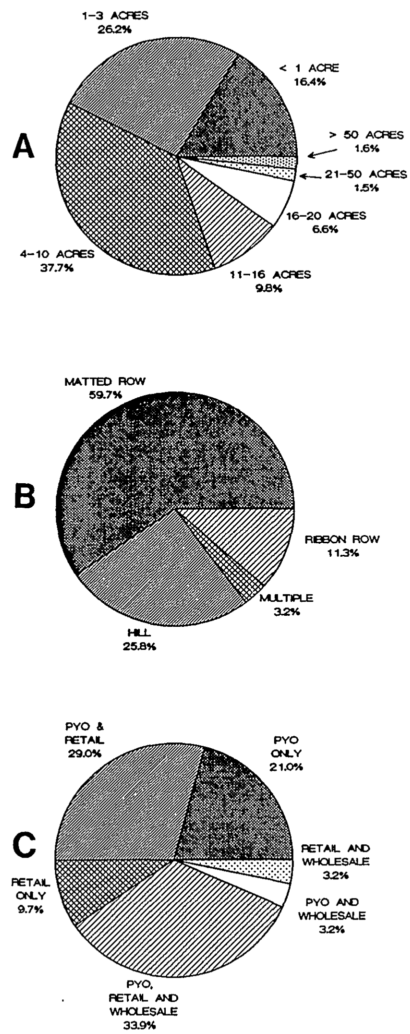


Table 2. Strawberry cultivars grown by Ohio producers in 1988.

Cultivar	No. growers planting	Perceived strengths[1]	Perceived weaknesses[2]
Earliglow	41	A, B, C, F, J, K, L, M, O, P, Q, R, S, T	d, e, g, h, j, m
Allstar	33	B, C, F, K, M, O, P, Q, S, T	a, f, j
Honeoye	24	A, B, D, F, K, L, P, Q, S	c, d, j, l, m, n, q
Redchief	19	A, B, M, O, P, Q	a, b, c, o
Guardian	17	A, B, G, I, K, O, Q, S	c, i, k, p
Lester	16	C, E, F, K, L, M, N, O	g
Lateglow	10	G, K, L, O	
Jewel	9	G, K, M, O, Q	
Kent	9	A, B, D, K, O	c, j
Raritan	7	B, M, O, Q	b, c
Scott	5	A, B, D, I, K, M, Q	i, l
Delite	4	G, H, I, K, O	c, f, m, n
Crimson King	3	F, K	n
Cardinal	2		
Marlate	2	B	n
Redglow	2	B, C, F, H, K, P, T	
Surecrop	2	B	
Vesper	2	K	n
Bounty	1		
Fern	1	H	
Fletcher	1		
Gilbert	1		
Micmac	1	K	i
Midway	1		
Redcoat	1		
Tribute	1		n
Tristar	1		

[1]Perceived strengths:

Plant characteristics

A. Consistent performance
B. High yielding
C. Disease resistant
D. Winter hardy
E. Good stand/runnering
F. Early bearing
G. Late bearing
H. Ext. bearing/maint. size
I. Easy to pick

Fruit characteristics

J. Consumer recognition
K. Optimum (large) size
L. Good appearance/shape
M. Good color
N. Good internal color
P. Sweet
O. Good flavor
Q. Firm
R. Rot resistant
S. Long shelf life
T. Good processing char.

[2]Perceived weaknesses:

Plant characteristics

a. Erratic performance
b. Poor yielding
c. Susceptible to disease
d. Winter sensitive
e. Short-lived
f. Overabundant foliage
g. Brief bearing/lose size

Fruit Characteristics

h. Poor (small) size
i. Poor appearance/shape
j. Poor color
k. Poor internal color
l. Poor flavor
m. Sour, tart
n. Soft
o. Rot susceptible
p. Hollow centered
q. Poor processing char.

Table 3. Frequency at which perceived strengths and weaknesses were included in descriptions of strawberry cultivars grown by Ohio producers.

Perceived strengths	Freq. of mention	Perceived weaknesses	Freq. of mention
Plant characteristics		**Plant characteristics**	
Consistent performance	6	Erratic performance	3
High yielding	23	Poor yielding	2
Disease resistant	6	Susceptible to disease	7
Winter hardy	4	Winter sensitive	4
Good stand/runnering	1	Short-lived	1
Early bearing	19	Overabundant foliage	2
Late bearing	5	Brief bearing/lose size	7
Ext. bearing/maint. size	4		
Easy to pick	3		
Fruit characteristics		**Fruit characteristics**	
Consumer recognition	2	Poor (small) size	2
Optimum (large) size	39	Poor appearance/shape	4
Good appearance/shape	6	Poor color	4
Good color	12	Poor internal color	1
Good internal color	1	Poor flavor	7
Good flavor	28	Sour, tart	4
Sweet	6	Soft	7
Firm	12	Rot susceptible	1
Rot resistant	1	Hollow centered	2
Long shelf life	4	Poor processing char.	1
Good processing char.	6		

the popularity of 'Earliglow', again expressed grower concern for the "bottom line", as early marketing often results in higher profits. Brief bearing season or the reduction of berry size during the season (an 'Earliglow' trait) was one of the most frequently mentioned cultivar weaknesses. The other major grower concern appeared to be disease susceptibility. Root rots were mentioned as limiting factors more often than foliar diseases.

Overwhelmingly, growers mentioned size as an important fruit characteristic of the varieties grown (Table 3). Large fruit size was attributed to 14 of the 27 cultivars and to four of the five most popular cultivars grown by respondents (Table 2). Larger fruit are more easily picked and are more marketable than their smaller counterparts. Fruit quality characteristics were also considered to be important elements in cultivar choice, especially good flavor, color and firmness. All three of these traits were recognized in the three most popular cultivars with the exception of 'Honeoye'. Internal color, an important characteristic in processing strawberries was only mentioned twice, positively in respect to 'Lester' and negatively in respect to 'Guardian'. However, growers alluding to good or poor fruit color may have included internal color in their quality assessment without mentioning it specifically. Fruit softness was mentioned frequently as a cultivar defect, especially in less popular cultivars. Fruit appearance/shape, sweetness and processed quality (freezer and/or preserve) were also considered to be of some importance in cultivar selection. Very few growers mentioned fruit rot resistance/susceptibility as positive/negative characteristics of the cultivars they grew, but again some growers may have included this trait in their statements about disease resistance in general.

The relative importance of traits for future cultivars could be deduced by descriptions of a hypothetical "ultimate" strawberry cultivar (Table 4), which directly revealed the growers' perception of traits lacking

Table 4. Frequency at which characteristics were included in descriptions of the ultimate strawberry cultivar for Ohio producers' current needs.

Plant characteristics	Freq. of mention	Fruit characteristics	Freq. of mention
Consistent performance	2	Optimum (large) size	34
High yielding	14	Optimum (medium) size	4
Growable at high densities	2	Good appearance/shape	6
Disease resistant	20	Exposed cap	1
Insect resistant	4	Good color	19
Herbicide tolerant	2	Good internal color	5
Winter hardy	4	Contrasting seed color	1
Good stand/runnering	4	Good flavor	22
Early bearing	5	Sweet	19
Late bearing	1	Juicy	1
Ext. bearing/maint. size	16	Firm	15
Day neutral	2	Rot resistant	5
Exposed berries	3	Storable on plant	2
Easy to pick	2	Long shelf life	18
		Good processing char.	4
		All purpose use	1

in existing varieties. Grower portrayal of the ultimate cultivar varied greatly among respondents indicating the diversity of individual situations and/or needs. However, yield, fruit size, consistent fruit size throughout the season, color, flavor and firmness were still considered to be of major importance by most growers. Growers also stipulated cultivars with sweeter fruit, basing their need, for the most part, on consumer comments on the tartness or sourness of existing varieties. Finally, about 25 percent of the respondents desired their ultimate variety to be shippable or have prolonged shelf life similar to that of the more successful California cultivars.

In addition, growers overwhelming desired to have cultivars with greater disease resistance. In this case, fruit rots were mentioned directly and most often, followed in order by root diseases (most notably red stele and verticillium wilt) and leaf diseases. One grower, who responded to the survey in depth, cited public attitude and lack of understanding about pesticides and their use to be the largest problem facing strawberry growers today and in the near future. As agrichemicals are withdrawn and restrictions on their use increase, the development of cultivars with greater tolerance to biological stresses will be of paramount importance in breeding programs and to the survival of the industry as a whole.

Cultural Practices: Strawberries are still predominately produced by matted row culture in Ohio (Figure 3B). However, 16 individuals acknowledged using a hill culture system (ridges or raised beds—often described as a matted row on beds) whereas seven growers indicated they were maintaining ribbon rows (close spacing). A small percentage of the growers responding said that they employed more than one planting scheme. Only three growers were presently using drip irrigation, but several others affirmed plans to "experiment" with the method in the near future. A substantial proportion (about 40 percent) of the respondents who specified their irrigation practice described it as "solid set" or "overhead" systems. Three growers professed to have no means of irrigation. Apparently, very few of the growers surveyed used row covers (five individuals) and/or plastic mulches (five individuals), but again several others indicated a willingness to try these production techniques. A grower's chosen cultural scheme apparently did not affect his/her response to other issues on the questionnaire.

Marketing Strategy: Over the last ten years, the strawberry marketing mechanism in the Midwest has evolved from a predominantly PYO scheme to a much more complex, mixed market system (2,3). According to Courter and Kitson (3), the PYO market of Illinois peaked in the early 1980's, but began to decline as early as 1983 due in part, to the following reasons: changing demographics (older population), increase in the number of two wage-earner families, improvement in the quality of California-grown berries, and loss of price advantage over berries sold in the supermarket. Like their neighbors, Ohio growers have also experienced the decline in the PYO's importance. Only 21 percent of the survey respondents listed PYO as their sole market outlet (Figure 3C), whereas 75 percent of the strawberries sold in 1976 were marketed under the PYO system (1).

Courter and Kitson (3) suggested expanding market outlets, providing pre-picked berries for retail and wholesale as well as expanding on farm or roadside stand products or services and implementing more effective and thorough advertising campaigns as means to increase profitability. In Ohio mixed marketing schemes comprised 70 percent of those reported in the present survey. Growers who marketed their strawberries using PYO and farm market/roadside stands (retail) sold 60 percent of the crop PYO and 40 percent of the crop retail, whereas, those selling PYO, retail and wholesale (grocery chains) proportioned this crop 40:30:30 among the three outlets, respectively. These figures indicated the persistence of PYO as a very viable marketing option when used in mixed-market scheme. Again, no clear cut relationships between marketing strategies and other grower decisions could be discerned from the survey results.

Future Situation

Because the breeding of new strawberry cultivars is a long-term process, grower projections for the industry's future were of special interest. Questions posed in this section (Table 1) were designed to ascertain whether growers anticipated drastic changes in the strawberry industry in Ohio, and if so, what traits might be of importance to the success of cultivars produced under these new regimes/systems.

