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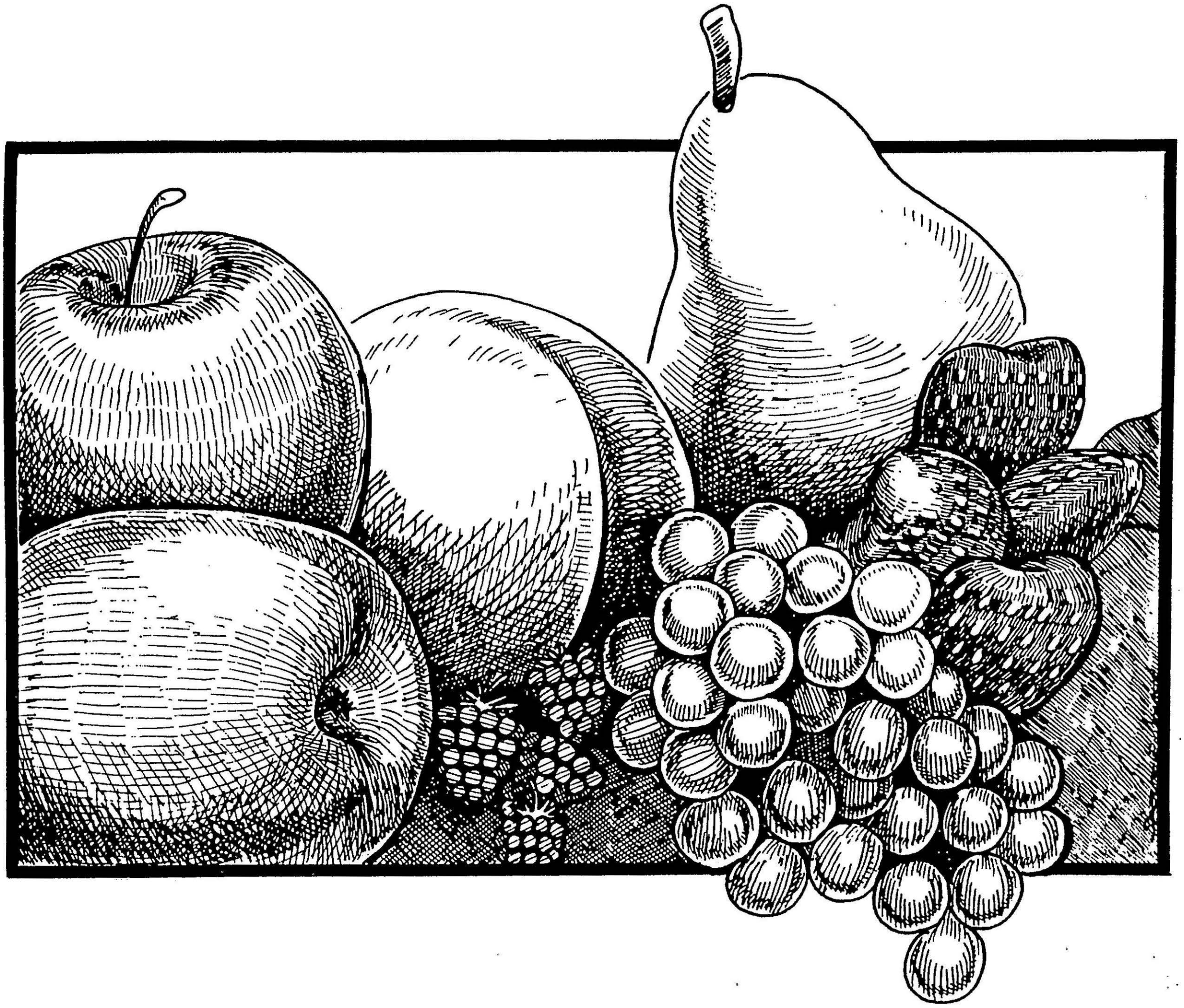

The Ohio State University
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Contents

Effects of Nitrogen Fertilization on Total Yield, Different Yield Components, and Foliar Levels of 'Heritage' Raspberry: *D.R. Baral, G.A. Cahoon* 1

Influence of Training Stakes and Various Pruning and Bending Techniques on Early Performance of 'Fuji' Apple Trees: *D.C. Ferree, J.C. Schmid* 11

Pilot Project For Integrated Pest Management in Ohio Apple Orchards: *C. Welty* 18

Relationship of Canopy Micro-Climate and Apple Tree Fruit and Leaf Performance: *D. Ferree, J. Tew, D. Miller, R. Brazee, R. Fox* 26

Effect of Root Pruning on Shoot Tip Ethylene Production and Xylem Concentrations of Cytokinin and 1-aminocyclopropane-1-carboxylic Acid in Young Apple Trees: *J.R. Schupp, D.C. Ferree* 38

Rootstock Effects on Spur Characteristics, Spur Leaf Nitrogen Content and Early Production of Apple Trees: *M. Rottgerman, D. Ferree, J. Schmid* 43

Inhibition of Growth of Crown-Gall-Causing Bacteria (*Agrobacterium tumefaciens*) by Polyamine Synthesis Inhibitors: *T. Ponappa, A.R. Miller* 51

Relationships Among Apple Weight, Seed Number, Seed Weight, Germination Date and Apple Seedling Vigor: *D.D. Miller, K. Kaiser* 56

Evaluation of Organic and Conventional Fungicide Programs for Control of Apple Scab in Ohio: *M.A. Ellis, L.V. Madden, L.L. Wilson, D.C. Ferree* 63

Evaluation of Commercially Available Serological Test Kits for Diagnosis of Apple Crown and Root Rot Caused by *Phytophthora* Spp in Ohio: *M.A. Ellis, S.A. Miller* 68

A Survey of the Pest Management Practices, Information Sources, Needs, and Decision Making Criteria of Ohio Apple Growers: *F.A. Hale, F.R. Hall* 73

Effects of Cultural Systems on the Horticultural Performance and Fruit Quality of Strawberries: *J.C. Scheerens, G.L. Brenneman* 81

Performance of New or Uncommon Strawberry Cultivars Grown Under Ohio Cultural Conditions: *G.L. Brenneman, J.C. Scheerens* 99

A Comparison of Spray Drift Deposited on Ground and Airborne Spray Collectors and on Soybean Plants: *R.D. Fox, S.M. Hussein, D.L. Reichard, R.D. Brazee, F.R. Hall* 109

Experimental vs. Computer-predicted Air Velocities for a Cross-Flow Sprayer: *R.D. Fox, R.D. Brazee, S.A. Svensson, D.L. Reichard* 115

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Effects of Nitrogen Fertilization on Total Yield, Different Yield Components and Foliar Levels of 'Heritage' Raspberry

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Introduction

Because raspberry is a minor crop, very little reliable information is available on its N nutrition or its interaction with growth, yield, productivity and foliar analysis levels. This is especially true for the 'Heritage' raspberry cultivar. Since 'Heritage' has a unique primocane fruiting habit, its N requirement may be different from other common raspberry floricane fruiting cultivars. It is also known that raspberry plants are more variable in their leaf element content within cultivars than most other crops (14).

Raspberries have been shown to respond to N in almost every region of the world (19). Several workers during the mid- to late-1960s used $Ca(NO_3)_2$ as the nitrogen source in their experiments and obtained a reduction in yield (20,21,22,28). During a 4-year study, Lawson and Waister (18) made the observation that high N (56 Kg N/ha) increased yield during the first two years, but decreased it in the next two years, as compared to low N (22.5 Kg N/ha). Lockshin (23,24) and Ourecky and Tompkins (26) working with 'Heritage' raspberry under different climatic and environmental conditions recommended 50 to 112 kg actual N per hectare. Chaplin and Martin (5) in a recent study showed that N application increased leaf N, increased fruit size, but had no effect on yield. Kowalenko (16,17) reported that N application increased the four-year yield of raspberries with maximum production occurring from 134 kg-N/ha.

Soil tests and visual methods have been used to show the relationship between rate of N fertilization, growth and yield. The most common technique is to compare growth and yield with the foliar N level of the plant. Studies directed toward establishing critical levels for N in the raspberry by means of foliar analysis include those of Ramig (27), who reported that the level for non-bearing raspberry plants grown in water culture was 2.9 percent dry weight. This level was based on analysis of recently matured leaves. Ljones (21,22) concluded that the critical point between the optimum and excess range for leaf N in relation to crop yield, was approximately 2.9 percent. Chaplin and Martin (5) could not decide on an optimum leaf level for N. However, they suggested that it was probably under 2.4 percent for mid-August leaf sampling.

Early work of Darrow and Waldo (9) indicated that the number of canes, cane diameter and length, number of buds, and laterals per unit of row, and number of berries per lateral were all indicators of vigor and cropping capacity. Crandall *et al.* (8) in a 3-year study of 'Willamette' red raspberry found that the number of berries per lateral and the number of berries per cane were positively correlated. Several workers have associated yield of raspberry canes to their diameter (8,9,11). An increase in stem diameter was also correlated with cane height, total number of berries, berries per lateral and fruit buds per foot of cane (8). Berry size and berry number are the major yield components associated with adequate N and vigor (9). Cane density and yield per cane both contributed to enhanced yield (10,12). Khanmai *et al.* (15) suggested that the weight of raspberry leaflets may be used as a basis for developing a relationship between the size of the leaf (leaf area) and productivity of the plants.

With this background and information, an experiment was initiated to elucidate the role of various levels of soil-applied N on yield, growth characteristics, and foliar N levels. Emphasis was given to the establishment of an optimum foliar N level that could be used by producers of 'Heritage' which would result in optimum yield and growth.

Materials and Methods

Experimental Design: The experiment was initiated in the spring of 1980 at Horticulture Unit II of the Ohio Agricultural Research and Development Center, Wooster, Ohio. The planting consisted of two blocks with 36 plots in each block. Each plot was 0.91 meters by 1.83 meters. Spacing between plots and rows was 1.52 meters x 2.13 meters, respectively.

Fifteen cm sections (rooted handles) of 'Heritage' raspberry cultivar were planted 0.3 meters apart in each plot in the spring of 1979.

Each rooted handle was allowed to sucker freely until it produced hedgerows 0.91 meters wide and 1.83 meters in length. The experimental design was as follows: six levels of NH_4NO_3 nitrogen (0,45,91,136,183,227g/plot) were applied in April of 1980, 1981 and 1982 to randomly designated plots. The actual amount of N applied was 0, 15, 30, 45, 60 and 75 g/1.67 m². Based on the actual area under cultivation, this would be 0, 27, 54, 82, 109 and 136 kg/ha. All other management factors were kept constant. Soil was classified as Wooster silt loam with pH 6.5. Soil tests indicated sufficient quantities of all other nutrients except potassium. In spring 1981 and 1982, 150 g commercial K_2SO_4/plot (269 kg K_2SO_4/ha) was applied to all plots.

Insects, diseases and weeds were controlled with a regular pesticide spray schedule (1). Areas between rows and plots were sodded and mowed to keep grass competition at a minimum and plot size within limits. Plants began suckering in late April 1979.

Leaf sampling and analytical procedures: Fifteen leaflets were sampled from each plot at one-month intervals from May 15 to Sept. 15. Leaflets were taken randomly from the seventh to 12th nodes from the terminal 51 cm as suggested by Hughes and Chaplin (13). Sample leaves were dried in a force-draft oven at 70°C for 48 hours, ground in a Wiley mill to pass through a 20-mesh screen and sealed in airtight polyethylene bags until ready for analysis.

Determination of total N was done by a modified Kjeldahl procedure (4) using an 0.5 gm sample of well-ground leaves. A direct-reading emission spectrograph was used for determination of P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Al and Na (2).

General harvesting procedures: Yield was recorded at each harvest date during the season and accumulated to obtain total production. Plots were generally picked twice per week, or nine to 11 times per season. Fifty-berry samples were taken for weight measurements at each harvest date. Plant height was measured at three locations in each plot at one-month intervals from June until a constant final height was obtained.

Fresh leaf weight and leaf area were determined for the July 15 and Aug. 15 leaf samples using a Licor portable area meter (Model LI-300, Lambda Instruments Corp.). Specific leaf weight in mg/cm² was computed by dividing the dry weight of leaves in mgm by the leaf area in square centimeters.

After harvest, 10 canes from each plot were randomly selected to determine the total number of nodes, number of fruiting laterals, average length of internodes and basal diameter. Total number of canes and fresh and dry weight were recorded on a whole-plot basis. Yield per cane was calculated by dividing total yield by total number of canes. Similarly, number of berries and dry weight of cane were also computed on a per-plant basis.

All data were subjected to Analysis of Variance (ANOVA), LSD, DMRT and, where appropriate, regression analysis. Most of the results presented were obtained from 3 years of consecutive experimentation.

Results and Discussion

Total number of canes: Total number of canes per plot were generally unaffected by N application rates. Only in 1981 was a significant increase obtained (Table 1). These results were in contrast to results of Lawson and Waister (18) and Wood *et al.*, (31) who stated that cane numbers were significantly increased by N fertilization and contributed to enhanced berry yield.

A high density of primocanes is desirable for maximum fruiting surface and high production. 'Heritage' in this experiment was a prolific primocane-producing cultivar. However, if this is typical of the behavior of 'Heritage,' then an initial closely spaced (high-density) planting would only be justified to obtain increased production the first season. Primocane density during succeeding seasons tends to remain relatively constant.

Cane height: During the early growth period, May and June 1982, an increase in the application rate of N did not result in a significant increase in cane height (Fig. 1), but as the season progressed, the height did increase. In 1982, vegetative growth was very rapid immediately following the spring flush (early May) until flower initiation during the first to second week of July. After the second week of July, the growth rate began to decline, and growth completely terminated by the end of July. There was a similar trend in 1981, except time of flower initiation and date of maximum attained growth was 15 days later in the season. This more rapid rate of attainment of physio-logical maturity of the canes and hence, greater and earlier flowering in 1982

Table 1. Effects of increasing rates of soil applied N on total canes per plot, total yield and percent leaf N content, 1980-82.

N Applied		Total canes/plot			Total yield mt/ha[-1]			Leaf N content (percent dry wt.)		
g/1.67 m	kg/ha[-1]	1980	1981	1982	1980	1981	1982	1980	1981	1982
0	0	104	71ab[1]	95	5.26b	6.29	8.72c	1.73	1.80	1.84
15	27	91	62b	88	5.65b	6.52	9.88c	1.82	1.98	2.05
30	54	93	75ab	89	7.00ab	6.33	10.08bc	2.01	2.13	2.25
45	82	90	83a	98	7.62ab	7.88	12.33a	2.22	2.41	2.54
60	109	95	82a	104	8.43a	7.32	12.10a	2.30	2.49	2.64
75	136	84	85a	97	7.31ab	7.78	10.66ab	2.35	2.67	2.79
Linear		ns	*	ns	*	ns	**	**	**	**
Quadratic		—	—	—	—	—	—	—	—	**

[1]Mean separation within columns by Duncan's New Multiple Range Test, 5 percent level.
NS,*,**: Non-significant (ns), significant at 5% (*) or 1% (**).

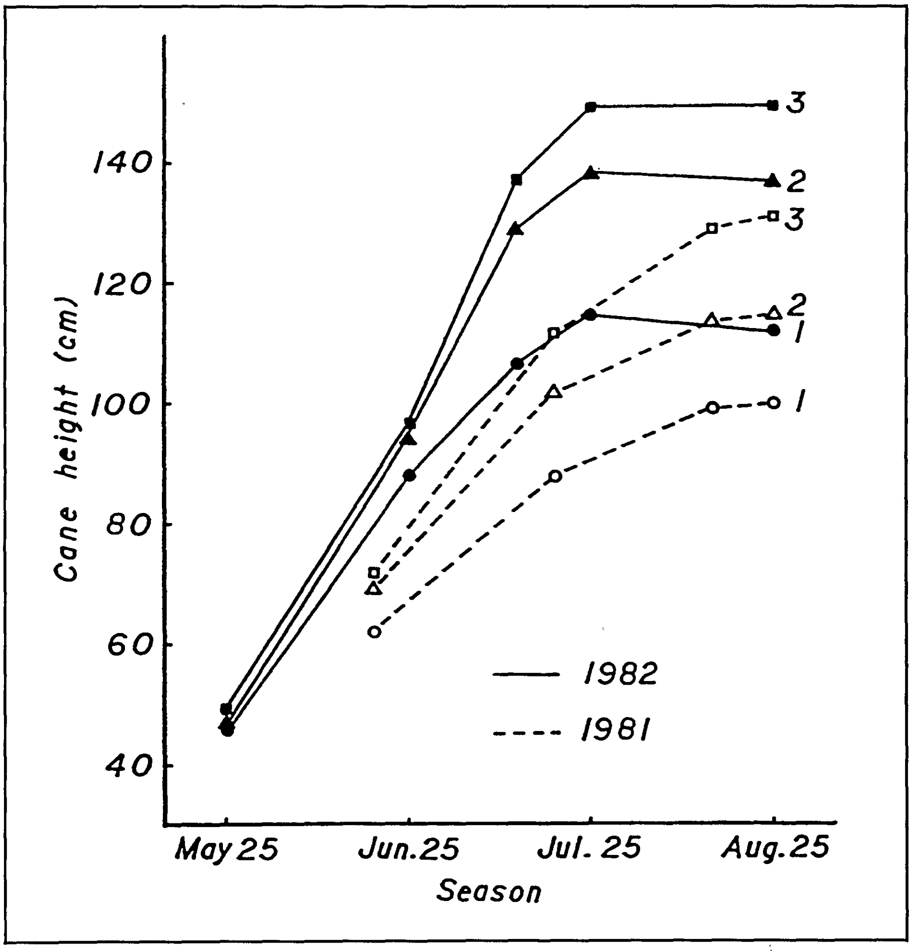


Figure 1. 'Heritage' cane growth as a function of season and N application rate.
1.= 0 g N/1.67m2
2.= 15 g N/1.67m2
3.= 60 g N/1.67m2

was probably due to better growing conditions (increased solar radiation, temperature, adequate nitrogen and soil moisture) during the season. Slate (29) stated that earliness is a response to a faster attainment of physiological maturity (a shorter juvenile period) induced by warmer temperature and possibly better growing conditions. Greater cane height was obtained in 1982 than in 1981.

Total yield: Three years of results (Table 1) show that there was a significant increase in yield with an increase in soil supplied N in 1980 and 1982. In 1981, the numerical increase was not statistically significant. However, trends were very similar all three years. Maximum yield was obtained at 45 g N per 1.67 m² (82 kg N/ha) except in 1980, when maximum yields were recorded at 60 g N per 1.67 m² (109 kg N/ha).

The N requirement for 'Heritage,' as a primocane fruiting raspberry cultivar, does not appear to be much different from floricane fruiting cultivars (16,25,26). However, an N application rate of 82 kg N/ha was found to produce optimum yield under the soil conditions of this experiment, a rate that is generally higher than previous workers recommended (18). Recommendations of Lockshin (23,24) and Ourecky and Tompkins (26) ranged from 50 to 112 kg N/ha. There were noticeable year-to year variations in total fruit yield. Better production was obtained during the final year than in either of the previous two years.

Crop yield is due to a combination of genetic potential of a particular cultivar and the environment in which it grows. Variation in temperatures, moisture or rainfall, solar radiation, incidence of diseases and anthropod pests between years can significantly change the yield. In addition, plant conditions and yield improved with age. The maximum productive stage for raspberry is 5 to 7 years after planting.

Leaf N Content: In all three years, differential levels of soil-applied N resulted in a direct linear increase of total leaf N (Table 1). Similar relationships have been shown by previous investigators working with raspberry (21,22,23,27). These data suggest that the maximum foliar N content has not been reached at the highest application of 75 g N per 1.67 m^2 (136 kg N/ha). Identical N application rates also resulted in gradually increasing foliar N contents every year of the experiment (Table 1). The reasons for this are not clearly understood. Possible causes are: 1) variation of climate resulting from changes in temperature, moisture and light conditions (7,28). This effect would not be critical unless these factors were in excess or below optimum levels; 2) differential effects of changing climatic conditions on availability of nutrients in the soil and absorption capacity of roots; 3) the residual effect of the previous year's applied N; 4) the use of simazine as a herbicide; and 5) the result of organic residues (such as leaves) deposited over the years and finally released as inorganic nitrogen to the soil by microbial decomposition.

Table 2. Regression of total berry yield of 'Heritage' on total leaf N content at various stages of growth for 1980, 1981 and 1982.

		Regression	
Variable	Year	Linear R^2 values[1]	Quadratic
Yield vs. leaf N on	Aug. 15, 1980	0.47**	0.48**
Yield vs. leaf N on	June 15, 1981	0.22**	0.22**
Yield vs. leaf N on	July 15, 1981	0.18**	0.23**
Yield vs. leaf N on	Aug. 15, 1981	0.37**	0.51**
Yield vs. leaf N on	Sept. 15, 1981	0.31**	0.40**
Yield vs. leaf N on	June 15, 1982	0.21**	0.21**
Yield vs. leaf N on	July 15, 1981	0.24**	0.26**
Yield vs. leaf N on	Aug. 15, 1981	0.39**	0.42**
Yield vs. leaf N on	Sept. 15, 1981	0.34**	0.37**

[1] R^2, coefficient of determination
ns, *, ** Non-significant (ns), significant at 5% (*) or 1 % (**).

Total yield vs. leaf N content: Regression analysis of total berry yield on foliar N content at various stages of growth for 1981 and 1982 data showed highly significant linear and quadratic relationships (Table 2) as judged on the basis of coefficient of determination (R^2). For all years combined (1980-82), the best fit was usually quadratic. Among the four sampling dates, the Aug. 15 foliar N content produced the best relationship with total berry yield. A simple correlation analysis also showed that total leaf N concentrations at all four dates were positively correlated with berry yield (Table 3). Again, the best and statistically higher 'r' values were found in the mid-August sampling data than at any other time.

Thus, the mid-August sampling data was chosen as the best time to study the detailed relationship between leaf N and total yield.

The nature of this relationship for 1980, 1981 and 1982 is shown in Table 1. A leaf N content of 2.3 to 2.6 percent dry weight produced maximum yield during all three years. This "optimum concentration range" varied somewhat from year to year, but a common feature was a rapid increase in yield until the 2.4 percent leaf N concentration was reached. Yield was significantly reduced and also visible leaf deficiency symptoms were observed when foliar N levels fell below 2.0 percent.

A comparison of the data in Figure 2 with Table 1 reveals that in 1980 and 1981, yield/leaf N relationships were very similar. Quadratic regressions (R^2) are essentially the same, while 1982 is significantly different. However, the leaf N content in 1980 never reached 2.4 percent. Leaf N content in 1981 attained a maximum of 2.7 percent, but production did not increase significantly beyond 2.4-2.6 percent N. In 1982, maximum production was reached with an average content of 2.54 percent N, but leaves actually increased in content to 2.79 percent N.

This "optimum range" (2.4 to 2.6 percent) was not in agreement with Cline (7), Hill (11) and Ramig (27). Such differences in leaf composition may be due to cultivar differences (13,14). 'Heritage' is a fall-bearing, primocane fruiting cultivar and may have differences in nutrient requirement or an ability to assimilate nutrients better than floricane fruiting cultivars. It is also possible that this study was carried out under more realistic field conditions rather than greenhouse conditions. Another reason for this variation in optimum leaf N value would be the differences in region or climate under which the various studies were conducted. Some workers were in close agreement with this study (3,5,21,22).

The mineral content of 'Heritage' raspberry leaves obtained from the optimum N plots was as follows: P, 0.19%; K, 1.2-1.3%; Mg, 0.40-0.48%; Ca, 0.8-1.0%; B, 25-35 ppm; Cu, 6-8 ppm. Iron, Mn, Zn, Al and Na were unstable within and between years and ranges for these nutrient elements could not be effectively determined. All analyses were based on the Aug. 15 sampling date.

Seasonal production trends: Yield data has not been presented for each of the picking dates because of the nonsignificant effect of treatments at a single date. An examination of berry yield at each picking data during the season, all three years, showed that N rate did not affect initial yields but did increase yields the latter part of the picking season. The cumulative effect of the N rate on yields was ultimately reflected on total berry yield. Literature reports in this respect were also controversial. Kowalenko (16) reported that an increase in N application decreased initial yield but increased it at later picking dates, whereas Lockshin (23) and Childs (6) reported opposite results.

Table 3. Correlation coefficients (r) between total leaf N at various sampling dates and total berry yield.

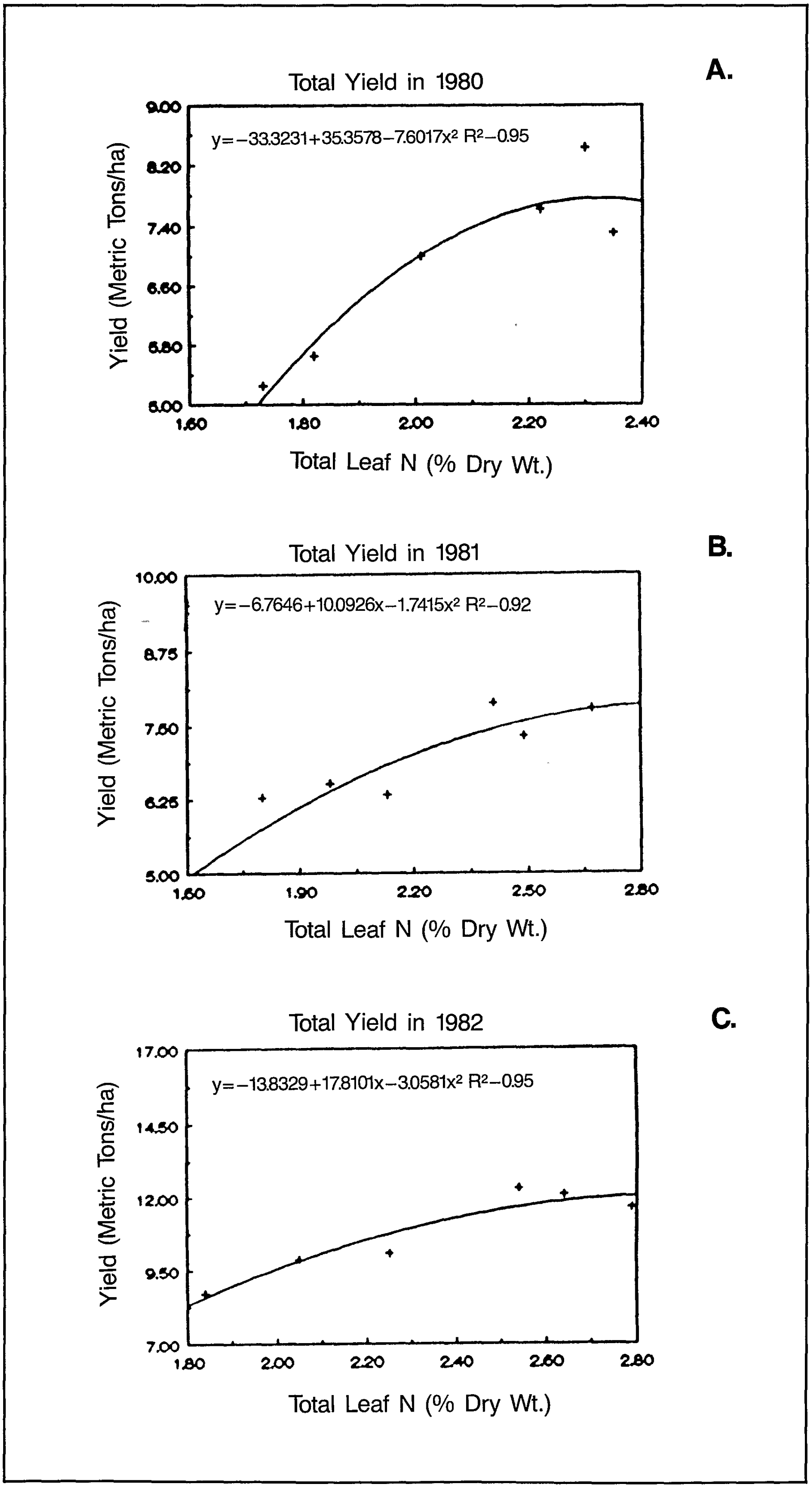
	Total yield		
Total leaf N	1980	1981	1982
June 15		0.46**	0.46**
July 15		0.42**	0.49**
August 15	0.61**	0.61**	0.62**
September 15		0.56**	0.58**

ns, *, **: Non-significant (ns), significant at 5% (*) or 1% (**).

Berry weight, yield/cane, cane basal diameter, number of fruiting laterals and total number of nodes/cane: Differential N application rates had no significant effect on average berry weight during the 1981 harvesting season (Table 4). Similarly, nonsignificant effects of N were found in 1982 for three early picking dates. Later in the season (Sept. 3 to Sept. 20) there was a significant increase with an increase in N application rate. Similar effects of N on berry size and finally on yield has been reported by previous workers (16,18,22,28). The nonsignificant effect of N in 1981 appeared to be due to an overriding influence of soil moisture. The maximum seasonal berry weight of 1.88 and 1.98 g in 1981 and 1982, respectively, was reached by the N application rate of 45 g per 1.67 m^2 (82 kg N/ha) (Table 4). There were noticeable year-to-year, as well as within season, variations. In general, berry size decreased as the season progressed, particularly during the early picking period. But, later in the season, berry size fluctuated and no systematic pattern of variation was observed. Some of these fluctuations appear to be related to deviations in the soil moisture status. It is postulated that if an adequate supply of N (82 kg N/ha under local conditions) and soil moisture were maintained throughout the growing season, a standard weight of about 2 g/berry could be maintained through the entire picking season. The maximum number of fruiting laterals (15.4) was produced by the N application rate of 75 g N/1.67 m^2 (136 kg N/ha) in 1982, as compared to 13.6 laterals produced in control plots (Table 4).

The number of fruiting laterals and total number of nodes/cane showed a positive relationship with N content in leaves (Table 5). As with total yield, leaf N content on the latter two sampling dates (August and September) was more closely related to berry weight than the earlier two dates. Maximum berry weight and number of fruiting laterals were attained within the 2.4-2.6 percent N leaf content.

The effect of N application rate on berry number per cane and berry number per lateral was statistically nonsignificant in both 1981 and 1982. An increase in the N application rate



from 0 to 75 g per 1.67 m^2 was shown to increase yield per cane significantly in 1982 but not in 1981, but trends were similar both years (Table 4). This increase in berry number and yield per cane was in contrast to the work of Lawson and Waister (18) and Ljones and Shakshaug (22), in which they reported a reduction by higher N application rates. Since total number of canes produced in this experiment was only slightly affected by soil-applied N and poorly correlated with N content of the foliage, there were no cane density problems. As a result, there was no overcrowding of canes, which in turn reduced the possibility of cane death or incidence of cane diseases by poor aeration or-sanitation. Also, there was a reduced possibility of shading of some parts of the canes by others (18). This might be one possible reason why an increase in yield per cane occurred at the higher N rates. Profuse flowering, higher percent fruit set and a greater number of berries per lateral have been reported to be increased by higher N application rates (21,22,23).

Quadratic regression produced the best fit between leaf N and yield per cane (Table 5). The N content in the mid-August leaf sampling was also more closely related to yield per cane than at other sampling stages. The optimum leaf N to produce the maximum yield per cane was again within the range 2.4 to 2.6 percent dry weight.

The best relationship between berry number per cane and per lateral was produced when the leaf sample was taken on the mid-August sampling date (Table 5). Maximum response

Figure 2. Relationship between mid-August total leaf N content and berry yield of 'Heritage' red raspberry, 1980-82.

Table 4. Effect of N application rate on different yield components of 'Heritage' raspberry, 1981-1982.

Actual N/plot (g N/1.67 m²)	Berry wt.		# Fruiting lats/cane		Total no. nodes/cane		Yield/ cane (g)		Cane basal diam.(mm)	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
0	1.80	1.78c[1]	—	13.6c	—	35b	49.1	49.1b	7.1	8.4c
15	1.84	1.84bc	—	14.4bc	—	37a	59.1	59.0a	7.9	9.4b
30	1.82	1.88bc	—	14.9ab	—	38a	45.2	60.3a	7.6	9.7ab
45	1.88	1.98a	—	14.7ab	—	37a	53.9	67.8a	7.4	9.4ab
60	1.84	1.94ab	—	15.0ab	—	38a	49.5	63.0a	8.4	9.8ab
75	1.84	1.90ab	—	15.4a	—	37a	51.8	65.8a	7.9	10.1a
Sig.	ns	**		**		**	ns	**	ns	**

[1]Mean separation within columns by Duncan's New Multiple Range Test, 5% level.
ns, *, **: Non-significant (ns), significant at 5% (*) or 1% (**) level.

was obtained within the 2.4 to 2.5 percent leaf level.

The effect of N application on cane basal diameter was found to be non-significant in 1981 but highly significant in 1982 (Table 4). Larger diameter canes were found in all treatments in 1982 as compared to 1981.

Cane diameter was more closely related to total leaf N for the Aug. 15 sampling date than at any of the other dates (Table 5). In 1982, as foliar N levels increased from 1.8 percent to 2.4 percent dry weight, the basal cane diameter increased rapidly and leveled off beyond 2.4 percent.