Shifts in strawberry production centers and methods of production have occurred previously and the industry continues to evolve today. Hypothetically, Ohio's opportunity for market share might increase in the future due to advances in strawberry culture, to changes in the agricultural situation in other production centers, to an increased demand for strawberries or to the development of alternative marketing systems. If such a pattern were to develop, over half of the respondents to the survey (57 percent), indicated a willingness to expand their operation. The major uncertainty about expansion seemed to be the availability of harvest labor. Of those that answered negatively (16 percent), their reasons for refusal included lack of space and water, and the lack of time resulting from commitments to other fruit crops. In addition, a few respondents feared that increased production and competition would ultimately saturate existing markets and lower the profitability of strawberry production as it has in the past. Other respondents failed to answer or agreed conditionally with the premise. In the same spirit, 78 percent of the respondents voiced a willingness to alter their production schemes if profit margins were concurrently increased. Respondents answering "no" to this question all declined to comment on their response.

Almost all growers answered "yes" when asked if the ultimate cultivar for their future needs was similar to that for their current situation. Many respondents added desirable traits to those they previously listed, but collectively, the only additional traits mentioned were machine harvestability and tolerance to nematodes.

Even though only a small percentage (5 percent) of Ohio growers currently cultivate day neutral varieties ('Fern', 'Tristar' and 'Tribute', Table 2), and though day neutrality was mentioned as a characteristic of the ultimate cultivar only twice (Table 4), approximately 41 percent of the respondents indicated a desire for an everbearing cultivar specifically suited to Ohio's conditions. Some of those respondents answering yes were very enthusiastic about the potential of day neutral varieties for their specific production/marketing situation. Others in agreement qualified their answers by stipulating that small berry size, yield fluctuations throughout the season and other drawbacks associated with currently available cultivars would have to be rectified in the new cultivars before day neutral varieties would benefit them. However, a nearly equal percentage (40 percent) of respondents felt that day neutral cultivars would be of no use under their current situation or in the future. Those answering no, did so most often because of the progression of duties in a diversified production scheme and commitments to other crops in later summer months, or because of the seasonality in consumer demand for PYO or farm market fruits.

Although it is unlikely that a processing berry industry will develop in Ohio under our current production level and economic situation (6), growers were asked to indicate their interest in the development of processing cultivars. Twenty-four of the growers surveyed indicated that they were interested, 23 asserted that they had no interest, 12 were unsure of the benefits of a processing strawberry, and three failed to respond to the question. Independent of the response, growers who qualified their answers unanimously questioned the profitability of a strawberry processing industry in Ohio due to the fresh market potential (concentrated population and high standard of living) and to the price differential between berries sold to the fresh and processing markets. One grower, with an implied interest in the potential of the processing market, expressed fear at "becoming a contracted puppet to the processing industry" whereas another, who was vehemently opposed to the establishment of processing industry, felt that mechanized harvest "would put all small growers out of business". A third stated that "growing for processing would be dangerous because in years of good production, the processor may not be able to use all the berries resulting in excess berries that no one wants."

Finally, 65 percent of the respondents to this survey acclaimed the development of cultivars with improved fruit quality characteristics as a very important goal for strawberry breeders if Ohio's industry were to be strengthened. An additional 14 percent indicated that this objective was important. Comments by those who considered quality to be important often mirrored their previous answers, but shippability, long shelf life and ability to compete against California-grown strawberries were mentioned most frequently as being paramount to the success of new cultivars. In contrast, only 13 percent rated fruit quality as being unimportant, citing the consumer's inclination to purchase large, less expensive berries regardless of quality as the reason for their disinterest.

Conclusions: Impact of Survey Responses on the Ohio Strawberry Breeding Program

As a principal objective of this study was to obtain grower input at the initial stages of varietal development, survey results are summarized herein in terms of their impact on future breeding objectives and selection practices of the OARDC strawberry breeding program. Although most Ohio strawberry growers have limited acreages under production, they consider strawberry culture and marketing to be an important part of their overall operation. Additionally, growers are willing to test and adopt new cultivars as they are released. These "grower" characteristics suggest an eager market for the products of a breeding program (i.e., improved varieties) if they are specifically advantageous to production/marketing schemes, and lend credence to the potential usefulness of a state-supported program to the citizens of Ohio.

By their answers to the five questions concerning strawberry varieties, survey respondents indicated a desire for cultivars that were high yielding and disease resistant, especially to fruit rots. However, perhaps the characteristic most often mentioned as important to new cultivar success was fruit size. Most individuals wanted large-fruited cultivars that would maintain their size throughout the season. Moreover, growers overwhelmingly considered fruit quality to be of paramount importance to their business and to be a primary concern for new cultivar development. Quality traits most often mentioned were flavor, color, firmness and post harvest durability (shippability and shelf life). The latter trait seemed particularly important in view of the mixed marketing strategies currently used by most Ohio growers. All of the above mentioned characteristics will be included as selection criteria for cultivars developed by the OARDC breeding program. Augmenting breeding efforts, developmental, physiological and genetic studies of strawberry quality (e.g., flavor, color and firmness) are currently underway.

In addition, production/marketing schemes were varied enough that a substantial portion of the respondents professed interest in day neutral cultivars for their specific situation. Therefore, day neutral germplasm will also be developed and screened for possible improvement over existing everbearing varieties. However, selection for mechanically-harvestable varieties will not likely be a major goal of the program, because of the lack of potential for an Ohio processing industry under our current situation and because of grower skepticism about marketing primarily to processors.

Most growers are still using the traditional matted row system of production. However, several respondents had successfully adopted alternative schemes and an even greater number indicated a willingness to alter their current system if the new methods proved to be profitable. The adaptability and diversity of grower practices necessitates that advanced selections be tested under various production regimens (e.g., matted row, ribbon row, etc.) before they are released. Although it compounds the effort necessary to adequately evaluate potential varieties, multiple testing will ultimately indicate the production system to which new cultivars are optimally suited.

References

1. Carter, C., H. Carter, K. Ackers, M. Evans, E.J. Stang, and R.N. Williams. 1978. Ohio's strawberry, raspberry, and blackberry industry: potentials and problems of an expanding industry. OARDC Res. Cir. 242.
2. Courter, W.J. 1989. Profile of the strawberry consumer in Illinois. p. 28-37. In Proc. 1989 IL Strawberry School. 8 Mar 1989. Mt. Vernon, IL. Univ. IL Coop. Ext. Svc. Hort. Ser. 77.
3. Courter, W.J. and M. Kitson. 1988. 1987 Survey of pick-your-own strawberry consumers. Adv. Strawberry Prod. 7:39-41.
4. Galletta, G.J. 1988. A progress report on strawberry variety development. p. 110-119. In Proc. 1988 Ann. Meeting No. Am. Strawberry Growers Assn. 7-10 Feb. 1989, Tampa, FL.
5. Luby, J.J. 1989. Midwest and plains states strawberry cultivars. Fruit Var. J. 43:22-31.
6. Rhodus, W.T. 1990. Marketing Ohio strawberries. Fruit Crops 1990: A Sum. of Res. 63-71.

Orchard Crop Loss Assessments: A Precondition for Improved Crop Protection Decisions

Franklin R. Hall
Department of Entomology

Introduction

Recent news stories have implied that spraying fruits and vegetables for cosmetic purposes has led to an excessive use of pesticides. With the general public being frequently bombarded with such claims and headlines, we need quantitative information on actual pesticide use and insect- and disease-induced crop losses experienced by fruit growers. There are few accurate assessments of current pesticidal usage *and* crop losses on certain crops, and yet proponents of various new pest management programs and application methods claim "we'll save you 50-80 percent of your spraying costs."

In 1965 the USDA Handbook, *Losses in Agriculture*, reported dollar values as losses to the public rather than to the farmer. Most of the information represented *estimates* by the specialists and were not validated, which creates serious problems in obtaining credible economic and biological appraisals of pest related losses. The major concern is not that we derive positive benefits from the use of pesticides but rather whether the current use patterns are *optimal*. An improved pesticide information strategy has been suggested with the Pesticide Benefit Assessment (PBA) model being utilized to address benefits, as well as externality costs [groundwater and worker safety, pest resistance, etc.] associated with alternative crop protection strategies (6).

Improved pest management strategies require an understanding of the precise problems (and perception of crop protection) that growers face in their daily tasks (2, 10). Many fruit growers, because of increased costs, better pest management practices, or low volume spray applications, have already substantially reduced their use rates of chemicals (1, 4). Accurate infor-mation on benefit/risk relationships is needed so that fruit growers won't be forced into programs that will lead to problems in pest control or lose the progress already made in integrated control. Pest control decisions made with uncertainty will usually be improved with information (13). The forms of information most useful are "those associated with frequency and extent of pest damages." Miranowski (7) concluded that information for improved pest control decisions would reduce pesticide use more than would insurance support for pest damage.

Pimentel et al. (12) noted that an estimated 33 percent of all crops is lost annually to pests (13 percent to insects, 12 percent to pathogens, and 8 percent to weeds) in spite of pesticidal controls. Since the 1940's, crop losses due to insect pests have on the average increased nearly 2-fold despite a 10-fold increase in insecticide use. The average dollar return in pesticide controls was estimated by Pimentel et al. to be about $4 (12). Many scientists admit, however, that these are only estimates and hence, data gaps previously mentioned clearly need to be filled establishing the extent of fruit losses being experienced by orchardists. The pesticide survey by Hall (3) illustrated this need for quantitative economic analysis of crop losses in commercial fruit operations. If new crop protection strategies are to be fully implemented, then baselines of current fruit losses must be established. Although percent damage by individual fruit pests was reported by Hall (4), the specific crop loss/benefit relationships were not discussed. Consequently, the objective of this paper is to (1) review the concepts of Hall and Lemon (6) with respect to the benefit/loss relationships of certain pesticides under different marketing situations with the current federal and state grade regulations, and (2) address the economic benefits of potential adjustment strategies.

Materials and Methods

Apple growers were selected from 16 counties throughout northern and southcentral Ohio. Orchards in this study (18 in 1979 and 19 in 1980) averaged ca. 6 acres for each block under study. Growers and blocks were selected so that there was equal representation of the three Ohio marketing methods, i.e., wholesale, retail, and pick your own (PYO). All growers sold fresh fruit only, which is the usual marketing situation in Ohio. Methods of block section and data capture from individual orchards, pesticide use information and records management information were as reported by Hall (4). At harvest, samples of each variety were randomly collected (after harvest) from the study block and check trees for evaluation of insect and disease injury. The size of sample was dependent upon the size of the study block and number of varieties but ranged from 1-2 bushel per tree (up to 10 trees/variety). Fruit diameter by variety was also recorded at the same time. Records were kept for each grower on yields per acre by variety for each block. Packout and prices received per grade class and variety, as well as cull yields and reason for cullage were recorded by each grower.

Data gathered in 1979 and in 1980 included (1) crop losses (yield/-acre) and (2) changes in crop quality due to principle insects and diseases. With each block under study, unsprayed or check trees/block were monitored to validate benefit/cost/ risk aspects of each chemical strategy. Interactions between crop losses due to yield reduction vs. quality reduction were assessed according to pesticide use and marketing strategy. In 1980, each study and check block was evaluated for reduction in bloom by variety. Data were correlated to 1979 disease and insect control ratings and production figures.

Results and Discussioin

The major insect and disease injury ratings as percent damaged fruit for each variety at harvest in 1979 and 1980 were reported by Hall (4). These assessments also included unsprayed fruit ratings for each grower whenever possible in each year. As summarized in Table 1 for Red Delicious in 1980, the major insect and disease damage totaled ca. 2 percent for protected orchards while hail alone ranged up to 24 percent. The range of insect and disease pressure of up to 10 percent in some cases indicated that particular growers had some problems with one or more pests. The unsprayed data shows a relatively low incidence of pest problems in the second year of non-treatment with the exception of plum curculio [*Conotrachelus nenuphar* (Herbst)] (up to 31 percent) and apple scab [*Venturia inequalis* (Cke)] (up to 65 percent). In most cases, the untreated groups of trees were within the sprayed block and probably were affected by the area spraying. However, it is clear that some disease problems such as apple scab can be devastating from year to year depending upon the local temperature and rainfall conditions.

To determine the possible effects of non-treatment in 1979, bloom density of these trees was measured in 1980 (Table 2). The data show a trend between high levels of fruit damage in 1979 and reduced bloom density in 1980. For example, on Red Delicious (Grower 20) where fruit damage averaged 60 percent in 1979, the return bloom in 1980, average blooms/m in 1980 were reduced to less than 3 percent of the bloom density in the sprayed trees. Similar data on Red Delicious were also noted for Grower 09 which does suggest a degree of cultivar sensitivity to certain crop stresses. Cultivar sensitivity differences were noted as in the case of Growers 02 and 08 where 50 percent fruit damage to Red Gold and Gallia Beauty from the previous year resulted in only slightly to moderate reductions in bloom density in 1980. Where low fruit damage was noted in unsprayed trees in 1979, no detectable difference in bloom densities were noted in 1980 (Grower 17). Fruit damage levels of 50 percent are not likely to be experienced by commercial growers, but the data illustrate the potential for insects and disease to significantly influence crop yields the year following damage by various pests.

Observations made in these orchards showed that, although there were opportunities for assessment of yield, quality, size, cull factor identification and quantification, little advantage [adjusting crop protection strategies] was being made of them. In addition, block and variety information was minimal although fruit being placed in short/long term storage was generally identified by block, variety, etc. The factors such as pressure of the harvesting operations, time and weather, along with labor constraints, appear to play a major role in limited data collection at this time of year.

Table 3 and 4 summarize a 1980 crop packout analysis for growers of wholesale/retail and PYO fruit, respectively. The analysis illustrates the variety of grades utilized by growers, as well as the dollar income by grade category and marketing option and/or alternative. For example, Grower 12, by upgrading the #2 grades into the Fancy grade, could have boosted his income/acre by 17 percent (Table 3). Additionally, Grower 02 could have increased his dollar return/acre by *3½ times* if he had been able to upgrade his #1's into the Fancy grade. Finally, Grower 04 (Table 4) could have increased his

Table 1. Average pest damage in Ohio sprayed and unsprayed orchards (Red Delicious) in 1980 (after publication 4).

Pest	Average % Damage	Range (%)
SPRAYED		
Plum curculio	0.5	0-2.5
Leafrollers	0.4	0-1.8
Codling Moth	0	0
Apple Scab	1.3	0-10.5
Hail	—	13-24%
UNSPRAYED		
Plum curculio	9.2	0-31.1
Leafrollers	2.3	0-5.0
Codling Moth	2.2	0-6.5
Apple Scab	22.5	0-64.8
% Insect or Disease Free	35.4	0-85.1

Table 2. 1980 bloom density of apple varieties in selected Ohio orchards.

		Avg. #Blooms/Meter[a]		
Grower	Variety	Unsprayed in 1979	Sprayed in 1979	% Fruit Damage unsprayed (1979)
02	Red Gold	65	70	47
20	Red Delicious	1	40	60
12	Jonathan	61	73	81
17	Red Delicious	61	57	4
08	Gallia Beauty	11	38	54
09	Red Delicious	4	35	80

[a]On second year growth of 5-10 trees of selected varieties in 1980.

gross income/acre by $400 if he had been able to utilize those lost or dropped fruit. While other examples of increased income potential are prevalent in these two tables, depending upon the marketing options available to a grower, there may be not only opportunities for marketing an *array* of grades (Fancy,# 1 and # 2's), but it might be a *necessary* strategy in order to serve their respective clientele (i.e., their markets).

The major reason for grade reductions and the impact of those grader reductions on dollar return for 1979 is shown in Table 5. Pest damage ranged from 1 to 32 percent. For example, in 1979, six growers had fruit placed into lesser grades (# 2) primarily because of poor color, while seven growers had apple scab as the major cull factor. Grower 18 had 32 percent culled because of apple scab on Red Delicious. If he had been able to reduce that to 2 percent, he potentially could have increased his dollar return/acre by $160. This was also the case for Grower 19, who could have returned over $357/acre in additional income if he had been able to reduce losses from apple scab to 2 percent. Costs of a scab spray were typically under $6.00/acre and thus either grower would have greatly benefited from a more timely application(s). Field assessment of the potential damage based on intensity of foliar infection would have, in these cases, been a cost effective strategy.

Tables 6 and 7 present similar data for 1980. Pest damage ranged from 2 to 36 percent for the wholesale/retail grower and 4 to 36 percent for the PYO grower. Major cull factors for 1980 were identified as inadequate color (seven growers), small size of fruit (six growers), and four growers had excessive problems with apple scab. In 1980, hail damage was experienced by three growers. If insect/disease damage had been reduced to 2 percent levels by crop protection adjustments [i.e., frequency of treatment, timing and/or choice of product, etc.], several growers could have gained considerable income per acre; i.e., Grower 18 (Table 6) and in Table 7, Grower 03 on a PYO program.

The major problem identified by this phase of the study was that crop losses were not being identified (nor quantified) as the fruit comes out of the orchard or storage, other than very superficially. Consequently, little or no information is available to the grower at an optimum time, to demonstrate the potential for income

Table 3. Packout analysis for Ohio wholesale and retail apple growers in 1980[a].

Grower I.D.		Extra Fancy	Fancy	#1	#2	Bagged (Various Grades)	Culls/Drops Cider	Culls/Drops Juice
01	Yield (bu)		340				72	
	$		2493				440	
02	Yield		59	527				103
	$		644	3688				155
05	Yield	185		355		32	68	
	$	3332		4263		256	751	
06	Yield			778				61
	$			5445				102
07	Yield		239	273				205
	$		1374	2322				365
08	Yield	298						23
	$	1550						26
09	Yield	226		338		102	258	
	$	2707		3295		612	1915	
11	Yield		694					58
	$		4887					98
12	Yield	300	14		103		28	37
	$	2681	66		466		223	56
15	Yield		1014		66			22
	$		7306		364			37
17	Yield (bu)		708			3	86	
	$		4090			14	172	
18	Yield	417		120			141	99
	$	2978		857			864	166
20	Yield		348		39			
	$		5573		445			
21	Yield		81		34		25	
	$		1028		241		227	

[a]Yields=bu/acre and $/acre based on yield and selling price for that grade.

Table 4. Packout analysis for Ohio PYO apple growers in 1980[a].

Grower I.D.		Fancy	#1	#2	Bagged (Various Grades)	Cider	Culls/Drops Juice	Culls/Drops Lost (Not Picked)
03	Yield (bu)		128		68			38
	$		766		204			114
04	Yield		557	266	142			414
	$		3900	1064	425			1241
10	Yield	432				48		
	$	3238				270		
14	Yield		1136			235		
	$		7321			1460		
16	Yield		400					116
	$		2707					197
21	Yield		142		6			
	$		1139		24			

[a]Yields=bu/acre and $/acre are based on yield and selling price for that grade.

gains by various pesticide management options. Data in Tables 5-7 strongly suggest that the dollar gain/acre values, if predicted or simulated on the basis of "WHAT IF" questions during the season, would be a distinct advantage to a grower in the crop management/protection decision-making process. This would represent an excellent opportunity to utilize the DSS (Decision Support System) tools, especially MARKET MODEL, for exploring the cost/benefit relationships (5, 6) of crop protection strategies.

Table 8 shows Ohio apple production from 1975 through 1988. Of particular interest is the fact that although 1980 was the largest apple crop since 1951, the large fluctuations from year to year (−40 percent in 1981 to +67 percent in 1980) seem to be the norm for Ohio. It should also be noted that with a few exceptions (1982, 1984, 1985) the average seasonal prices received by these apple growers were ca. $.05/lb higher than national average. At 850 bu/acre(averaging 40 lb/bu), this would yield ca. $1,700/acre extra for Ohio growers. This is an extraordinary price advantage, probably as a result of the large urban populations in Ohio and as a result, the large numbers of farm markets/PYO sales, etc. (i.e., direct sales outlets) shows the year-to-year yield consistency (in yields) is also a factor in profitability and Table 9 shows fluctuation of individual orchardists from 1979 to 1980. Most growers had greatly increased yields in 1980 but based on an average of 690 bu/acre, many growers (10 of 19) or almost 50 percent were below that average. Clearly, the production/acre even in 1980 could be higher. Additionally, the percent change (increase) from 1979 to 1980 was significant and as indicated by the state (Ohio) yield data depicted graphically in Figure 1, emphasizes the problem of *production consistency*. It is well known to growers that besides weather, varietal differences can make a significant difference in yield potentials as well as tree age and rootstock/variety combinations. However, all of the sample orchard sites had reached full bearing maturity and the data reflect the lack of consistency that plagues fruit growers in many areas of the country. Year-to-year fluctuations in yields because of frost or winter injury appear to have the major impact on income/acre and is frequently irrespective of pest problems. In addition, these wide fluctuations tend to increase risk aversion behavior on the part of the grower.

Table 5. Crop loss analysis for Ohio apple orchards, 1979.

Grower[b]	Total Bu # 1	Total $ received # 1	Total Bu # 2	$Loss[a] (difference) # 1 to #2	Major reason for loss	% Total cull due to insect & disease	If reduced to 2% injury: additional bu # 1 & $ potential: # Bu/acre	$/acre
01 J	253	$1961	172	$430	color	4%	9	$ 23
R	316	2844	56	210	color	3%	4	15
02 RG	533	3464	9	36	scab	1.6%	—	
04 G	496	3472	24	—	scab	13%	—	
05	81	972	35	105	color	30%	33	99
06	412	5768	286	2002	hail	5%	21	147
07	368	4416	225	1040	color	2.5%	3	13
08 GB	192	1440	57	200	color	4%	5	18
09 R	337	3033	26	91	cork spot	7.5%	19	67
10	163	1183	—	—	p. bug & leafroller	4%	—	—
11	190	1425	50	225	frost	3%	5	23
12 J	42	378	13	20	color	4%	2	5
14	582	4074	18	9	scab	1%	—	—
15	548	4384	61	152	color & size	4%	11	61
16	266	1862	—	—	p. bug	2.5%	—	—
17 J	289	1734	51	179	leafroller	4%	7	25
RM	252	2016	135	743	deform cat.	6%	15	83
18 J	555	4107	23	25	scab/rot	4%	12	13
R	265	2120	100	170	scab	32%	94	160
19	194	2134	51	395	scab	21%	46	357
20	168	2856	17	85	scab	9%	13	65
29	251	2761	19	147	scab & p. bug	7%	14	109

[a]Based on difference in selling $ for each grower between #1 and #2 or cider option.
[b]J=Jonathan; R=Red; RM=Rome, G=Gold.