Total number of nodes (Table 4) was significantly increased with N application rate in 1982.

The quadratic relationship at the July 15 sampling date was superior to the linear relationship in explaining variation in various yield components (Table 5). The maximum cane height was obtained when the foliar N levels ranged from 2.4 to 2.6 percent dry weight.

Regression analysis of final cane height on leaf N content for 1982 showed highly significant quadratic relationships (Table 5). The best relationship was obtained at the Aug. 15 sampling date. Canes were stunted and brittle when foliar N levels fell below 2.0 percent N.

Total cane dry weight, leaf area, fresh leaf weight and specific leaf weight (SLW): Cane dry weight, leaf area and fresh leaf weight all were increased by N application (Table 6). Values for total cane dry weight and leaf area were greater in 1982 as compared to 1981. Specific leaf weight decreased as N application rate increased.

An increase in leaf N level was associated with a greater cane dry weight. A maximum weight was not reached at the 2.79 leaf N content. The leaf N content of all but the first sampling date (June 15) was equally correlated with cane dry weight (Table 6).

Leaf area and fresh leaf weight increased with a foliar N level increase (Table 6). Mid-August and September were equal in showing the relationship between leaf area, fresh leaf weight and leaf N levels (Table 5). The specific leaf weight was shown to decrease as the foliar N levels increased. The leaf N content at the August leaf sampling date was more closely related to the specific leaf weight than at any other date (Table 5).

The direct components of raspberry yield include the following: 1) berry size; 2) yield per cane; 3) berry number, including berry number per cane and number of berries per lateral and per plant; 4) number of fruiting laterals per cane; 5) total number of nodes; and 6) total number of canes per acre. In addition, the factors that indirectly contributed or were related to increased yield in raspberry include: 1) cane height; 2) cane dry weight; 3) leaf area; and 4) fresh leaf weight. All these factors directly or indirectly contributed to enhance a berry yield. Nitrogen fertilization was found to strongly effect the vegetative growth, yield and yield components. All these different variables were strongly related to each other.

Summary and Conclusions

Optimum yields were obtained at the 82-109 kg N/ha application rate.

Table 5. Regression of growth variables and characters of 'Heritage' on total leaf N content at various leaf sampling dates for 1982.

Variable	Leaf sampling stages	Regression Linear	Regression Quadratic
		R^2 values[1]	
Total number of canes	June 15	0.03 ns	0.08 ns
	July 15	0.06 ns	0.07 ns
	Aug. 15	0.09*	0.09 ns
	Sept. 15	0.07 ns	0.07 ns
Berry weight	June 15	0.22**	0.20**
	July 15	0.18**	0.20**
	Aug. 15	0.27**	0.28**
	Sept. 15	0.29**	0.29**
Number of fruiting laterals	June 15	0.30**	0.33**
	July 15	0.25**	0.30**
	Aug. 15	0.31**	0.31**
	Sept. 15	0.29**	0.30**
Berry number/cane	June 15	0.17**	0.23**
	July 15	0.18**	0.27**
	Aug. 15	0.30**	0.42**
	Sept. 15	0.25**	0.37**
Berry number/lateral	June 15	0.05 ns	0.09 ns
	July 15	0.05 ns	0.10 ns
	Aug. 15	0.18*	0.26*
	Sept. 15	0.09*	0.21*
Yield per cane	June 15	0.24**	0.28**
	July 15	0.23**	0.31**
	Aug. 15	0.38**	0.46**
	Sept. 15	0.35**	0.42**
Final height	June 15	0.45**	0.49**
	July 15	0.43**	0.54**
	Aug. 15	0.50**	0.67**
	Sept. 15	0.50**	0.63**
Cane basal diameter	June 15	0.37**	0.40**
	July 15	0.37**	0.44**
	Aug. 15	0.39**	0.47**
	Sept. 15	0.34**	0.44**
Total number of nodes	June 15	0.30**	0.33**
	July 15	0.23**	0.37**
	Aug. 15	0.18**	0.33**
	Sept. 15	0.18**	0.34**
Cane dry weight	June 15	0.53**	0.57**
	July 15	0.55**	0.60**
	Aug. 15	0.57**	0.61**
	Sept. 15	0.56**	0.61**
Leaf area	June 15	0.61**	0.63**
	July 15	0.69**	0.71**
	Aug. 15	0.76**	0.77**
	Sept. 15	0.76**	0.77*

(Continued on page 9)

Maximum N content was not attained at the 136 kg N/ha application rate. The mid-August sampling date from the four-to seven-leaf position was found to be optimal; mid-September was considered to be the next best sampling date. A mid-August N content of 2.4-2.6 percent is near optimum for yield of 'Heritage' under Ohio conditions. The application of N produced positive and significant responses to most growth variables measured. These variables were also strongly correlated with yield and mid-August leaf N content. Exceptions were the specific leaf weight, pulp pH and soluble solids.

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Table 5. (continued from p. 8)

Regression of growth variables and characters of 'Heritage' on total leaf N content at various leaf sampling dates for 1982.

Variable	Leaf Sampling stages	Regression Linear	Quadratic
		R^2 values[1]	
Leaf fresh weight	June 15	0.57**	0.59**
	July 15	0.63**	0.66**
	Aug. 15	0.69**	0.71**
	Sept. 15	0.71**	0.73**
Specific leaf weight (SLW)	June 15	0.13**	0.13*
	July 15	0.17**	0.19**
	Aug. 15	0.27**	0.30**
	Sept. 15	0.22**	0.26**

ns, *, **: Non-significant (ns), significant at 5% (*) or 1% (**) level.
[1]R^2 level, coefficient of determination.

Table 6. Effect of N application rate on the total cane dry weight and leaf characteristics of 'Heritage' raspberry, 1981-1982.

Actual N/plot (g N/1.67 m²)	Leaf (area cm²)		Fresh weight/ 15 leaf (g)		Total cane dry weight/plot (g)		Specific leaf weight (mg/cm²)	
	1981	1982	1981	1982	1981	1982	1981	1982
0	39.3c[1]	65.7c	—	17.7c	776b	913c	—	7.00
5	48.5bc	87.5b	—	23.2b	1100a	1206bc	—	6.81
30	52.9b	92.7b	—	24.2b	998ab	1363b	—	6.83
45	57.1ab	108.7a	—	28.2a	1066a	1471ab	—	6.56
60	66.4a	114.9a	—	29.8a	1225a	1694a	—	6.49
75	63.9a	115.9a	—	29.5a	1197a	1514ab	—	6.60
Sig.	**	**		**	*	**		ns

[1]Mean separation within columns by Duncan's New Multiple Range Test, 5% level.
ns, *, **: Non-significant (ns), significant at 5% (*) or 1% (**) level.

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Influence of Training Stakes and Various Pruning and Bending Techniques on Early Performance of 'Fuji' Apple Trees

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Introduction

Many techniques have been used over the years to control growth and increase production of young trees. The introduction of new apple cultivars with the potential for very high prices for fruit encourage testing of various combinations of treatments that might induce early production. The high value of early crops may make techniques economic that were too costly on cultivars with lower fruit prices.

Bending of branches has been commonly practiced to reduce shoot extension (6,11,13,21,22) and promote flowering (6,11,13,18). However, increased flowering has not been consistently found in studies utilizing bending (9). Tromp (17) showed that enhanced flower bud formation on horizontal apple shoots was due to a direct effect of shoot orientation and was not related to the associated growth reduction. However, Luckwill (8) attributed enhancement of flowering to the reduction in shoot growth. Hamzakeyl *et al.* (6) showed that previous horizontal orientation had less influence on flowering than the actual stress induced by bending. In fact, shoots trained to the horizontal produced the greatest number of watersprouts and the least flowering. Although current recommendations for managing slender spindle trees and trees in some other high-density systems advocate bending as a means of reducing growth and inducing flowering in young apple trees, the effects are not always consistent and beneficial.

Many of the new intensive orchard management systems (axis, HYTEC, slender spindle, etc.) require staking as a means of training and controlling the leader (11,13). Training stakes have also been used with trees on rootstocks that normally would be free-standing. Preston (14) established a planting of 'Cox's Orange Pippin' on M.2 and MM.104 (normally free-standing rootstocks) on an exposed windy site and found staking had no effect upon growth and cropping during the 15 years of the study. Thus, the value of staking normally free-standing trees is questionable, but it does offer the potential to alter heading height or use other training techniques that could induce earlier cropping. Several studies (7,12) show that staking increases tree height, while reducing basal trunk girth. Staking has also been advocated as a means of reducing early stress on unions between scions and dwarfing rootstocks such as MARK (12).

The study reported here was initiated to evaluate the influence of staking and various heading heights at planting. These treatments were coupled with various bending techniques in an attempt to induce earlier cropping of the new cultivar 'Fuji.' Although 'Fuji' has not been widely grown in the United States previously, recent sales have resulted in high fruit prices. These prices encourage the use of training techniques to improve early cropping.

Materials and Methods

'Fuji' apple trees on M.7A rootstock were planted on April 13, 1988, by a tree planter. Spacing was 3.1 x 6.2 m (10 ft. x 20 ft.) in east/west rows in a commercial orchard at Pataskala, Ohio. Several crabapple cultivars were interplanted as pollenizers. The nursery trees were vigorous, generally unbranched and had been headed at the nursery at 1.5 m to fit in the shipping containers. After planting, the trees were either headed at 85 cm (34 inches) or left unheaded. Metal conduit was used on some trees as a training stake and all trees were trained to a central leader system. (See top of page 12 for the 11 treatments applied.)

The treatments were arranged as a randomized block design within a single row of trees with 11 replications.

Shoots intended to be part of the tree's permanent framework were tied down or spread to an approximate 60° angle with the central leader during March. Those that were considered excess were tied or weighted in March to or slightly below horizontal. However, shoots with weights often ended up in a pendant position and the wire used to fasten the weight often partially girdled the limbs by the end of the growing season (Figure 1).

In 1988 and 1989, the number of shoots below a height of 85 cm were counted and shoot length of 10 shoots/tree measured. Trunk area, flowers/tree, fruit/tree and fruit set were determined annually. In the year of planting, 1988, a significant drought

Treatment	Heading	Staking	Treatment of shoot growth and unwanted scaffolds
1	85 cm	0	clothespins, removed by pruning
2	85 cm	0	competing shoots pinched
3	85 cm	0	tied down or spreaders
4	85 cm	0	weights attached, unpruned
5	85 cm	0	competing shoots pinched
6	0	0	weights attached, unpruned
7	0	1	clothespins, removed by pruning
8	0	1	tied down or spreaders
9	0	1	weights attached
10	0	1	unpruned
11	renewal 40 cm (16″)		unpruned, spreaders

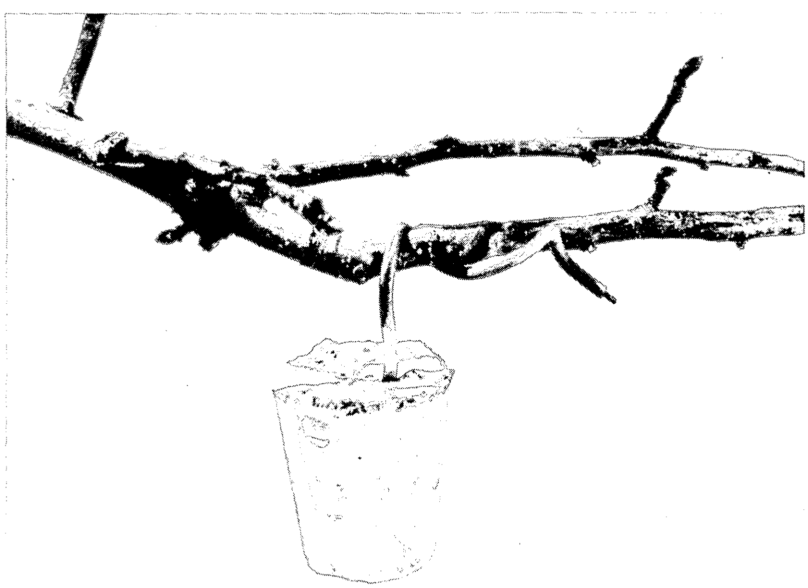

Figure 1. Concrete weight showing partial girdling of limb.

occurred in the early part of the season and lasted until late July, when significant rains occurred. A mulch of Comptil was applied around each tree soon after planting and the grower applied several gallons of water/tree on several occasions. Between 10:00 and 12:00 a.m. on July 18, 7 days after any water had been applied, stomatal conductance and transpiration of a well exposed mid-terminal shoot leaf on each tree was measured with a Li-Cor 1600 steady state porometer.

Experiment 2: The objective of this study was to determine the effect of different times of heading on growth and flowering of 'Fuji.' In 1989, trees in an adjacent row were selected and 25 percent of the growth on the main scaffolds that grew in 1988 was removed by heading at the following times: 1) control unpruned; 2) dormant (March); 3) bloom (May 8); 4) June 1; 5) July 1; and 6) Aug. 1. The treatments were arranged as a randomized complete block with 10 replications. Trunk area, shoot length (10 shoots not on headed scaffolds), regrowth on three headed scaffolds/tree, and flowers and fruit/tree were counted.

Experiment 3: The objective of this study was to determine if growth regulators could induce early flower initiation and fruit set of 'Fuji'. On May 23, 1990, foliar sprays of growth regulators were applied with an airblast sprayer to drip to multiple groups of five trees selected in a third row. The following treatments were applied: 1) control, unsprayed; 2) daminozide, 2.4 g/l (2 lbs/100 gal); and 3) daminozide, 2.4 g/l plus ethephon 2.5 ml/l (2 pts/100 gal). The treatments were applied as a randomized complete block with 6 replications. In 1991, two of the center trees of the five sprayed in each rep were selected and bloom/tree and fruit/tree were counted.

Results

Experiment 1: Heading at 85 cm increased the number of shoots produced by 'Fuji' trees the year of planting and in the following year (Table 1). Heading increased average shoot length and decreased trunk cross-sectional area in the year of planting, but had no influence in subsequent years. Staking increased the number of shoots the year of planting on headed trees, but had no

Table 1. Influence of training stakes or heading at planting and various pruning and bending techniques on growth of 'Fuji' apple trees on M.7A rootstock planted in 1988.

Treatment	Number shoots Below 85 (cm)		Average shoot Above 85 (cm)	Trunk cross-sectional length (cm)			Trunk area (cm²)			Degree of lean
	1988	1989	1989	1988	1989	1990	1988	1989	1990	
Headed vs. unheaded										
(non-staked trees)										
4 Headed										
(34") 85 cm	9.2a	33.6ab	0.0d	63.1a	81.5bc	41.8b	4.3cd	11.9ab	27.9a	5.0ab
6 Unheaded	3.3c	14.0cd	2.6b	35.7b	90.4abc	39.6b	5.7a	14.0a	27.9a	5.0ab
Staked vs. unstaked										
Headed trees										
2 Unstaked	10.9a	29.2ab	.1d	56.0ab	81.0bc	41.6b	4.5bc	12.8ab	29.5a	5.0ab
5 Staked	8.7b	27.1b	.5d	64.5a	81.3bc	41.9b	4.1cd	12.5ab	36.2a	0.0b
Unheaded trees										
6 Unstaked	3.3c	14.0cd	2.6b	35.7c	90.4abc	39.6b	5.7a	14.0a	27.9a	5.0ab
10 Staked	3.4c	13.0cd	3.2a	51.8abc	88.0abc	42.8b	4.8bc	13.4ab	27.0a	0.0b
Bending treatments										
Headed trees										
(all unstaked)										
1 Pruned	10.1ab	28.9ab	.2d	56.4ab	81.5bc	40.4b	5.0ab	12.1ab	26.3a	7.7a
3 Tie limbs	10.6ab	35.4a	.3d	57.3ab	81.6bc	38.6b	4.4bcd	11.9ab	27.9a	3.6ab
4 Weight limbs	9.2a	33.6ab	0.0d	63.1a	81.5bc	41.8b	4.3bcd	11.9ab	27.9a	—
Unheaded										
(all staked)										
7 Pruned	3.5c	13.8cd	2.3bc	44.5bc	90.6ab	45.4ab	4.6bc	11.4b	25.0a	0.0b
8 Tie limbs	3.0c	12.7cd	2.7ab	47.9abc	89.3abc	41.8b	4.6bc	12.9ab	20.3a	0.0b
9 Weight limbs	2.9c	14.2cd	2.6b	47.9abc	80.7c	39.0b	4.35cd	11.8ab	26.4a	0.0b
Renewal Pruned										
(40 cm)	3.7c	8.0d	.3d	58.5ab	88.2abc	50.9a	3.6d	7.2c	17.0b	0.0b

Mean separation within columns by Duncan's Multiple Range test, P=.05. Means with the same letter are not different. Note treatments 4 and 6 are repeated in the table for ease of comparison. Each mean is an average of 11 observations.

influence in subsequent years. With unheaded trees, there was no effect of staking on growth. Bending techniques had no influence on shoot or trunk growth. The number of shoots produced by trees headed at 40 cm in renewal pruning were similar to unheaded trees, but fewer than trees headed at 85 cm. Average shoot length on renewal pruned trees tended to be longer and trunk area smaller than other treatments.

Total shoot growth the year of planting (1988) was five times greater in trees headed at 85 cm compared to those unheaded and nearly three times greater than those headed at 40 cm (renewal pruned) (Table 2). There was no influence of staking, pruning or bending on total growth, stomatal conductance or transpiration in the year of planting. Headed trees had higher stomatal conductance then unheaded trees.

Unheaded trees had more flowers and fruit in 1989 than headed trees, but there was no influence of heading

Table 2. Total shoot growth, transpiration and stomatal conductance of 'Fuji' apple trees planted in the drought year of 1988 as influenced by various training treatments.

Treatment	Total shoot Growth (cm)	Stomatal conductance cms^{-1}	Transpiration $\mu g\ H_2O\ cm^{-2}s^{-1}$
Headed vs. unheaded			
4 Headed (34") 85 cm	580a	1.14a	13.0ab
6 Unheaded	114b	.94bc	11.3bcd
Staked vs. unstaked			
Headed trees			
2 Unstaked	591a	1.14a	13.3a
5 Staked	568a	1.09ab	12.6abc
Unheaded trees			
6 Unstaked	114b	.94bc	11.3bcd
10 Staked	170b	1.09ab	12.7abc
Bending treatments			
Headed trees (all unstaked)			
1 Pruned	576a	.96bc	11.4abcd
3 Tie limbs	590a	1.05abc	12.6abc
4 Weight limbs	580a	1.14a	13.0ab
Unheaded (all staked)			
7 Pruned	142b	.95bc	10.8cd
8 Tie limbs	153b	1.04abc	12.2abc
9 Weight limbs	132b	1.01abc	12.0abc
Renewal pruned (40 cm)	202b	1.10ab	12.5abc

Mean separation within columns by Duncan's Multiple Range test, P=.05. Means with the same letter are not different. Note treatments 4 and 6 are repeated in the table for ease of comparison. Each mean is an average of 11 observations.

at planting on flowering or fruiting in subsequent years (Table 3). Staking these trees on M.7 rootstock did not increase flowering, fruiting or fruit set. In the headed trees, there were no differences between removing unwanted branches by pruning or retaining them and tying or weighting them down. The latter treatments required considerably more time. In unheaded trees, leaving limbs in and weighting them down tended to increase flowering and fruiting in comparison to removal by pruning. Tying limbs or using spreaders was in between. Renewal pruning dramatically reduced both flowering and fruiting.

Experiment 2: Heading the primary scaffold had little influence on trunk cross-sectional area (Table 4). Average shoot length in the remainder of the tree was reduced by heading dormant scaffolds compared to no heading or heading in July or August. Regrowth on scaffolds headed in the dormant period was longer than any other treatment. Regrowth decreased as heading was delayed. The smallest amount of regrowth occurred on trees headed in August. Regrowth from the August treatment tended to be very thin and weak and prone to winter injury. Heading in July induced more regrowth shoots than heading at other times. Flowering the following year was increased by heading in the dormant period compared to the unpruned or heading at bloom, June or August. However, fruit number/tree did not differ among treatments.

Experiment 3: The combination spray of daminozide and ethephon increased flowering of 'Fuji' trees in 1991 (Table 5). However, fruit/tree and fruit set were highest in unsprayed trees, followed by trees receiving the daminozide spray with the fewest fruit and lowest fruit set on those that received the daminozide and ethephon sprays the previous year.

Discussion

The increase the year of planting in number of shoots, average shoot length and total shoot growth due to heading at 85 cm may be related to the hot, dry conditions that persisted in 1988 after the trees were planted. The tendency for headed trees to have higher levels of stomatal conductance and transpiration indicates that these trees with vigorous growth were surviving the drought better than those that had not been headed. Renewal pruning (heading at 40 cm) did not

Table 3. Influence of training stakes or heading at planting and various pruning and bending techniques on flowering, fruiting and fruit set of 'Fuji' apple trees planted in 1988.

Treatment	Flowers/tree			Fruits/tree				Fruit set (%)		
	1989	1990	1991	1989	1990	1991	Total	1989	1990	1991
Headed vs. unheaded										
4 Headed	7.9bc	57.3abcd	396abc	0.9b	4.0abc	207a	213ab	6.6a	5.5abcd	62.6
6 Unheaded	15.2a	76.0ab	423ab	3.4a	8.8a	223a	236ab	25.9a	10.7ab	54.2
Staked vs. unstaked										
Headed										
2 Unstaked	.7d	60.4abc	362abc	0.0b	2.7bc	226a	229ab	0.0a	4.0bcd	68.8
5 Staked	2.4cd	29.5de	326abc	0.9b	1.09c	222a	223ab	2.5a	4.4bcd	68.9
Unheaded										
6 Unstaked	15.2a	76.0ab	423ab	3.4a	8.8a	223a	236ab	25.9a	10.7ab	54.2
10 Staked	6.6bcd	61.4abc	329abc	1.0b	4.36abc	212a	218ab	8.8a	6.5abcd	62.6
Bending treatments										
Headed (all unstaked)										
1 Pruned	5.0cd	36.2cde	374abc	0.4b	2.3c	195a	199ab	8.1a	5.0abcd	52.5
3 Tied	1.5cd	60.2abc	454a	0.0b	4.9abc	204a	209ab	0	6.5abcd	48.7
4 Weighted	7.9bc	57.3abcd	396abc	0.9b	4.1abc	207a	213ab	6.6a	5.5abcd	62.6
Unheaded (all staked)										
7 Pruned	1.9cd	45.9bcd	285bcd	0.0b	1.4c	173a	176b	0	2.5cd	63.3
8 Tied	5.1cd	59.2abcd	417ab	0.6b	7.6ab	237a	246a	27.9a	12.0a	61.7
9 Weighted	4.1cd	80.6a	454a	0.5b	8.1a	234a	245a	4.3a	9.6abc	56.5
Renewal pruned										
(40 cm)	1.2d	15.1e	157d	0.0b	.25	843	84.2b	0.0a	1.0d	75.4

Mean separation within columns by Duncan's Multiple Range test, P=.05. Means with the same letter are not different. Note treatments 4 and 6 are repeated in the table for ease of comparison. Each mean is an average of 11 observations.

Table 4. Influence of various times of heading in 1989 of terminal shoots on growth and flowering of young 'Fuji' apple trees planted in 1988.

Heading treatment	Trunk area cm²	Shoot lgth cm	Regrowth on limbs headed: Avg. lgth (cm)	Regrowth on limbs headed: Shoot no.	1990: Flower clusters/ tree	1990: Fruit/ tree
Control	21.2ab	45.8ab	63.2b	4.2ab	19.7b	0.6
Dormant	22.8a	42.1c	76.0a	3.5bc	39.0a	3.9
Bloom	20.5ab	45.1bc	62.3b	3.7bc	12,7b	1.6
June 1	18.4b	47.8bc	51.2b	4.1bc	13.8b	1.1
July 1	20.3ab	51.8ab	36.8c	5.0a	26.1ab	1.9
Aug. 1	19.0ab	58.0a	13.1d	3.3c	10.7b	2.5

Table 5. Influence of growth regulator sprays in 1990 on flowering and fruiting of young 'Fuji' apple trees in 1991.

Treatment	Flower/ tree	Fruit/ tree	% Fruit/ set
Control	159.2b	88.3a	55.2a
Daminozide	181.7ab	59.5b	32.1b
Daminozide & Ethephon	201.5a	36.5c	18.8c

Note: There were 2 trees of each treatment in each of six replications.

increase number of shoots, shoot length or total growth compared to unheaded trees and thus was obviously too severe. Renewal pruning was once (20) advocated as a means of improving growth and crotch angles of primary scaffolds on newly planted trees. The results from this study indicate that growth is not enhanced and flowering delayed by renewal pruning.

Planting well-branched (feathered) nursery trees enhances cropping in intensive orchard systems (11,13,15,19) and in semi-intensive free-standing orchards (5). Generally, the greater the amount of growth, the earlier the flowering. Ferree (3) demonstrated any combination of propagation method and transplanting that resulted in increased early growth resulted in increased flower clusters per tree on several rootstocks. Hamzakheyl *et al.* (6) found that trees unpruned after initial heading at 75 cm produced more total shoot growth, more spurs and more flower clusters on 'Delicious' trees compared to pinching treatments that channelled growth into three primary scaffolds and then bending those scaffolds. In this study, the five-fold increase in total growth induced by heading at 85 cm the year of planting did not result in increased flowering; in fact, the unheaded trees had more flowers and fruit in 1989. The same trend, although not significant, persisted in subsequent years. Unheaded trees had more shoots distributed above 85 cm on the central leader than the headed trees. Since early flowering was sparse and tended to often be on the ends of shoots, the increase in shoot numbers in the upper portion of the trees would account for part of the increase in flowering.

Staking did not increase either growth or flowering of 'Fuji' on M.7A rootstocks in this study. This is similar to the findings of Preston (14) with 'Cox's Orange Pippin.' Staking could not be recommended because no subsequent treatment increased flowering or fruiting. In fact, the unstaked unheaded trees had more flowers in 1989 with a similar but non-significant trend in subsequent years.

It is interesting to note that the unheaded unstaked trees had a larger trunk cross-sectional area in 1988 than unheaded trees that were staked. The unheaded trees were fastened to the stakes with a stapled plastic tie. Following a storm in 1988, some of these ties broke and four of the trees leaned severely and had to be uprighted and permanent ties fastened to all trees. However, none of the unstaked unheaded trees leaned. Studies with staking ornamental trees (7) have shown that staking reduces trunk cross-sectional area and the taper of the trunk. Often these plants fall over when planted to the landscape, unless support is maintained.

In unheaded trees, pruning resulted in fewer flowers and fruit than leaving unnecessary shoots in and tying or weighting them down. Weights in particular were beneficial and often due to the continuous action of the weight, many of these branches became pendant and had reduced growth and increased spur formation and subsequent flowering. The extra time and expense for these treatments may be warranted on a high-value apple like 'Fuji.' Interestingly, these treatments were not beneficial on trees headed at 85 cm. Possibly the increased growth induced in 1988 was too vigorous and thus less likely to form flower buds than the less vigorous growth on the unheaded trees. Average shoot length in 1989 and 1990 did not differ between headed and unheaded trees and likewise, flowering in 1990 and 1991 was similar.

The response to heading shoots of 'Fuji' at different times during the growing season was similar to past Ohio findings with 'Delicious' and 'Jersey Mac' (4,10). However, the increase in flowering caused by the dormant heading was unexpected. This response could be related to the reduction in average shoot length over the tree that may have been caused by the increase in regrowth on the headed scaffolds. Elfving (1,2) has shown that annual dormant heading of 'Delicious' and 'Empire' reduced yield. The heading cuts used would have been similar in severity to those in this trial. The suggestion (personal communication with growers) that 'Fuji' trees in California can be vegetatively controlled and induced to flower by altering the time of summer pruning does not appear to be true in Ohio.

The increase in flowering due to foliar sprays of daminozide or a combination of daminozide and ethephon was similar to past responses with other apple cultivars under Ohio conditions (16). Generally an increase in flowering is associated with a corresponding increase in fruiting. It was surprising that the control trees that had fewer flower clusters had more fruit/tree and a correspondingly higher fruit set.

In summary, 'Fuji' does not appear to be precocious on M.7A rootstocks under Ohio conditions. Leaving the trees unheaded and avoiding pruning by tying or weighting unnecessary shoots increased early production. Using a training stake was not beneficial.

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Pilot Project for Integrated Pest Management in Ohio Apple Orchards

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Introduction

Integrated pest management (IPM) combines preventive cultural control, conservation of natural biological controls and optimally timed selective pesticides into a system where specific management decisions are based on biological monitoring. Benefits of this effort to reduce our dependence on pesticides are: 1) cost savings by eliminating unnecessary pesticide applications; 2) improved control by optimal timing of pesticide application; 3) improved records that document the need for specific pest management practices; 4) delay of problems with pesticide resistance; and 5) improved public relations that result from minimal pesticide residues on food crops.

Apple production is well-suited to the IPM approach because of the nature of pest problems and the availability of a variety of techniques for managing these problems. Control of fruit-feeding pests (direct pests) with broad-spectrum insecticides has induced to pest status some of the foliar-feeding arthropods (indirect pests) by eliminating their natural enemies. Many foliar pests can be tolerated at low or moderate levels, and thus are appropriate for management based on pest monitoring, action thresholds and biological control. Most fruit-feeding pests cannot be tolerated even at low levels, but monitoring can determine the optimal timing of control with selective insecticides. Selective insecticides, which are toxic to the key pests but of low toxicity to beneficial arthropods, are a key tool in the IPM system. Conservation of natural enemies is essential for some pests such as spider mites, for which few acaricides are now available due to the rapid development of resistance.

In major apple-producing states such as Michigan and New York, techniques have been developed for monitoring many of the direct and indirect pests by either trapping or scouting, and rules have been developed for using the monitoring information to make decisions on management practices. Ohio is the United States' 11th-ranked apple producer, with annual production valued at $21 million on 9,500 acres scattered throughout the state. The principles of IPM are familiar to most Ohio apple growers, but many growers who are interested in implementing IPM are unsure of specific procedures to use and whether the guidelines developed in other states are suitable for Ohio. Many are familiar with trapping techniques but are unsure of how to use trap information when making management decisions. The objectives of this project were to collect baseline data on the seasonal abundance of pests and natural enemies in central Ohio orchards, to evaluate the suitability for Ohio of IPM guidelines developed in other areas, and to compare the inputs (pesticide applications) and outputs (fruit quality) of blocks where the grower was supplied with weekly information on pest presence versus blocks managed by standard practices. If the pilot project showed that existing IPM guidelines were suitable, then their use could be promoted for use in Ohio orchards. The pilot project also allowed the opportunity to determine whether research on specific IPM components would be needed before use of the guidelines could be promoted.

Materials and Methods

In 1991, 13 blocks of apples in central Ohio were included in this study: 11 blocks on three commercial farms in Licking County and two blocks on a research farm in adjacent Fairfield County. Most blocks were 5 to 15 acres in size. The maximum distance between blocks was 35 miles. Participating growers were encouraged to use an extended protectant strategy for disease management. A hygrothermagraph with a leaf-wetness sensor (Belfort Inc.) was installed and monitored in one block at the research farm, and data were recorded from two similar existing units on one of the commercial farms to help evaluate the disease control program. Fruit quality was evaluated at harvest; 200 apples of at least one cultivar per block were rated for injury by insects and diseases. Pesticide application records were obtained for each block at the end of the season.

Weekly pest monitoring from half-inch green through harvest included several specific scouting procedures at critical times as well as a general scouting procedure for natural enemies and pests such as leafhoppers and aphids that were not covered by the specific procedures. In the general scouting procedure, five spur clusters and five terminals were inspected on each of five randomly selected trees from different areas within each block. The specific procedures that were developed in New York (Agnello *et al.*, 1991) were: 1) at pink, 10 clusters on each of 10 trees were examined for rosy apple aphid (*Dysaphis plantaginea*); 2) at pink, three clusters on at least three trees were examined for eggs of spotted tentiform leafminer (*Phyllonorycter blancardella*); 3) at petal-fall, three clusters on at least three trees were examined for early mines of leafminer's first generation; 4) in early summer, five terminal leaves on at least three trees were examined for early mines of leafminer's second generation; and 5) from mid-May until mid-August, four leaves on at least five trees were examined for presence or absence of European red mite (*Panonychus ulmi*). For mite scouting, an early-season chart based on a threshold of 2.5 mites per leaf was used from mid-May until mid-June, a mid-season chart based on a threshold of 5 mites per leaf was used from mid-June until mid-July, and a late-season chart based on a threshold of 7.5 mites per leaf was used from mid-July until mid-August. There are unfortunately no acceptable guidelines yet available for monitoring plum curculio, which is a key pest of apple.

Weekly pest monitoring also included trapping for codling moth (*Cydia pomonella*), spotted tentiform leafminer, San Jose scale (*Quadraspidiotus perniciosus*) and apple maggot (*Rhagoletis pomonella*). Sticky wing traps with pheromone lures (Scentry Inc.) were used to monitor adult males of the codling moth and spotted tentiform leafminer. Sticky tent traps with pheromone lures (Trece Inc.) were used to monitor adult males of the San Jose scale. Trap sticky panels were replaced weekly and lures were replaced every 4 weeks. Red sphere traps (Great Lakes IPM) covered with glue (Tanglefoot Co.) and baited with apple volatile lures (Consep Membranes Inc.) were used to monitor apple maggot flies. One codling moth trap, one leafminer trap, one scale trap, and three maggot traps were set up in each block.