These crop fluctuations significantly add to the difficulty of making cost benefit analyses and emphasize the problems the growers face in maintaining *consistent* marketing avenues. Year-to-year yield consistency is a *goal* of each grower and thus pest control via IPM strategies becomes a secondary rather than primary goal. Lack of predictable cost benefit analyses and low dollar returns would appear to be significant and practical constraints to any real change from current pesticide use patterns especially under the current economic climate.

Crop losses from insects and diseases were low in this 2-year study, with many less than 2 percent although there were exceptions to this trend. In addition, although fruit bruising (during the harvest operation) and subsequent grade downgrading was not quantified in this study, color was a frequent factor for grade reduction. Hail also represented a significant economic loss for some growers. The quantification of certain types of cull factor information could reveal options for grade improvement with a concurrent increase in dollar return per bushel. These opportunities for crop loss information do exist at each grower's packing line, although the pressures of the harvesting operation under constraints of labor and weather, make this difficult although not impossible for growers. In general, the recordkeeping process for yields, quality and pesticide use strategies by variety and block are

Table 6. Crop loss analysis for Ohio wholesale and retail apple growers in 1980.

	Extra Fancy+#1		#2+Culls & Drops		$	Major Reason	% Total Loss Due	If reduced to 2% injury: Additional bu Ex. F+ #1 and $ potential	
	Bu Total	$ Received	Bu Total	$ Received	Loss Diff.	For Loss	To Insect & Disease	#Bu/acre	$/acre
01	340	2493	73	444	70	Color	10%	33	234
02	586	4331	103	155	609	Color	4%	14	102
05	540	7595	100	1007	422	Hail	3%	6	91
06	778	5445	61	102	324	Scab Hail	3%	8	59
07	512	3696	205	365	1106	Color	6%	29	206
08	298	1550	26	26	109	Color	15%	42	219
09	564	6002	360	2527	1304	—	2%	—	—
11	694	4887	58	98	313	Size Russett	3%	8	53
12	315	2747	168	745	717	Color	5%	15	126
15	1014	7306	88	401	234	Size	3%	11	79
17	708	4090	89	186	329	Color	2%	—	—
18	537	3835	240	1031	684	Color Hail	24%	171	1221
20	348	5573	39	445	174	Russett	2%	—	—
21	81	1082	60	468	330	Size Scab	12%	14	188

Table 7. Crop loss analysis for Ohio PYO apple growers in 1980.

	Extra Fancy+#1		#2+Culls & Drops		$	Major Reason	% Total Loss Due	If reduced to 2% injury: Additional bu Ex. F+ #1 and $ potential	
	Bu Total	$ Received	Bu Total	$ Received	Loss Diff.	For Loss	To Insect & Disease	#Bu/acre	$/acre
03	128	766	106	204	432	—	36%	80	477
04	557	3900	821	1489	4259	Russett	5%	41	289
10	432	3238	48	270	90	Scab	6%	19	144
14	1136	7321	235	1460	56	—	4%	27	177
16	400	2707	116	—	785	—	8%	31	210
21	142	1139	6	24	24	Size Scab	12%	15	119

inadequate for the purpose of increased profits via improved pesticide decision-making.

Pedigo et al. (11) discussed the necessary integration of multiple pest scenarios which increasingly result in "conceptual fatigue" of the threshold concept. Zadoks (18) and others (9, 10) suggested more realistic approaches and decreed that researchers better understand farmer needs and concerns which reach beyond crop protection alone. This was defined as the need to integrate the system, to see and define problems as the farmer does, and finally, to present benefits in monetary terms. Consequently, crop loss assessments should denote crop losses in terms of $/acre by loss factor. The integration and development of strategies then takes on the parameters of loss, strategy, and resources to change the course of action. It is at this point in technology transfer that researchers should be cognizant of the need to provide decision rules that are simple enough to be implemented but which also recognize variances of risk aversion. In other words, the rules must identify time, weather and resource constraints present on the individual farm (e.g., be site specific).

From the enclosed data set and other studies (1, 16), it is clear that grower perception of pest and disease problems, hence, number of treatments/acre/season vary considerably from farm to farm between growers of similar crops (4, 16, 17, 18) and within the same region. Zadoks (18) suggests that logical course of action is to delineate the expected added value of reasonable assumptions and leave the decision to the growers. Schmidt and Blonnigen (14) and Steffen and Zeller (15) suggest that improved decision-making could be aided by simulation models which explore long term system behavior and intensity effects while taking into consideration the uncertainly factor. Thus, interdisciplinary cooperation is stimulated as well as the need for increased financial and ecological information which can be used for the assessment of necessary actions.

The total mileage from Wooster to these orchards scattered throughout the state was ca. 1990 miles. Driving time alone to and from each orchard in the study was estimated at ca. 40 hours, thus indicating the relative inefficiency of an on-farm scouting program for Ohio tree fruit. However, with the advancement of computer-assisted information delivery systems, an opportunity exists for increased "real-time" support to growers to aid in making pest management decisions. These

Table 8. Ohio apple yields, 1975-1988[a].

Year	Seasons Avg. Price Rec. by Growers Ohio(cents/lb)	Ohio Mil. Lbs.	U.S. (cents/lb)	US Mil. lbs.
1975	9.6	160	6.5	7,103
1976	14.4	105	9.1	6,473
1977	15.5	65	10.6	6,643
1978	14.3	140	10.4	7,554
1979	15.7	105	10.9	7,750
1980	14.5	170	9.5	8,707
1981	20.6	100	13.2	7,740
1982	13.5	150	15.3	8,122
1983	15.9	100	13.2	8,373
1984	16.1	135	16.7	8,333
1985	14.4	145	16.0	7,922
1986	17.4	90	13.1	7,914
1987	15.8	150	8.7	10,452
1988	17.7	95	12.6	9,108

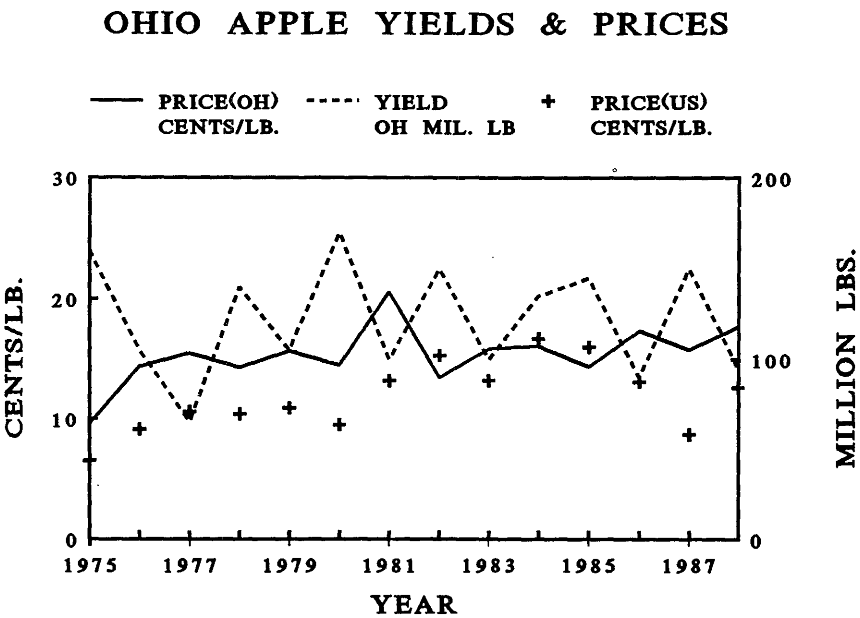
[a] Source: Ohio Ag. Statistics—H. Delong.

Table 9. Yield changes in selected apple orchards from 1979 to 1980[a].

Grower	Yield Changes: (% above (+) or below (−) orchard study average) 1979	1980	% Changes from Grower Yield in 1979 (+)
01	12+	40−	2+
02	50+	0.1−	27+
03	No crop	66−	234+
04	9+	100+	248+
05	68−	7−	453+
06	93+	22+	20+
07	49+	4+	33+
08	31−	53−	30+
09	0.3	34+	154+
10	55−	30−	194+
11	34−	9+	213+
12	85−	30−	778+
13			
14	45+	99+	161+
15	68+	60+	81+
16	29−	25−	102+
17	3+	16+	113+
18	23+	13+	75+
20	49−	44−	109+
21	NA	58−	NA

[a] Basis of average yields of 362 bu/acre in 1979 and 690 bu/acre in 1980.

Figure 1. Ohio apple yields and prices vs. U.S. prices, 1975-1988. Source: Ohio Ag. Statistics—H. DeLong.



survive in the 1990's, will need predictive capability to make cost-benefit analyses and decisions that systems science and effective information management can provide. If new crop protection strategies are to be fully implemented, certain base lines of current crop protection expenditures and fruit losses must be identified. These appear to be legitimate requirements for the implementation of a practical pesticidal strategy which will continue the economic and ecological advances already made in the use of pesticides in fruit production (5).

management decisions which are now made with uncertainty and lack of information, would be substantially improved with more detailed on-farm information. The recently developed (computer) decision aid [MARKET MODEL] for on-farm use (5, 6) utilizes the principle that cost/benefit analyses are a fundamental step towards the goal of improved decision making. Thus, MARKET MODEL gives the user an opportunity to quickly examine basic relationships between production/price/revenue and is designed to *stimulate* the process of on-farm recordkeeping which in this study was observed to be underutilized in the crop protection decision process.

Conclusions

The production of apples in Ohio is a high risk venture. The crop has a high value and high potential for profit (especially under fresh market options) based primarily upon successful management of factors that control yield and quality. Many growers are successful from year to year but the average yield values based on potential cropping estimates of many of the orchards show that maximum yields are infrequent. Apples have a complex pest profile which most growers handle well with the use of pesticides, the level of which is not excessive and, in fact, well below recommendations (4). However, recent events [the Alar episode] concerning the public "perception" of U.S. food safety should make agriculturists aware of the sensitivity and, in fact, the volatility of this issue and the need for accurate and informative *scientific* studies. Consequently, the Ohio family fruit grower who is going to

Acknowledgement

Financial support for this project was granted by the North Central Region Pesticide Impact Assessment Program and the National Agricultural Pesticide Impact Assessment [NAPIAP] of the USDA. Additional thanks are extended to Sherry Crassweller, Dena Myers and John Gregory for their technical assistance and, of course, to the individual fruit growers who took the extra time and effort to participate in this assessment.

References Cited

1. Carden, P. W. 1987. Supervised control of apple pests in southern England. Crop Protection. 6(4):234-243.
2. Fenemore, P. G., and Norton, G. A. 1985. Problems of implementing improvements in pest control: a case study of apples in the UK. Crop Protection. 4:51-70
3. Hall, F. R. 1977. Survey shows how Ohio fruit growers use orchard pesticides. Ohio Report. May-June.

4. Hall, F. R. 1983. Pesticide useage patterns for Ohio apple growers. J. Econ. Entomol. 76:584-589.
5. Hall, F. R., J. R. Lemon, and R. C. Funt. 1987. Cash in on CASH. Am. Fruit Grower, March, 52-53.
6. Hall, F. R., and J. R. Lemon. 1990. The CASH System of On-Farm Decision Tools for Horticultural Enterprizes. ACTA Hort. In press.
7. Miranowski, J. A. 1980. Estimating the relationship between pest management and energy prices, and the implication for environmental damage. Am. J. Agric. Econ. 62:995-1000.
8. Mumford, J. D., and G. A. Norton. 1984. Economics of decision making in pest management. *Ann. Rev. Entomol*. 29: 157-74.
9. Norton, G. A. 1976. Analysis of decision making in crop protection. *Agro-Eco-Systems* 3:27-44.
10. Norton, G. A., and Mumford, J. D. 1983. Decision making in pest control. In: Advances in Applied Biology, Vol. 8, pp. 87-119 (ed. by T. H. Coaker). New York: Academic Press.
11. Pedigo, L. P., S. H. Hutchins, and L. G. Higley. 1986. Economic injury levels in theory and practice. Annual Review of Entomol. 31:341-368.
12. Pimentel, D., J. Krummel, D. Galahan, J. Hough, A. Merril, I. Schreiner, P. Vittum, F. Koziol, E. Back, D. Yen, and S. Fiance. 1978. Benefits and costs of pesticide use in U.S. food production. BioScience. 28:772-783.
13. Reichelderfer, K. H., G. A. Carlson, and G. A. Norton. 1984. Economic guidelines for crop pest control. FAO Plant Production and Protection Paper 58: Rome, pp. 1-93.
14. Schmidt, H., and P. Blonnigen. 1987. Experimental crop cultivation and its value as an aid to decision-making on the farm current status and potential for future development. Berichte uber Landwirtschaft 65(4): 555-569.
15. Steffan, G. and M. Zeller. 1987. Assessing crop rotations and the employment of the means of production using dynamic management and control models. Berichte uber Landwirtshaft 65(4): 570-595.
16. Tait, E. J. 1982. Farmers' attitudes and crop protection decision making. BCPC Monogr. 25: 43-52.
17. Tait, J., and B. Napompeth. 1987. Management of Pests and Pesticides: Farmer's Perceptions and Practices. (ed.), Westview Studies in Insect Biology, Westview Press, Boulder and London. 244 pp.
18. Zadoks, J. 1985. On the Conceptual Basis of Crop Loss Assessment: The Threshold Theory. Ann. Rev. Phytopathol. 23: 455-73.

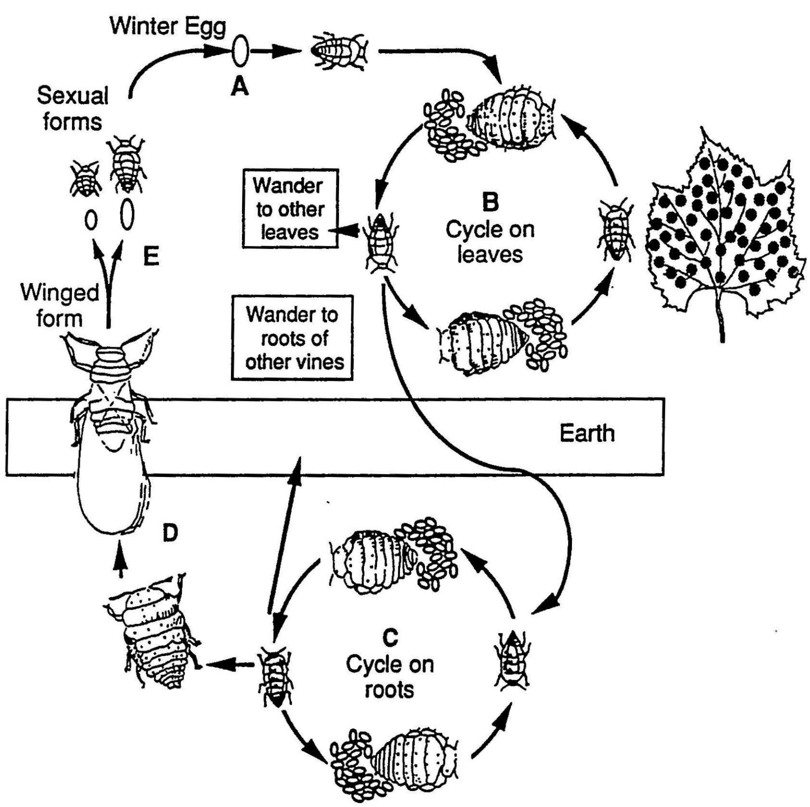
Evaluation of Compounds for Control of Foliar Grape Phylloxera, *Daktulosphaira vitifoliae* (Fitch) in Ohio

Murdick J. McLeod and Roger N. Williams
Department of Entomology

Introduction

Grape phylloxera, *Daktulosphaira vitifoliae* (Fitch) (Homoptera: Phylloxeridae) is a serious pest of grape worldwide, and occurs as both a root (radicola) and foliar (gallicola) form. The root form of grape phylloxera is very devastating to the vine and nearly destroyed the French wine industry in the late 1860's (Howard 1930). American vines are resistant to the root form of phylloxera, however, French-American hybrids are quite susceptible to the foliar form. Leaf galling causes distortion, necrosis, and premature defoliation (Stevenson 1966). Widespread planting of French-American hybrids in the Eastern United States has resulted in increased awareness and concern for foliar phylloxera (Jubb 1976, 1978, Stevenson 1966).

Figure 1. Life cycle of grape phylloxera, *Daktulosphaira vitifoliae* (Fitch), (After Williams, 1938). (A) Winter egg. (B) Foliar form (Gallicola). (C) Root form (Radicola). (D) Winged adult. (E) Sexual stage.



The grape phylloxera has a very complex life cycle (Figure 1). The pest may overwinter either as a winter egg under the bark of old trunks or as immature nymphs, or crawlers, on grapevine roots. When spring arrives, the overwintering egg hatches and gives rise to the fundatrix, or stem mother. This parthenogenetic female crawls to a nearby shoot tip and begins feeding by piercing the leaf tissue with her stylet-like mouthparts. Feeding by the female phylloxera results in the formation of a small, spherical gall on the lower surface of the leaf, within which the female is located. Upon reaching maturity, the female begins laying eggs from which subsequent generations arise. As these eggs hatch, newly emerged crawlers leave the gall and move to nearby shoot tips to begin feeding. Throughout the summer, foliar phylloxera crawlers may move actively or passively to the soil and infest roots. There are three to five generations of foliar phylloxera per season.

Nymphs overwintering on grapevine roots begin feeding as soil temperatures increase in the spring. This parthenogenetic root form causes two types of galls on roots. Nodosities are small galls formed on young, apical rootlets which are thought to result in little damage to the plant. Tuberosities are larger galls formed on older portions of the root which, if sufficiently abundant, may eventually result in death of the vine. Several generations of the root form occur in a season.

From July to October a portion of the root form develops wing buds and eventually becomes winged adults. These winged adults deposit two types of eggs: a larger one which gives rise to female progeny and a smaller which gives rise to male phylloxera. This is the only sexual stage in the life cycle. After mating occurs, each female deposits a single overwintering egg under bark of older wood which will serve as the initial source of foliar infestation the following spring.

Various insecticidal compounds are effective in controlling foliar grape phylloxera in eastern North America (Stevenson 1970; Williams 1976, 1979). However, the current requirement for re-registration of chemical compounds will play an important role in the number of compounds available for use in vineyards. Some standard insecticides have already been removed from the market, which makes it necessary to search for other compounds that are less toxic and more environmentally sound but that still provide effective control of the pest. This report summarizes results of insecticide efficacy tests against foliar grape phylloxera conducted at Wooster, Ohio from 1981 to 1989.

Materials and Methods

Experimental and commercial insecticides were tested at various rates in foliar and subsurface applications for efficacy against foliar grape phylloxera. Insecticides tested were esfenvalerate, fenpropathrin, endosulfan, chlorpyrifos, phosalone, cyfluthrin, carbofuran, carbosulfan, fenvalerate, diazinon, aldicarb, cypermethrin, carbaryl, and thiodicarb. Unsprayed vines served as controls. Treatments were evaluated in a 26-year-old 'Clinton' vineyard for the entire length of the study and in a 20-year-old 'Concord' vineyard from 1983 to 1985. A randomized complete block design with four replicates per treatment was used for all experiments. Replicates ranged from one to six vines depending on the year.

Tests were conducted from May 2 to August 6 to correspond with seasonal activity of phylloxera. Granular insecticides were applied once per season by hand and incorporated in a five cm furrow 0.45 m on either side of the row and 0.3 m outward from the end vine of the plot forming an ellipse around the plot. Soil moisture was considered adequate in all trials so granules were not watered in.

Foliar sprays were applied using a hand-held CO_2 sprayer operated between 3.2 and 4.2 kg/cm^2. Sprays were applied from both sides of the row at spray volumes of 495 to 1870 l/ha to provide thorough coverage but not to the point of runoff. Sprays timed 7 to 10 days apart were applied 2 to 5 times per year beginning at bloom, except from 1986 to 1988 when treatments were applied beginning when shoots were 25 cm long.

Efficacy of treatments was determined approximately one month after treatment by randomly selecting ten shoots from each plot, half from each side of the row. Gall counts were obtained from the ten apical leaves of selected shoots by counting galls on one side of the midrib of the leaf and doubling this number (Jubb 1977). Analysis of variance of gall counts was used to detect differences among treatments and Duncans New Multiple Range Test was used to separate treatment means for a given year.

Results and Discussion

Mean percentage gall reduction for all insecticides and rates tested is summarized in Table 1. Esfenvalerate, fenpropathrin, endosulfan, chlorpyrifos, phosalone, cyfluthrin, carbofuran, carbosulfan, and fenvalerate all gave better than 80 percent reduction in gall numbers at one or more of the rates tested in any one year. Chlorpyrifos, carbofuran, carbosulfan, and cypermethrin were the only compounds that provided statistically better control than the check for every year tested. Phylloxera pressure was very low in 1986 due to a late frost and also in 1988 due to severe drought. Several compounds provided control in those two years but differences were not significant due to low number of galls on check vines. If we were to disregard the results of those two unusual years, we could add fenpropathrin, endosulfan, phosalone and cyfluthrin to the list of compounds that consistently gave significantly better control than the check. Diazinon, carbaryl, and thiodicarb were the only compounds that failed to provide significant gall reduction for all rates and years tested. No phytotoxicity was observed from any of the compounds tested in this study.

Based on results of this study, endosulfan should remain the standard for control of foliar grape phylloxera. Phosalone consistently provides excellent control, but it is no longer available to producers. Other compounds that appear to hold promise for phylloxera control

Table 1. Summary of control of foliar grape phylloxera in small field plots with various insecticidal treatments, Wooster, Ohio, 1981-1989.