Pest monitoring could affect four treatment decisions: 1) whether an insecticide was needed at pink; 2) whether an insecticide for leafminer, leafhopper or aphids needed to be added to petal-fall or cover sprays, because these foliar pests are not controlled by standard materials used in cover sprays; 3) whether a cover spray could be omitted or the interval between covers extended during periods of low activity by codling moth and apple maggot; and 4) whether acaricide applications were needed. To evaluate these decisions, 12 blocks were paired as IPM blocks and comparison blocks; both blocks in a pair were in the same vicinity and the same or similar in cultivar, age and management history. One additional IPM block had no comparison block. Pests were monitored weekly by a research scout in all blocks, but growers were given pest monitoring reports for only the IPM blocks, not for the comparison blocks. Reports included recommendations on the need for treatment only for rosy apple aphid, leafminer and European red mite as determined by the specific procedures described above. Growers were advised of tentative thresholds for leafhoppers, aphids and codling moth, but were requested to make their own decisions on managing these pests based on the monitoring reports.

Results and Discussion

Scouting for Specific Pests: Rosy apple aphid—The scouting procedure for rosy apple aphid at pink (April 14), in which 10 clusters on each of 10 trees were examined, indicated that this aphid was not present in any of the 13 blocks. Later in the season, general scouting detected a few rosy apple aphids in six blocks on a single date per block: May 4 in two blocks, June 17 in two blocks, June 24 in one block, and August 9 in one block. They were found on only one or two of the 25 clusters examined, except for one block on May 4 where they were found on 11 of 25 clusters.

Spotted tentiform leafminer—Scouting for spotted tentiform leafminer indicated that all 13 blocks were below threshold at all three critical times: pink, petal-fall and early summer. Detection was most difficult at pink, when eggs were counted on three clusters on each of three trees. Because leafminer eggs are small, transparent and often present at very low densities, new scouts may need considerable practice at recognizing leafminer eggs before confidence in the procedure will be developed. Scouting for early mines at petal-fall and early summer was easier than scouting for eggs. Scouting for second-generation early mines was done in mid-June, which was ca. 660 degree days (base 43F), or 3 weeks, after pheromone traps indicated the

Table 1. Pest infestations detected by scouting in a pair of representative apple blocks, 1991; LMI=IPM block[1]; LMC=comparison block[2]. Both blocks cv 'Red Delicious', 20-year-old trees, 14-20 acres.

Date	Leafhopper (% infested clusters)		Green apple aphid (% infested clusters)		Red mite (% infested clusters)		Leafminer (# new mines/leaf)	
	LMI	LMC	LMI	LMC	LMI	LMC	LMI	LMC
4/20	0	0	0	0	—	—	—	—
4/27	8	16	0	0	—	—	—	—
5/4	12	0	0	0	—	—	—	—
5/11	20	0	0	0	—	—	—	—
5/18	4	0	12	12	—	—	—	—
5/25	36	8	8	20	33	48	—	—
6/1	24	16	8	8	90*	95*	—	—
6/8	12	8	0	4	20	38	—	—
6/15	0	4	0	0	13	66	0	0
6/22	4	8	48	0	100*	—	—	—
6/29	0	0	16	40	0	15	0.7	—
7/6	0	8	4	1	20	—	—	—
7/13	0	0	0	0	5	0	2.0	0.2
7/20	0	0	0	0	15	10	0.3	0.4
7/27	0	0	0	0	0	77	1.0	0
8/3	0	0	0	0	10	48	3.0	0.3
8/10	0	0	0	0	85*	95*	—	—

[1]Insecticides applied in LMI block: 5/3 (phosmet), 5/13 (phosmet), 6/3 (chlorpyrifos), 7/9 (phosmet), 8/12 (phosmet + endosulfan).
[2]Insecticides applied in LMC block: 5/3 (phosmet), 5/13 (phosmet), 6/3 (chlorpyrifos), 7/9 (phosmet), 8/12 (phosmet).
[3]Acaricide (propargite) sprayed after this day.

beginning of the second adult flight (May 25); scouting was thus done exactly as called for in the New York protocol. The mid-June scouting indicated that no new mines were present in any of the 13 blocks. The scouting procedure was repeated weekly for an additional 6 weeks to determine when new mines would be detected. New mines were detected throughout the period from late June until early August (Table 1). The mines did not exceed the threshold level until late July, when an average of three new mines per leaf were detected in three blocks, although by that time the leafminer was apparently in the third generation; the threshold used was probably lower than needed since it was the threshold intended for the second generation. Growers were concerned about the large number of leafminers present late in the season, which they felt were contributing to premature fruit drop in a year when trees were under stress from a prolonged drought.

European red mite—The presence/absence scouting procedure for European red mite was easy to use with the aid of sequential sampling charts. Weekly data from a pair of representative blocks is presented in Table 1. The number of leaves examined ranged from 20 to 80; in 39 percent of the sampling counts, the minimum number of 20 leaves was adequate for making a decision, and in 80 percent of the sampling counts the sample size was not over 40 leaves. During the first month that the low threshold (2.5 mites per leaf) was used, there were 29 samples where a block was below threshold and 18 samples over threshold. During the second month when the intermediate threshold (5 mites per leaf) was used, there were 49 samples under threshold and nine samples over threshold. During the third month, there were 22 samples under threshold and 16 over threshold, although it was later found that a mistake in the chart caused the low threshold (2.5 mites per leaf) to be used rather than the intended high one (7.5 mites per leaf); many of the samples declared as over threshold during this time period were in fact under the true threshold. There were 13 samples when a block was over threshold for more than one consecutive week after the threshold had first been exceeded; if timely acaricide applications had been made, the populations may have not continued to exceed the threshold in these blocks.

General Scouting: The general scouting procedure, in which five clusters and five terminals were examined on each of five trees, provided adequate data on the seasonal abundance of apple grain aphid (*Rhopalosiphum fitchii*), green apple aphid (*Aphis pomi*) and white apple leafhopper (*Typhlocyba pomaria*), as well as predaceous arthropods. Several other pests were occasionally found, including Japanese beetle (*Popillia japonica*), tarnished plant bug (*Lygus lineolaris*), redbanded leafroller (*Argyrotaenia velutinana*), fruittree leafroller (*Archips argyrospila*) and obliquebanded leafroller (*Choristoneura rosaceana*). Plum curculio (*Conotrachelus nenuphar*) was never seen but its typical damage on fruit was observed. Data obtained from this procedure would be more useful if the sample units were more precisely defined; rather than having a terminal as a sample unit, it may be more appropriate to examine the endmost five leaves of the terminal. It seems unnecessary to examine both spur clusters and terminals throughout the season; spurs were the most common location for pests through petal-fall but terminals were more commonly infested after petal-fall.

Apple grain aphid—This species is noticeable because of its widespread occurrence and its abundance early in the season, but it is not an economically important species. Injury by the apple grain aphid was not evident, although aphids were found in 12 of the 13 blocks during a 6-week period from half-inch green (April 6) until one week after petal-fall (May 11). The percentage of clusters infested averaged 20 percent (range 4 to 52 percent), with a mean of 4 aphids per infested cluster.

Green apple aphid—Green apple aphid was first detected on May 11, during the same week that apple grain aphid was last detected. Green apple aphid was found in all 13 blocks, with the most widespread occurrence during the last 2 weeks of May. It was not found after July 8 in nine of the 13 blocks; it lingered through August in the remaining blocks. At peak populations, 36 to 48 percent of terminals were infested in six blocks, 16 to 28 percent were infested in five blocks, and 8 percent were infested in two blocks (Table 1). Our tentative threshold was 10 percent of terminals with at least 50 aphids per terminal, which is similar to the threshold used in Ontario (Hagley and Roberts, 1987). Although the species observed was assumed to be *A. pomi*, it is possible that the population was a mixture of *A. pomi* and *A. spiraecola*, the spirea aphid. Although 11 of our 13 blocks had >10 percent of terminals infested, none approached a density of 50 aphids per terminal; in most cases there were less than 5 aphids per terminal.

White apple leafhopper— White apple leafhopper was also found in all 13 blocks. It was present from bloom (April 27) until harvest, with peak numbers in late May and early June. Few leafhoppers were found during the last 3 weeks of July. A rise in numbers of nymphs during the first week of August indicated the start of the second generation. During the first generation, eight blocks had 8 to 16 percent of terminals infested and five blocks had 20 to 44 percent of terminals infested (Table 1). Although leafhoppers were not counted on a per leaf basis, it was common to see only several nymphs on a terminal of at least 10 leaves. Infestations were always below our tentative threshold of 1 nymph per leaf at petal-fall; this is lower than the 2 to 5 nymphs per leaf threshold used in Ontario (Smith and Ker, 1987) but higher than the 0.5 nymph per leaf threshold used in New Jersey (Polk, 1990). Despite first generation populations occurring below threshold levels, second generation populations developed to high densities in some blocks and were a concern to some growers. A lower threshold such as 0.5 nymph per leaf needs to be tested in Ohio.

Natural enemies—Eight major types of predaceous arthropods were detected, with the greatest diversity in the second half of the season (Figure 1). The three predators found in the greatest numbers were lacewings, thrips and syrphid (hover) flies. Lacewings were most abundant during July, although a few were found in May and June; the predaceous life stages were detected in only 5 percent of the positive samples (larva 3 percent, adult 2 percent), whereas 95 percent of observations were of the egg stage. The black hunter thrips was present throughout the season but was most frequently observed in June. Both lacewings and thrips were found in all 13 blocks at some point during the season. Syrphids were the most common predator detected during April, when they were associated with apple grain aphid. Syrphids were found in 12 of 13 blocks; 85 percent of observations were of the egg stage, 14 percent larvae and 1 percent adults. Predators found at lower frequency were minute pirate bugs, spiders, lady beetles (mostly adults; some larvae and eggs), cecidomyiid larvae and predaceous mites. Several species of lady beetles were present, but *Stethorus punctum*, an important predator east and south of Ohio, was not among the species observed. It is likely that predaceous mites were underestimated by visual searches; intensive sampling using a leaf-brushing device would more accurately determine their presence. Predators found in this project were similar to those reported previously in central Ohio (Holdsworth, 1972).

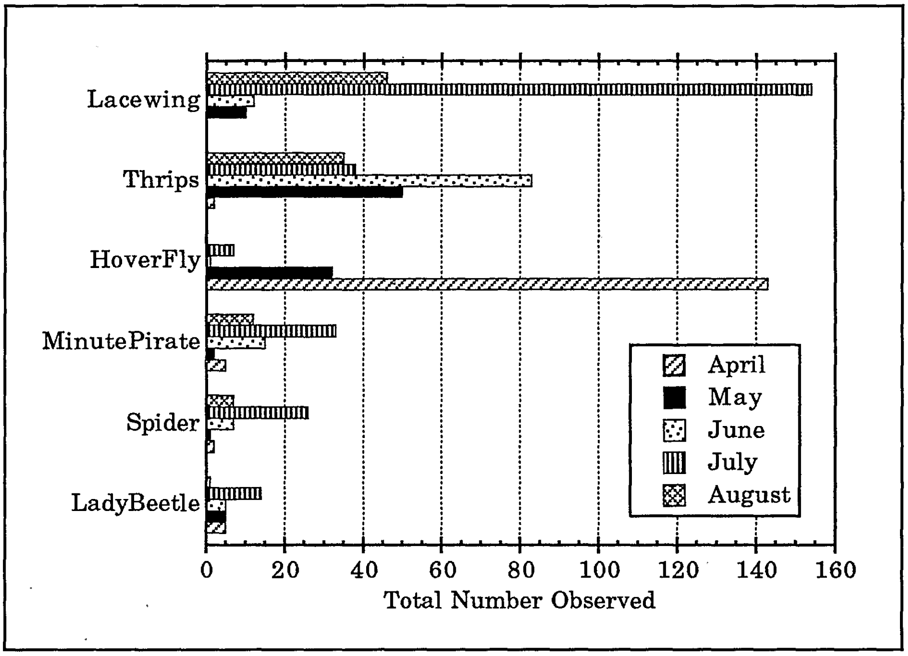

Figure 1. Monthly totals of predaceous arthropods in 13 apple orchards as detected on five spur clusters and five terminals on each of five trees per block per week.

Trapping: Codling moth—Pheromone traps were used to monitor codling moth populations from pink to harvest. Eight of the 13 blocks had the first codling moth catch during the week of May 18, which was 2 weeks after petal-fall; these eight blocks included the most southern and the most northern blocks. The remaining blocks had earlier catches: two blocks had the first catch during petal-fall, and three blocks had the first catch 1 week after petal-fall. Three generations of codling moth were detected. A trap monitored in an unmanaged block adjacent to one of the research blocks indicated codling moth population dynamics without the influence of insecticide applications: the first generation peaked at 29 moths per week in late May, the second generation peaked at 42 moths per week in mid-July, and the third generation peaked at 107 moths per week in late August. In most of the commercial blocks, trap catches were under 8 moths per week during the first generation, and under 20 moths per week during the second generation. During peak of the third generation, all traps had at least 7 moths and as many as 56 moths per week (Table 2).

One trap per block was used to monitor codling moth, with the exception of one large (40 acre) block that had two traps. There was a great difference between catches in the two traps in this block; the trap located at the north end of the block adjacent to a small abandoned orchard caught about four times as many moths as the trap at the south end of the block adjacent to a wooded area.

A codling moth management rule developed in Michigan needs to be evaluated in Ohio; data on codling moth catch in pheromone traps combined with degree-day accumulations can be used to determine when cover sprays should be applied for optimal control of hatching larvae (J.W. Johnson, pers. comm.). Three traps should be used per block when this rule is to be followed so that an average trap catch can be determined. An insecticide cover spray should be applied 250 degree-days (base 50F) after an average trap catch of 3 or more moths per week; no treatment is needed if the average trap catch is less than 3 moths per week.

Spotted tentiform leafminer—Pheromone traps for spotted tentiform leafminer indicated that the first-generation adult population peaked at pink (mid-April). Peak catches ranged from 115 to 3,800 moths per week. Most blocks showed a peak of second generation adults in mid-June. Due to fairly constant high numbers after the second generation peak, it was difficult to determine whether three or four generations occurred; trap catches of 2,000 to 3,000 moths per week were common in most blocks throughout July and August (Table 2). On one commercial farm where few insecticide applications were made, leafminer catches were noticeably lower, in the range of 500 moths per week during June and July, and up to 1,500 moths per week in August. The most valuable use of the pheromone trap was in helping to determine when to scout for early mines of the second generation, as discussed above in the section on specific scouting procedures.

San Jose scale—Adult males of the San Jose scale were trapped in all eight blocks where traps were established, although this pest was not considered by growers to be of commercial importance in any of these blocks. There was a large peak 1 to 2 weeks after petal-fall (May 10-17), with 17 to 1,450 scales per trap during the peak week. A small second generation peak was detected in early July, with 64 or fewer scales per week during the peak week (Table 2). The scout looked for crawlers 4 to 6 weeks after peak catches but none were detected.

Apple maggot—Apple maggot flies were caught on baited red sphere traps in moderate numbers in two blocks (up to 22 flies per trap per week), in low numbers in ten blocks (up to 7 flies per trap per week), and no flies were found on traps in one block (Table 2). Maggot traps were set up in mid-June. The two blocks with the highest fly catches showed peak numbers in early and mid-July. Central Ohio is in the transition zone between northern areas where maggot is a key pest and southern areas where it does not occur. The trap catches indicated that populations are prevalent enough to warrant monitoring by traps. A rule developed in New York is that a cover spray for maggot control should be applied once a cumulative total of 15 flies have been caught on three traps (Agnello *et al.*, 1991); this rule needs to be tested in Ohio.

One trapping technique that is available but not yet tested in Ohio is a white sticky trap for monitoring tarnished plant bug. These traps were developed in Massachusetts, where they are used from silver-tip until 2 weeks after petal-fall with a threshold of 3 adults per trap through tight cluster, or 4.4 adults per trap through late pink (Prokopy *et al.*, 1982).

Pesticide Applications: The number of insecticide applications per block averaged six and ranged from two to nine, and the number of miticide applications ranged from zero to three (Table 3). All blocks also received a delayed-dormant oil treatment, which was not included in these totals. The insecticides used were phosmet (Imidan) in 56 percent of applications; azinphos-methyl (Guthion), in 22 percent; chlorpyrifos (Lorsban), in 11 percent; endosulfan (Thiodan), in 8 percent; and oxamyl (Vydate) in 3 percent of applications. With the exception of oxamyl, all of these materials are generally compatible with IPM due to their relatively low toxicity to natural enemies. Propargite (Omite) was used for all acaricide applications; this material is IPM-compatible. The number and choice of pesticides were nearly identical in paired IPM and comparison blocks. It is likely that in some cases the IPM report did influence treatment decisions, but influenced treatment in the comparison block as well as in the IPM block.

Because rosy apple aphid was not detected in any block at pink, growers were encouraged to not use an insecticide at pink in the IPM blocks. Growers normally used an insecticide at pink, so they were encouraged to do so in the comparison blocks. There was only one pair of blocks where this differential application was made; in four pairs, insecticide was not used

Table 2. Number of target pests trapped per week in a pair of representative commercial blocks (LMI, LMC) and an abandoned block (SHA) in central Ohio, 1991.

	Codling moth (1 trap)			Apple maggot (mean of 3 traps)			Leafminer (1 trap)		Scale (1 trap)
Date	LMI	LMC	SHA	LMI	LMC	SHA	LMI	LMC	SHA
4/13	0	0	—	—	—	—	1700	115	—
4/20	0	0	—	—	—	—	216	110	—
4/27	0	0	—	—	—	—	167	12	—
5/4	0	0	—	—	—	—	220	76	1
5/11	0	0	0	—	—	—	130	27	116
5/18	4	3	29	—	—	—	13	10	56
5/25	3	2	26	—	—	—	233	163	0
6/1	4	3	14	—	—	—	2802	3680	0
6/8	0	0	4	—	—	—	3402	2754	0
6/15	1	0	14	0	0	—	3294	1836	0
6/22	3	1	8	0.3	0	—	1800	980	0
6/29	1	2	17	0	0	—	1825	525	3
7/6	4	4	39	0	0	—	2648	2528	9
7/13	4	2	5	0.3	0	3.0	3640	2240	1
7/20	9	2	42	0	0	1.0	3942	3258	—
7/27	0	1	30	0	0	1.3	2754	3024	10
8/3	1	0	32	0.3	0	0.7	2563	2376	0
8/10	3	2	19	0	0	0.1	2322	3132	0
8/17	4	2	51	1.7	0	0.7	2106	2862	0
8/24	13	7	38	1.0	0	0.3	2142	1566	0
8/31	8	0	107	0	0	0	—	—	59
9/7	—	—	18	—	—	—	—	—	—
9/14	—	—	3	—	—	—	—	—	—

Table 3. Number of insecticide and acaricide applications, and percentage of fruit damaged by insects, in IPM and comparison blocks.

		Insecticide applications		Acaricide applications		Insect Damage (%)	
Location	Cultivar[1]	IPM	Comparison	IPM	Comparison	IPM	Comparison
OL	JO,RD,GD	7	8[3]	2[5]	2[5]	12	20
LE	PG,JO,RD	3[2]	—	1[2]	—	5	—
LM	RD	5	5	3	2	5	1
LS	RD	6	6	2	2	8	5
LF	JO	6	6	1	1	1	8
HW	RD	2	2	1[4]	1	13	18
LH	JO,CL,GD	9[3]	9[3]	0	0	3	6

[1]Cultivars: JO=Jonathan, RD=Red Delicious, GD=Golden Delicious, PG=Prime Gold, CL=Cortland.
[2]LE site had no pesticide applications after June 25 due to hail damage.
[3]Included an insecticide application at pink.
[4]One Dikar application not included.
[5]Two Karathane applications per block not included.

at pink in either the IPM or comparison blocks, and in one pair, insecticide was used in both the IPM and comparison blocks. If insecticide is not used at pink, tarnished plant bug is a pest of potential concern. In the one pair of blocks that was differentially treated at pink, plant bug injury was slightly higher in the comparison block treated at pink (7.5 percent of fruit injured) than in the IPM block not treated at pink (6.3 percent of fruit injured), thus indicating that skipping insecticide at pink did not contribute to an increase in plant bug injury.

Another concern at pink is control of adult leafminers. Although the IPM approach advocates waiting until petal-fall to make a decision on whether control of leafminer larvae is needed, the only insecticides available for leafminer control at petal-fall are usually disruptive to natural enemies and can thus lead to mite infestations. It is possible that treatment at pink is less disruptive to natural enemies, even if it means treating leafminer populations that may be below threshold. An evaluation is needed to quantify the trade offs between leafminer control and mite control as related to choice of whether or not to treat at pink, and what insecticides to use at pink and petal-fall.

Harvest Evaluations: Among 3,400 apples evaluated, the leading cause of insect injury was plant bug feeding, which was found on 3.5 percent of fruit. Other injuries were due to codling moth (1.9 percent), plum curculio (1.1 percent), leafrollers (1.1 percent), apple maggot (0.5 percent), fruitworms (<0.1 percent), and San Jose scale (<0.1 percent). Codling moth injury was primarily due to third generation larvae. Other injuries were due to hail (6.6 percent), cork spot (4.5 percent) and scab (3.4 percent). Only 74.8 percent of fruit were free of insect, disease and mechanical injuries. An average of 8 percent of the fruit in each block showed some sign of insect injury (Table 3). Two of the six pairs of blocks had insect damage somewhat higher (3 to 4 percentage points) in IPM blocks than in comparison blocks, while four of the six pairs had lower insect damage (3 to 8 percentage points) in the IPM than in comparison blocks.

Fruit injury was also evaluated in an unmanaged block adjacent to one of the research blocks. Among 300 fruit examined, codling moth caused the most injury (on 29.3 percent of fruit), followed by leafrollers (7.0 percent), apple maggot (4.3 percent), plum curculio (3.3 percent), plant bugs (2.3 percent) and fruitworms (0.3 percent); other injuries were due to scab (90.5 percent) and cork spot (16.5 percent), leaving only 2.0 percent clean fruit.

Conclusions

This project was valuable in obtaining baseline data on the seasonal abundance of pests and natural enemies as monitored by scouting and trapping. A more intensive sampling scheme for predaceous mites is needed to make the natural enemy survey more complete. The pest monitoring guidelines for specific pests appeared to be suitable for

Ohio; one of the most useful activities was the presence/absence scouting procedure for European red mite. The general scouting procedure could be streamlined to focus on white apple leafhopper, green apple aphid and natural enemies from petal-fall until early summer. Trapping was useful for codling moth and apple maggot; both of these traps need to be further evaluated as a basis for determining the cover spray schedule. Because the only available materials for leafminer control often lead to mite outbreaks due to their toxicity to natural enemies, further information is needed to help growers evaluate the options for managing these two pests, especially under stressful conditions such as a drought. Now that several IPM techniques have been tested and baseline data obtained, a more rigorous attempt should be made to compare blocks managed by an IPM system with blocks managed by standard practices to assess whether the adoption of IPM techniques offers significant advantages to apple producers.

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Relationship of Canopy Micro-Climate and Apple Tree Fruit and Leaf Performance

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Introduction

The influence of tree shape, size, training system and other cultural factors on light distribution in apple canopies has been reviewed recently (9,14), and the numerous studies cited illustrate the importance of canopy architecture on canopy light penetration. Measurement of light transmission in trees of various orchard management systems demonstrates some common characteristics among systems such as a decline in photosynthetic photon flux transmission (PPFT) from top to bottom of the canopy of systems differing dramatically in size and shape (3,5). However, differences were also evident in canopies of similar size but different shapes (3,5,6). PPFT can change dramatically from year to year in newer trellis systems, such as the Lincoln canopy, due to changes in pruning techniques (5).

Rom *et al.* (15) reported more fruit on the east side of north-south peach hedgerows, and spur quality was better on the east side of large 'Starkrimson' apples on seedling rootstocks (4). In one year, but not another, 'Golden Delicious' had higher spur quality on the east side in several management systems (5). Jacyna and Soczek (11) reported that the east sides of hedgerows with alleyways up to 2.5 m wide receive more full sunlight than the west sides. They found that the differences in light intensity between the two sides of a hedgerow decreased with an increase in width of the alleyway. However, fruit quality was better in fruit from the west side of the hedgerow (10). Ferree (3) reported a trend toward more fruit on the east side than on the west side of 'Golden Delicious' trees, but no differences were obvious in percent PPF transmission values or spur quality. Mika and Antoszewski (13) found no differences in photosynthetic efficiency expressed relative to fruit set or foliage area between the east and west side of north-south apple hedgerows. However, in recent work, Ferree *et al.* (6) in measurements over the season on leaves from several orchard systems found significantly higher net photosynthesis (Pn) in leaves on the east side compared to the west, while transpiration (E) did not differ. Thus, the evidence for the east side of north-south hedgerows to be more productive and have greater leaf efficiency than the west side is conflicting. The present study was undertaken to look at a broad range of canopy micro-climate factors as well as such factors as bee activity and pollination and relate them to fruiting pattern and physiological response of leaves on the east and west sides of the canopy.

Materials and Methods

Fourteen-year-old 'Golden Delicious'/MM.106 trained as free-standing central leader trees, spaced 4.3 x 5.5 m in north-south hedgerows were selected for detailed light measurements over the season. The trees were 4.5 m in height with a spread of 4.5 m. Tree height was divided into thirds, and the middle and bottom levels were divided into thirds in N-S and E-W directions. A Li-Cor line quantum sensor (LICOR-191 SB) was held horizontally in the center of each delineated segment (E,S,W,N and center), and measurements were taken at the following times on 5 days over the season with uniform light conditions: early morning, 8:00-9:00 a.m.; late morning, 11:00-12:00 a.m.; early afternoon, 1:30-2:30 p.m.; and late afternoon, 4:00-5:00 p.m.

PPFT was calculated as the percentage of frequently taken unobstructed measurements. At harvest the fruit from each of the segments described above was counted and weighed; a random sample of 15 apples rated for color (1=yellow to 5=green) and russet (1=no russet and 5=completely russeted); and the length to diameter ratio determined. These data and all subsequent data were taken on 5 replicate trees. At early bloom (April 30, 1987), 4 clusters as close as possible to the center of each segment were tagged and hand-pollinated with purchased 'Rome Beauty' pollen. The same clusters were hand-pollinated a second time on May 4. At harvest, fruit from these spurs were harvested and weighed, the seeds were removed and divided into good (plump and viable) and bad (shriveled, thin); and the seed weight of each class was determined. These data were then correlated with the above light readings.

On August 6, net photosynthesis (Pn) and transpiration (E) were measured with a portable infrared gas analyzer (ADC Model LCA 2 with Parkinson leaf chamber) on peripheral, well exposed, fully expanded shoot leaf. Four different levels of shade were placed over the leaf chamber after a steady reading at ambient light was achieved. The entire series of readings took between 2-3 minutes and subsequent repeat readings on ambient light indicated no deleterious influence on the Pn rate of the leaves. The light response determinations were made in the morning and afternoon on the east and west sides of the canopy at a height of approximately 1.5 meters.

Light quality was measured with a portable spectroradiometer (LI-Cor 1800) with a fiber-optic probe (LI-Cor 1800-10) on the remote cosine collector (LI-Cor 1800-11). The sensor was located at the same cardinal location in the lower canopy as the PAR sensor mentioned previously in mid-morning (9:30-10:30 a.m.) and mid-afternoon (2:30-3:30 p.m.). Measurements were made in all 4 cardinal locations on 4 dates and only in the E and W on 2 additional dates using 3 scans at 10 nm intervals.

Synoptic and within-canopy microclimate data were required as background for this investigation. The principal observations needed for this work were as follows: wind magnitude and direction (azimuth), and humidity. Within the canopy, air temperature and humidity data were obtained and, in early season, bud temperatures were also recorded. All data were logged directly into a computer for either on-line processing or to be stored for later analysis and plotting.

Synoptic data from outside the orchard canopy were obtained with a system similar to that described by Fox *et al.* (7). Air temperature profiles were measured with an aspirated and shielded thermocouple manifold. Wind direction and azimuth data were obtained with a tower-mounted, three-component, propeller anemometer (R.M. Young Model 27002). Synoptic humidity data were obtained with a General Eastern System 1100DP dew point hygrometer.

Within the orchard canopy, bud temperatures were measured with 0.05 mm (0.002 in) copper-constantan thermocouples inserted into buds at selected locations on the trees. Similar thermocouples, fixed in protected locations near the buds, were used to obtain air temperatures. Humidity data were obtained with a computer-controlled, multi-point system using an Electromagnetic Research Corporation Model BLR Lyman Alpha Humidiometer. All humidity data were processed with an adaptation of the software PSYCHRO (1,2).

Eight beehives, each having an average population of 45,000 bees, were placed adjacent to the plantings just prior to bloom. Tree canopies were visually divided into upper and lower halves on the tree's east and west sides. During a walk around the tree (1 minute), an estimate of the number of foraging bees within each quadrant was taken. Counts were made at different times during the day throughout the period when viable bloom was present on the trees.

Results

Generally more fruit were produced in the mid-canopy level and this fruit was more yellow, with less russet, and had a greater length/diameter ratio (Table 1). Cardinal position had minimal influence on most aspects of fruit quality. There was no significant difference in number of fruit between the bottom and middle canopy levels in the east and north, but in all other positions the middle canopy level had more fruit than the bottom (Fig. 1). Fruit weight decreased from the top of the tree to the bottom and was highest on the west and lowest in the central position of the canopy (Table 1). The number of filled or aborted seeds and the seed weight was unaffected by canopy level or position. Fruit were more yellow in the middle canopy level at all positions, compared to the bottom level, with the greatest differences between levels occurring on the north and tree center (Fig. 2).

Observations of bee foragers indicate that 42.2 percent of the 569 observed bees during the hours of 0900-1200 were in the upper east quadrant of the tree (Table 2). During the same time period, 27.1 percent of the 569 monitored bees were in the upper west quadrant of the tree.

During the hours 1300-1700, 29.7 percent of the 900 bees observed were in the upper east quadrant, while 27.3 percent were in the upper west quadrant. During morning and afternoon, both lower quadrants had lower levels of foraging bees. The least number of bees was found in the lower east quadrant during morning hours (12.7 percent).

Measurements of air temperature at various canopy heights on the east and west sides during bloom on April 30

Table 1. Influence of canopy level and position on fruit distribution size, quality and seed number of 'Golden Delicious' apples in central leader trees.

Canopy level[1]	Number of fruit	Color[2] rating	Russet[2] rating	Length/ diameter	Fruit weight g	Seeds/Fruit filled	Seeds/Fruit aborted	Seed weight (g)
Middle	208a	3.8b	2.3b	.94a	116a	8.4	1.7	.38
Bottom	112b	4.6a	2.4a	.92b	105b	8.0	2.0	.36
Canopy position								
East	135bc	4.0b	2.2b	.93	109b	8.3	1.7	.37
South	212a	4.2ab	2.4a	.92	110b	8.1	1.9	.37
West	117c	4.2ab	2.5a	.92	118a	8.0	2.0	.37
North	188ab	4.3ab	2.4a	.93	111b	8.6	1.5	.39
Central	148bc	4.4a	2.4a	.94	103c	8.0	2.1	.36
F-Significance								
Level (L)	**	**	**	**	**	NS	NS	NS
Position (P)	**	*	**	NS	**	NS	NS	NS
L X P	**	**	NS	NS	*	NS	NS	NS

[1]Number of observations in each mean are as follows: level 35, position 14.
[2]Rating systems: Color 1=yellow to 5=green; Russet 1=no russet to 5=completely russeted.
NS, *, ** Non-significant or significant $P<0.05$ or 0.01, respectively.

show that temperatures during the morning on the east side were higher than the west side in the upper levels of the trees (Fig. 3). When the temperatures were higher in the afternoon, the temperatures were slightly higher on the west, particularly at the lower canopy levels. The temperature differences between canopy sides were small, being around 0.5 to 1.5°C.

Later in the season, canopy temperatures differed little between east and west sides, being generally 0.5 to 1.0°C higher in the east in the morning with the opposite trend in the afternoon (Table 3). Windspeeds were generally light and variable or low for the July 29 and August 6 experiments. Wind direction was WSW to WNW on July 26, while on August 6, wind direction varied from easterly through northerly to westerly. These light winds are typical of the summer season, and would tend to be further suppressed with turbulent mixing enhanced to some extent due to the presence of full foliage. There were no obvious patterns of airflow among the experimental results that would appear to influence productivity differences between east and west sides of the hedgerows.

Although differences in relative humidity between east and west canopy sides were small, there was a tendency for them to be slightly higher in the west in the morning with the reverse in late afternoon (Table 4). The small differences observed in temperature and humidity at various times over the season would not be expected to cause significant changes in the basic physiological functions of the tree.

PPFT declined rapidly at all the canopy levels as the canopy developed and plateaued for the remainder of the season beginning at the June 24 measurements (Table 5 and Fig. 4a). In April, when the canopy just began to develop, PPFT was higher in the south position, but in September the east position had the highest PPFT. (Fig. 4b). The tree center, as expected, had the lowest PPFT over the entire season. Early in the season, PPFT was highest in late afternoon, but after the June 24 measurement there was little difference between the late afternoon and late morning measurements (Fig. 4c). PPFT measurements in the south and center positions changed less over the day than measurements at other canopy positions (Fig. 5). In late morning, PPFT was highest in the east and lowest in the west, with just the opposite relationship in late afternoon.

Neither east or west canopy position nor morning or afternoon influenced light penetration in the lower canopy for the various wave bands

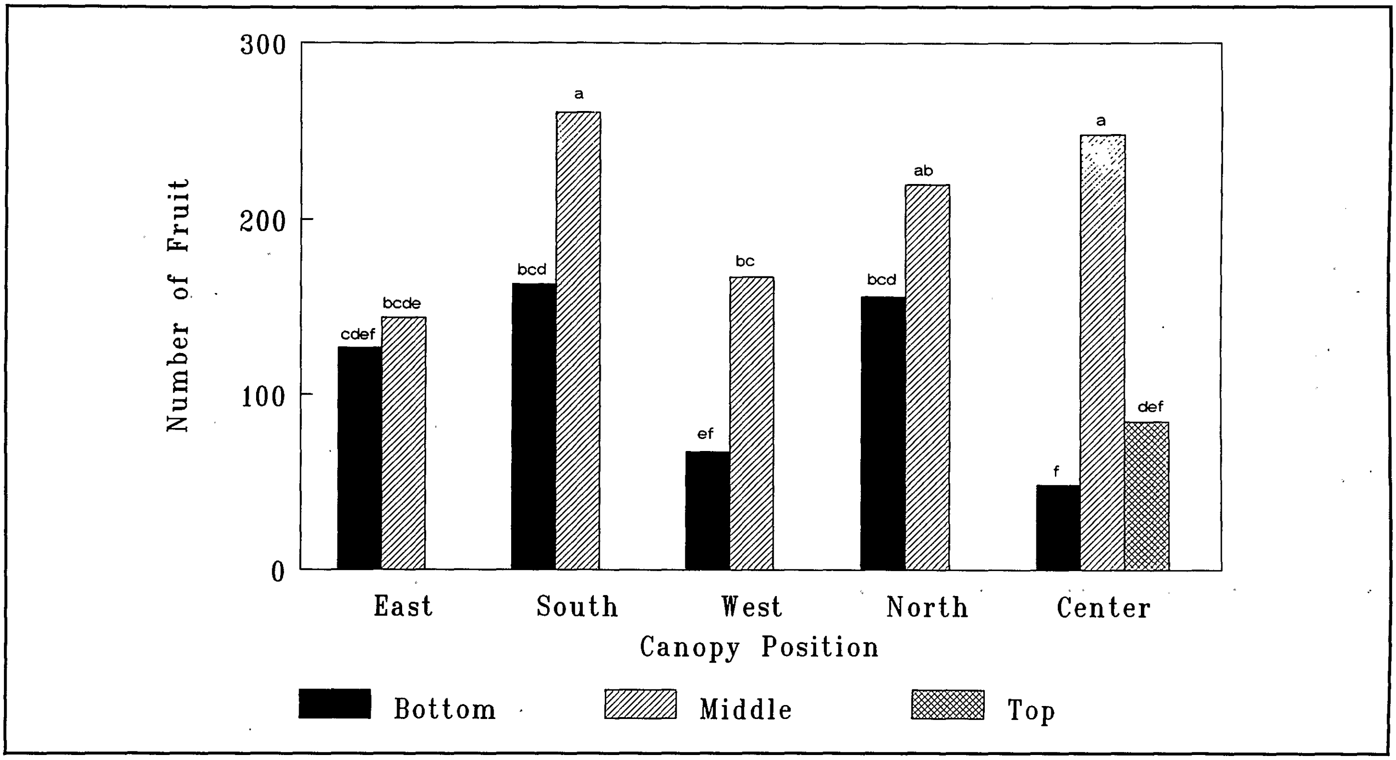

Figure 1. Distribution of 'Golden Delicious' apple fruit as influenced by canopy height and position in central leader trained trees.

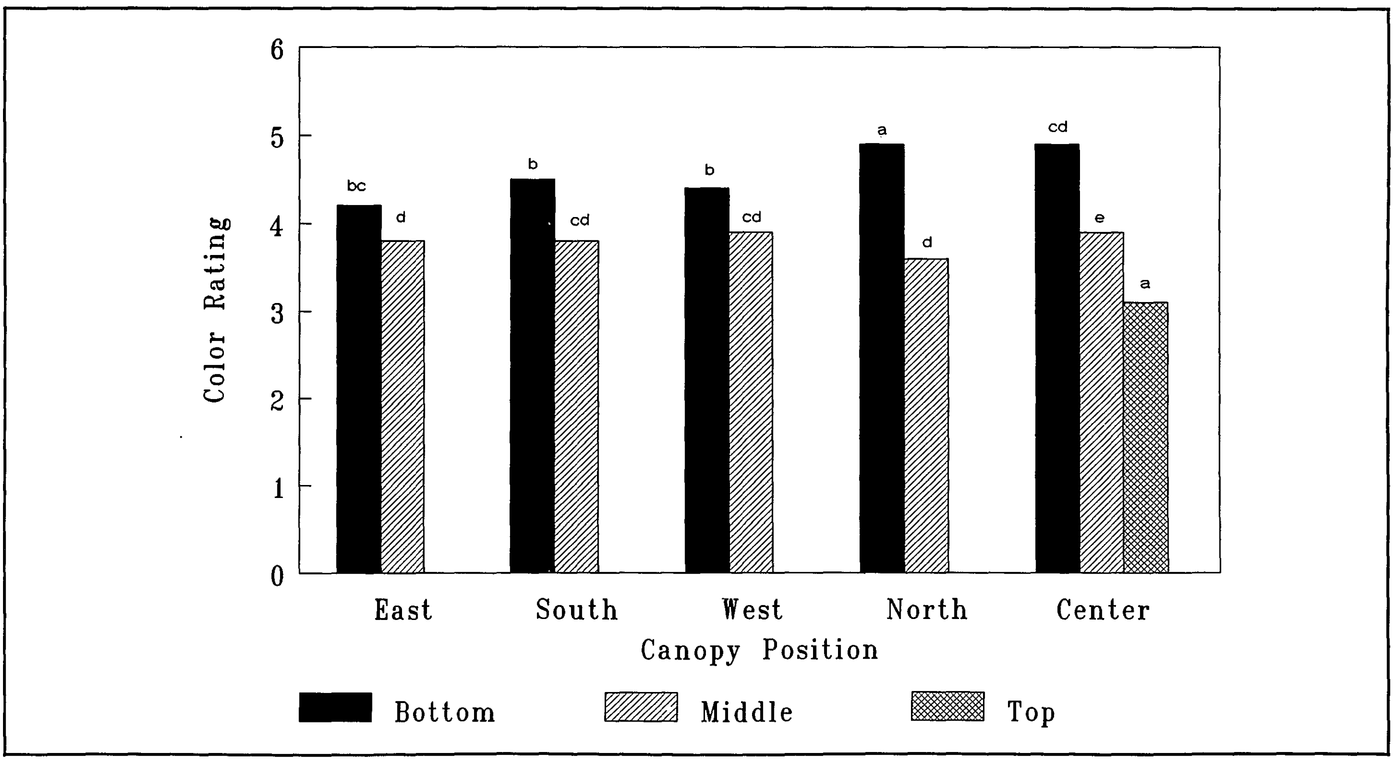

Figure 2. Fruit color of 'Golden Delicious' apples as influenced by canopy height and positon in central leader trained trees. Color rating: 1=yellow to 5=green.

Table 2. Location of honeybee foragers at various canopy locations of 'Golden Delicious' apple trees.

	East side of tree				West side of tree				Total	
	Top		Bottom		Top		Bottom		foragers	Total
Time	number	%	number	%	number	%	number	%	per hour	foragers
Morning										
0900	21	47.7	2	4.5	14	31.8	7	15.9	44	
1000	120	43.6	47	17.0	59	21.4	49	17.8	275	
1100	88	35.2	48	19.2	70	28.0	44	17.6	250	
Averages	76	42.2	32	12.7	47	27.1	33	17.1	—	569
Afternoon										
1300	59	30.8	38	19.8	54	28.2	40	20.9	191	
1400	133	33.5	74	18.7	115	29.0	74	18.7	396	
1600	86	24.7	70	22.4	86	24.7	71	22.7	313	
Averages	92	29.7	60	20.3	85	27.3	61	20.8	—	900

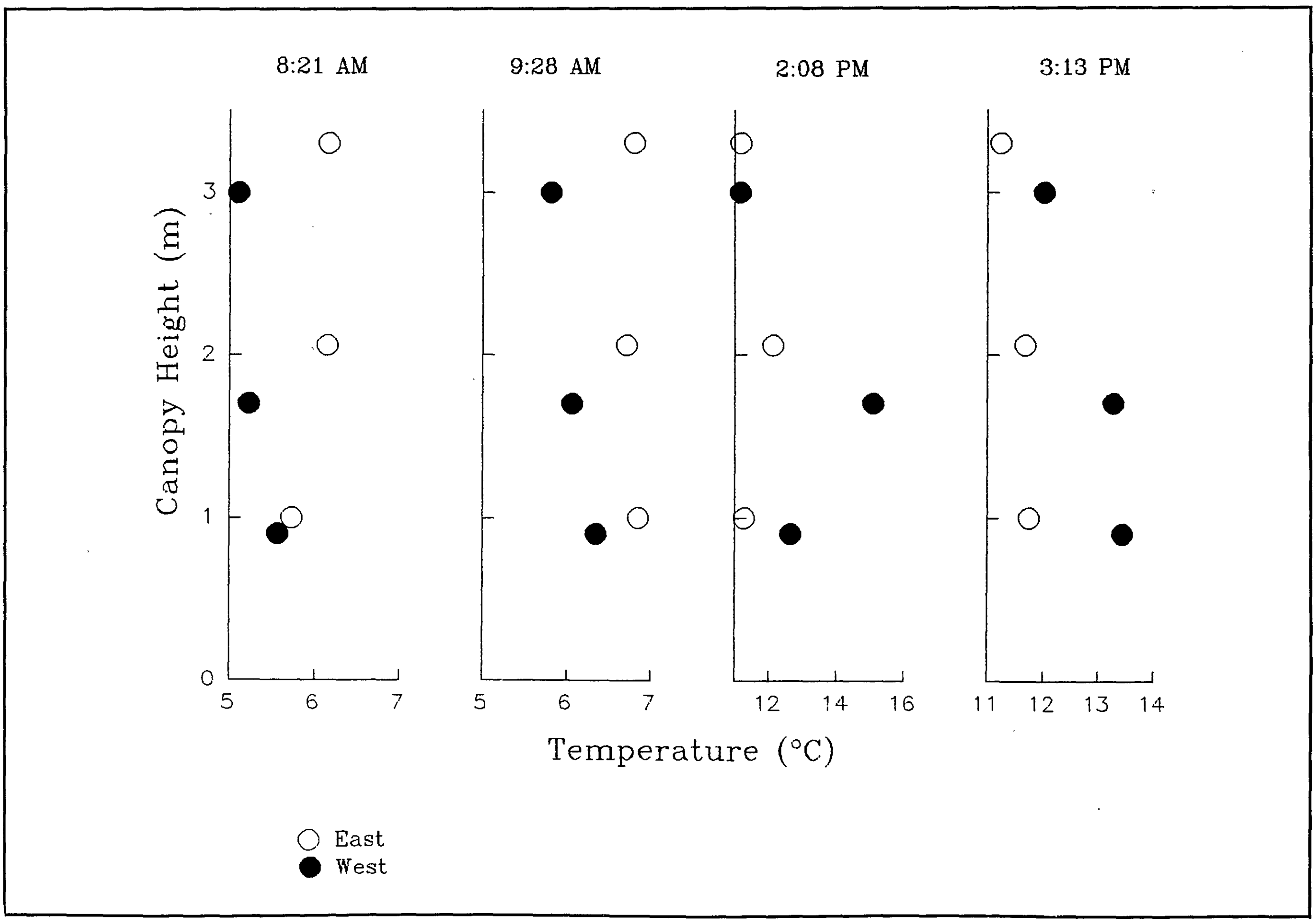

Figure 3. Within-canopy air temperature (°C) profiles in 'Golden Delicious' apple trees during bloom on April 30.

selected (Table 6). Additional measurements (data not shown) taken on the north, south and tree center taken on 4 dates over the season also showed no influence due to these positions. Light levels tended to be highest on August 6 and May 5 with little difference among the other 4 dates, and this pattern was observed at all wave bands. The significant interaction among date, time of day and canopy position revealed that on the days of high light levels (May 4 and August 6) east-morning and west-afternoon measurements were much higher than measurements in the east-afternoon and west-morning, while other days the differences were not great (Figs. 6abc). The wave band in the blue and red portions of the spectrum shows very similar patterns to the PAR 400-700 band.

A light response curve developed in the east and west sides of the canopy indicates a gradual increase in Pn, with a plateau occurring at about 900 μmol m^2s^{-1} on the east side, which is a very normal pattern for a light response curve (Fig. 7a). The very low ambient light levels in the morning on the west side of the canopy resulted in a response to light below that on the east side. In the afternoon, (Fig. 7b) Pn of leaves on the west side appeared more responsive to changing light then those on the east side. A similar pattern in responsiveness due to canopy was evident with E (Fig. 7cd), but again the very low levels of E on the east side in the morning resulted in no clear pattern of responses because of the very low light levels.

Table 3. Synoptic windspeed (meters/sec, m/s) and azimuth (measured in degrees clockwise from north) and within-canopy air temperatures through the days of July 29 and August 6.

Time	Windspeed m/s and Azimuth°	Air temperatures, °C East side of tree Height, m			Air temperatures, °C West side of tree Height, m		
		1.0	2.06	3.3	0.9	1.7	3.0
July 29							
8:52 AM	L/V[1]	21.9	22	24.3	21.3	—	21.4
9:52	0.5/270°	24.9	24	24.7	23.2	23.3	22.8
10:54	0.6/270°	26	26	26.1	24.6	24.9	24.7
11:54	0.7/280o	27	27.5	26.9	26.2	26.3	25.6
12:55 PM	0.6/300o	25.2	25.2	25.3	25.1	25.3	25.3
1:55	1.2/200°	27.4	27.1	27.4	27.4	27.9	27.4
2:56	1.4/250°	27	26.4	26.8	26.8	26.7	26.6
3:41	0.9/250o	26.8	26.6	26.9	27.4	27.3	27.2
August 6							
7:34 AM	L/V[1]	16.6	16.6	17.5	16.7	16.3	17
8:34	0.8/037°	19.3	20.2	20.5	19	19	19.6
9:35	0.7/035°	21.8	21.8	21.7	20.7	20.7	20.4
10:50	0.8/005°	24	24.2	24.3	22	22.5	22
11:52	0.4/087°	24.4	23.9	24	23	23.4	23
12:53 PM	0.8/300°	24.1	24.3	24.1	23.9	24.3	24.2
1:53	0.8/330o	25.1	25.2	24.8	25.4	25.8	25.3
2:54	1.0/300o	25.7	25.6	25.1	25.8	26.3	25.5
3:39	0.7/270o	25.7	26	25.7	26.3	26.8	26.5

[1]Light and variable

Discussion

The concentration of fruit in the middle level of the central leader 'Golden Delicious' trees in this study confirms distributions reported for similar trees in other studies (3,4,5). The decrease in fruit quality as measured by greener color, more russet and flatter shape and smaller size in the bottom third of the canopy follows the lower light levels in this region of the canopy. The rather dramatic decline in fruit size and quality associated with lower light levels has been a consistent result in apple canopies of many shapes and sizes (3,4,5,10,14,16).

The difference and reason behind this difference between the east and west sides of the canopy in mature central leader trees in north-south hedgerows was not clearly shown in this study. While numerically there were more fruit on the east side of the canopy than the west (Table 1, Fig. 1), the difference was not significant, a result similar to some previous work in another orchard at this site (3).

In hand-pollinated apples at various canopy positions, there were no differences in seed number or quality (Table 1). However, several reports indicate that meteorological factors, particularly temperature, may limit bee flight and pollen availability (8,12,17). Several authors indicate that foraging flights normally do not begin until the temperatures rise above 10°C (12). Since the temperatures reported in Figure 3 are close to this minimum level and slightly higher on the east

Table 4. Synoptic and within-canopy percent relative humidities throughout the days of April 30, July 29 and August 6.

Time	Windspeed m/s and Azimuth°	Synoptic % RH	Relative Humidities East side of tree Height, m 1.0	2.06	3.3	Relative Humidities West side of tree Height, m 0.9	1.7	3,0
April 30								
8:21 AM	1.3/200°	58	51	49	48	52	52	51
9:28	2.6/330°	61	44	43	43	47	47	46
2:08 PM	0.8/165°	43	57	51	51	54	42	54
3:18	1.3/172°	44	50	47	47	46	43	44
July 29								
8:52 AM		72	88	87	76	98	90	90
9:52		55	68	72	69	74	74	77
10:54		51	59	60	65	64	64	65
11:54		43	54	53	54	57	57	59
12:55 PM		52	60	61	59	60	60	60
1:55		45	57	59	57	57	55	57
2:56		46	59	63	60	60	61	66
3:41		46	58	60	59	57	58	57
August 6								
8:34 AM		81	98	93	91	100	100	96
9:35		64	79	79	80	84	84	86
10:50		53	68	67	66	76	73	75
11:52		53	66	68	67	71	70	71
12:53 PM		53	67	66	66	67	67	67
1:53		52	67	66	66	65	64	64
2:54		49	64	65	65	63	62	63
3:39		47	65	64	64	62	60	60

side of the canopy, the small differences in temperature may partially explain the increased bee foraging activity on the east in the morning. Bees also tend to forage more in the areas of the canopy well exposed to light and avoid shaded sections as well as use the sun for flight orientation, which may further explain some of the results observed (8,12,17).

The pattern of light distribution within the canopy of these trees over the season (Table 5, Figs. 4,5) confirm previous reports (3,5,6,9,10,11,14). In late morning, light was highest on the east side of the canopy and lowest in the west, with the opposite relationship in the afternoon. Of course, net photosynthesis closely followed these differences in ambient light levels. In Australia, Ferree *et al.* (6) found with multiple measurements over the season that leaves on the east side of the canopy had higher photosynthetic rates than the west side, while transpiration rates did not differ. On the east side of the canopy, photosynthesis of leaves from shoots and nonflowering spurs did not differ, while on the west side of the canopy nonflowering spurs had significantly lower photosynthetic rates than shoots. In a West Virginia study on 'Golden Delicious' (5), trees trained on a palmette trellis and central leader forms had higher Pn on the east compared to the west side in the morning, with the reverse occurring in the afternoon. This pattern was not evident in the slender spindle or Lincoln canopy trees.

The data presented in Figure 7 was an attempt to evaluate the ability of leaves under these different levels of ambient light to react to rapidly changing conditions imposed by applying various levels of shade over the leaf chamber. In the morning, leaves on the east side under high ambient light conditions were very responsive (both photosynthesis and transpiration) to decreasing levels of light (Fig. 7a,c). However, for leaves on the west side under low ambient light conditions and very low levels of photosynthesis and transpiration, the response as expected was much lower. In the afternoon, levels of light were much higher, with the west being slightly higher than the east. Under these conditions, leaves on the west side were more responsive (both photosynthesis and transpiration) to rapidly decreasing light levels than those on the east (Fig. 7b,d).

In a previous study (6) conducted to determine if shoot leaves that developed on different training systems responded differently to changing light levels, response in photosynthesis of leaves on the Tatura trellis to increasing shade was more marked than leaves from the palmette. Leaves from the minimal pruned system and Ebro were not different from either of the above systems. Response of leaves in the lower level of the canopy was greater to changing light at or above saturation than leaves near the top of the canopy. The difference in response between time of day or side of the canopy was not investigated in this study. These studies show that apple leaves differ in their ability to respond to rapidly decreasing light levels due to past light exposure that has been influenced by training system, canopy side or time of day.

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Table 5. Influence of canopy level and cardinal position, time of day and season on photosynthetic photon flux transmission (PPFT %) in the canopy of 'Golden Delicious' central leader apple trees.

Level	PPFT %	Position	PPFT %
Top	43.5a[1]	East	20.8a
Middle	23.6b	South	22.6a
Bottom	15.2c	West	19.5a
		North	20.0a
		Center	14.2b
Date		**Time**	
April 5	36.9a	Early morning	17.0b
May 15	25.3b	Late morning	19.5b
June 24	10.1d	Early afternoon	18.5b
July 22	11.6cd	Late afternoon	22.5a
Sept. 4	13.1c		
F-Significance			
Level (L)	**		
Position (P)	**		
L x P	**		
Time (T)	**		
T x L	NS		
T x P	**		
T x P x L	NS		
Date (D)	**		
D x L	**		
D x P	**		
D x P x L	NS		
D x T	**		
D x T x L	NS		
D x T x P	**		
D x T x P x L	NS		

[1]Number of observations in each mean are as follows: Level 500; position 200; time 250; date 200. Means separated by Duncan's Multiple Range Test, 5 percent.
NS, *, ** Non-significant or significant at P x 0.05 or 0.1, respectively.

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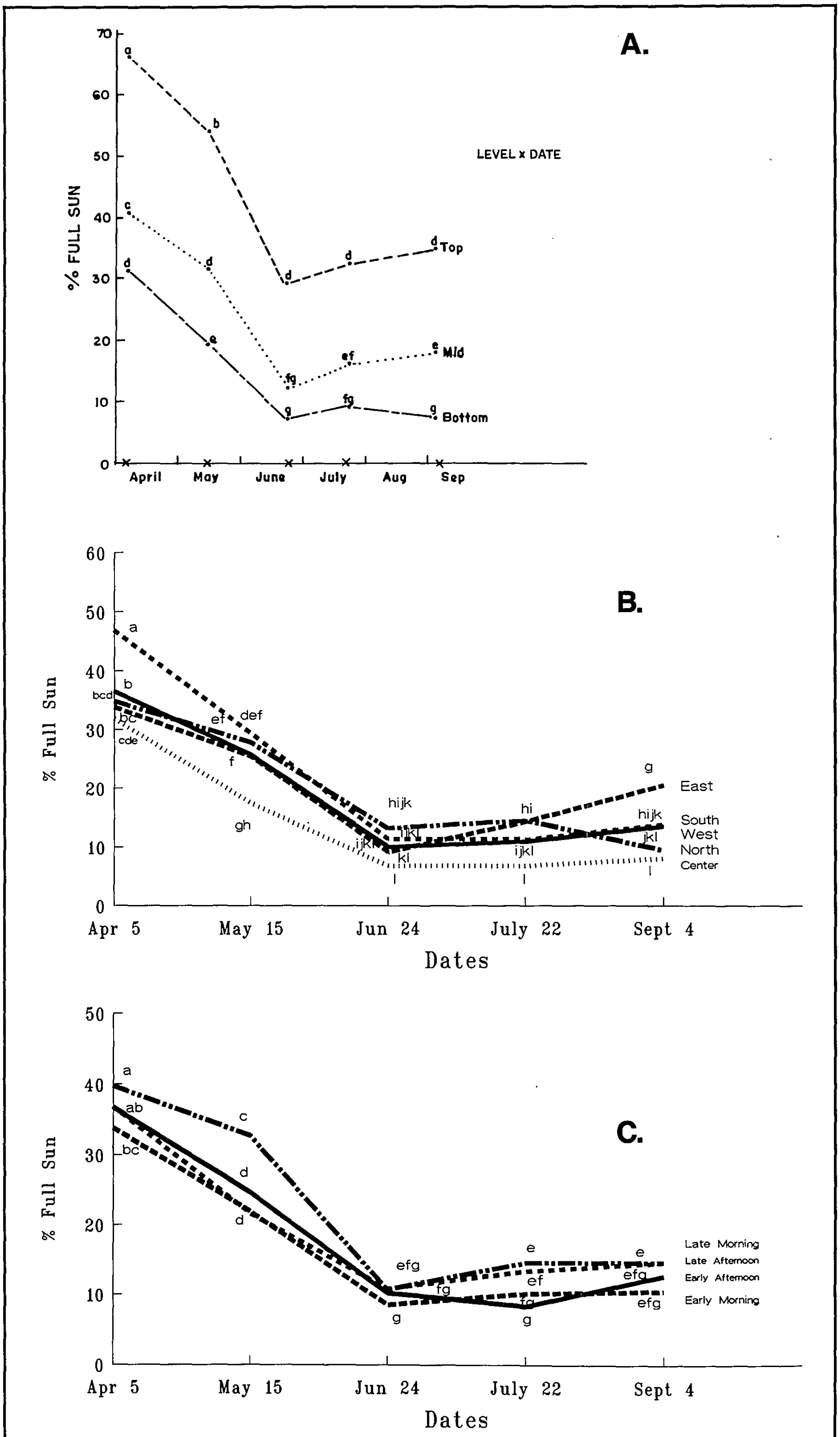

Figure 4. Influence of canopy height (a), position (b), and time of day (c), on photosynthetic photon flux transmission (% full sun) in canopies of 'Golden Delicious' apple trees trained as central leaders.

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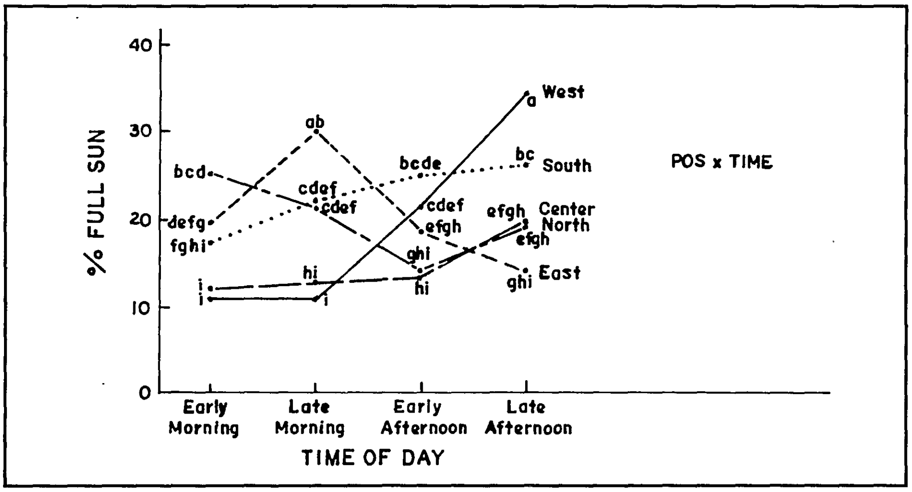

Figure 5. Interaction of canopy position and time of day on photosynthetic photon flux transmission (% full sun) in canopies of 'Golden Delicious' apple trees trained as central leaders.

Table 6. Influence of canopy position, time of day and season on light quality in the lower canopy of central leader 'Golden Delicious' apple trees ($\mu mol.s^{-1}.m^{-2}$).

Position	Waveband (nm) 430-480	600-650	650-690	690-730	400-00	R/FR
East	4.3	6.1	5.0	5.8	27.1	.47
West	5.4	7.2	6.0	6.6	33.4	.52
Time						
A.M.	4.3	6.1	5.1	5.7	27.1	.47
P.M.	5.4	7.3	6.0	6.7	33.3	.52
Date						
5/4	8.2b[1]	11.7b	9.6b	11.2a	51.9b	.58b
5/14	2.8c	4.1c	3.4c	4.2b	18.6c	.56b
6/24	1.8c	2.5c	2.0c	2.5b	11.4c	.28c
7/22	1.2c	1.4c	1.1c	1.6b	7.2c	.34c
8/6	12.3a	16.4a	13.8a	13.6a	75.0a	.87a
9/4	2.7c	3.9c	3.2c	3.9b	17.4c	.35c
F-Significance						
Position (P)	NS	NS	NS	NS	NS	NS
Time (T)	NS	NS	NS	NS	NS	NS
P x T	**	**	**	**	**	**
Date (D)	**	**	**	**	**	**
D x P	NS	NS	NS	NS	NS	NS
D x T	NS	NS	NS	NS	NS	NS
D x T x P	**	**	**	**	**	**

[1]Mean separation by Duncan's Multiple Range Test, P=0.5.
Number of observations in each mean are as follows: Position, time, date.
NC,*,** Non-significant or significant P x 0.05 or 0.01, respectively.

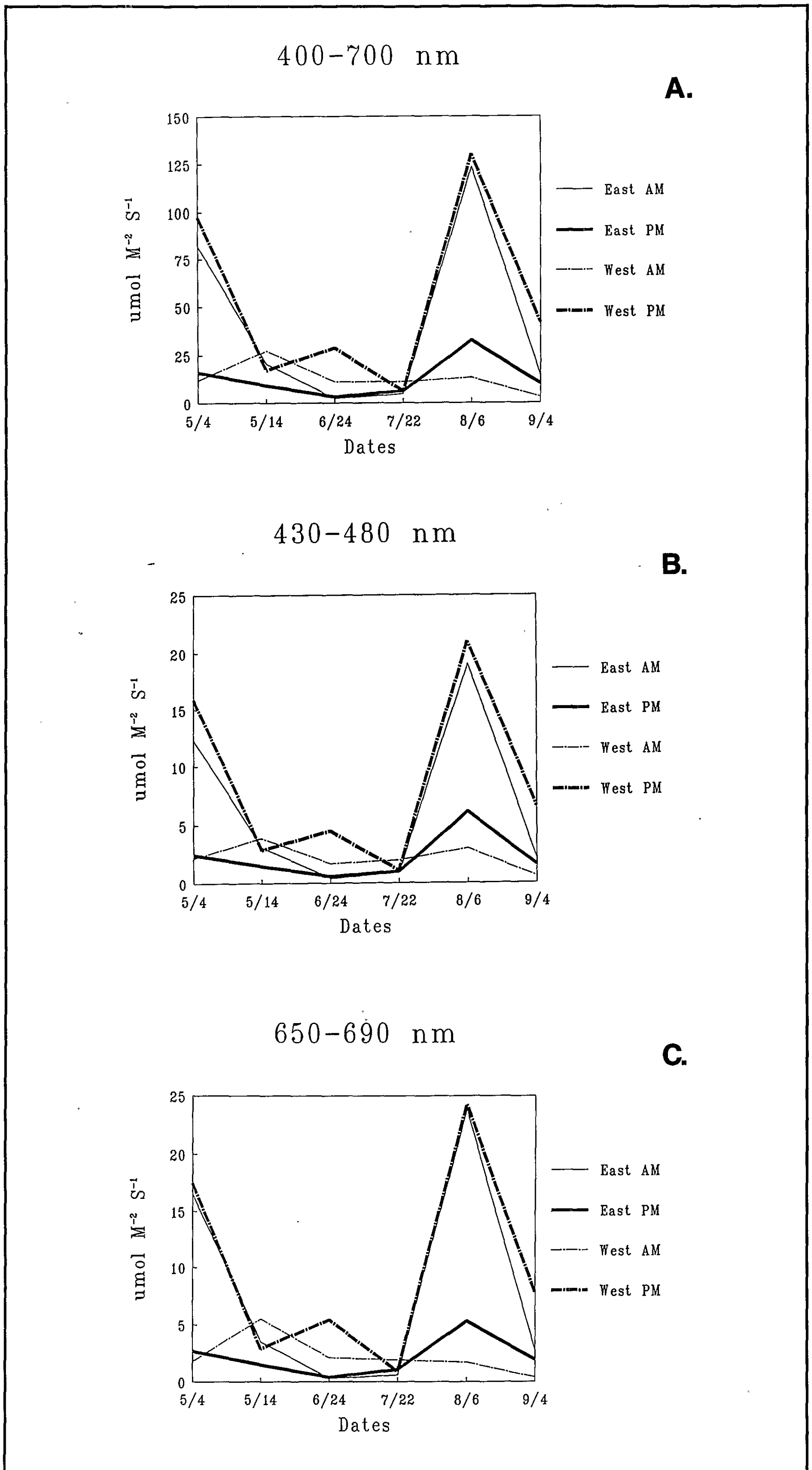

Figure 6. Influence of time of day over the season of photosynthetic active radiation in the 400-700 nm waveband (a), in the 430-480 nm blue band, (b), and 650-690 nm red band (c), in canopies of 'Golden Delicious' apple trees trained as central leaders.