Chemical	Formulation	Rate kg ai/ha	Foliar or Soil	Mean percent gall reduction	Years tested
esfenvalerate	1.9EC	0.08	foliar	100	1988
fenpropathrin	2.4EC	0.34	foliar	100	1988
fenpropathrin	2.4EC	0.11	foliar	100	1988
esfenvalerate	.66EC	0.03	foliar	99	1989
endosulfan	50WP	1.68	foliar	99	1987-1989
esfenvalerate	1.9EC	0.04	foliar	99	1987-1988
chlorpyrifos	4E	1.12	foliar	99	1985
chlorpyrifos	4E	1.68	foliar	98	1985
phosalone	3.0EC	1.68	foliar	98	1987-1989
cyfluthrin	2EC	0.42	foliar	97	1985
carbofuran	4F	0.84	foliar	97	1983
fenpropathrin	2.4EC	0.22	foliar	96	1987,1989
carbosulfan	4E	0.67	foliar	95	1983
fenvalerate	2.4EC	0.22	foliar	93	1984-1985
esfenvalerate	.66EC	0.06	foliar	90	1989
endosulfan	50WP	1.40	foliar	89	1985
endosulfan	50WP	1.12	foliar	85	1981-1984
fenvalerate	2.4EC	0.11	foliar	80	1985
phosalone	3.0EC	1.12	foliar	72	1981,1983
carbosulfan	4E	0.56	foliar	69	1982
diazinon	AG500	0.42	foliar	69	1989
endosulfan	50WP	1.49	foliar	68	1986
aldicarb	20G	4.48	soil	65	1982-1983
cyfluthrin	2EC	0.04	foliar	61	1986
cypermethrin	3E	0.17	foliar	60	1982
aldicarb	15G	4.48	soil	59	1981-1984
fenvalerate	2.4EC	0.17	foliar	50	1984
carbofuran	10G	11.21	soil	49	1982
fenvalerate	2.4EC	0.28	foliar	46	1986
carbaryl	80S	2.24	foliar	24	1984-1985
thiodicarb	3.2F	0.67	foliar	21	1984
thiodicarb	80DF	0.67	foliar	0	1984

include chlorpyrifos, carbofuran, and synthetic pyrethroids such as fenvalerate, esfenvalerate, and fenpropathrin. Chlorpyrifos is registered on grapes for control of grape root borer but is not registered for foliar applications. Carbofuran is labeled for control of root phylloxera in California, but it has a higher mammalian toxicity than endosulfan, and cost would likely be prohibitive for use in eastern North America. Fenvalerate has a considerably lower mammalian toxicity than endosulfan but is highly toxic to fish. Esfenvalerate and fenpropathrin have only slightly lower mammalian toxicities than endosulfan and both are highly toxic to fish. However, none of the synthetic pyrethroids is currently registered for use on grapes in the eastern United States.

Literature Cited

1. Howard, L.O. 1930. History of applied entomology. Smithson. Misc. Collect. 85:564 pp.
2. Jubb, G.L., Jr. 1976. Grape phylloxera:incidence of foliage damage to wine growers in Pennsylvania. J. Econ. Entomol. 69:763-766.
3. Jubb, G.L., Jr. 1977. Estimating grape phylloxera (Homoptera: Phylloxeridae) gall numbers on single grape leaves. Entomol. News 3,4:77-80.
4. Jubb, G.L., Jr. 1978. Grape phylloxera key pest in state's wine vineyards. Sci. Agric. 25:3.
5. Stevenson, A.B. 1966. Seasonal development of foliage infestation of grapes in Ontario by Phylloxera vitifoliae (Fitch) (Homoptera: Phylloxeridae). Can. Entomol. 96:979-987.
6. Stevenson, A.B. 1970. Endosulfan and other insecticides for control of the leaf form of the grape phylloxera in Ontario. J. Econ. Entomol. 63:125-128.
7. Williams, J.L. 1938. Phylloxera and the Phylloxera Board of South Australia. J. South Aust. Dep. Agric. 41:853-859.
8. Williams, R.N. 1976. Chemical control of phylloxera. Proc. Ohio Grape-Wine Short Course. Ohio Agric. Res. Dev. Cent., Horticul. Series 438:19-23.
9. Williams, R.N. 1979. Foliar and subsurface insecticidal applications to control aerial form of the grape phylloxera. J. Econ. Entomol. 72:407-410.

Marketing Ohio Strawberries

W. T. Rhodus, Departments of Horticulture and Agricultural Economics and Rural Sociology
R. C. Funt, Department of Horticulture

Introduction

Per capita consumption of fresh and processed strawberries in the U.S. has increased between 1978 and 1988 by 43.8 percent and 16.1 percent, respectively. However, expansion of production to meet this need has not occurred uniformly across the various production regions. During this time, strawberry acreage in California increased by 36.8 percent and volume of production increased by 65.9 percent; while acreage in Ohio declined 13.3 percent and volume of production declined 16.1 percent. As a result, California strawberry production accounts for approximately 78 percent of the total fresh market supply and 63 percent of the processing market and Ohio accounts for only one percent of the fresh and none of the processing market.

These trends are the result of several factors. First, large amounts of money invested in strawberry research and promotion by California growers have led to improved varieties, new cultural practices, and market acceptance of California strawberries. Second, changing demographics have lead to a decline in the popularity of pick-your-own on-farm marketing for Ohio strawberries. Third, a shorter marketing season in Ohio is a disadvantage when trying to establish long term market relations with fresh market buyers.

To increase the marketing opportunities for Ohio strawberries, it is necessary to evaluate: (1) current production and marketing practices within Ohio, (2) production and marketing practices of other producing regions, and (3) feasible production and marketing alternatives which may increase Ohio's competitiveness, e.g. mechanical harvesting, strawberry cultivars with extended harvest season, and processing markets. Following this evaluation, recommendations can be presented which will address ways to exploit the most promising market opportunities and highlight changes which must occur in order for growth to be maintained.

Strawberry Production in Ohio

Strawberries are the second largest source of income for Ohio fruit growers after apples, generating $5.037 million of farm value in 1988. This placed Ohio as the seventh largest strawberry producing state in the United States. Since 1978, Ohio production has varied between 5.7 and 13.3 million pounds of strawberries, with peak production of 13.3 million pounds occurring in 1980 and 7.3 million pounds being produced in 1988. The maximum amount of land planted to strawberries, 1,900 acres, was during the years 1979 to 1983. Since 1983, acreage has been declining with a total of 1,300 acres being harvested in 1988 (4).

Ohio's strawberry yields per acre have been below the 1978 level of 5,800 pounds per acre for eight of the past 10 years. While peak yield occurred in 1980 at 7,000 pounds, yield per acre in 1988 was 5,600 pounds. Prices received by growers have steadily increased from 1978. In 1978, the average price per pound was $0.44 and by 1988, the average price had increased to $0.69, a 57 percent increase. However, the increase in prices received during the 1978 to 1988 period did not keep up with inflation. During the same period, the Consumer Price Index had increased by 84.8 percent. After adjusting for inflation, the "real" revenue per acre for strawberries [(yield per acre) times (price per pound adjusted for inflation)] in 1988 was 18 percent less than that of 1978. As a result, the relative attractiveness of producing strawberries in Ohio has been declining between 1978 and 1988 and this may well explain the 13.3 percent drop in harvested acreage since 1978.

The uncertainties associated with strawberry production in Ohio are compounded by uncertainties with marketing the crop. Harvesting of strawberries in Ohio is accomplished entirely by hand harvesting, either as pick-your-own, where the consumer picks their own berries or by hired workers who receive wages based on the number of containers harvested. Following harvest with hired labor, growers can either sell to wholesale buyers or directly to consumers through retail farm market stands. In 1987, 10 percent of all sales were to wholesale buyers, 20 percent were retail, and 64 percent were pick-your-own (3). Given the heavy emphasis on pick-your-own as a marketing strategy, Ohio growers are in a position of risk because of changing demographics and lifestyles of consumers. As the number of two income households increases, fewer individuals are available to pick their own strawberries and convenience of purchasing becomes a primary factor influencing demand for fresh strawberries. Thus, there is decreasing demand for pick-your-own and increasing demand for strawberries sold through supermarkets.

Evidence of this shift in demand is presented by the volume of sales which Ohio strawberry growers sold through each of the three market channels. In 1982, Ohio growers sold 83 percent of their crop, 10,408,200 pounds, through pick-your-own. In 1987, pick-your-own accounted for only 64 percent of the crop or 4,659,200 pounds, a decrease of 55 percent as measured by volume of strawberries. Alternatively, growers sold 2,620,800 pounds of strawberries through retail or wholesale channels in 1987, an increase of 23 percent over 1982 levels. However, selling wholesale or retail requires hiring labor for hand harvesting and providing a uniform sized/quality product, both of which lead to increased costs of production.

Expected costs per pound for strawberries produced in Ohio and sold to the wholesale or retail market are greatly influenced by the yield per acre. Using cost coefficients developed by Rhodus and yield per acre of 5,600 pounds (state average in 1988), cost per pound for fresh straw-berries is estimated to be $0.856 (7). If yield is increased to 11,000 pounds per acre, cost per pound drops to $0.585, well below the average selling price of $.69 per pound in 1988. Therefore, growers who are attempting to switch from pick-your-own to retail/whole-sale markets, must carefully examine their potential to produce in excess of 10,000 pounds per acre.

In addition to the need for increased yields, Ohio growers must also convince wholesale buyers to carry their product. By positioning their product as locally produced and therefore fresher than out-of-state strawberries, Ohio growers may be able to further penetrate the wholesale market for fresh strawberries. However, wholesale buyers may be unwilling to interrupt long standing agreements with out-of-state suppliers during a three to four week supply of locally produced strawberries. This will force progressive growers to find ways of extending the growing and marketing season in order to appeal to large scale wholesale buyers (2).

Expanding the amount of fresh strawberries sold to wholesale markets is one alternative to the declining popularity of pick-your-own as a marketing strategy but Ohio growers have another option, selling to a processing buyer. Currently, so few strawberries in Ohio are being sold to processors that the Ohio Agricultural Statistics Service combines fresh and processing strawberry sales when reporting Ohio production levels. By developing contacts with both fresh market wholesale buyers and processing market buyers, Ohio growers can expand their overall level of sales and generate additional revenue for covering overhead expenses. Given that the cost per pound for processing strawberries is less than that of fresh strawberries, due to the decreased cost for containers and the greater efficiency with which the crop can be hand harvested. Consequently, a marketing strategy which targets both the fresh and processing markets will be the most profitable. If 70 percent of the strawberries in a field are saleable to the fresh market, then selling the remaining 30 percent of the crop to a processing buyer will increase profit per acre by $461, $577, $692, and $808 when initial yield is 8,0000, 10,000, 12,000, or 14,000 pounds, respectively (fresh market price of $0.69/lb. and processing price of $0.40/lb.).

Strawberry Production in California

California production of strawberries in 1988 totaled 856,113,000 pounds or 74 percent of all strawberries produced in the U.S. (5) California has increased its volume of production by 65.9 percent since 1978. Of the total California production in 1988, 76 percent of the crop was sold to fresh market buyers and 24 percent to processing buyers. These proc-essing sales represented 62.9 percent of all processing berries produced in the U.S. during 1988.