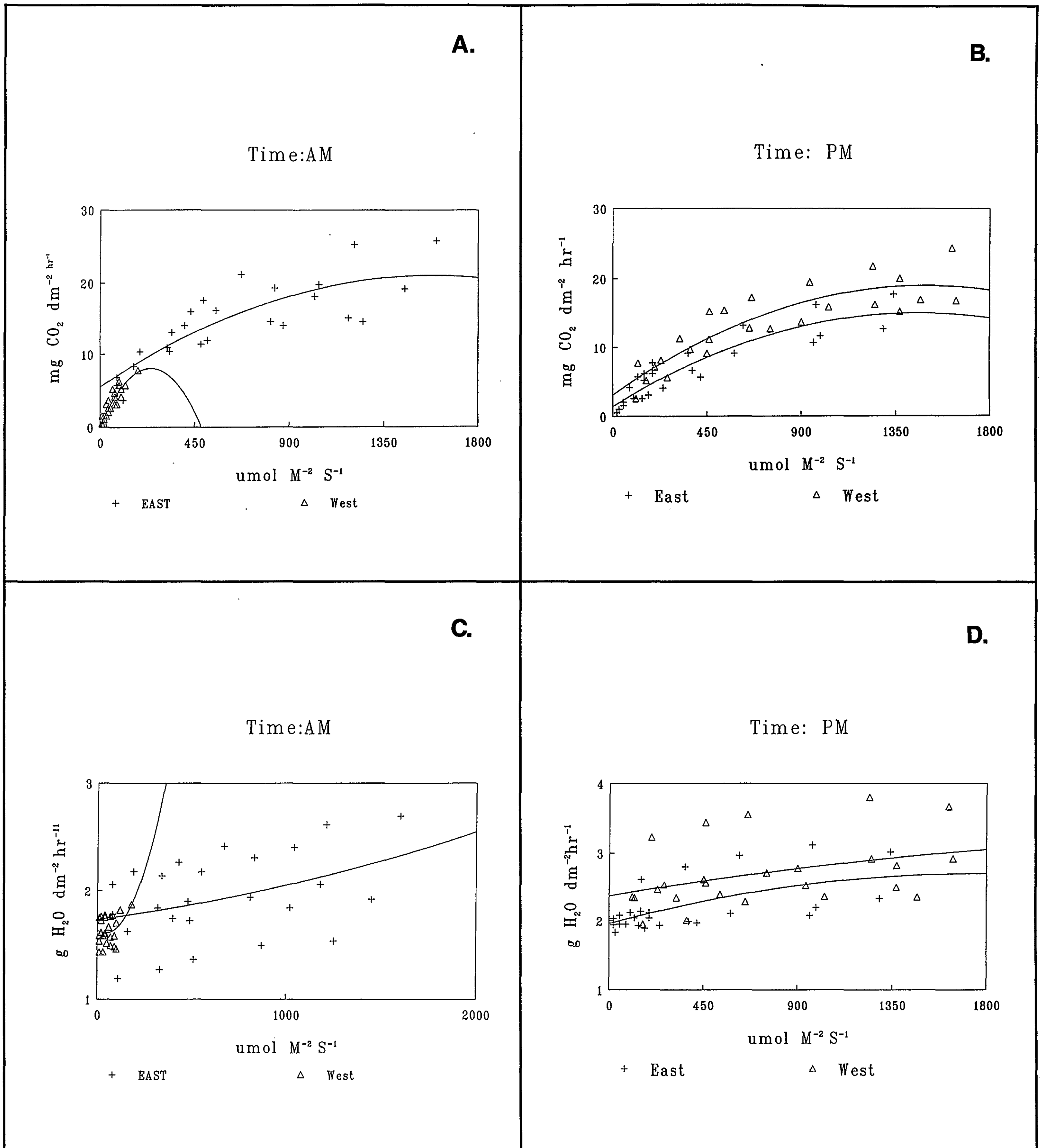

Figure 7. Influence of a series of decreases in light on the east or west side of the canopy of 'Golden Delicious' apple trees on net photosynthesis in the morning (a) or afternoon (b) and transpiration in the morning (c) or afternoon (d).

Effect of Root Pruning on Shoot Tip Ethylene Production and Xylem Concentrations of Cytokinin and 1-Aminocyclopropane-1-Carboxylic Acid in Young Apple Trees

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Introduction

Root pruning reduces growth of young apple trees and, under greenhouse conditions, the growth reduction lasts 4-6 weeks (11,23). The physiological mechanisms by which root pruning reduces plant growth are not fully understood. Roots are important for water and nutrient uptake, and for the biosynthesis and transport of plant growth substances (5,14,27). Thus, interference with one or more of these functions may explain the reduction of plant growth that results from root pruning.

Root pruning had little effect on (21,23,25) or increased (20) leaf mineral nutrient concentration. Thus, present evidence does not support the hypothesis that root pruning reduces vegetative growth of fruit trees through limiting mineral nutrient uptake, while a number of studies have shown root pruning causes water deficits (11,20,22,23).

Ethylene levels of shoots increase as a result of water stress (1,3) and may, therefore, be implicated in growth reductions caused by root pruning. Waterlogging tomato root systems increased concentration of 1-aminocyclopropane-1-carboxylic acid (ACC) in xylem sap and led to increased ethylene production and reduced growth in the shoot (5). The effect of root pruning on ACC and ethylene levels has not been investigated.

Root pruning reduced cytokinin levels in the tissues of herbaceous annual plants (8,24). Conversely, Carlson and Larson (7) found increased cytokinin activity in the xylem sap of red oak seedlings after removal of all the root tips. The root system is an important source of cytokinins for the whole plant (26) and a cytokinin-like substance with similar properties to trans-zeatin riboside has been reported in apple xylem sap (2,6,27) and tissues (16). The influence of root pruning on cytokinin levels of apple is not known.

The objectives of this study were to determine the effect of root pruning on water relations, ethylene levels, and concentration of ACC and cytokinins in xylem sap of young apple trees, during the 4 to 6 weeks that growth was reduced by such treatment.

Materials and Methods

In May 1987, two rooted layers of MM.106 apple rootstocks were planted in 30 cm x 30 cm x 30 cm wooden containers in a medium of 1:2:1 (vol), soil:perlite:peat, and placed in the greenhouse. Trees were pruned to 4 cm above the soil line and trained to a single shoot. When shoot length averaged 100 cm, 48 containers were selected for uniform growth of both trees, and half were root pruned by making a vertical cut with a metal blade at a distance of 5 cm from the stem on 2 sides of the trees.

Four replicates (8 trees of each treatment) were collected at 1100 h on: 1, 3, 9, 17, 23, and 31 days after treatment for the following analyses.

Shoot length of all trees was measured just prior to root pruning and at each collection time, except 1 day after pruning. Following measurement of water relations and ethylene, root systems were gently washed free of medium with a low pressure water stream and root fresh weight was determined.

Transpiration and stomatal conductance of the 3rd, 4th and 5th most distal fully expanded leaves of each tree were measured with a Licor LI-1600 steady state porometer, and leaf water potential was measured with a PMS Instruments pressure bomb.

The distal 5 cm of each terminal shoot was removed and weighed, then both shoot tips from each container were sealed in a 1-liter screw-capped canning jar fitted with a serum stopper. After 3 hours, ethylene production was determined by removing 2 ml of air from each container and injecting this into a Hewlett-Packard 5890A Gas Chromatograph equipped with a flame ionization detector and a 2.4 m x 2 mm (i.d.) glass column packed with 100/200 mesh PoraPak N (Alltech).

Xylem sap was extruded from the proximal 100 cm segments of shoots by means of the vacuum extrusion technique described by Bollard (4).

Each shoot yielded, on average, 4.5 ml of sap (20 percent of the total moisture of the shoot segment). No variation in extractable xylem sap volume was attributable to root pruning or harvest date. The sap was collected into polypropylene cryotubes, frozen in liquid nitrogen, and stored at −20°C prior to analysis. 1-aminocyclopropane-1-carboxylic acid (ACC) levels in xylem sap were determined by a method (18) modified from that of Lizada and Yang (17). The efficiency of ACC oxidation to ethylene, which averaged 84 percent, was estimated by analyzing replicate samples containing internal standards of ACC.

Cytokinin levels in xylem sap were determined by an enzyme-linked immunosorbent assay, using the trans-zeatin riboside (t-ZR) kit prepared by Idetek, Inc. Triplicate 100 ul samples of sap or standard were analyzed with a Bio-Tek, Inc., EL310 vertical path photometer. Prepurified samples prepared on an octadecyl silica cartridge (Sep-pak) had a 7-percent loss in cross-reactivity compared to unprepared samples, and similarly, octadecyl silica preparation of a trans-zeatin riboside standard (Sigma) resulted in a 10-percent loss of cross-reactivity. Unpurified xylem sap spiked with 2 and 10 pmol/ml internal standards showed no loss of cross-reactivity, thus it was determined that sap could be analyzed without purification.

Cross-reactivity of a number of other cytokinins, non-cytokinin adenine analogs, amino acids and other plant growth substances were tested and results compared to a list of cross-reactants provided with the kit.

To fractionate xylem sap further, a 30 ml composite sample of sap was collected on an octadecyl silica Sep-pak cartridge, washed with 40 mM ammonium acetate buffer (pH 6.5), and eluted with 1.5 ml methanol. One hundred ul of eluate was injected into an HPLC (LC/9533), equipped with 4.5 x 250 mm octadecyl silica column 5 u particle size (IBM Instruments). The column was eluted at a flow rate of 1 ml/min using a linear 15 to 100 percent methanol gradient. One ml fractions were collected, taken to dryness *in vacuo* and redissolved in 25 mM tris-saline buffer (pH 7.5). Cytokinin activity of the fractions was then determined by immunoassay.

Results

The root pruning treatment removed 35 percent of the root fresh weight. Root pruning reduced shoot elongation and root fresh weight for 23 days, but growth had recovered to levels similar to the controls after 31 days (data not presented). Root regeneration was first observed after 9 days.

Leaf water potential was reduced by root pruning for 17 days, during which time stomatal conductance and transpiration were lower in root pruned trees (Table 1). Previous research (11,20) has shown root pruning reduces size of the root system and that plant water uptake was reduced until root volume regenerates. Consequently, root pruning induced growth reductions are partially explained by the increased water deficit. Reductions in vegetative growth in response to water deficits reduce the number and size of leaves and so reduce the transpirational demand for water (9,15,23).

Root pruning reduced the level of ethylene produced by the shoot tip compared to that of the controls at 3, 9 and 17 days after treatment (Table 2). This finding is in contrast with the expected results, as water stress increased ethylene production in wheat (1) and citrus (3). Hoffman *et al.* (13) found similar decrease in ethylene production in water-stressed wheat leaves and a concomitant increase in

Table 1. Effect of root pruning on leaf water potential, stomatal conductance, and transpiration of greenhouse grown MM.106 apple trees.

Treatment	Days after treatment 1	3	9	17	23	31
	Water potential (-MPa)					
Control	1.1b[1]	1.2b	0.8b	1.0b	1.0	1.2
Root pruned	1.9a	1.6a	1.3a	1.3a	1.2	1.2
	Stomatal conductance (cm sec^{-1})					
Control	0.82a	0.83a	0.71a	0.59a	0.83	0.79
Root pruned	0.27b	0.19b	0.29b	0.41b	0.70	0.72
	Transpiration (ug H_20 cm^{-2} sec^{-1})					
Control	8.5a	8.9a	8.4a	8.8a	8.8	8.6
Root pruned	3.8b	2.6b	4.7b	7.3b	8.5	8.5

[1]Mean separation within a column by F-test, P=.05.

their level of 1-(malonylamino) cyclopropane-1-carboxylic acid (MACC) content. The metabolism of ACC to MACC is essentially irreversible, so this pathway represents a method by which the plant can regulate ethylene in its tissues (13). These results suggest that this control mechanism may be in place in apple, but further research is needed to confirm this hypothesis.

The concentration of ACC in xylem sap averaged 220 pMol/ml. Bradford and Yang (5) found increased ACC in xylem sap of waterlogged tomato plants, but in our study root pruning did not produce a similar rise in ACC levels in xylem sap of apple trees. No role for ethylene in the response of young apple trees to root pruning can be determined from this experiment.

None of the non-cytokinin substances cross-reacted with the t-ZR antibody in the Idetek immunoassay kit. However, isopentenyladenosine (IPA) yielded 100 percent cross-reactivity in competition with an equimolar concentration of labeled t-ZR (Table 3). This finding is in contrast with the level of cross-reactivity reported by Idetek Inc. and confirms a previous finding (R.O. Morris, personal communication). In consideration of these findings, cross-reactivity of plant extracts in this assay should be referred to simply as cytokinin.

Root pruning reduced cytokinin levels in xylem sap at 1, 3 and 9 days after pruning (Table 4). This is in agreement with previous findings in studies with herbaceous annual plants (8,10,24). It also supports the hypothesis of a hormonal basis for shoot growth regulation by the root.

Cytokinin levels would be expected to increase with regeneration of the root system (10), as was the case between days 3 and 9 in the present study, the period in which first root primordia became visible and in which cytokinin concentration in xylem sap nearly doubled (Table 4).

Cytokinin activity was found in four

Table 2. Effect of root pruning on shoot tip ethylene production of greenhouse grown MM.106 apple trees.

	Days after treatment					
Treatment	1	3	9	17	23	31
	Ethylene (pmol/g fresh weight/hr)					
Control	45	58a1	38a	53a	72	50
Root pruned	39	30b	18b	23b	44	50

[1]Mean separation within a column by F-test, P=.05.

Table 3. Cross-reactivity of a number of substances with the Idetek trans-Zeatin Riboside Immunoassay kit.

Cross-reactivity cytokinin	%	Cross-reactivity reactivity compounds and amino acids	%	Cross Non-cytolinin adenine Substances	%
Dihydrozeatin	2.2[1]	Adenine	<1	Abscisic Acid	<1
6-Benzyladenine	2.0	Adenosine	<1	1-Aminocyclopropane-	<1
6-Benzyladenine	5.0	Adenosine Triphosphate	<1	1-carboxylic acid	<1
Riboside		Asparagine	<1	Gibberellin 3	<1
trans-Zeatin	100	8-Azaadenine	<1	Gibberellin 4+7	<1
trans-Zeatin Riboside	100	Cyclic Adenosine-	<1	Indoleacetic Acid	<1
Cis-Zeatin	2.2	monophosphate	<1	Indolebutyric Acid	<1
Isopentenyladenosine	100	Glutamine	<1		
Kinetin	<1	Guanine	<1		
Kinetin Riboside	<1	6-Methylpurine	<1		
		Nicotinamide	<1		
		Dinucleotide	<1		
		Urea	<1		
		Uridine	<1		

[1]Cross-reactivities determined from labeled trans-Zeatin Riboside displacement at equimolar concentrations of 100 Pmol ml-1.

HPLC fractions of the xylem sap. Sixty-six percent of the cross-reactivity co-eluted with t-ZR, 19 percent with trans-Zeatin, 5 percent with IPA and the remaining 10 percent eluted with 80 percent methanol, 2 ml after IPA. These findings are similar to those of Morris *et al.* (19), who found 5 cytokinin-like fractions in Douglas fir xylem sap. Further research is needed to confirm the identity of each of the fractions, to determine if each occurs *in vivo*, and to determine the changes in cytokinin synthesis or metabolism that result in decreased cytokinin levels in xylem of root-pruned trees.

Root pruning non-selectively removes a large portion of the root system, which causes water deficits lasting until the root system regenerates sufficiently to meet transpirational demand. During the interim, the plant reduces water use by stomatal closure and minimizes transpirational surface through reduced growth. The role of ethylene mediating the response of young apple trees to root pruning is unclear. However, cytokinin levels in xylem sap are reduced, suggesting that reduced cytokinins from the root may play a role in altering behavior of root pruned apple trees; *eg.*, flowering (21), preharvest drop (21), and perhaps growth previously reported (11,21,22,23).

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Table 4. Effect of root pruning on cytokinin levels in the xylem sap of greenhouse-grown MM.106 apple trees.

	Days after treatment					
Treatment	1	3	9	17	23	31
	Cytokinin (pmol/ml)					
Control	5.5a	4.0a	5.5a	5.8	4.4	3.8
Root pruned	2.7b	1.6b	3.0b	4.2	3.1	3.3

[1]Mean separation within a column by F-test, P=.05

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Rootstock Effects on Spur Characteristics, Spur Leaf Nitrogen Content and Early Production of Apple Trees

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Introduction

High costs and changing market conditions are forcing fruit producers to improve production efficiency and fruit quality to remain competitive. Orchard intensification utilizing trees on dwarfing rootstocks is the approach most often taken to achieve these goals. A recent study showed that rootstocks can increase tree production efficiency of 'Starkspur Supreme Delicious' apple trees by 65 percent (26).

Spur characteristics have an important influence on fruit quality and tree performance (3,19). The total spur leaf area or average leaf size appears to be related to tree productivity, efficiency and yield variations (20). Reduction of spur leaf area decreased yield 30-80 percent (8). Conversely, increased leaf area and large spur buds were associated with improved fruit set, fruit size and fruit Ca level at harvest (8). In recent work, Voltz (24) reported that spur leaf area was 20 times more efficient in increasing fruit Ca than bourse leaf area. DeJong (7) found a high linear correlation between photosynthetic capacity and N-content per leaf area of peach leaves (r^2=.91). Ferree and Forshey (9) reported a positive relationship between various spur quality parameters in mature 'Starkrimson' apple trees and level of nitrogen per unit leaf area.

The variable effects of apple rootstocks on scion trunk cross-sectional area (TCA), yield and yield efficiency have been reported (4,6,11,12,16,21,22, 27), but few data are available on rootstock influences on leaf number per spur, leaf area per spur, average leaf size, specific leaf weight (SLW), and bud diameter (21,25). The objective of this study was to investigate tree performance and vigor indices of new apple rootstocks and determine their influence on spur characteristics.

Materials and Methods

The investigation was divided into the following 3 studies involving separate orchards.

Study 1: NC-140 Orchard at Wooster. 'Starkspur Supreme Delicious' budded on 18 rootstocks were planted in 1984 at a spacing of 3.5 m x 5.5 m in a randomized block design.

Study 2: Vigorous Orchard at the Southern Branch of OARDC, Ripley, Ohio. Ohio trees of 'Macspur' budded on 20 rootstocks were planted in 1986 at a spacing of 2.75 m x 5.5 m in a randomized block design.

Study 3: Dwarfing Orchard at Ripley. Trees of 'Macspur' and 'Redchief' budded on 21 and 17 rootstocks, respectively, were planted in 1986 at a spacing of 1.80 m x 4.80 m in a randomized block design.

Trees in Study 1 and Study 2 were free-standing orchards, while trees in Study 3 were supported on a two-wire trellis. All trees were in north-south rows and trained as central leaders with minimal pruning and received pesticides and nitrogen fertilizer as needed. In each of the orchards, samples of 5 non-fruiting spurs (5 cm or less) per tree were cut from the 2-year-old section of 5 branches in the well-exposed area of the canopy. The samples were collected in mid-August from 5 replicate trees in each orchard.

The following measurements were recorded for each spur: leaf number and leaf area (Portable Area Meter—Model Li-Cor 3000, Lambda T.C.) and terminal bud diameter. The leaves were dried in a forced-air dryer at 60°C until their weight stabilized and the dry weight determined. The average leaf size (leaf area/spur ÷ leaf number/spur) and the specific leaf weight (dry weight ÷ total leaf area) were calculated. For the total N analysis by the Kjeldahl method, the dry leaves were ground with an Oster coffee mill and nitrogen content expressed as the weight of nitrogen per cm^2 leaf area. Yield per tree, cumulative yield and trunk cross-sectional area were recorded annually.

Results

Rootstocks did not influence leaf area/spur in any study, while specific leaf weight and nitrogen per unit leaf area were influenced in all studies (Table 1). Leaf number per spur was influenced by rootstock on 'Macspur', but not on the 'Delicious' strains.

Table 1. F-significance of rootstocks on spur quality, tree size and yield in three trials.

Variables	Study 1 Wooster NC-140 'Starkspur'	Ripley Study 2 vigorous 'Macspur'	Ripley Study 3 Dwarfing 'Redchief'	Ripley Study 3 Dwarfing 'Macspur'
Leaf no./spur	NS	X	NS	XXX
Leaf area/spur (cm²)	NS	NS	NS	NS
Leaf area/leaf (cm²)	NS	XXX	X	NS
Specific leaf weight (mg cm²)	XX	XXX	XXX	XX
Bud diameter (mm)	X	XXX	XX	NS
N-content (mg cm²)	XXX	XXX	XXX	X
TCA (cm²)	XXX	XXX	XXX	XXX
Cumulative yield (lbs.)	—	XXX	XXX	XXX
Yield efficiency (lbs cm²)	—	XXX	XXX	XXX

X,XX,XXX Significant at P=0.05, 0.01 or 0.001, respectively.
NS=not significant.

Average leaf size was only influenced on vigorous rootstocks on 'Macspur' (Study 2). Rootstock greatly influenced TCSA, cumulative yield and yield efficiency in all studies. In each study only the data where significant differences occurred are presented.

Study 1: Early yield performance and tree size for the 1984 NC-140 trial have been published (14), but the 1990 data are presented here as a reference for tree size relative to the spur quality measurements (Table 2). Rootstocks producing vigorous or semi-dwarf trees did not differ in SLW or bud diameter. However, nitrogen content was less in spur leaves of P.18 than in vigorous CG.24 and MAC.1 or semidwarf M.7EMLA and P.1. Of the trees in the dwarf size class, trees on C6 and B.9 tended to have heavy SLWs, while leaves on MAC.39 were lighter. Spur bud diameter on B.9 was smaller than on any of the rootstocks in the dwarf class. Nitrogen per unit leaf area tended to be higher in trees in the dwarf class ($\bar{X}$=1.43) than in the vigorous trees ($\bar{X}$=1.74) with the highest level on CG.10 and lowest level in leaves from trees on MAC.39. Differences in spur quality characteristics were small on trees in the very dwarf size class.

Study 2—Ripley Vigorous 'McSpur McIntosh': Trees on MAC.24 were the largest trees in this study and were 49 percent larger than trees on M.7A and 22 percent larger than trees on seedling rootstock (Fig. 1a). Cumulative yield efficiency (yield/TCA) was highest on the very dwarf trees on P.16 (Fig. 1b). However, trees of M.7A, MM.106, MM.106EMLA had relatively high yield efficiencies of the semidwarf trees and trees on Ant.306, Seedling, MAC.1 and MAC.24 had low efficiencies. The correlation of cumulative yield efficiency and trunk area over 5 years was highly negative (r=−0.71).

Of the trees larger than MM. 111EMLA, the average leaf size was small on MAC.24 and Seedling, while leaf number on spurs of MM.104 EMLA and M.2EMLA tended to be large (Table 3). Trees on MM.106 EMLA were similar in size to trees on MM.106 and had significantly larger spur leaf size but did not differ in other spur quality characteristics. Spurs from trees on the virus-free M.7EMLA compared to M.7A had similar leaf size, spur diameters and N content, but had significantly lower SLW. Of the rootstocks producing smaller trees, the SLW of spur leaves on M.7A were higher than any of the others and trees on M.7A also had a relatively large bud diameter and high N content. Trees on P.18 and MAC.1 had low N-content in spur leaves compared to MM.104EMLA, MM. 106EMLA, M.7EMLA, M.7A and P.16.

Study 3—Ripley Dwarfing 'Redchief Delicious': Trees on MAC.46, MAC.10 and V.4 tended to be the largest in this planting and have the lowest yield efficiency (Fig. 2). Mark, P.2 and P.22 tended to be smallest and along with V.1, V.2, V.7 and M.26EMLA had high yield efficiency.

Table 2. Influence in 1990 of rootstock on tree size, yield, specific leaf weight (SLW), spur bud diameter and nitrogen content per unit spur leaf area of 'Starkspur Supreme Delicious' in the NC-140 trial at Wooster established in 1984 (Study 1).

Rootstock	TCA (cm^2)	Size relation to seedling (TCA) (%)	Yield/ tree (Kg)	Yield efficiency (Kg/cm^2)	Spur quality SLW/ (mg/cm^2)	Spur quality Bud diameter (mm)	Spur quality N-content (mg/cm^2)
Vigorous							
Seedling	113.1a	100	71.1ab	.63def	10.61	3.73	2.67
Ant. 313	102.7ab	91	40.6cde	.39ef	10.56	3.54	2.67
P.18	106.6b	89	54.5abcd	.52ef	10.20	3.67	2.53
B.490	92.7bc	82	29.2def	.32f	10.64	3.79	2.70
CG.24	90.5bc	80	47.5bcde	.53ef	10.49	3.62	2.79
MAC.1	89.9bc	79	58.4abc	.65def	10.68	3.62	2.76
Semi-dwarf							
M.4	80.4cd	71	32.2cdef	.39ef	10.65	3.73	2.62
M.7EMLA	73.3d	65	29.5def	.39ef	11.28	3.70	2.81
P.1	71.0d	63	49.3	.72de	11.26	3.81	2.85
Dwarf							
M.26EMLA	57.0e	50	76.7a	1.35ab	10.87	3.66	2.90
C6	55.3e	49	57.6abcd	1.00bcd	11.52	3.81	2.95
MAC.39	38.5f	34	57.6abcd	1.46a	10.29	3.47	2.59
B.9	35.3f	31	30.2cdef	.93cd	11.25	2.78	2.82
CG.10	27.9fg	24	38.1cde	1.36ab	10.87	3.54	3.06
Very dwarf							
P.2	20.7gh	18	30.7cdef	1.16abc	10.57	3.43	2.70
P.16	12.9h	11	20.5ef	1.26abc	10.79	3.38	2.84
B.491	12.4h	11	11.2f	.90cd	10.96	3.46	2.96
P.22	10.9h	10	9.8f	.90cd	10.56	3.33	2.76
LSD<.05					.61	.28	.17
Mean					10.78	3.62	2.78

[1]Means with letters separated by Duncan's Multiple Range Test, P=.05.

Spurs from 'Redchief' trees on M.26EMLA had larger leaf sizes than any other rootstock except V.1 and V.7 (Table 4). Trees on Mark and MAC.9 had higher SLW than spurs from trees on M.9EMLA, MAC.39, V.7, and V.4. There appeared to be a trend for increasing bud diameter with decreasing tree size.

Trees of M.26EMLA and those smaller in size tended to have large bud diameters (r=.84) and higher leaf N-contents (r=−.68) than some of the larger trees, but the differences were not always significant.

Since 21 rootstocks were involved in the 'MacSpur McIntosh' part of Study 3, they were divided into size classes to ease discussion of the results (Table 5). Trees on MAC.46 were 31 percent larger than trees on M.7EMLA and thus would be nearly standard size trees. Although similar in size to M.7EMLA, trees on V.7, V.4, V.2 and P.1 had higher yields, and the latter three stocks had a higher yield efficiency.

OAR1 is known to be non-precocious with low yields (15) and had the same tendency in this trial. V.4 was precocious with a good yield efficiency and had a higher SLW than V.2, OAR1, V.7 and MAC.10. The N-content of spur leaves did not differ among the rootstocks classified as semi-dwarf.

In the dwarf classification, C.6 and M.9EMLA had the highest yields/tree and tended to have high-quality spurs.

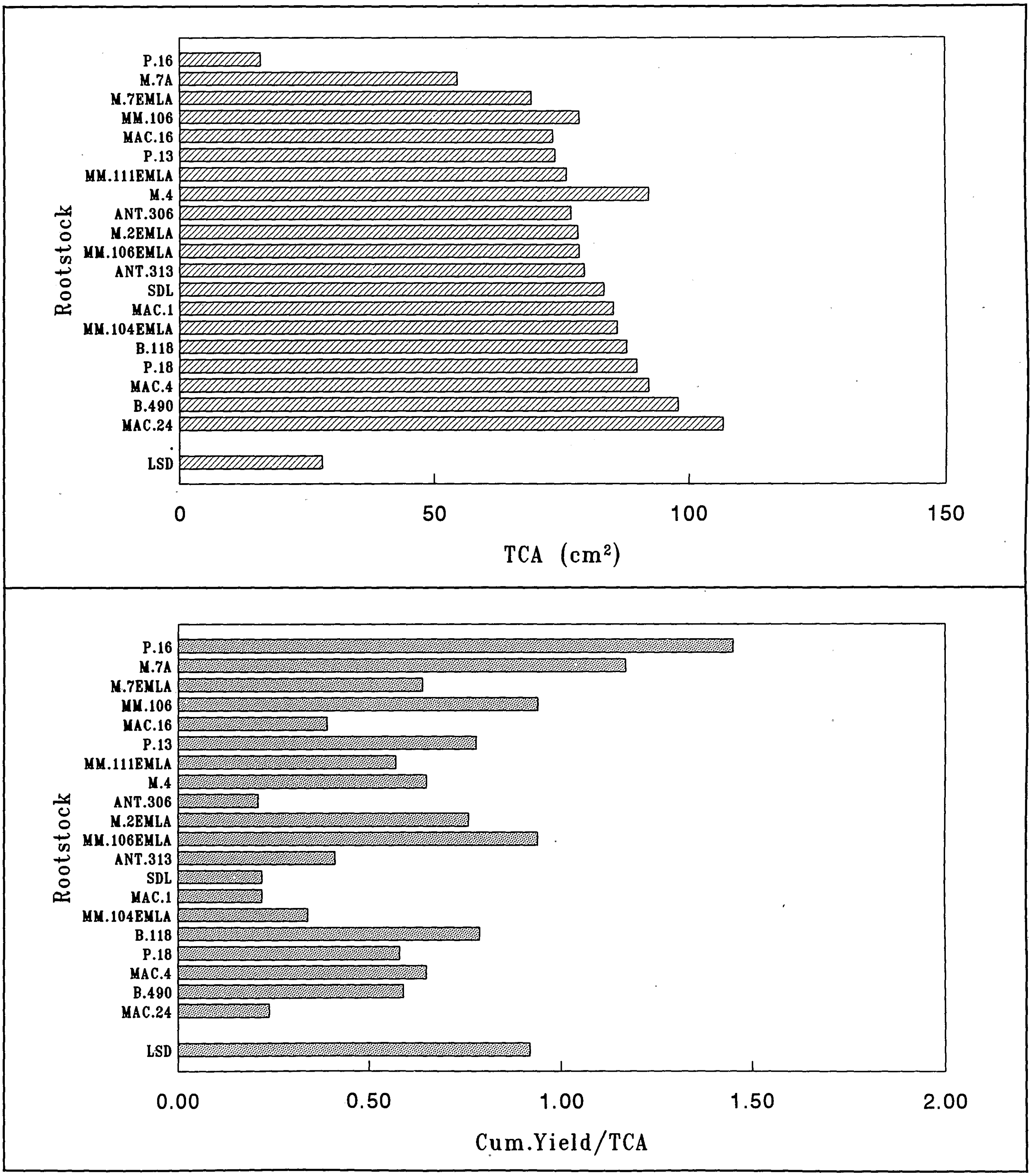

Figure 1. Trunk cross-sectional area (a) and early efficiency as measured by cumulative yield/TCA (b) of five-year-old 'Macspur McIntosh' apple trees on a range of vigorous rootstocks.

V.3 had a higher yield efficiency than all the rootstocks in this size class except B.9 and MAC.39 and spur quality ranked high, particularly the N-content. Of the rootstocks in this size class, P.2 tended to rank low in all the spur quality characteristics.

In the very dwarf size class, M.27EMLA had high yields/tree and yield efficiency and a higher SLW than any of the other rootstocks in this size class. However, there was no difference in the leaf area/spur and N-content.

Specific leaf weight was positively correlated with bud diameter in all studies (Table 6). The positive correlation between SLW and spur leaf N content and yield efficiency was significant in all studies. Trunk cross-sectional area of 'Macspur' trees was negatively correlated with bud diameter, SLW and spur leaf N-content, while this relationship was not present with 'Redchief'. Cumulative yield efficiency was positively correlated with bud diameter and SLW. There was a significant negative correlation between TCA and cumulative yield efficiency of these young trees, indicating that trees on more dwarfing rootstocks had greater yield efficiency than on rootstocks that produced larger trees.

Table 3. Influence of 20 rootstocks on spur leaf number, average leaf size, SLW and bud diameter and leaf N-content of 'Macspur' in the vigorous rootstock trial at Ripley (Study 2).

Rootstock	Leaf no./ spur	Leaf area/ leaf (cm^2)	SLW (mg cm^2)	Bud diameter (mm)	N-content (mg/cm^2)
MAC.24	23.4	6.70	9.74	3.19	2.07
Bud.490	23.1	7.06	9.64	3.10	2.03
MAC.4	24.2	7.36	10.23	3.17	2.01
P.18	24.6	7.57	9.86	3.13	1.96
Bud.118	24.4	7.09	10.03	3.21	2.01
MM.104EMLA	23.3	7.79	11.49	3.43	2.24
MAC.1	24.8	7.25	9.49	3.07	1.96
SDL	24.6	6.78	9.95	3.08	2.12
Ant.313	23.9	7.01	10.07	3.30	2.12
MM.106EMLA	24.3	7.56	10.78	3.20	2.26
M.2EMLA	24.5	7.74	10.02	3.36	2.12
Ant.306	23.1	7.22	10.14	3.12	2.10
M.4	22.3	7.52	10.29	3.26	2.08
MM.111EMLA	24.4	6.98	10.18	3.40	2.15
P.13	23.7	7.97	10.06	3.17	2.03
MAC.16	25.1	7.51	10.06	3.31	2.13
MM.106	23.9	6.58	10.07	3.16	2.10
M.7EMLA	23.7	6.97	10.78	3.20	2.26
M.7a	22.5	7.35	12.67	3.41	2.43
P.16	22.1	9.07	11.72	3.58	2.39
LSD P= <0.05	1.6	0.90	0.88	0.22	0.21
Mean	23.8	7.35	10.37	3.23	2.13

At leaf number per spur a square transformation was required for analysis; true mean presented. Rootstock in order of decreasing tree size.

In the present study and past research reports (14,15), trees on MAC.24, MAC.1, and Seedling had low production efficiencies and often had low spur quality characteristics. Rom and Ferree (20) found a close association of long-term yield of 9 cultivars and spur quality. Previous work (21,25) evaluating the influence of 9 rootstocks on 'Starkspur Supreme Delicious' in the NC-140 trial demonstrated that rootstocks influenced spur quality. Other factors such as cultivar, strain, light conditions and soil type also influence spur quality (5,18,20,25). Some of the variability between studies in this trial was likely due to cultivar and strain differences. For example, TCA and SLW were highly positively correlated in the two 'Macspur' trials, but not in the trial with 'Redchief.' All the spur quality characteristics were positively correlated with tree size (TCA) when 'Macspur McIntosh' was the scion cultivar, but the relationship was not present with spur 'Delicious' (14,15).

Rom *et al.* (21) reported no influence of rootstock on spur leaf N level on a dry weight basis in the NC-140 trial. However, Lord *et al.* (12), West (26), and Autio and Lord (1) reported N levels were influenced by rootstock. Recent studies have shown the high linear relationship between leaf N content on a per unit leaf area basis and CO_2 assimilation of peach (7) and citrus leaves (23). Work with apple (2,9) has shown a similar relationship between N/unit leaf area on photosynthetic rate, light level and SLW. In this study, a high correlation

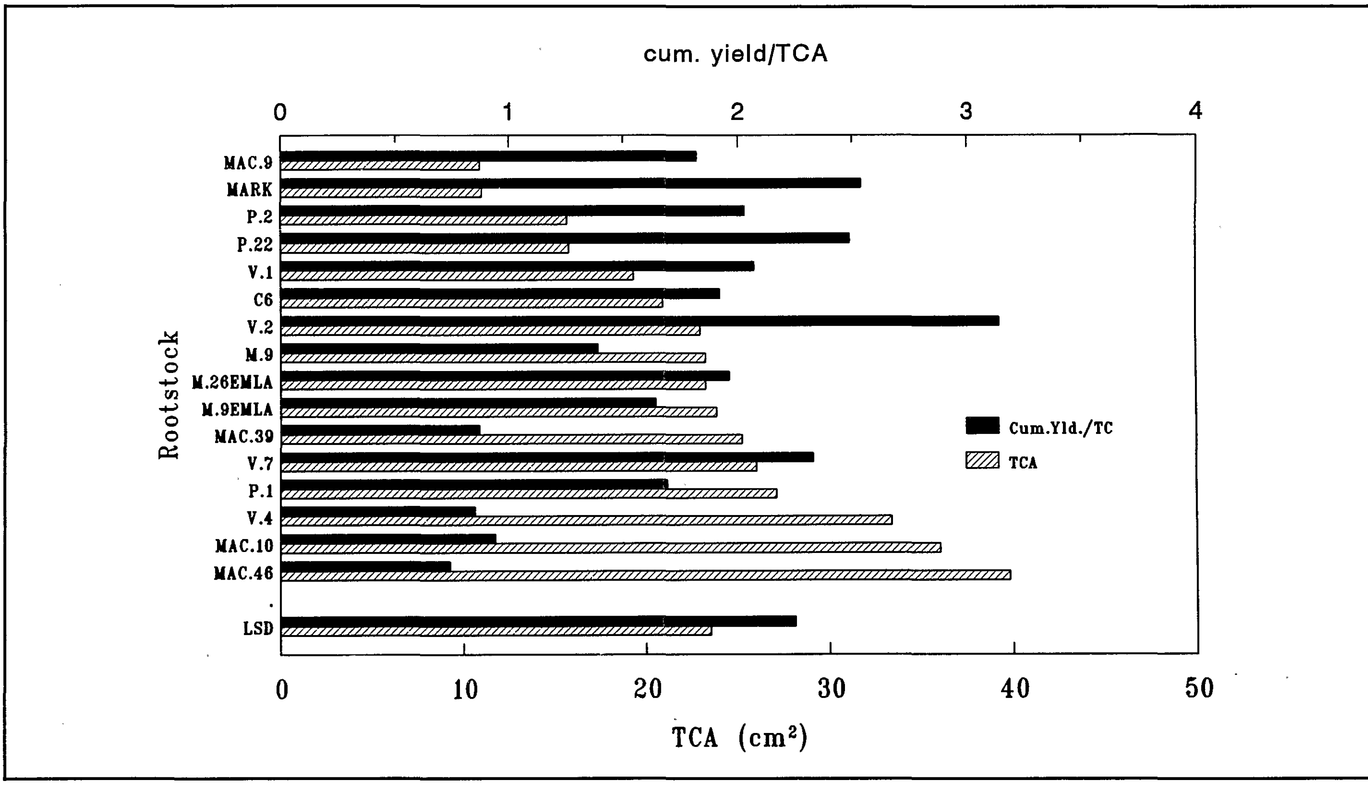

Figure 2. Trunk cross-sectional area (TCA) and early efficiency as measured by cumulative yield/TCA of 'Redchief Delicious' on a range of dwarfing rootstocks.

Table 4. Influence of 16 rootstocks on spur quality and spur leaf N-content of 'Redchief' in a developing rootstock trial at Ripley.

Rootstock	Leaf area/ leaf (cm^2)	SLW (mg/cm^2)	Bud diameter (mm)	N-content (mg/cm^2)
MAC.46	7.31	10.86	3.15	2.34
MAC.10	8.43	10.70	3.21	2.40
V.4	7.76	11.35	3.46	2.33
P.1	7.64	11.76	3.49	2.63
V.7	8.57	11.27	3.40	2.51
MAC.39	7.82	11.12	3.46	2.54
M.9EMLA	7.96	11.11	3.41	2.39
M.26EMLA	9.88	11.98	3.83	2.69
V.1	8.45	11.86	3.60	2.71
P.22	8.24	11.78	3.76	2.66
P.2	7.27	11.77	3.71	2.65
MARK	7.56	12.56	3.68	2.69
MAC.9	6.77	12.55	3.75	2.46
LSD P= <0.05	1.46	0.92	0.34	0.22
Mean	8.03	11.50	3.51	2.54

existed between N/unit leaf area and SLW and there was a consistent influence of rootstock on N/unit leaf area. Barritt and Schonberg (5) have shown that SLW was the spur characteristic with the highest correlation to fruit size and quality characteristics.

The influence of rootstocks in this study on tree size are in general agreement with other reports (4,6,16,17,27). There were no significant size differences between trees of EMLA virus-free status and the older untested or unknown forms of M.7, M.9 and MM.106 rootstocks. To date Mark, the virus-free form of MAC.9, and MAC.9 were nearly identical in tree size, yield, performance and spur quality.

This study confirms that some characteristics of scion spurs can be

Table 5. Influence in 1991 of rootstock on tree size, yield efficiency and spur leaf area, SLW and N-content of 'Macspur McIntosh' planted in 1986 at Ripley (Study 3).

Rootstock	TCA (cm^2)	Cumulative yield (Kg/tree)	Cumulative yield (kg/cm^2)	Leaf area/ spur (cm^2)	SLW (mg/cm^2)	N-content (mg/cm^2)
Semi-dwarf						
MAC.46	86.4	10.3	.14	21.5	11.5	2.38
MAC.10	76.3	4.5	.06	23.3	10.7	2.10
V.7	64.6	23.6	.36	23.3	10.7	1.88
M.7EMLA	60.0	17.4	.29	23.5	11.1	2.07
OAR 1	59.9	1.2	.02	24.1	10.4	2.03
V.4	58.2	28.1	.53	21.9	12.1	2.03
V.2	52.7	22.5	.43	23.1	10.4	1.92
P.1	48.2	22.5	.51	23.9	11.9	2.15
V.1	46.3	18.8	.44	21.6	11.9	2.08
Dwarf						
C6	39.6	24.6	.63	22.3	11.9	2.08
M.9EMLA	38.7	24.1	.60	22.1	11.7	2.04
MAC.39	33.0	17.9	.71	22.8	11.0	1.97
P.2	32.4	18.2	.58	20.7	10.9	1.96
M.9	28.4	17.6	.65	21.8	10.4	1.93
V.3	27.0	21.3	.79	21.3	11.7	2.21
B.9	21.8	16.4	.75	20.3	11.5	2.14
Very dwarf						
M.27EMLA	12.3	9.8	.78	21.5	12.7	2.14
P.16	11.5	7.4	.59	21.5	11.1	2.00
MARK	11.4	6.6	.59	21.6	11.4	1.95
MAC.9	10.5	5.2	.48	21.5	11.3	2.06
B.146	9.1	4.3	.45	21.2	10.8	2.05
LSD	28.7	3.0	.10	1.8	1.20	.22

influenced by rootstock. However, other factors, particularly cultivar, also influence spur characteristics. Generally, yield efficiency was consistently related to the spur quality characteristics of bud diameter and SLW.

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Table 6. Correlation coefficients between spur characteristics and yield indices of rootstocks in three trials.

Variables	Study 1 Wooster NC-140 'Starkspur'	Ripley Study 2 Vigorous 'Macspur'	Ripley Study 3 Dwarfing 'Redchief'	Ripley Study 3 Dwarfing 'Macspur'
SLW x bud diameter	0.95	0.76xx	0.65xx	0.85xx
SLW x bud diameter	0.71xx	0.87xx	0.53x	0.67xx
lf area/spur x lf no./spur	0.46	0.59xx	0.66xx	0.26
TCA x bud diameter	—	−0.66xx	−0.38	−0.85xx
TCA x SLW	—	−0.66xx	−0.18	−0.88xx
TCA x N-content	—	−0.67xx	0.29	−0.68xx
TCA x lf no./spur	—	0.46x	0.58xx	0.12
yield effic. x bud diameter	—	0.57xx	0.43x	0.53x
yield effic. x SLW	—	0.60xx	0.46x	0.49x
yield effic. x N-content	—	0.57xx	−0.13	0.44
yield effic. x lf. no./spur	—	−0.34	−0.56xx	−0.39
yield effic. x TCA	—	−0.71xx	−0.73xx	−0.65xx

x,xx Significant at P=0.05 or 0.01, respectively.

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Inhibition of Growth of Crown-Gall-Causing Bacteria (*Agrobacterium tumefaciens*) by Polyamine Synthesis Inhibitors

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Introduction

Crown-gall can be a serious disease in many fruit crops, including apple, grape, pear, peach, cherry and caneberries (Westwood, 1978). Young apple and pear trees are highly susceptible to crown-gall injury, and in some nurseries 80 percent or more of the trees may be culled following an epidemic (Moore, 1990). Crown-gall can also cause permanent stunting in young pear trees affected by the disease (Moore, 1990). Certain apple rootstocks (*e.g.*, Mark) are much more susceptible to crown-gall than others (David C. Ferree, personal communication). In grape, the disease can be devastating, reducing growth and often killing the vine (Graves *et al.*, 1988). Results from a grower survey (Goldy, 1988) indicated that greater than 26 percent of the vines in some vineyards were infected with crown-gall, and some growers reported that 100 percent of the vine death observed was due to crown-gall.

The causal organism of crown-gall, the bacterium *Agrobacterium tumefaciens*, typically invades plant tissue at wound sites and results in a disease that is characterized by the formation of tumorous plant growths (galls) (Nester *et al.*, 1984). The bacterium apparently recognizes specific chemical signals that are released from wounded, and therefore susceptible, tissue (Stachel *et al.*, 1985). In the field, wounding can result from insect or rodent damage (Westwood, 1978), freeze damage (Goodman, 1988), pruning (Moore, 1990), normal cultivation practices and propagation in the nursery (David C. Ferree, personal communication). Once inside the wound, the bacterium transfers genes controlling hormone synthesis into neighboring plants cells that begin to divide rapidly and thus produce a gall.

Among the methods studied to reduce crown-gall incidence are chemical treatments, streptomycin dips combined with biological control (Moore, 1990), soil sanitation, and careful cultivation (Goldy, 1988). None of these methods is completely effective, but killing or reducing the *Agrobacterium* population at the wound site may inhibit gall formation. While investigating polyamine metabolism in *A. tumefaciens*, we recently demonstrated that growth of strain A6 of the bacterium could be reduced by inhibiting the biosynthesis of polyamines (Ponappa *et al.*, 1992). Polyamines are naturally occurring compounds that are essential for normal cell division and growth of several bacteria, fungi and plants (Galston, 1983). Specific inhibitors of polyamine synthesis reduce growth of several fungal plant pathogens (Slocum and Galston, 1987). As a first step to investigate the use of polyamine inhibitors for controlling *Agrobacterium* infection, we conducted experiments to determine the effects of several polyamine inhibitors individually or in combinations on the growth of cultures of *A. tumefaciens*, strains A6 and A66.

Material and Methods

Polyamine inhibitors. The polyamine inhibitors α-difluoromethylornithine (DFMO), α-difluoromethylarginine (DFMA) and α-difluoromethyllysine (DFML) were gifts from Merrell-Dow Pharmaceuticals. Cyclohexylamine (CHA) and polyamines (putrescine and spermidine), were purchased from Sigma Chemical Co. (St. Louis, MO).

Bacterial strains and growth conditions: *A. tumefaciens* strains A6 and A66 were obtained from Dr. Andrew Binns (Dept. of Biology, Univ. of Pennsylvania, Philadelphia, PA). Stock cultures were maintained on M9 minimal medium as previously described (Ponappa *et al.*, 1992). To determine polyamine inhibitor effects on growth, 0.1 ml of actively growing bacterial suspension was transferred into 5 ml of M9 medium with or without the inhibitor(s) in 15 x 125 mm culture tubes. Culture tubes were placed on a rotary drum and spun at 60 rpm. Growth was monitored by measuring absorbance at 550 nm. Absorbance increased with increasing viable cell number (Ponappa *et al.*, 1992).

Results and Discussion

A. tumefaciens (strain A66) cells grown on M9 minimal medium lacking additives (control) exhibited an extended lag phase (approximately 10 h) followed by a growth phase from 10 h to 38 h (Fig. 1). Inclusion of the polyamine inhibitor DFMO (1 mM) into the medium reduced growth by about 37 percent after 24 h and 33 percent after 38 h. Simultaneous feeding of the polyamine putrescine completely reversed the effects of DFMO (Fig. 1).

In a second experiment, we determined the effect of other polyamine inhibitors on growth of another strain of *A. tumefaciens* (A6) that grew more rapidly than strain A66 under similar conditions. DFMO (1 and 10 mM) reduced growth of the bacterium by 34 percent after about 20 h (Fig. 2). DFMA (1 and 10 mM) did not reduce growth of the bacterium; instead it slightly stimulated growth. DFML and CHA significantly reduced growth of *A. tumefaciens* strain A6 at all concentrations tested. CHA has been shown to inhibit growth of other bacteria, and DFML inhibits *Mycoplasma* growth (Bitonti and McCann, 1987). Since none of the inhibitors administered individually reduced growth 100 percent (Fig. 2), in subsequent experiments we attempted to further reduce growth of the bacterium by combining inhibitors as described by Bitonti *et al.* (1982).

Combinations of various inhibitors tested were more effective at inhibiting growth than individual inhibitors (Table 1). Of the combinations tested, the most effective treatment for inhibiting growth of *A. tumefaciens* strain A6 was the treatment of DFMA+DFMO+DFML+CHA. Further, the effects of one inhibitor combination (DFMA+DFMO+CHA) were reversed partially by simultaneously adminstering the polyamines, putrescine and spermidine. Incomplete reversal of inhibition suggested that inhibition of polyamine biosynthesis was not the sole reason for reduced growth.

Previously, we showed that growth of *A. tumefaciens* could be reduced by inhibiting the activity of ornithine decarboxylase, a key enzyme for putrescine biosynthesis, and thereby reducing polyamine levels (Ponappa *et al.*, 1992). In the present paper, we have shown that DFMO, a specific inhibitor of ornithine decarboxylase, reduced growth of both strains tested, and that its effect could be reversed by supplying putrescine to the bacterium. Unfortunately, DFMO did not completely inhibit *A. tumefaciens* growth in our studies, and it may not inhibit growth of other strains of this bacterium cultured under different conditions (Hamana *et al.*, 1989). DFML and CHA were also effective inhibitors of growth. CHA inhibits spermidine synthesis in other bacteria (Bitonti and McCann, 1987), but in *A. tumefaciens* CHA does not reduce spermidine levels (Ponappa *et al.*, 1992) despite reducing growth (Fig. 2). Hence, the action of CHA in *A. tumefaciens* does not appear to be specific to spermidine synthesis. Bitonti and McCann (1987) suggest that depletion of spermidine may be more critical for inhibition of bacterial growth than depletion of putrescine. Therefore, if a specific inhibitor of *A. tumefaciens* spermidine synthesis were available, one could possibly reduce growth to a greater extent than observed in the present study. The enzyme affected by DFML (lysine decarboxylase) is apparently not present in *A. tumefaciens,* but DFML does inhibit ornithine decarboxylase activity (Ponappa *et al.*, 1992).

In conclusion, the use of polyamine inhibitors to reduce growth of *A. tumefaciens* may have potential for disease control. Combinations of inhibitors reduced growth of the bacterium more than the individual compounds. The use of DFMO to control *A. tumefaciens* growth would rely on the ability of plant cells to synthesize polyamines by alternate pathways that may compensate for DFMO-induced putrescine inhibition (Slocum and Galston, 1987). *A. tumefaciens* is present systemically in plants and has been shown to move in vascular tissue of grapes (Tarbah and Goodman, 1987; Burr and Katz, 1984). Therefore, another advantage of using DFMO is that it is translocated in plants (Burtin *et al.*, 1991), and appears to have a protective effect against pathogens not only at the point of application, but also in other regions of the plant (Slocum and Galston, 1987; Rajam *et al.*, 1985). Conversely, a disadvantage of the antibiotics and other chemical compounds currently used is that they may not affect the latent bacterial population in the plant since they are poorly translocated (Sorensen and Wynne, 1988).

The next phase of this research will be to apply the inhibitors individually or in combination to wounded grape vines or apple scions during grafting, in the presence of *A. tumefaciens*, to determine their effectiveness for inhibiting crown-gall formation. Also, we plan to evaluate any new polyamine synthesis inhibitors that become available, for reducing crown-gall formation in fruit crops.

Acknowledgements

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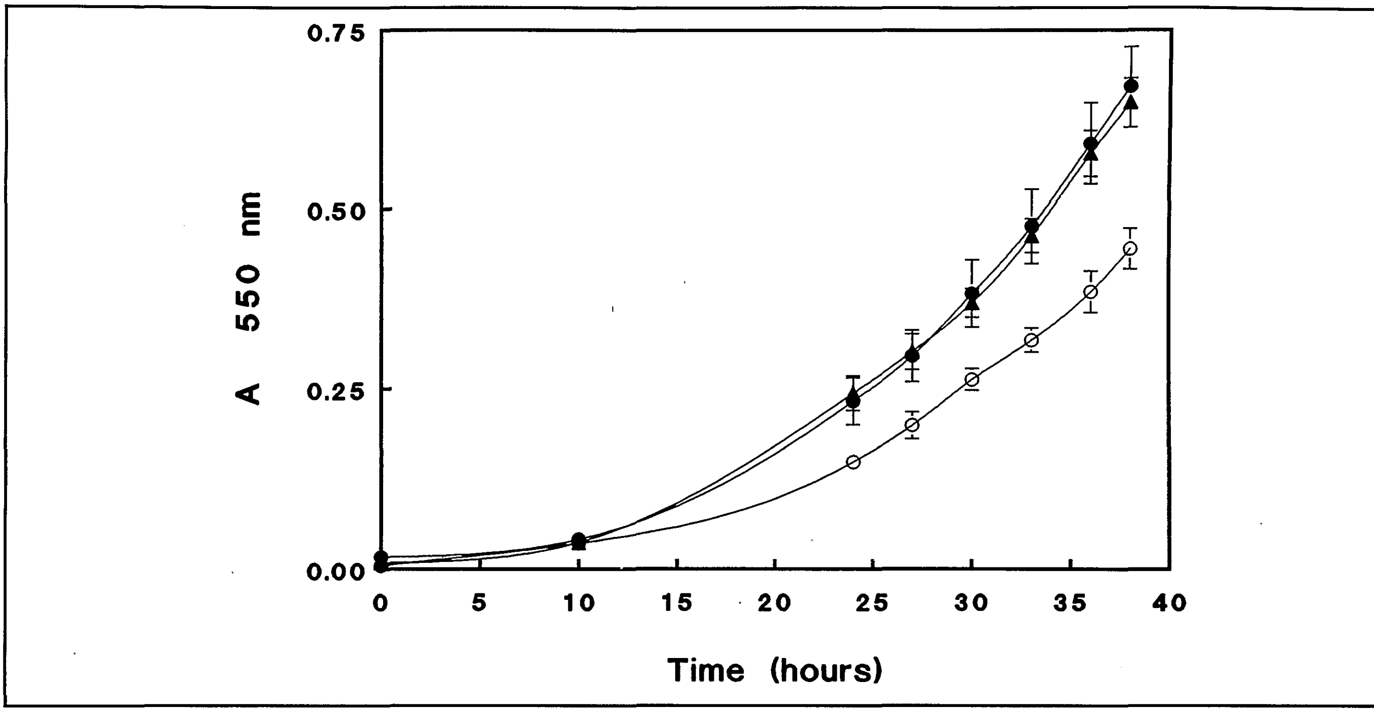

Figure 1. Growth of *Agrobacterium tumefaciens*, strain A66, in liquid M9 medium without additions (●), with 1 mM DFMO (○), or with 1 mM DFMO and 1 mM putrescine (▲). Each point represents the mean value for four culture tubes and vertical bars represent the standard errors of the mean.

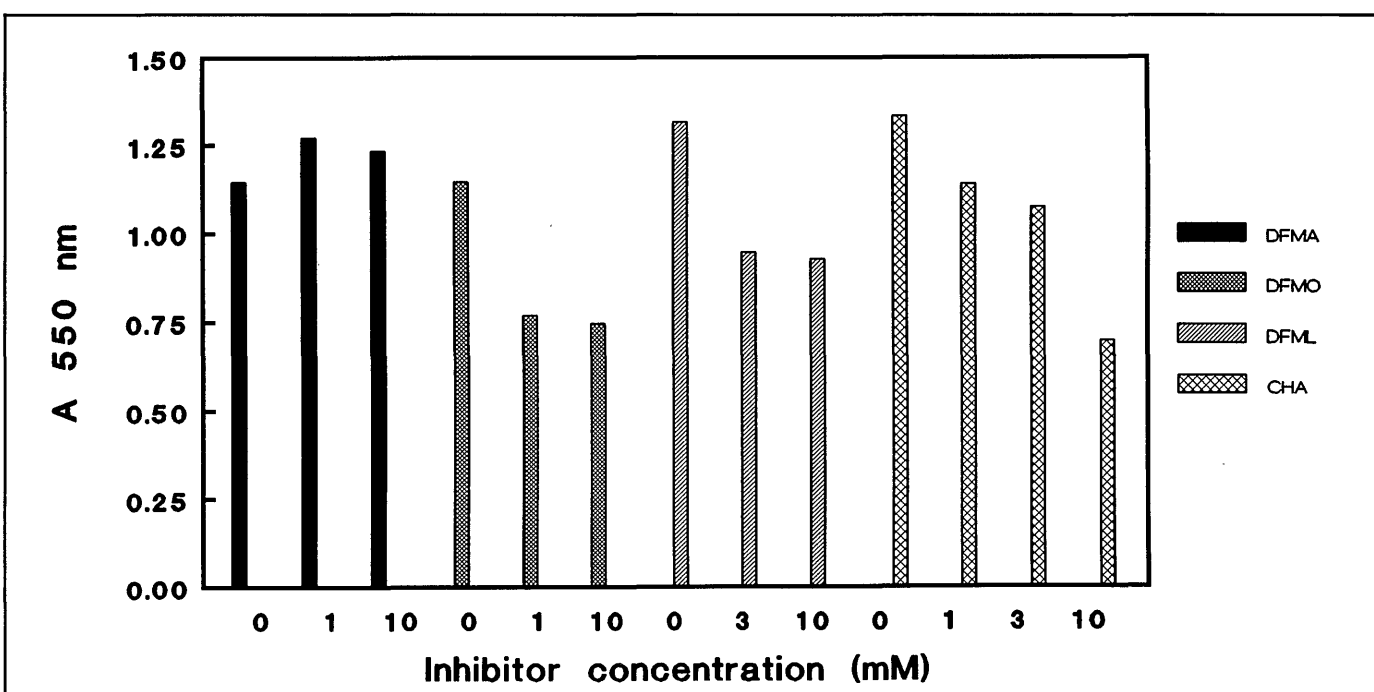

Figure 2. Effects of different concentrations of individual inhibitors on growth (A 550 nm) of *A. tumefaciens,* strain A6, about 20 h after inoculation, when control cells were at late log-early stationary phase (A 550 nm of 1.2 corresponded to approximately 3×10^9 cells/ml). The means of at least four replicate culture tubes are represented (+standard error).

Table 1. Effects of polyamine biosynthetic inhibitors alone and in combination, on growth (A 550 nm) of *A. tumefaciens* strain A6, approximately 20 h after inoculation, when control cells were in late log-early stationary phase.

Treatment	A550 nm	Percent of control
Control	1.03±0.03[1]	100
1 mM DFMO	0.74±0.03	72
10 mM CHA	0.58±0.02	56
1 mM DFMO; 10 mM CHA	0.53±0.01	52
Control	1.32±0.01	100
3 mM DFML	0.95±0.03	72
3 mM DFMA; 3 mM DFMO; 10 mM CHA	0.65±0.02	49
3 mM DFMA; 3 mM DFMO; 3 mM DFML; 10 mM CHA	0.43±0.02	33
Control	1.27±0.01	100
3 mM DFMO; 10 mM CHA	0.55±0.02	43
3 mM DFMA; 3 mM DFMO; 10 mM CHA	0.66±0.02	52
3 mM DFMA; 3 mM DFMO; 10 mM CHA; 5 mM Putrescine; 5 mM Spermidine	1.00±0.03	79

[1]Values represent the mean±standard error of at least four replicate culture tubes.

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Relationships Among Apple Weight, Seed Number, Seed Weight, Germination Date and Apple Seedling Vigor

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Introduction

We have used apple seedlings as the plant symbiont for research on vesicular-arbuscular mycorrhizae (VAM) (Miller *et al.*, 1985; Miller *et al.*, 1989) to circumvent problems encountered with clonally propagated material. Field-grown clonal liners proved unsuitable for use as they likely were already colonized with VAM fungi. Micropropagated clonal material resulted in variable numbers of young roots and nonuniform initiation of shoot tip elongation. Seed-derived plants, however, were readily obtained throughout the year from stratified seed, were certain to be initially non-mycorrhizal and were easy to inoculate with VAM fungi at the primary root stage, but introduced genetic variability into the VAM symbiosis. The purpose of this study was to examine apple fruit and seed to determine if selection criteria for fruit/seed/seedlings exist that will predict seedling growth and uniformity, enabling us to minimize variability of experimental units for use in mycorrhizae studies. In the process, it was possible to examine the relationships among apple weight, seed number and seed weight.

Studies with other plant species have shown that factors such as seed weight, seed size and time to germination influence seedling performance. Seed weight of Chinese chestnut was a good predictor of plant diameter (R^2=0.67) and dry weight (R^2=0.81) after 42 days growth (Shepard *et al.*, 1989). Height, leaf area and dry weight of 1-year seedlings of chestnut oak were positively correlated with acorn weight (McComb, 1934). Slash pine seed weight influenced germination and seedling survival with lightweight seeds inferior to heavier seeds (Belcher *et al.*, 1984). Large-sized seed of loblolly pine germinated more quickly and produced a larger seedling after 28 days growth than small seed (Dunlap and Barnett, 1983). However, with chestnut, no relationship was found between seed weight and days to shoot emergence (Shepard *et al.*, 1989). Germination rate was positively correlated with seedling size in loblolly and slash pine seed (Barnett and McLemore, 1984). Righter (1945) found no correlation between Pinus seed size and seedling size and concluded that environmental influences controlled tree growth more than did inherent vigor.

The relationship between apple seed number and fruit size has been studied, but results appear inconsistent. Heinicke (1917) reported that fruit size was positively correlated with viable seed number. Williams (1979) found that at least 7 seeds/fruit were necessary for maximum 'Delicious' fruit size. Marsh *et al.* (1960) reported that 'McIntosh' trees carried many fruits to harvest without any viable seed, providing the apples contained high numbers of aborted seed. Likewise, triploid cultivars can set and mature fruit with few or no viable seed. Webb *et al.* (1980) correlated number of mature seed with fruit weight (R=0.23, P=0.05) and concluded that seed number was not a determining factor of apple fruit weight. It is the hormonal stimuli produced by seeds and imparted to the fruit that affect apple development, especially in preventing fruit abscission and increasing cortical cell division (Crane, 1969). Luckwill (1953) found that the hormonal stimuli from developing seeds 3-4 and 7-10 weeks after petal fall prevented the inherent tendency of the apple to abscise. Preharvest drop, 18-20 weeks after petal fall, did not correlate with hormone production from the seed and it was concluded that after completion of June drop, viable seed are unnecessary for continued growth of the apple fruit (Luckwill, 1953).

Apple seed development is completed many weeks before fruits mature. Luckwill (1953) reported that embryo abortion typically occurred 5-6 weeks after petal fall, while sound seed completed development by 7-10 weeks after petal fall. Apple fruit cell division, believed to be a major component determining fruit size, is reported to be completed by 3-4 weeks after pollination (Bain and Robertson, 1951). Cell expansion begins soon after pollination and continues throughout the season (Denne, 1960). Final fruit size can, however, be predicted by 50-70 days after full bloom as small, medium and large fruit at this time will be relatively the same at harvest (Williams, 1979). While seed development, at least to some critical period, appears essential for fruit development, we found no information on a relationship between fruit size and the vigor of the seeds contained within.

Materials and Methods

One hundred apples each of 'Jonathan', 'Golden Delicious' and 'Rome Beauty' were randomly selected in October 1986 by leveling off bushel crates of just-harvested apples at a commercial orchard in Indiana. Apples were numbered, weighed and refrigerated at 0°C prior to seed extraction. Apples were carefully sliced open, number of sound (*i.e.*, plump) and aborted (*i.e.*, shriveled and undersized) seeds counted, and fresh weight of sound seeds/fruit obtained. Sound seeds were placed in numbered petri dishes and air-dried at room temperature (21°C). After surface drying, individual seeds were weighed to the nearest 0.1 mg. Seeds from each fruit were arranged, using a template, in a gridded plastic flat filled with moist vermiculite such that each seed could be identified by an apple number and a seed number. The template was then removed and additional moist vermiculite added to each flat to lightly cover the seeds. Each flat was placed in a clear plastic bag and refrigerated at 0°C from Nov. 19-25, 1986, to Feb. 26, 1987, roughly 2,300 hours.

Ten additional apples of each cultivar were weighed both fresh and dry (7 days at 70°C in forced air oven) to obtain percent moisture content. Additionally, 30 observations of air dry weight of seed, seed coat, and embryo plus cotyledons were obtained for each cultivar.

Flats were removed from the cooler Feb. 26, 1987, and placed in the greenhouse at 24-27°C day, and 18-21°C night, temperatures. High-pressure sodium lights supplemented ambient light from 6:00 a.m. until 11:00 p.m. for a photoperiod of 17 hours. Seed germination date was recorded daily as number of days out of the cooler, *i.e.*, day 1=day after flats removed from cooler. A seed was considered germinated when the hypocotyl uncrooked, the cotyledons parted, and the shoot tip became visible. Seedlings were transplanted into 10 cm³ Leach Super Cell tubes (Ray Leach Cone-Tainer Nursery, Canby, OR) filled with Metromix 350 growing medium, labeled with apple and seed number, and randomly assigned to location within holders. Plant height (cm) was measured from the soil line to shoot tip on Mar. 20, Apr. 3, and Apr. 16, approximately 2, 4, and 6 weeks after mean germination date of the population. Stem diameter (mm) at approximately 2.5 cm above the soil line was measured Apr. 20. Plants were then dried to wilt in the tubes and soil mix was shaken from the root systems. Whole plants were placed in paper bags, dried in a forced air oven at 70°C, and dry wt (g) was determined.

Statistical analyses were performed using the General Linear Models, Statistical Analysis System (Goodnight, 1982).

Results

Apple fresh weight and total seed fresh weight were correlated across the three cultivars ($R=0.68$, $P<0.01$) (Table 1). Within cultivars, the correlation was lower (Table 1) but statistically significant ($P<0.01$). The range of 'Jonathan' apple fresh weight was 58.1 g to 171.1 g, with a mean of 118.4 g±22.6 g; total seed fresh weight ranged from no seeds to 0.6432 g with a mean of 0.370 g±0.113 g (Table 2). For 'Golden Delicious', apple fresh weight ranged from 81.5 g to 189.0 g, with a mean of 137.9 g±22.1 g; total seed fresh weight ranged from 0.0573 g to 0.6877 g, with a mean of 0.469 g±0.099 g. 'Rome Beauty' was the largest of the cultivars in both apple fresh weight and total seed fresh weight. Fresh weight ranged from 105.3 g to 244.8 g, with a mean of 176.0 g±32.3 g; seed weight ranged from 0.1435 g to 0.8066 g, with 0.575 g±0.130 g as the average.