Yields per acre in California increased from 40,000 pounds in 1978 to 48,400 pounds in 1988, a 21 percent increase; acreage in production increased from 12,900 acres to 17,650 acres, a 36.8 percent increase; and total revenue generated by strawberry sales increased from $148,839,000 to $388,998,000, a 161 percent increase. During this same time, 1978 to 1988, U.S. per capita consumption of fresh strawberries increased from 2.17 to 3.12 pounds, a 44 percent increase and per capita consumption of processed strawberries increased from 1.49 to 1.73, a 24 percent increase.

The success of the California strawberry system is due to several important factors. First, the climate and soil of California are well suited for producing the crop over an extended period of time. Shipments of fresh strawberries from California to the Cincinnati wholesale market were reported 44 out of 52 weeks in 1987 (1). Second, a high degree of organization exists within the California industry. Growers are organized into cooperatives and utilize marketing orders. Their marketing order assesses $9.00 per ton and generates approximately $3.5 million annually, of which $500,000 goes to research and $2.5 million to promotion and advertising (8). Third, approximately $1 million and 10 scientist years are dedicated annually to strawberry research. By developing larger berries and higher yields per acre, the breeding program in California has significantly positioned the industry so as to be able to take advantage of growing consumer demand for fresh and processing strawberries.

However, production of strawberries either in California or Ohio is still dependent upon hired labor, which accounts for 84.7 percent and 83.2 percent of harvesting costs in Ohio and California, respectively. As labor availability decreases due to changing demographics and labor wages increase due to labor shortage, alternatives to hired labor will need to be examined.

The Mechanical Harvest Challenge

Research on mechanical harvesting of strawberries has been motivated by several factors. First, because strawberries are harvested by hand, it is more expensive and less efficient to harvest the smaller berries at the end of the season, compared to the larger fresh market berries earlier in the season. Second, as fruits and vegetables mature in other regions, hired labor becomes more difficult to obtain for picking processing strawberries. Third, because frozen berries are often imported into a region, there is a natural incentive to try and expand the supply of locally produced strawberries in order to supply the local processing buyers.

The first experimental mechanical harvester for processing strawberries was developed in 1967 by the University of Arkansas and has been under constant refinement by Blueberry Equipment, Inc. (BEI) of South Haven, Michigan. Continued refinement of mechanical harvesting has continued between BEI, Michigan State University Agricultural Engineering Department, and Canadian researchers at Simcoe, Ontario.

In Europe, mechanical harvesting units are being tested in Belgium, East Germany, and Italy and are functional in Denmark. In Europe, as well as North America, machines have been tested on the current single row system. More recently, however, they have been tested on a full field system. These machines are either self-propelled or pulled by a tractor. The self-propelled models are approximately three times more expensive than pull types and use a large amount of horsepower for powering fans which remove the leaves during harvesting.

Beginning in 1982, a comprehensive research program was initiated in Ontario, Canada with a goal to provide information and tools to allow domestic growers to displace much of the strawberries imported into Canada. A complete systems approach of growing, harvesting, processing, and quality evaluation was incorporated in the project. In 1985, Ontario processed 900 tons of whole strawberry puree and juice with seven processing lines, including two that were using mechanically harvested berries. Eight hectares of solid bed strawberries, which had different cultural practices and cultivars were established on farms and replicated research plots. With an average yield per acre of 14,025 pounds, cost of mechanical harvesting was determined to be approximately $0.27 (Canadian) per kilogram, considerably less than the $0.40 (Canadian) per kilogram for conventional hand harvesting. Nineteen research projects were proposed and a $1 million dollar budget was funded by industry, the Ontario government, and the federal government (6, pg. 8).

The self-propelled harvester used in Canada, cuts a four-foot swath of solid bed strawberry plants with a front mounted sickle bar. It conveys foliage and berries onto an inclined conveyor belt. Plants parts are separated from the berries inside the harvester by controlled air streams and berries with stems are conveyed into containers. The pick-up efficiency (amount of trash picked up in addition to strawberries, 100 percent implies no trash) with the matted row system was 82 percent and 98 percent for the machine and hand harvesting, respectively.

In order to facilitate mechanical harvesting, a large number of berries must be ripe at one time without a large number of under ripe (white) or over ripe (soft, moldy) berries. The berries must be easily separated from the plant. If they do not separate during the harvesting operation, leaves and stems clog the machine and need to be removed by another machine at a processing plant. Of the currently available cultivars, Midway and Cardinal have shown high yields, good separation from the plant, and easy decapping at the processing plant (6, pg. 2).

Once the strawberries (plus trash) leave the machine they are put into containers and transported to the processor, where they are precooled and dumped into a wash tank. A machine then declusters the berries and moves them to a decapper. Small immature berries are sorted and used for puree. All berries are sorted into three grades, No. 1, juice, or puree. Most of the berries mechanically harvested in Canada during 1985 went into puree.

Profitability of Mechanical Harvesting

The profitability of producing strawberries in Ohio and harvesting the crop by hand was calculated at varying yield levels and percentage of the crop being sold to the fresh market (Table 1). Results indicate that as the percentage of crop being sold fresh increases (percentage being sold for processing decreases), profit per acre increases. Similarly, profit per acre increases with yield per acre. As a result, a target level of profit can be reached by either increasing yield or increasing the share of the crop being sold to the fresh market.

Table1. Estimated profit per acre from producing strawberries in Ohio using hand labor at varying yield levels and percentage of crop sold to fresh market.[1]

Fresh Market	Yield Per Acre (Pounds)				
Percentage	5,000	10,000	15,000	20,000	25,000
0%	$(2,242)[2]	$(1,391)	$(540)	$311	$1,163
10%	(2,174)	(1,255)	(336)	583	1,502
20%	(2,107)	(1,120)	(133)	854	1,841
30%	(2,039)	(984)	71	1,126	2,181
40%	(1,971)	(848)	275	1,397	2,520
50%	(1,903)	(712)	478	1,669	2,859
60%	(1,835)	(577)	682	1,940	3,199
70%	(1,767)	(441)	886	2,212	3,538
80%	(1,699)	(305)	1,089	2,483	3,878
90%	(1,631)	(169)	1,293	2,755	4,217

[1] Given a fresh market price/lb of $0.61, processing market price/lb. of $0.40, and paying hired labor $0.19/lb. and $0.17/lb. to pick fresh and processing berries, respectively.
[2] Parenthesis indicates a negative number.

Table 2. Basic Cost and Performance Assumptions For Two Mechanical Harvesters.

Item	Belgian Model[1]	Canadian Model[2]
Initial Cost	$75,000	$90,000
Capacity per hour[3] (lbs.)	4,400	3,500
Cutting Swath (ft.)	5.3	4
Pick-up Efficiency[4]	80%	80%
Maximum Forward Speed (m.p.h.)	1	0.75

[1]Source: [7, pg.23]
[2]Source: Mechanical Demonstration at International Strawberry Symposium, Sponsored by International Society for Horticultural Scientists, Italy. May, 1988.
[3]Volume of strawberries plus trash which the machine can handle.
[4]Percentage of capacity representing strawberries.

Basic cost information for the Canadian and Belgian mechanical harvester is presented in Table 2. The two machines differ on each measure except pick-up efficiency. Both harvesters were assumed to have a useful life of 10 years and a salvage value of 10 percent. Both harvesters were than examined under varying levels of yield and percentage of crop sold to the fresh market.

Results indicate that the mechanical cost per pound (costs directly related to the harvester) associated with the Belgian harvester, when operated for 72 hours per harvest season, are competitive with a hand harvesting rate of $0.17 per pound, Table 3. As expected, mechanical cost per pound decreases with increasing yield but increases with the percentage of the crop being sold to the fresh market. Similar results were observed for profit per acre. Maximum profit per acre of $2,487 was achieved with a yield of 25,000 pounds per acre and selling 100 percent of the crop to processing, Table 3.

Maximum acreage per machine was calculated subject to the following constraints: number of hours per day used for harvesting, number of days per season which the crop can be harvested, maximum harvesting capacity per hour (berries plus trash), maximum forward speed, and amount of berries being harvested, Table 3. By specifying the harvest season to be six days long and 12 hours per day available for harvesting, a maximum of 72 hours of machine time were available per season. With this time constraint, maximum profit per acre of $2,487 was achieved with a total of 10.1 total acres.

As yield per acre increases, the forward speed of the harvester decreases, provided processing capacity is at the maximum, Table 4. As yield per acre decreases, the harvester is driven faster to maximize processing efficiency until its maximum forward speed is reached. As can be seen, profitability per acre was greatest when the Belgian harvester was operating at maximum capacity and not constrained by maximum forward speed.

Increasing the number of machine hours available during the harvesting season to 156 hours lowered the mechanical cost per pound and increased both the profit per acre and the maximum acreage, Table 5. As a result, adoption of mechanical harvesting will certainly be influenced by the availability of new strawberry cultivars or cultural practices which enable the grower to extend the harvesting season. Alternatively, by developing a custom harvesting approach to mechanical harvesting, an owner of a harvester may be able to contract acreage in different locations which are maturing at different times and spread the length of the harvesting season over a longer period of time.

Table 3. Performance of Belgian harvester at varying yield levels and percentage of crop sold to fresh market, 6 day, 12 hour (72 machine hours) harvesting season.

Fresh Market Percentage	Yield Per Acre (Pounds) 5,000	10,000	15,000	20,000	25,000
Mechanical Cost Per Pound					
0%	$0.161	$0.080	$0.070	$0.070	$0.070
10%	0.199	0.099	0.077	0.077	0.077
20%	0.251	0.126	0.087	0.087	0.087
30%	0.328	0.164	0.109	0.099	0.099
40%	0.447	0.223	0.149	0.116	0.116
50%	0.643	0.322	0.214	0.161	0.139
60%	1.005	0.503	0.335	0.251	0.201
70%	1.787	0.893	0.596	0.447	0.357
80%	4.020	2.010	1.340	1.005	0.804
90%	16.080	8.040	5.360	4.020	3.216
Profit Per Acre					
0%	$(3,714)[1]	$(1,928)	$(383)	$1,052	$2,487
10%	(3,830)	(2,069)	(460)	949	2,358
20%	(3,968)	(2,233)	(537)	847	2,230
30%	(4,139)	(2,429)	(720)	744	2,102
40%	(4,358)	(2,674)	(990)	642	1,974
50%	(4,654)	(2,996)	(1,338)	321	1,846
60%	(5,085)	(3,453)	(1,820)	(188)	1,445
70%	(5,787)	(4,180)	(2,574)	(967)	640
80%	(7,166)	(5,585)	(4,003)	(2,422)	(841)
90%	(11,250)	(9,694)	(8,139)	(6,583)	(5,027)
Maximum Acreage Per Machine					
0%	21.9	21.9	16.9	12.7	10.1
10%	19.7	19.7	16.9	12.7	10.1
20%	17.5	17.5	16.9	12.7	10.1
30%	15.4	15.4	15.4	12.7	10.1
40%	13.2	13.2	13.2	12.7	10.1
50%	11.0	11.0	11.0	11.0	10.1
60%	8.8	8.8	8.8	8.8	8.8
70%	6.6	6.6	6.6	6.6	6.6
80%	4.4	4.4	4.4	4.4	4.4
90%	2.2	2.2	2.2	2.2	2.2

[1]Parenthesis indicates a negative number.