Apple fresh weight was also correlated with number of sound seed ($R=0.48$, $P<0.01$) (Table 1) across the three cultivars. 'Jonathan' averaged 5.8±1.7 sound seed/fruit (Table 2), with a range of 0 to 10, and 3.0±1.7 aborted seed/fruit, with a range of 0 to 8. 'Golden Delicious' averaged 7.4±1.6 sound seed/fruit (range 1 to 10) and 2.5±1.7 aborted seed/fruit (range 0 to 9). 'Rome Beauty' averaged 7.8±1.9 sound seed/fruit (range 2 to 12) and 1.2±1.2 aborted seed/fruit (range 0 to 5). Fruit with large numbers of sound seed had few aborted seed and vice versa, but we found no fruit with small numbers, *i.e.*, <4, of both sound and aborted seed.

Total seed fresh weight and number of sound seed proved to be the predictive variables for apple fresh weight at harvest. The best model ($P<0.01$) for apple fresh weight, across cultivars, was:

expected apple fresh weight (g)=100+350 (total seed fresh weight(g))−15 (number of sound seed)$R^2=0.56$

Table 1. Simple correlation coefficients of apple fruit and seed parameters for 'Jonathan', 'Golden Delicious' and 'Rome Beauty', P<0.01.

Variable	with	Variable	Correlation 'Jonathan'	'G.Delicious'	'Rome'	All
Apple fresh weight		Total seed weight	0.40	0.51	0.53	0.68
Apple fresh weight		Number of sound seed	0.19	0.37	0.41	0.48
Apple fresh weight		Individual seed weight	0.48	0.18	0.17	0.34
Apple fresh weight		Dry wt. of seedling at 42 days	0.13	NS[1]	0.15	NS
Individual seed weight		Germination date	NS	NS	NS	0.08
Individual seed weight		Height day 14	0.17	0.13	0.25	0.10
Individual seed weight		Height day 28	NS	NS	0.33	0.08
Individual seed weight		Height day 42	NS	NS	0.29	0.08
Germination date		Height day 14	−0.52	−0.57	−0.50	−0.58
Germination date		Height day 28	−0.40	−0.49	−0.45	−0.52
Germination date		Height day 42	−0.33	−0.34	−0.26	−0.38
Germination date		Seedling diameter at 42 days	−0.26	NS	−0.14	−0.12
Germination date		Dry wt. of seedling at 42 days	−0.11	NS	−0.18	−0.19
Individual seed weight		Seedling diameter at 42 days	0.10	NS	0.16	NS
Individual seed weight		Dry wt. of seedling at 42 days	0.16	0.08	0.37	0.14

[1]NS=nonsignificant.

Separate regression equations for each cultivar were derived, but estimates of coefficients were not significantly different. Therefore, only the equation combining cultivars is presented. It should be noted, however, that the R^2 of this equation was higher than that of the regression equations for any of the cultivars, demonstrating the within-cultivar variability.

There was a significant difference among cultivars in the weight of fruit produced (g)/seed weight (g) (mean separation by Duncan's Multiple Range Test) with 'Jonathan'=347 a, 'Rome Beauty'=319 b, and 'Golden Delicious'=308 b. Similarly, 'Jonathan', which averaged fewer sound seed/fruit than the other two cultivars, (Table 2) had a higher correlation between apple fresh weight and individual seed weight (R=0.48; P< 0.01) (Table 1). Individual air-dried sound seed of 'Jonathan' averaged 0.0455 g± 0.0052g, 'Golden Delicious' 0.0449 g±0.0052 g and 'Rome Beauty' 0.0484 g±0.0055 g (Table 2). The ratio of embryo plus cotyledons to seed coat weight was 1.8 with 'Jonathan', 1.9 with 'Golden Delicious', and 2.0 with 'Rome Beauty'. The correlation of seed air-dry weight with seed coat weight was R=0.70 (P< 0.01). Larger seeds, therefore, differ from smaller seeds predominately in embryo plus cotyledons weight instead of seed coat weight.

Cultivar influenced days to seed germination, with 'Jonathan' requiring 7±.5 days, 'Golden Delicious' 8±1.5 days, 'Rome Beauty' 9±1.5 days (Table 2). Individual seed weight was not correlated with days to seed germination, within cultivars, although across cultivars there was a slight positive relationship (R=0.08, P< 0.01) (Table 1) undoubtedly due to differences in mean germination times among cultivars. Initial seed germination, across cultivars, was 97 percent. Sixteen percent of all seed germinated to the first true leaf stage and then died. Typically, the cotyledons and shoot tips of these seedlings emerged yellowish, then the shoot tip browned, and the seedling collapsed. The problem did not appear to be pathological. Consequently, 81 percent of seeds germinated and grew into seedlings. Two of 1,563 seedlings were red-leafed (a rate of 0.13 percent).

Across cultivars, seedling heights at the three measurement times reflected differences in germination date and are presented as days after mean germination of the population (Fig. 1). Once germinated, seedlings from each of the cultivars increased in height at approximately the same rate, 1 cm/3 days. Seedling height at the time we would make selections for mycorrhizae studies (*i.e.*, at the

Table 2. Apple weight, seed number and weight, and germination and seedling growth from open-pollinated 'Jonathan', 'Golden Delicious' and 'Rome Beauty' apples.

Parameter	'Jonathan'	S.D.[1]	n[2]	'Golden Delicious'	S.D.	n	'Rome Beauty'	S.D.	n	All	S.D.	n
Apple fresh wt.(g)	118.4	22.6	100	137.9	22.1	100	176.0	32.3	100	147.2	35.6	300
Total seed fresh wt/fruit (g)	0.370	0.113	100	0.469	0.099	100	0.575	0.130	100	0.483	0.141	300
Number sound seed/fruit	5.8	1.7	100	7.4	1.6	100	7.8	1.9	100	7.1	1.9	300
Number aborted seed/fruit	3.0	1.7	100	2.5	1.7	100	1.2	1.2	100	2.1	1.7	300
Individual seed air dry weight (g)	0.0455	0.0052	505	0.0449	0.0052	692	0.0484	0.0055	731	0.0464	0.0056	1928
Days to germination	7	1.5	495	8	1.5	676	9	1.5	702	8	1.7	1873
Seedling diameter (mm) after 6 wk growth	2.04	0.19	393	2.00	0.54	584	1.91	0.22	586	1.98	0.37	1563
Seedling dry wt. (g) after 6 wk growth	1.67	0.34	393	1.62	0.35	584	1.46	0.43	586	1.57	0.39	1563

[1]Standard deviation of the population.
[2]Number of observations.

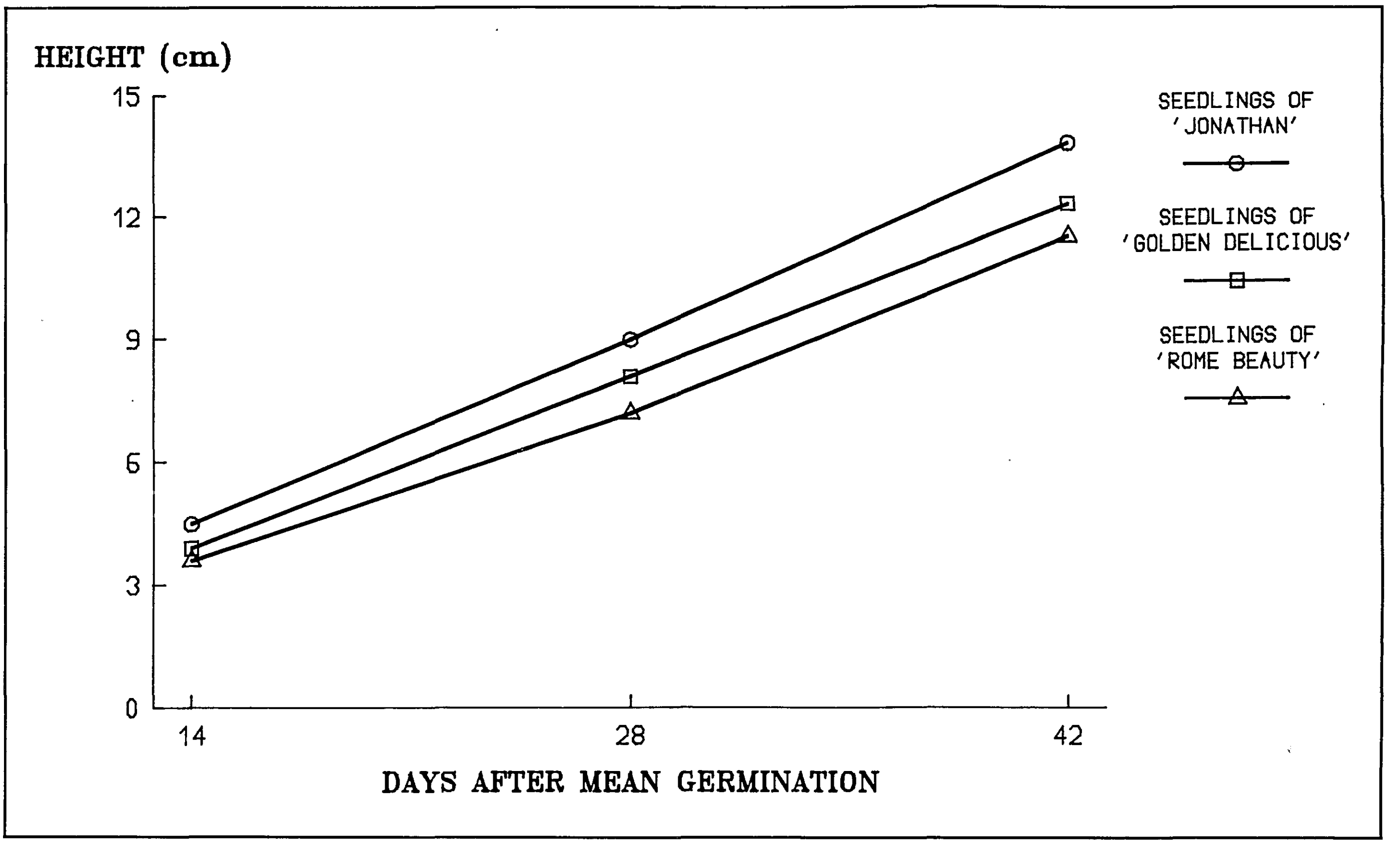

Figure 1. Apple seedling heights (cm) 14, 28 and 42 days after mean germination date of the population. Means significantly different within each measurement time ($P < 0.01$); largest standard error of the mean, among cultivars, day 14=0.05 cm; day 28=0.10 cm; day 42=0.70 cm. Seedlings were greenhouse grown, in 10^3 cm tubes; Columbus, OH, 1987.

expanded first true leaf stage, roughly 10-14 days after germination) could be predicted predominantly by germination date and, to a lesser extent, by seed weight. The best model ($P < 0.01$) for seedling height, across cultivars, at this time was:

expected apple seedling height (cm)=5.4+27 (seed weight (g))—0.33(germination date) $R^2=0.35$

Germination date remained the best predictive variable of seedling height by the third measurement time (approximately 6 weeks after germination) and seed weight continued to explain a very small, but significant, amount of the variation seen. The best model ($P < 0.01$), across cultivars, after 6 weeks growth was:

expected apple seedling height (cm)=15.4+65 (seed weight (g))—0.74 (germination date) $R^2=0.15$

Similarly, stem diameter and dry weight after 6 weeks growth were significantly affected ($P < 0.01$) by germination date and seed weight, but the best fit equation explained little of the variation seen ($R^2=0.14$) and plots of residuals showed random distribution. No predictive information on seedling height, diameter or dry weight was obtained from apple fresh weight once the partial correlation with seed weight was removed.

Discussion

Apple fruit size is known to be affected by genetic, environmental and cultural factors and likely there are year to year differences in factors limiting fruit size. Since, in general, the same weight of fruit is worth more if allocated in large apples than in small apples, large fruit size is a major goal of orchardists. The apples evaluated in this study were from a well-managed commercial orchard containing many cultivars, in a year of favorable weather during pollination and no frost. Under these circumstances, total seed fresh weight and number of sound seed explained more than half (R^2=0.56) of the differences among fruit in fresh weight. Although it is not the seeds themselves that stimulate fruit size, but the hormonal stimuli emanating from the developing seeds (Luckwill, 1953), hormone effectiveness in preventing fruit abscission and increasing cell division (Denne, 1960) can be evaluated by seed fresh weight and number. Numbers of aborted seed or aborted plus sound seed were not correlated with fruit size. However, no fruit were found with small numbers of both sound and aborted seed, indicating such fruit naturally abscissed or responded to chemical thinning.

While fruit size is correlated with total seed weight and number of sound seed, the genetic component determining fruit size should not be overlooked. In this study, cultivars differed in fruit weight produced/seed weight even though 'Jonathan', 'Golden Delicious' and 'Rome Beauty' could all be categorized as cultivars that produce medium or large-sized fruit. Cultivars producing fruit typically smaller or larger than those tested here are likely to differ more in fruit weight produced/seed weight. We would expect, however, that within cultivars, the relationship of increased fruit size with increased total seed weight and number of sound seed would be maintained.

We were interested in determining if knowledge of apple fresh weight provided any predictive information on the vigor of the seed/seedlings contained within. Prior to this study, we had usually collected seed from large 'Golden Delicious' apples because these contained many sound seed which seemed vigorous in days to germination. This study showed that while large apples contained more sound seed, predictions of individual seed weight or days to seed germination (the two factors predicting seedling vigor) cannot be made.

Cultivar did influence seedling growth by affecting germination time. Seedlings from 'Jonathan' apples germinated quicker than those from 'Golden Delicious', which were quicker than those from 'Rome Beauty'. This evidence for a genetic influence on seedling growth makes us conclude that selection of seedlings from among half-sibs will help to achieve a uniform population. The maternal parent accounts for only one-half of the seedling's genes, however, and the pollen parent is usually unknown. Seedling uniformity might be increased if only one pollen parent were responsible for pollination. Another possibility to achieve uniformity is the use of apomictic seed, but apomixis is often only 60-70 percent, so seedling selection criteria for uniformity still must be established, and the major *Malus* species exhibiting apomixis do not include *M.* x *domestica* (Miller and Ferree, 1988).

Apple seedling selection for uniformity should be made after the first true leaf has expanded, 10-14 days after germination, as 16 percent of all seeds in this study germinated to the first true leaf stage and then died. This phenomenon is common in seedling populations and especially in highly heterozygous populations such as tree seedlings (Alston, 1976). The percentage of seedlings that die depends upon the genetic load, *i.e.*, how many deleterious genes the population is carrying, and is the result of lethal gene segregation. It appeared that the seedlings died at the time when they were switching from dependence on stored reserves to dependence on current photosynthate. Other abnormalities such as curly-leaved and red-leaved seedlings were seen but were quite rare.

Weighing individual seeds contributed a very small (R^2= 0.02−0.08 among cultivars) but significant ($P<$ 0.01) amount of information about seedling early height growth, while tracking germination date contributed considerably more information (R^2=0.25-0.31 among cultivars, $P<0.01$). Heavier apple seeds contained more embryo plus cotyledons weight, *i.e.*, more stored reserves. Seed weight was not a factor in germination date. In practical terms, however, the information gained by weighing individual seeds does not justify the time involved. Based on the results of this study, the following protocol is suggested: extract 5-10 times more plump seeds of a single cultivar than needed; layer them uniformly in a germination flat in moist vermiculite; store covered with plastic in a cooler (0°C) until needed (at least until the chilling requirement is met); place flat in greenhouse; record germination dates; and select and transplant from among similar-date germinators the most uniform seedlings at the expanded first true leaf stage (10-14 days after germination).

Apple seedlings are good subjects for mycorrhizae and other cultural and environmental studies because they are dependent for only a short time on reserves translocated from cotyledons, *i.e.*, on the seed-size effect. The dry weight of seedlings harvested after 6 weeks growth averaged 36 times the weight of the seed, indicating a strong dependence on current photosynthate and environmental factors influencing plant metabolism. In a mycorrhizae study where fungal inoculations failed, our first clue of problems was continued uniform growth of the seedlings. This differs considerably from results obtained with large-seeded species such as chestnut. After 6 weeks growth, chestnut seedlings had not doubled in dry weight from seed, suggesting early growth is much more dependent on reserves translocated from the cotyledons than on current photosynthate and environment (Shepard *et al.*, 1989).

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Evaluation of Organic and Conventional Fungicide Programs for Control of Apple Scab in Ohio

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Abstract

The efficacy of inorganic fungicides (copper, lime sulfur and sulfur) and conventional protectant fungicides (Captan and Benlate) applied in a traditional protectant program (7-day interval through primary scab, 14-day interval between summer cover sprays) was compared to conventional fungicides (Nova plus Captan) applied on an extended protectant program (10- to 14-day interval through primary scab, 14- to 21-day interval between cover sprays) for control of apple scab. In 1990, organic programs using early season applications of Kocide (copper) and lime sulfur provided fair to good control of primary scab. Cover sprays of 95 percent wettable sulfur alone on a 14-day schedule did not provide adequate control of secondary scab infections on leaves or fruit. Conventional fungicides applied in the protectant or extended protectant programs provided excellent scab control.

In 1991, a reduced rate of lime sulfur was used instead of sulfur in the organic summer cover sprays. Good to excellent control of scab was obtained. There was no significant difference in the level of fruit scab control between any of the fungicide programs tested.

Kocide 101 applied after ½ inch green tissue was present resulted in phytotoxicity to green leaf tissue and poor fruit finish. An organic fungicide program using lime sulfur provided commercially acceptable scab control under heavy disease pressure in 1991. In both years of testing, the extended protectant program resulted in three fewer fungicide applications than the standard protectant program and resulted in excellent scab control.

Today's consumers demand high-quality, blemish-free fruit, and to maintain these high standards growers depend heavily on preventive chemical programs for pest control. More than 20 diseases require control measures on an annual basis for high-quality apple production. Thus, 20 or more pesticide applications may be needed over the growing season on apple (1). Glass and Lienk (7) reported that leaving a small commercial block of apples unsprayed resulted in a crop that was commercially worthless in the first year. This heavy usage and dependency on pesticides results in apple ranking sixth among individual crops in total volume of pesticides used nationally and first among major crops on pesticide usage per acre (1).

Throughout the midwestern and northeastern United States, control of apple scab, caused by *Venturia inaequalis* (Cke.) Wint., is achieved primarily through a protectant fungicide spray program. In a program using only protectant fungicides such as captan or mancozeb for primary apple scab control, fungicides are generally applied after every 7 days of new growth or 1 inch (2.54 cm) of rain. In most cases, fungicide is applied regardless of whether infection periods have occurred. An alternative to a protectant program is the after-infection or curative spray program where the fungicide is applied after the initiation of an infection period, but before symptom development. The relatively new ergosterol biosynthesis inhibiting "sterol inhibiting" (SI) fungicides such as Rubigan and Nova are currently registered for use on apple in Ohio, and both provide excellent curative activity. Since Mills (8, 9) developed the environmental parameters necessary for apple scab development, we have had the ability to monitor apple scab infection periods.

Although the new SI fungicides such as Nova and Rubigan are currently registered and commonly used in Ohio (4, 5), most growers are not using after-infection spray programs based upon environmental monitoring. Instead, many growers are currently using an extended-protectant program that uses the curative properties of the SI fungicides combined (tank-mixed) with the strong protectant properties of the old protectant fungicides (5). In programs such as this, growers can extend the spray interval to 10 days, and even up to 14 days during dry growing seasons. This extended interval usually results in a reduction in the number of sprays per season (2, 6).

Current public concerns over pesticide residues in food have generated interest in "organic" apple production. In the midwestern and northeastern U.S., this generally implies the use of inorganic fungicides such as copper and sulfur within an "organic" production program (3). Due to the lack of interest in the inorganic fungicides by commercial growers over the past 25-30 years, we have not extensively evaluated the efficacy of these fungicides in season-long disease control programs. The feasibility of developing "organic" apple orchards based primarily on the use of inorganic fungicides needs to be evaluated.

The purposes of these studies are to evaluate the efficacy of inorganic fungicides such as sulfur and copper for control of apple scab, and to compare the efficacy of inorganic fungicides with conventional organic fungicides in a standard protectant and extended protectant spray program.

Materials and Methods

Fungicide Trial, 1990: Treatments were applied to four single-tree replicates of McIntosh apple trees on MM1.06 rootstock. The 20-yr-old trees were spaced 15 ft. apart with 29 ft. between rows. Soil type was Wooster silt loam. Trees were sprayed to runoff (400 gal water/A) with a handgun at 450 psi. Treatments (Table 1) were applied using one of the following spray programs: 1) traditional protectant program with 7 days between applications using only inorganic (sulfur and copper) fungicides; 2) traditional protectant program using Benlate and Captan; and 3) an extended protectant program with 10-14 days between applications using Nova plus Captan. Spray dates and growth stages for the traditional protectant program were: 12 Apr (half-inch green), 19 Apr (tight cluster), and 26 Apr (pink); 2 May (bloom), 11 May (petal fall), and 19 May (first cover). Additional cover sprays were made on: 26 May; 2, 13 and 27 Jun: 16 and 31 Jul; and 15 Aug. Spray dates for the extended protectant program were: 12 Apr (half-inch green) and 23 Apr (open cluster); 6 May (petal fall), and 19 May (first cover). Additional cover sprays were made on: 30 May; 13 and 27 Jun; 16 and 31 Jul; and 15 Aug. Percentage of leaves with primary scab (at least 1 lesion per leaf) was determined for the cluster leaves plus the first 5 terminal leaves on 10 shoots per tree on 12 Jun. Percentage of leaves with secondary scab (at least 1 lesion/leaf) was determined on the 10 most terminal leaves on 10 shoots per tree on 10 Aug. Percentage of fruit infected by scab (at least 1 lesion/fruit) was determined for 25 fruit per tree (100 fruit/treatment) on 17 Aug. Russet and scarf skin were rated on 10 fruit per tree (40 fruits per treatment) at commercial harvest date (Sept. 10). Ratings were based on a scale of 1 to 5, where 1=no russet or scarf skin and 5=severe russet or scarf skin.

Fungicide Trial, 1991: The trial was repeated as previously described for 1990. Treatments (Table 2) were applied to McIntosh and Golden Delicious trees using one of the following spray programs: 1) traditional protectant program with 7 days between applications using only inorganic (sulfur and copper) fungicides; 2) traditional protectant program using Captan only; and 3) an extended protectant program with 10-14 days between applications using Nova plus Captan. Spray dates and growth stages for the traditional protectant program were: 6 (½ inch green), 12 (tight cluster), 18 (open cluster) and 25 (Pink) Apr; and 5 May (petal fall). Additional cover sprays were made on the following dates: 10 and 20 May; 3 and 18 Jun; 2, 16 and 31 Jul; and 14 and 28 Aug. Spray dates for the extended protectant program were: 12 (tight cluster) and 23 (pink) Apr; 7 (petal fall), 17 (first cover) and 31 (second cover) May. Additional cover sprays were applied on 14 and 28 Jun; 12 and 26 Jul and 8 and 22 Aug.

Percentage of leaves with primary scab (at least 1 lesion/leaf) was determined for all cluster leaves plus the first 5 terminal leaves on 10 shoots per tree on 23 and 24 May. Percentage of leaves with secondary scab (at least 1 lesion/leaf) was determined on the 10 most terminal leaves on 10 shoots per tree on 22 and 23 Aug. Percentage of fruits infected by scab (at least 1 lesion/fruit) was determined on 25 fruits per tree on 26 and 27 Aug. Russet and scarf skin ratings were conducted as described for 1990 on commercial harvest date (Sept. 10).

Results

In 1990, disease pressure from scab was very high. From April 10 to June 4, a total of eight scab infection periods were recorded. Both organic programs provided fair control of primary scab, but did not provide satisfactory control of secondary (Table 1).

Benlate plus Captan in a traditional protectant program, and Nova plus Captan in an extended protectant program provided excellent scab control. The extended protectant program, with 10 applications, resulted in 3

Table 1. Efficacy of inorganic "organic" and conventional fungicide spray programs for control of apple scab, 1990.

Program[1]	Treatment, rate product/A and (timing)	% primary[2] scab	secondary[3] scab	%fruit scab	Russet[5] (Golden Del.)	Scarf Skin[6] (Rome)
Traditional protectant (organic)	Lime sulfur 29% 8 gal (half in green—bloom) then Sulfur 95W 24 lb (petal fall—cover sprays)	8.2 bg[7]	43.7 b	48.7 b	2.07 bcd	2.97 bcdef
Traditional protectant (organic)	Kocide 101 77W 8 lb (half in green—pink) then Sulfur 95W 24 lb (bloom—cover sprays)	6.5 b	35.5 b	22.0 c	3.31 a	3.86 a
Traditional protectant (conventional)	Benlate 50W 12 oz PLUS Captan 50W 4 lb (full schedule)	1.6 c	5.7c	6.0 d	1.99 bcd	2.39 gh
Extended protectant	Nova 40DF 5 oz PLUS Captan 50W 4 lb (10-14 day through fourth cover) then Captan 50W 6 lb (remaining covers)	0.9 c	4.5c	1.1d	2.10 bcd	2.92 cdef
Untreated controls		100 a	100 a	100 a	3.07 a	1.72 i

[1]Traditional protectant=applications made on a 7-day interval through primary scab, then on a 14-day schedule for summer cover sprays. Extended protectant=applications made on a 10-14 day schedule through primary scab, then on a 21 day schedule for summer cover spray. Organic=only inorganic fungicides were used (copper, lime sulfur or sulfur) Conventional=Currently registered organic fungicides (Captan, Benlate and Nova) were used.
[2]All scab data was taken on the cultivar McIntosh. Primary scab based on the percentage of leaves with at least 1 scab lesion on all cluster leaves and the first 5 terminal leaves on 10 shoots per tree.
[3]Based on the percentage leaves with at least 1 lesion per leaf on the 10 most terminal leaves on 10 shoots per tree.
[4]Based on the percentage of fruits with at least 1 lesion on 25 fruit per tree.
[5]Based on rating of 1 to 5 where 1=no russet and 5=severe russet. Rating was conducted on 40 fruit per treatment.
[6]Based on a rating of 1 to 5 where 1=no scarf skin and 5=severe scarf skin. Rating was conducted on 40 fruit per treatment.
[7]Numbers followed by the same letter within columns do not differ significantly according to the Walker-Duncan bayesian T test (P=0.05).

fewer sprays than the traditional protectant program which had 13 applications.

Russet was fairly high in all treatments. There was no significant difference in russet between treatments containing lime sulfur and sulfur, benlate and captan and Nova plus captan. Kocide resulted in significantly more russet than all other fungicide treatments, but was not significantly different from the unsprayed control (Table 1). All treatments had significantly more scarf skin than the untreated control. Kocide had significantly more scarf skin than any other treatment and reduced fruit set by approximately 65 percent as compared to the other treatments (unpublished data, Ellis and Ferree).

In 1991, disease pressure from scab was also very high. From April 4 to June 30, a total of 17 infection periods were recorded. All treatments provided excellent control of primary scab. Control of secondary scab was generally less for the lime sulfur and sulfur treatment, however, good to excellent control was achieved. All treatments provided excellent control of fruit scab. A total of 14 applications were made in the traditional protectant program. Three fewer sprays were made in the extended protectant program with a total of 11 applications.

There was no significant difference between any of the treatments, except Kocide, in fruit russet. Kocide provided unacceptable fruit russet. In addition, Kocide applied at tight cluster caused severe damage (necrosis) to all green tissues and severely reduced fruit set. Kocide also resulted in significantly more scarf skin than all other treatments.

Table 2. Efficacy of inorganic "organic" and conventional fungicide spray programs for control of apple scab, 1991.

Program[1]	Treatment, rate product/A and (timing)	% primary[3] Scab MB[2]	% primary[3] Scab D	% secondary[4] Scab MC	% secondary[4] Scab D	% fruit[3] Scab MC	% fruit[3] Scab D	Russet[6] GD	Scarf Skin[7] R
Traditional/ protectant (organic)	Kocide 101 77W 8 lb (1/2 inch green and tight cluster) then Lime sulfur 29% 8 gal (open cluster through 1st cover) then Sulfur 95W 24 lb (remaining covers)	0.6b[8]	0.5b	9.7b	10.7 bc	1.5bc	0.5b	2.4a	3.1a
Traditional protectant (organic)	Lime Sulfur 29% 8 gal (1/2 inch green through 1st cover) then (Lime Sulfur 29% 4 gal (remaining covers)	0 b	0 b	5.5bc	7.3 bc	0 c	0 b	1.0b	2.6ab
Traditional protectant (conventional)	Captan 50W 8 lb (1/2 inch green through 1st cover then Captan 50W 6 lb (remaining covers)	0 b	0 b	2.5cd	4.0cd	2.8b	0 b	1.0b	2.5bc
Extended protectant (conventional)	Nova 40W 5 oz PLUS Captan 50W 4 lb (tight cluster, pink, petal fall and 1st cover) then Captan 50W 6 lb alternated with Benlate 50W 12 oz (remaining covers)	0 b	0 b	1.5d	0.3d	1.1bc	0 b	1.2b	2.7ab
Untreated controls		33.7a	38.2a	98.5a	100 a	100 a	100 a	1.0b	2.6

[1]Traditional protectant=applications made on a 7-day interval through primary scab, then on a 14-day schedule for summer cover sprays.
Extended protectant=applications made on a 10-14 day schedule through primary scab, then on a 14-day schedule for summer cover spray.
Organic=only inorganic fungicides were used (copper, lime sulfur or sulfur).
Conventional=currently registered organic fungicides (Captan, Benlate and Nova) were used.
[2]MC=McIntosh, D=Delicious, GD=Golden Delicious, R=Rome
[3]Based on percentage of leaves with at least 1 scab lesion for all cluster leaves and the first 5 terminal leaves on 10 shoots per tree.
[4]Based on percentage of leaves with at least 1 scab lesion on the 10 most terminal leaves on 10 shoots per tree.
[5]Based on percentage of fruit with at least 1 scab lesion on 25 fruits per tree.
[6]Based on a rating of 1 to 5 where 1=no scarf skin and 5=severe scarf skin. Rating was conducted on 40 fruit per treatment.
[7]Based on a rating of 1 to 5 where 1=no scarf skin and 5=severe scarf skin. Rating was conducted on 40 fruit per treatment.
[8]Numbers followed by the same letter within columns do not differ significantly according to the Waller-Duncan bayesian T test (P=0.05).

Discussion

The poor performance of the organic programs in 1990 is thought to be due to the poor performance of sulfur used alone for scab control. Under heavy disease pressure, sulfur may need to be applied as often as every 3 or 4 days (13). In this program, lime sulfur was applied on a 7-day schedule for primary scab control and wettable sulfur was applied on a 14-day schedule during cover sprays. This was apparently insufficient to provide adequate protection against infection. Kocide and Lime sulfur are superior to sulfur alone for controlling scab; however, their application was stopped at pink and bloom, respectively, due to concerns over fruit finish. This was an insufficient period to provide adequate protection against primary scab. The use of sulfur alone on a 7- day schedule between pink or bloom and second cover resulted in significantly more primary infections than conventional fungicides. When the spray interval was extended to 14 days for the protectant cover spray, sulfur alone could not provide adequate protection against secondary or fruit scab infection. This indicates that near perfect control of primary scab is required if sulfur alone is to be used in cover sprays on a 14-day schedule, especially if wet weather prevails during summer.

The reason for terminating the use of Kocide and lime sulfur at pink and bloom, respectively, during 1990 was concern over fruit finish problems. Whereas copper had a severe affect upon fruit finish, lime sulfur appeared to have little effect. The excellent control of scab achieved in the 1991 organic treatments is attributed to the extended use of lime sulfur through first cover, which provided satisfactory control of primary scab. We also feel that the reduced rate of lime sulfur (4 gallons as opposed to 8 gallons/A) used in the summer cover sprays also provided good control of secondary scab. In 1991, a full season program of lime sulfur had no apparent affect on fruit finish and provided good scab control. All treatments containing Kocide provided unsatisfactory phytotoxicity. This was observed as burned (necrotic) tissue and poor fruit finish. The apparent efficacy of sulfur in providing control of secondary scab in 1991 is probably due to the fact that many leaves that could have supported primary infections by apple scab were literally burned off by the application of Kocide at tight cluster. The use of copper for scab control should probably not be considered past ½ inch green, and possibly even green tip.

The extended protectant program with Nova plus captan resulted in three fewer fungicide applications than treatments applied in a standard protectant program in both years of testing. This reduction in fungicide application should be considered by growers that are interested in reducing their overall fungicide use. The use of inorganic fungicides as well as conventional protectant fungicides alone will continue to require a traditional protectant spray program that results in intensive fungicide use for scab control on susceptible varieties.