An analysis of the profitability per acre using the Canadian harvester is presented for 72 and 156 machine hours, Table 6. Results indicate that the Canadian harvester is not as profitable as the Belgian harvester. This difference in profitability is due to cost, harvesting capacity, and forward speed advantages of the Belgian harvester.

The difference in profitability per acre between hand harvesting and

Table 4. Performance of Belgian harvester at varying yield levels and percentages of crop sold fresh market.

Fresh Market Percentage	Yield Per Acre (Pounds) 5,000	10,000	15,000	20,000	25,000
	Forward Speed (M.P.H.)				
0%	1.00	1.00	0.69	0.47	0.36
10%	1.00	1.00	0.80	0.54	0.41
20%	1.00	1.00	0.94	0.63	0.47
30%	1.00	1.00	1.00	0.76	0.56
40%	1.00	1.00	1.00	0.94	0.69
50%	1.00	1.00	1.00	1.00	0.89
60%	1.00	1.00	1.00	1.00	1.00
70%	1.00	1.00	1.00	1.00	1.00
80%	1.00	1.00	1.00	1.00	1.00
90%	1.00	1.00	1.00	1.00	1.00
	Fruit Processed Per Hour (Pounds)				
0%	1,523	3,046	3,520	3,520	3,520
10%	1,371	2,742	3,520	3,520	3,520
20%	1,218	2,437	3,520	3,520	3,520
30%	1,066	2,132	3,198	3,520	3,520
40%	914	1,828	2,742	3,520	3,520
50%	762	1,523	2,285	3,046	3,520
60%	609	1,218	1,828	2,437	3,046
70%	457	914	1,371	1,828	2,285
80%	305	609	914	1,218	1,523
90%	152	305	457	609	762

mechanical harvesting (Belgian machine) was determined for a harvesting season of 72 and 156 hours, Table 7. Assuming that hired labor is paid $0.17 per pound to pick processing berries, hand harvesting is more profitable per acre than mechanical harvesting. However, as yields increase beyond 15,000 pounds per acre hand harvesting is less profitable. For those growers selling 40 percent of their crop to the fresh market and 60 percent to the processing market, a yield of 25,000 pounds per acre is required in order to justify switching from hand to mechanical harvesting. Of course, the yield per acre needed to justify the adoption of mechanical harvesters will decline as the harvesters become more efficient or as labor costs increase.

Research Questions To Be Addressed

This paper has presented a discussion of current strawberry production and marketing practices existing in Ohio. By emphasizing pick-your-own as the primary marketing strategy, strawberry growers are not likely to be expanding production in future years due to changing demographics. Therefore, in order to expand production, Ohio growers will need to develop contacts with wholesale and retail buyers. However, these buyers demand a uniform product of consistent quality, delivered over a marketing season as long as possible. This will require additional breeding and cultural research focusing on the development of new cultivars and practices which extend the harvest season.

As growers switch from a pick-your-own to a fresh market/wholesale marketing strategy, they will need to hire additional labor for harvesting strawberries. As the crop ripens, the large, early strawberries will be followed by smaller ones, requiring proportionally more hours to pick. However, by developing contacts with processing buyers, Ohio growers may be able to bring in additional revenue from selling the balance of the crop to a processing buyer and thereby increase overall profits.

This strategy of selling part of the crop to the fresh and processing markets is currently being practiced by California growers and could be implemented in Ohio, provided sufficient processing strawberries were available per year so as to attract the attention of a processing buyer. Unfortunately, this marketing strategy is heavily dependent upon hired labor for harvesting both the fresh and the processing strawberries. By considering mechanical harvesting for the processing crop, it may be possible to reduce the need for hired labor and also increase grower profits. After examining two mechanical harvesters, one developed in Canada and the other in Belgium, it appears that mechanical harvesters can be competitive with hired labor but only in those instances where a large amount of berries are being harvested each year. However, by focusing

Table 5. Performance of Belgian harvester at varying yield levels and percentages of crop sold to fresh market, 13 day, 12 hour (156 machine hours) harvesting season.

Fresh Market Percentage	Yield Per Acre (Pounds) 5,000	10,000	15,000	20,000	25,000
Mechanical Cost Per Pound					
0%	$0.091	$0.045	$0.039	$0.039	$0.039
10%	0.112	0.056	0.044	0.044	0.044
20_7	0.142	0.071	0.049	0.049	0.049
30%	0.185	0.092	0.062	0.056	0.056
40%	0.252	0.126	0.084	0.065	0.065
50%	0.362	0.181	0.121	0.091	0.078
60%	0.566	0.283	0.189	0.142	0.113
70%	1.007	0.503	0.336	0.252	0.201
80%	2.265	1.133	0.755	0.566	0.453
90%	9.061	4.530	3.020	2.265	1.812
Profit Per Acre					
0%	$(3,556)[1]	$(1,770)	$(121)	$1,466	$3,053
10%	(3,633)	(1,872)	(198)	1,364	2,925
20%	(3,722)	(1,987)	(274)	1,261	2,797
30%	(3,830)	(2,121)	(411)	1,159	2,669
40%	(3,965)	(2,282)	(598)	1,056	2,541
50%	(4,145)	(2,487)	(828)	830	2,412
60%	(4,401)	(2,768)	(1,136)	497	2,129
70%	(4,810)	(3,203)	(1,596)	10	1,617
80%	(5,604)	(4,022)	(2,441)	(860)	721
90%	(7,933)	(6,377)	(4,822)	(3,266)	(1,710)
Maximum Acreage Per Machine					
0%	47.5	47.5	36.6	27.5	22.0
10%	42.8	42.8	36.6	27.5	22.0
20%	38.0	38.0	36.6	27.5	22.0
30%	33.3	33.3	33.3	27.5	22.0
40%	28.5	28.5	28.5	27.5	22.0
50%	23.8	23.8	23.8	23.8	22.0
60%	19.0	19.0	19.0	19.0	19.0
70%	14.3	14.3	14.3	14.3	14.3
80%	9.5	9.5	9.5	9.5	9.5
90%	4.8	4.8	4.8	4.8	4.8

[1]Parenthesis indicates a negative number.

Table 6. Profit per acre using the Canadian harvester at varying yield levels and percentages of crop sold to fresh market.

Fresh Market Percentage	Yield Per Acre (Pounds) 5,000	10,000	15,000	20,000	25,000
Harvest Season of 72 Hours					
0%	$(4,706)[1]	$(2,919)	$(1,133)	$184	$1,466
10%	(4,903)	(3,143)	(1,382)	82	1,338
20%	(5,144)	(3,409)	(1,674)	(21)	1,210
30%	(5,447)	(3,737)	(2,028)	(318)	1,082
40%	(5,841)	(4,157)	(2,474)	(790)	894
50%	(6,383)	(4,725)	(3,067)	(1,409)	249
60%	(7,184)	(5,551)	(3,919)	(2,286)	(654)
70%	(8,500)	(6,894)	(5,287)	(3,680)	(2,073)
80%	(11,108)	(9,527)	(7,946)	(6,365)	(4,784)
90%	(18,881)	(17,326)	(15,770)	(14,215)	(12,659)
Harvest Season of 156 Hours					
0%	$(4,208)	$(2,422)	$(635)	$891	$2,398
10%	(4,329)	(2,568)	(808)	788	2,269
20%	(4,474)	(2,739)	(1,004)	686	2,141
30%	(4,653)	(2,944)	(1,234)	475	2,013
40%	(4,883)	(3,199)	(1,516)	168	1,852
50%	(5,195)	(3,537)	(1,879)	(221)	1,437
60%	(5,650)	(4,018)	(2,385)	(753)	880
70%	(6,392)	(4,785)	(3,178)	(1,571)	38
80%	(7,849)	(6,267)	(4,686)	(3,105)	(1,524)
90%	(12,169)	(10,613)	(9,058)	(7,502)	(5,947)

[1]Parenthesis indicates a negative number.

engineering research at increasing the operating speed and capacity of these machines, the economic feasibility of machine harvesting will increase.

References

1. Agricultural Marketing Service. "Fresh Fruit and Vegetable Wholesale Prices, Cincinnati, 1987." United States Department of Agriculture. 1988.
2. Funt, R.C. and W.T. Rhodus. "Profitability of U.S. Strawberry Production Under Alternative Management and Marketing Options." Acta Horticulturae 265:453-459. 1989.
3. Ohio Agricultural Statistics. "Fruit Summary for 1987." Columbus, Ohio.
4. Ohio Agricultural Statistics. "Vegetable Summary for 1988." Columbus, Ohio.
5. Processed Strawberry Advisory Board of California Annual Report. Watsonville, CA, pp. 1-16. 1988.
6. Processing Strawberry Research Corporation. "1985 Annual Research Report. Hort. Exp. Sta., OMAAF Simcoe, pp 1-101. 1986.
7. Rhodus, W.T. "Comparing Regional Cost of Production for Strawberries." in Fruit Crops 1987, A Summary of Research. Res. Cir. 295. Ohio Agr. Res. and Dev. Center, 1988. pp. 14-16.
8. Runsten, D. "Competition in Strawberries." in "Competitiveness at Home and Abroad, Marketing California Specialty Crops: Worldwide Competition and Constraints: UC Agr. Issues Center, Davis, CA, pp. 47-59. 1988.

Table 7. Difference in profit per acre between hand harvesting and Belgian mechanical harvester at varying yield levels and percentages of crop sold to fresh market.

Fresh Market Percentage	Yield Per Acre (Pounds) 5,000	10,000	15,000	20,000	25,000
Harvest Season of 72 Hours					
0%	1,472	537	(156)[1]	(740)	(1,324)
10%	1,655	814	124	(366)	(856)
20%	1,862	1,114	405	8	(389)
30%	2,100	1,446	791	382	79
40%	2,387	1,826	1,265	756	546
50%	2,751	2,283	1,816	1,348	1,014
60%	3,250	2,876	2,502	2,128	1,754
70%	4,020	3,740	3,459	3,179	2,898
80%	5,466	5,279	5,092	4,905	4,718
90%	9,618	9,525	9,431	9,338	9,244
Harvest Season of 156 Hours					
0%	1,313	378	(419)	(1,155)	(1,891)
10%	1,458	617	(139)	(781)	(1,423)
20%	1,616	868	142	(407)	(956)
30%	1,791	1,137	482	(33)	(488)
40%	1,995	1,434	873	341	(21)
50%	2,242	1,774	1,307	839	447
60%	2,566	2,192	1,818	1,444	1,070
70%	3,043	2,762	2,482	2,201	1,921
80%	3,904	3,717	3,530	3,343	3,156
90%	6,301	6,208	6,114	6,021	5,927

[1]Parenthesis indicates a negative number which implies that mechanical harvesting is more profitable than hand harvesting.

T · H · E
OHIO
STATE
UNIVERSITY

OARDC