Our results indicate that an organic fungicide program of lime sulfur should provide adequate control of apple scab under heavy disease pressure in Ohio. It is generally recommended that sulfur should not be applied if temperatures will rise above 80-85 F. We did not apply fungicides under these adverse conditions, and no phytotoxicity was observed.

If the use of lime sulfur or sulfur in organic apple production systems increases in the future, additional studies on the long-term effects of lime-sulfur and sulfur on nontarget organisms, tree physiology, and other important apple diseases should be conducted. We strongly encourage growers that are interested in organic apple production to grow only scab-resistant varieties, which require no fungicide for scab control.

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Evaluation of Commercially Available Serological Test Kits for Diagnosis of Apple Crown and Root Rot Caused by *Phytophthora* Spp in Ohio

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Abstract

Commercially available serological assay kits (ALERT, on-Site *Phytophthora* Disease Detection Kit) were compared to the culture plate method for detection of *Phytophthora* spp. in apparently diseased (Phytophthora root and crown rot) and apparently healthy apple roots and crowns. Over 3 years of testing, 26 tests were conducted on diseased apple roots apparently affected by *Phytophthora*. All diseased plants gave a strong positive reaction on test kits indicating that *Phytophthora* was present. Of the 26 trees that tested positive for *Phytophthora*, either P. *cactorum* or P. *megasperma* was isolated from 24 of the trees using the agar plate technique. The same test conducted on five apparently healthy trees and five trees affected by white root rot, caused by *Corticium galactinum*, resulted in negative reactions for *Phytophthora*, and no *Phytophthora* spp. were recovered. Our results indicate that the serological test kits provide the capability for rapid, dependable and on-site diagnosis of Phythophthora root and crown rot of apple.

Phythophthora crown and root rot of apple can be caused by several species of *Phytophthora* (6). In Ohio, the species most commonly isolated from apple roots are P. *cactorum* and P. *megasperma*. The disease is generally most severe on orchard sites where soil type, topography and environmental conditions result in regular or extended periods of excessive soil moisture (6). When these conditions are combined with highly susceptible rootstocks, such as MM 106 and M 26, Phytophthora crown and root rot can be a major cause of tree loss in Ohio apple orchards.

Traditionally, control of the disease has been through the use of cultural practices such as proper site selection (good soil drainage) and the selection and use of the more resistant apple rootstocks, such as M 7 and M 9. Today, cultural practices are still the most important control methods; however, the development and registration of two new fungicides (metalaxyl [Ridomil] and Fosetyl-Al [Aliette]) for control of Phythophthora crown and root rot on apple provide growers with additional control options that many are currently using (2, 3, 4). Both of these fungicides are quite specific for fungi in the class oomycetes, such as *Phytophthora* spp. They have little or no efficacy on the other root diseases of apple (5). Thus, the use of these fungicides for control of *Phytophthora* on apple places a new emphasis on timely and correct disease diagnosis. Obviously, these fungicides should not be used unless Phythophthora root rot is confirmed to be the problem. For example, in 1981, 20 percent of the trees in a 20-acre apple orchard in northeast Ohio died over a 3- to 4-week period. Dead trees of several varieties were 5 years old and all were on M 9 rootstocks. The grower assumed the trees were killed by *Phytophthora* root rot, and treated the entire orchard with Ridomil. The disease was eventually diagnosed as rootstock infection by *Erwinia amylovora*, the bacterium that causes fireblight. Thus, the cost of the fungicides applied as well as the time needed to apply it was wasted. In addition, an application of fungicide was made to the environment with no beneficial effect.

Positive diagnosis of Phythophthora root rot on apple has traditionally been accomplished through isolation of the pathogen from affected roots. The use of synthetic agar media that are selective to *Phytophthora* spp. have greatly increased our ability to diagnose the disease (11). However, isolating the pathogen still requires relatively sophisticated materials and equipment for preparation of the media, in addition to a considerable amount of effort, time and expertise required to identify the fungus.

The use of enzyme-linked immunosorbent assay (ELISA) to detect plant pathogens in samples of diseased plant tissue facilitates rapid, on-site and specific diagnosis of disease (1, 7, 8, 9, 10). Commercial development of an immunoassay Phytophthora F-Kit by Agri-Diagnostics Associates, Cinnaminson, NJ, allows commercial growers and plant health professionals to rapidly detect pathogens and diagnose plant diseases caused by *Phytophthora* without the need for time-consuming culture-plate methods.

From 1989 through 1991, we used these commercial Phytophthora test kits in conjunction with the culture-plate method to detect the presence of *Phytophthora* spp. in diseased apple roots from experimental and commercial orchards in Ohio. The purpose of this report is to summarize the results of these tests and to compare the efficacy of commercial test kits with the culture plate method for pathogen detection and disease diagnosis.

Materials and Methods

On Aug. 16, 1989, eight apple trees (variety 'McIntosh' on Mark rootstock) with typical above-ground symptoms of Phytophthora root rot (6) were dug at Snyder Farm, OARDC. All trees were 2 years old. Tops were removed from all trees and the crown and major roots from each tree were placed individually into separate plastic bags and transported in an ice chest to the laboratory. All samples were kept cool (on ice) during transport and stored at 4 C until they were assayed for the presence of *Phytophthora* spp. No samples were stored more than 3 days prior to conducting the tests. Each sample was tested for the presence of *Phytophthora* spp. using the culture plate method and commercial flow-through ELISA, Phytophthora F-Kits. Each test was conducted on the same region of each plant. Tests were also conducted on sections of non-discolored wood cut from below the soil line on three apparently healthy trees for comparison.

Culture Plate Method: Crowns and major roots from all plants were washed under running tap water to remove most of the soil. After washing, the main tap root and crown were observed for typical *Phytophthora* lesions. We considered a lesion to be an area of discoloration (reddish-brown to black) with a sharp line of demarcation between healthy (white) and diseased issues. The epidermis was removed by scraping with a scalpel and discolored tissue samples were taken from near the edge (line of demarcation) of the lesion. A minimum of 25 tissue pieces were placed on a medium selective for *Phytophthora* spp., pentachloronitrobenzene-benomyl-neomycin-chloramphenicol (PBNC) medium (11), and incubated at 24 C for 5 to 7 days. The recovery of *Phytophthora* spp. was recorded from day 5 through 7. Representative fungal isolates were kept for subsequent identification.

Immunoassay (flow-through) ELISA, Phytophthora F-Kit: Phytophthora F-Kits were obtained from Agri-Diagnostics Associates, Cinnaminson, N.J. All materials needed to perform the assays were included in the kits. All immunoassays were conducted on the same region on each root where tissue samples were removed for culture plating. Immunoassays were also conducted on tissue sections cut from the same area on apparently healthy trees where sections were taken for the culture-plate method. The area tested was vigorously rubbed with an abrasion pad, then the pad was placed in an extraction bottle with a filter tip and extraction solution provided with the rapid assay kit. The rapid assay kit utilizes a device with three closely spaced wells on the surface, through which the sample and reagents flow. One is an internal positive control, one is a negative control, and one is the sample well (Fig. 1). Root extract and kit reagents were applied to the flow-through device according to instructions supplied with the kit.

A positive reaction was observed as blue color development in the sample well, with the negative control remaining white. A negative reaction was observed by no color change in the negative control and sample well (both remain white). Tests were considered valid if the internal positive control well turned blue and the negative control well remained white.

In 1990, the procedures described above were repeated on 8 additional trees with typical Phytophthora root and crown rot symptoms. Four samples came from a commercial orchard in southern Ohio (6-year-old Delicious trees on EMLA 106 rootstock) and four samples came from the orchard located at Snyder farm, OARDC (3-year-old trees, two golden Delicious, one Rome and one McIntosh, all on Mark rootstock). Samples from southern Ohio were assayed on July 20 and those from OARDC were assayed on August 30. Tests were not conducted on healthy trees in 1990.

In 1991, additional tests were conducted on five apparently diseased trees from the same orchard at OARDC. All trees were McIntosh on Mark rootstock. Ten additional tests were conducted on trees from the same orchard in southern Ohio where trees were assayed in 1990. Assays were conducted on five trees with typical Phytophthora root and crown rot symptoms, and five declining trees with different below-ground symptoms that were typical of white root rot caused by the fungus

Table 1. Reaction of immunoassay test kits and recovery of *Phytophthora* spp. from apparently healthy and diseased apple crowns and roots, 1989.

	Roots and crowns with typical Phytophthora symptoms[1]		
Location	Sample No.	Reaction[2]	Isolation[3]
OARDC	1	+	+ P. cactorum
	2	+	+ P. cactorum
	3	+	+ P. cactorum
	4	+	+ P. cactorum
	5	+	+ P. cactorum
	6	+	+ P. megasperma
	7	+	+ P. megasperma
	8	+	+ P. cactorum
	Apparently healthy roots and crowns[4]		
Location	Sample No.	Reaction[2]	Isolation[3]
OARDC	9	—	—
	10	—	—
	11	—	—

[1]Roots and crowns were taken from trees showing typical above ground symptoms of Phytophthora root rot (*i.e.* foliar-chlorosis and stunted growth), and brown to brick-red lesions on roots.
[2]Color reaction of test kit, blue=positive (+) and white=negative (0).
[3]Isolations were made from the same area on roots or crown where the immunoassay test was conducted.
(+)=Phytophthora was recovered from roots or crowns.
(−)=no fungus was recovered.
[4]Tests were conducted on apparently healthy trees. Sections of non-discolored wood were cut from below the soil line and were used to conduct immunoassay tests. Pieces of wood from the same sections were also plated on PBNC medium.

Table 2. Reaction of immunoassay test kits and recovery of *Phytophthora* spp. from apple roots and crowns apparently affected by Phytophthora root and crown rot, 1990.

	Roots with typical Phytophthora symptoms[1]		
Location	Sample No.	Reaction[2]	Isolation[3]
OARDC	12	+	+ P. cactorum
	13	+	+ P. cactorum
	14	+	+ P. megasperma
	15	+	+ P. cactorum
	16	+	+ P. cactorum
	17	+	+ P. cactorum
	18	+	—
	19	+	+ P. cactorum

[1]Roots and crowns were taken from trees showing typical above ground symptoms of Phytophthora root and crown rot (*i.e.* foliar-chlorosis and stunted growth), and brown to brick-red lesions on roots.
[2]Color reaction of test kit, blue=positive (+) and white=negative (0).
[3]Isolations were made from the same area on roots or crown where the immunoassay test was conducted.
(+)=Phytophthora was recovered from roots or crowns.
(−)=no fungus was recovered.

Corticium galactinum. All were 7-year-old Delicious trees on MM 106 rootstock. All tests were conducted as previously described. Tests on white-root-rot-affected roots were conducted on decayed tissues located beneath white mycelial mats of the fungus. Assays also were conducted on two apparently healthy trees (4-year-old McIntosh trees on Mark rootstocks) from the orchard located at Snyder Farm, OARDC.

Results and Discussion

In 1989, all test-kit reactions for apparently diseased root tissues were positive (Table 1). *Phytophthora* was also isolated from all of the diseased roots tested. *Phytophthora cactorum* was the species isolated from the majority of the samples, and *P. megasperma* was isolated occasionally (Table 1). All ELISA tests conducted on apparently healthy root and crown tissues were negative. In addition, no fungi were recovered from these healthy roots.

In 1990, positive test kit reactions were obtained from all apparently diseased root and crown tissues tested from both locations (Table 2). *Phytophthora cactorum* was isolated from all samples except sample No. 14 and 18, from which *P. megasperma* and no fungi were isolated, respectively. Attempts to isolate Phytophthora were repeated on sample no. 18, again with negative results.

All immunoassay tests conducted in 1991 on roots apparently affected by Phytophthora root rot were positive (Table 3). *P. cactorum* was isolated from all samples except sample No. 22 and 26, from which *P. megasperma* was isolated, and sample No. 27, from which no fungus was recovered.

Attempts to isolate Phytophthora from sample No. 27 were repeated with negative results.

Tests conducted on roots apparently affected with white root rot or apparently healthy roots were all negative (Table 3), and no fungi were recovered from any of the samples. These results were expected because the causal fungus of white root rot, *Corticium galactinum*, will not grow on PBNC medium.

These data demonstrate the practical use and potential benefits that could be derived from diagnostic kits such as these. For example, the orchard in Scioto County had several trees dying from white root rot in a random manner over much of the orchard. If the grower had simply assumed that the trees were dying from Phytophthora root rot, he may have decided to apply metalaxyl (Ridomil) to certain portions or all of the orchard. Because Ridomil is not effective for control of white root rot, its application would have resulted in unneeded application of fungicides into the environment as well as financial loss to the grower. In situations where Phythophthora root rot is correctly diagnosed, applications of Ridomil may result in limiting spread of the disease.

Our results suggests that the Phytophthora F-Kit is highly effective in detecting the presence of *Phytophthora* spp. in diseased apple roots and crowns. The use of this new technology provides the capability for rapid, dependable and on-site disease diagnosis. Individual tests can be conducted in less than 15 minutes at the grower's location. This is in comparison to the culture-plate technique that requires a minimum of 4 to 7 days, in addition to a relatively sophisticated laboratory fir media preparation, etc. Actual isolation of the pathogen is generally desirable in most plant-disease-diagnostic situations. However, based upon the results of our studies, we feel that the Phytophthora test kits have sufficient reliability to be used as a basis for making fungicide recommendations in orchards where visible disease symptoms are present and positive test results are obtained. These test kits are commercially available and can

Table 3. Reaction of immunoassay test kits and recovery of *Phytophthora* spp. from apple roots and crowns that were apparently affected by Phytophthora root and crown rot, apparently healthy and apparently affected by white root rot, 1991.

	Roots and crowns with typical Phytophthora symptoms[1]		
Location	Sample No.	Reaction[2]	Isolation[3]
OARDC	20	+	+ P. cactorum
	21	+	+ P. cactorum
	22	+	+ P. megasperma
	23	+	+ P. cactorum
	24	+	+ P. cactorum
Scioto Co.	25	+	+ P. megasperma
	26	+	+ P. megasperma
	27	+	—
	28	+	+ P. cactorum
	29	+	+ P. cactorum
	Roots with typical white root rot symptoms[4]		
Location	Sample No.	Reaction[2]	Isolation[3]
Scioto Co.	30	—	—
	31	—	—
	32	—	—
	33	—	—
	34	—	—
	Apparently healthy roots[5]		
OARDC	35	—	—
	36	—	—

[1]Roots and crowns were taken from trees showing typical above ground symptoms of Phytophthora root and crown rot (*i.e.* foliar-chlorosis and stunted growth), and brown to brick-red lesions on roots.
[2]Color reaction of test kit, blue=positive (+) and white=negative (0).
[3]Isolations were made from the same area on root or crown where the immunoassay test was conducted.
(+)=Phytophthora was recovered from roots or crowns.
(−)=no fungus was recovered.
[4]Tests and isolations were conducted on root tissues with typical signs of white root rot (i. e. dry rot covered with white mycelial mats.)
([e]Tests were conducted on apparently healthy trees. Sections of non-discolored wood were cut from below the soil line and were used to conduct immunoassay tests. Wood from the same sections were also plated on PBNC medium.

be purchased by growers at a cost of approximately $15.00 each.

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A Survey of the Pest Management Practices, Information Sources, Needs, and Decision Making Criteria of Ohio Apple Growers

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Abstract

A questionnaire was administered to 49 Ohio apple growers. The growers produced a diversity of crops in addition to apples. Although preventive pesticide applications were generally used, growers also have integrated more cost effective and environmentally sound approaches to their pest control. The level of pest control was generally good, although a few growers had specific pest problems in need of much improvement. The European red mite, *Panonychus ulmi* (Koch), was the most troublesome insect or mite pests of apples, while the highest-ranked disease problem of tree fruit was apple scab, *Venturia inaequalis* (Cke.). The most important problem areas were frost and freeze damage and a lack of time. Spray application was not a highly ranked problem area and spray equipment was often infrequently calibrated. Most growers don't keep records of fruit quality although a majority kept records of yields. Field service from scouts and private consultants was not available to many growers although most would have welcomed more of this type service.

Ohio was ranked 10th among the states in commercial apple acreage in 1985 (USDA Statistical Reporting Service 1986). A survey of Ohio commercial apple growers can be an important tool for gaining a better understanding of many of the aspects of apple production. Our objective was to collect information on the management practices of Ohio tree fruit growers, especially concerning their use of pesticides, pest monitoring, available information sources, microcomputers, record keeping, and their perceptions of important economic loss factors, loss estimates, problem areas, research priorities, goals, and threats to the orchard business. This information is still relevant to the questions being asked and can thus serve as a baseline for economic assessments of future management strategies.

Materials and Methods

Questionnaire Development: The questionnaire was developed to follow-up a 1976 survey of Ohio apple growers by Hall (1977). The growers were also asked other relevant and often related questions in order to build a more comprehensive information base. Questions to determine the grower ranking of information sources and research priorities were adapted from a study of the information needs and types of activities of independent crop consultants in the United Kingdom by Bristow (1983).

Administration of the Questionnaire: A list of commercial tree fruit growers was obtained from the Ohio Cooperative Extension Service (OCES) and the Ohio Fruit Growers Society, Columbus, Ohio. Phone calls were made from the list until the desired number of growers throughout the state were contacted. Forty-nine Ohio apple growers (Fig. 1) completed the 60-question questionnaire during August and September 1984. Each grower was allowed to read and respond to the questions, which were read aloud. Each grower's response was immediately recorded. Later, if a response was found to be unclear or incomplete, a follow-up telephone call was used to get a more accurate response.

In some questions, growers were asked to rank categories. Each number-one ranking was given the same number of points as there were categories, and each number-two ranking was given one less point, and so forth. The number of points for all of the growers' responses were totaled separately for each of the categories to give a weighted index of response. When displayed in tabular form, the category having the greatest number of points was listed first.

Results and Discussion

Apple Acreage and Yield: The orchards surveyed contained 2,960

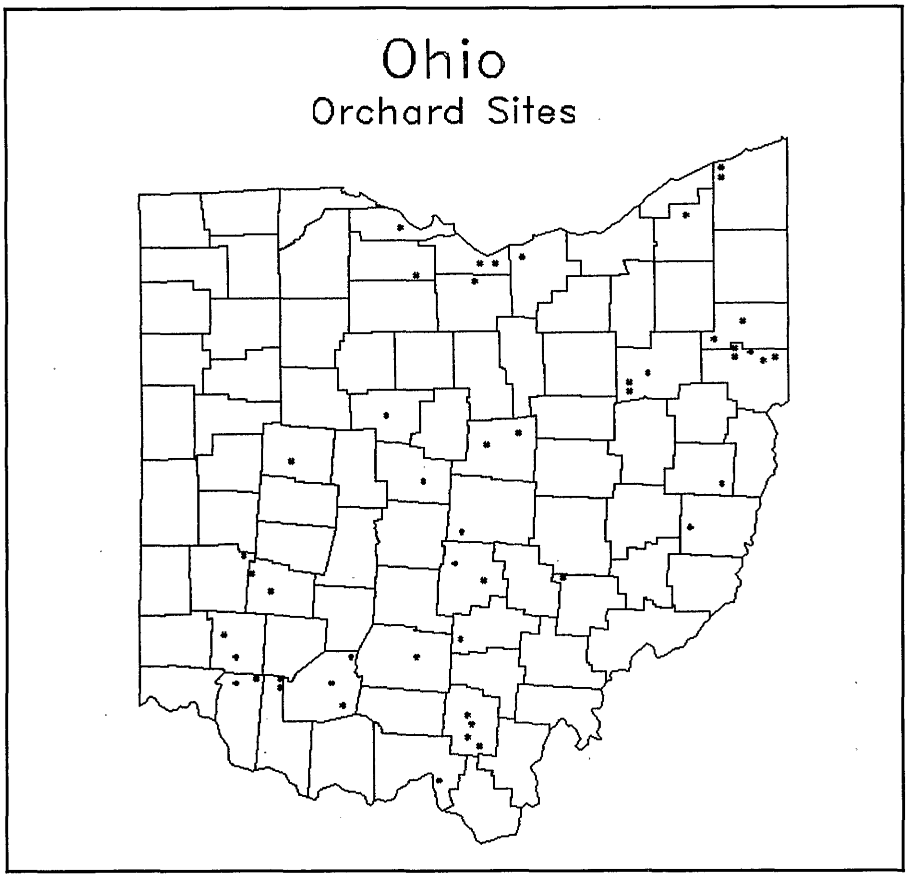

Figure 1. Orchards visited while administering a questionnaire to 49 Ohio apple growers in 1984.

acres of apple trees, which was approximately 30 percent of the commercial apple acreage in the state (Waldron *et al.*, 1986). The average size of the orchards surveyed was 60.4 acres with a range of 9-349 acres.

The average yields in 1983 for 43 of the orchards averaged 298.7 bushels/acre. The growers' estimates of the average yields in a year with more typical weather were 33 percent greater than in 1983. The lower yields in 1983 were attributed to an unusually hot, dry summer. Most growers had little control over weather-related injury or loss due to frost, hail and drought. Only two growers used expensive wind-generating devices to lessen the damage from extreme cold winter temperatures and frost damage in the spring.

Crop Diversity and Acreage: Of the 49 growers surveyed, 94.8 percent were diversified by producing at least one other crop, 71.4 percent had between one and four additional crops, and 22.4 percent had five or more additional crops. Twenty growers with 60 acres or more of apples had an average of three additional crops. In addition to apple, peach was the most common crop grown by 65.3 percent of the growers. In the small fruit category, strawberries were grown by 30.6 percent of the growers on an average of 8.1 acres. Sweet corn was the most common vegetable crop, grown by 24.5 percent of the growers. Excluding the 400 acres of sweet corn grown by one grower, the average acreage of sweet corn was 11 acres.

It would appear from these data that a high degree of crop diversity may be needed to maintain adequate cash flow, enhance retail sales, and as a hedge against crop failure in one or more of the enterprises. Sonka and Patrick (1984) noted that while an increase in crop diversity can reduce risk, the marginal risk reduction decreases with each additional crop. These high levels of crop diversity require a wider range of expertise and decision making by the grower, which increases the probability of making costly mistakes.

Pesticides and Pest Control: Application equipment and calibration. Engine-driven orchard sprayers were used by 50 percent of the growers, while 62.5 percent used power take-off (PTO), and 12.5 percent used both PTO and engine-driven sprayers. Hall (1977) reported that almost 70 percent of the growers used engine-driven orchard sprayers, with the remainder using the increasingly popular PTO because of the energy savings and the trend in smaller-size trees. The 62.5 percent of the growers using PTO sprayers in 1984 was at least twice that found in the earlier survey by Hall (1977).

The last time 55.1 percent of the growers calibrated their spray application equipment was during the spring months of 1984. Only 26.5 percent calibrate their sprayers more than once per season. Another 8.2 percent have not calibrated for a year or more, while 10.2 percent of the growers never calibrate. The use of reduced pesticide rates and low-volume sprayers makes frequent calibration more essential for tree fruit growers (Hall 1977). Calibration is important because worn nozzles can affect spray droplet size and make uneven spray distribution or overapplication of pesticides more of a possibility. Errors in calibration become much more critical as spray gallonage is decreased and the active ingredient concentration is correspondingly increased (Hayden [ed.] 1989). The 73.3 percent of the growers that calibrated their spray equipment one or fewer times per year could potentially benefit from calibrating their spray equipment more often.

Application Techniques: The alternate row-middle technique (ARM) (Lewis and Hickey 1967) only requires spraying one side of a row of trees during each spray application. The time interval between spray applications for ARM is usually shorter than with conventional every row spraying in order to maintain a comparable level of disease and pest control. ARM was used by 16 (32.7 percent) of 49 growers, with three (6.1 percent) using ARM for apple scab sprays only, 8.2 percent using ARM only on young non-bearing trees, and 4.1 percent using ARM on high-density dwarf tree plantings. A survey of Pennsylvania apple orchards showed that ARM comprised 95 percent and 94 percent of all sprays applied in 1978 and 1979, respectively (Hull et al. 1983). In a previous Ohio pesticide usage survey conducted in 1979 and 1980 by Hall (1983), only 11.1 percent and 10.5 percent of the growers surveyed used this technique, respectively. The increased use of ARM reflects the ongoing shift by growers from standard-size trees to the smaller semi-dwarf and dwarf trees. When using ARM, better spray penetration and coverage should be possible on the smaller trees than on the standard-size trees.

Thirty-six (73.5 percent) of 49 growers adjusted their spray application equipment for block density when applying pesticides. While 13 growers (26.5 percent) had not adjusted for block density, six of them did not because their plantings were all the same density, and one did not because the tree spacings within the rows were inconsistent.

Application Strategies and Intervals: Most growers apply cover (post-bloom) sprays from 7 to 14 days after the third cover spray (Table 1). The number of cover sprays applied per season ranged from 4 to 11. Insecticide was added to each cover spray by 40 (90.9 percent) of 44 growers, although two of the 40 growers do not always add insecticide to the last cover spray. Also, three of the four growers that did not add insecticide to each cover spray only left it out of the last one. Ohio tree fruit growers apparently rely heavily on scheduled pesticide use, possibly because it frees them from having to make many difficult and time-consuming decisions (Mumford 1982).

Table 1. The time interval between pesticide sprays after third cover for Ohio apple growers.

Spray interval (days)	% growers
5-7	2.0
7	6.3
7-10	4.2
7-14	2.0
10	10.4
10-14	25.0
10-15	2.0
12-14	2.0
13-14	2.0
14	39.6
14-21	4.2

n=48.

Pests Considered Important: The European red mite (ERM), *Panonychus ulmi* (Koch), was considered to be either the first or second most troublesome insect or mite pest of apples by 79.2 percent of the growers, while some key insect pests such as codling moth, *Cydia pomonella* (L.), and apple maggot, *Rhagoletis pomonella* (Walsh), ranked low (Table 2). Mite control was considered by the growers to be the third most important problem area, after frost and freeze damage, and a lack of time.

Pesticides Used: The use of horticultural grade oil in a dormant or delayed dormant application for the control of ERM and scale insects was used by 97.8 percent of the growers. One or more applications of summer miticide were applied to all or part of the orchard by 97.8 percent of the growers. Annually, the number of applications ranged from none used, to only using Dikar, to using five applications per season. An average of two miticide applications per season was made by 50.0 percent of the growers. Cyhexatin was the most preferred miticide used by 61.7 percent of the growers. These data suggest that the possibility of resistance by ERM to the labeled miticides should be a concern, especially after the voluntary withdrawal of Cyhexatin worldwide by the manufacturer in August 1987. Also, the remaining products may be less efficacious and the registration of new, effective products is slow.

One basic insecticide, predominantly phosmet or azinphosmethyl, was used to control insect pests by 69.4 percent

Table 2. Most troublesome insect or mite pests of tree fruit in Ohio.

Pest	Pest ranking (% growers' response) First	Second	Weighted response
European red mite	54.2	25.0	64
Plum curculio	6.3	8.8	15
San Jose scale	8.3	8.3	12
Spotted tentiform leafminer	6.3	10.4	11
Rosy apple aphid	8.3	2.1	9
Green apple aphid	4.2	8.3	8
White apple leafhopper	2.1	10.4	7
Redbanded & other leafrollers	4.2	0.0	4
Codling moth	2.1	4.2	4
Peachtree borer	2.1	2.1	3
Apple maggot	2.1	2.1	3
Apple grain aphid	2.1	0.0	2
Japanese beetle	0.0	4.2	2
Pear psylla	0.0	2.1	1

n=48.

of the growers. While 30.6 percent of the growers used two insecticides, azinphosmethyl and phosmet were used in a rotation by all but two of these growers.

One basic fungicide was used by 30.9 percent of the growers with captan, Dikar or Polyram being the main choices. The remaining 69.1 percent of the growers used more than one basic fungicide. Captan was used alone or as a mixture with benomyl by 71.1 percent of the growers. Polyram was used alone or as a mixture by 44.4 percent of the growers. Benomyl was used alone or as a mixture by 46.6 percent of the growers, and Dikar was used by 33.3 percent of the growers.

Although the pesticide use patterns may have changed since this survey was taken, preventive pesticide applications are still the primary strategy used for the control of most pests. Prokopy *et al.* (1990) are testing a second-stage apple IPM strategy that would reduce preventive insecticide use by spraying only the perimeter orchard trees and removing neighboring wild host trees for control of apple maggot. Prokopy *et al.* (1990) want to eventually eliminate the need for insecticide or acaricide after early June by ringing perimeter orchard trees with baited visual traps to intercept immigrating apple maggot flies. Computerized models for the prediction of apple scab (Ellis 1992) are used by some growers to let them know when apple scab infection periods have occurred. If a gap in the preventive spray schedule leaves the trees unprotected during an infection period, a sterol-inhibiting fungicide with curative activity can be used as an emergency treatment. Sterol-inhibiting fungicides are also being used with protective (preventive) fungicides to extend the spray interval (Ellis, 1992).

Pesticide Rates and Perceptions of Pesticide Overuse: Although scheduled pesticide sprays were used extensively in Ohio, the high cost of pesticides and possibly a feeling of overdependence on pesticides has led many growers to reduce rates significantly. While 20.4 percent of the growers had not specified the amount of reduction in the pesticide rates used compared to full dilute rates, 12.1 percent of the growers reduced rates 25.0-37.5 percent, 16.2 percent reduced rates 46.4-90.0 percent, and 28.6 percent of the growers used low-volume (LV) rates. The LV rates given in the Ohio Commercial Tree Fruit Spray Guide, bulletin 506-A (Funt, *et al.*, 1987), were a 20-percent reduction in pesticide per acre from the full dilute rates, based on a spray volume of 400 gallons per acre.

In another survey of Ohio apple growers, they were only using approximately 50 percent of the recommended full label dilute application rates for insecticides and fungicides (Hall 1983). In Pennsylvania, growers were using approximately 40 percent of the label rate for full dilute pesticide application (Hull *et al.*, 1983). Hall (1977, 1983) suggested that growers were using lower pesticide rates for a number of reasons, such as more use of low-volume sprayers and dwarfing rootstocks, which results in improved pesticide spray coverage with less pesticide needed. Also, more effective, though often more expensive, pesticides are being used (Hall, 1977, 1983).

Twenty-five (54.3 percent) of 46 growers stated that they may be applying pesticides too often and unnecessarily. The perception of applying pesticides too often and unnecessarily may be due to grower concerns about the toxicity of pesticides to the natural enemies of ERM, pesticide resistance and environmental contamination (Carson, 1962; National Research Council, 1989). These concerns may possibly be heightened whenever a pesticide is pulled from the market due to a previously unknown danger to public health or to the environment. Many growers are addressing these concerns by using pest control practices (Table 3) which allow for a reduction in the amount of pesticide used and the conservation of beneficial predators and parasites. These practices could be considered as the beginning steps of an integrated control program. Unfortunately, the development of integrated pest management programs has been hindered by the generally widespread location of Ohio apple orchards, which have made the use of private consultants and pest scouts difficult to support economically.

Monitoring: Field men, consultants and in-field pest scouting. Field service from private consultants or industry field men was not available to 54.2 percent of the fruit growers. Only 27.1 percent had a consultant or field man making more than 6 calls per season, 8.3 percent received 5-6 calls each season, and 10.4 percent received 2-4 calls per season. Also, 27 growers (56.3 percent) said that they would have used a consultant if one had been available. The amount of monitoring by the growers was probably adequate for a scheduled spray program. Still, grower reaction toward performing more intensive monitoring, as would be used in an IPM program, was favorable.

Pheromone and Lure Traps: Grower use of pheromone traps for pest monitoring was low, which was expected from a relatively new technology. Only 20.8 percent of the growers used pheromone traps to monitor insect pests in 1984, although an additional 20.8 percent had used them in past years. A pheromone trap for spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabricius), which had been used by 20.8 percent of the growers, was the most widely used trap. Pheromone trap catch data was difficult to interpret as a decision making aid, considering the many concurrent key pests occurring during the season and the lack of technical support.

Prediction of Apple Scab Infection Periods: Only one grower out of 49 had the computerized scab infection period predictor, while another grower used wetness, temperature and humidity recorders in conjunction with a microcomputer to make predictions. These two growers had the largest apple acreage of the growers surveyed, with 349.3 and 240 acres, respectively.

Information Sources: The identification of information sources is important because the information a grower receives differs somewhat depending on the source, and this will affect the ultimate decisions a grower makes in pest control (Lawson 1982). The OCES was the primary information source on which 70.8 percent of the fruit growers based their pest control decisions. Also, 66.6 percent of the growers said that the OCES, or specialists and county extension agents, were their primary sources of expertise. The five highest-ranked information sources in order of their usefulness were the grower's own experience, OCES bulletins, OCES and research staff, conferences and technical seminars, and other growers. Although access to information is important in determining whether a grower adopts a new practice, other influences on adoption behavior are grower age, farming experience, risk attitudes and farm structure (Napier, *et al.* 1986).

Table 3. Pest control practices used by Ohio apple growers.

Pest control practices	% growers using each control practice
Pesticides of low toxicity to predatory mites and insects	89.9
Lowered pesticide rates	44.9
Pesticide mixtures	42.9

n=49.

Personal Computers: Only 18.8 percent of the growers said that they used personal computers, and in a related question, 10.2 percent had used personal computers as an information source. If personal computers could help growers make pest control decisions, 87.5 percent of the growers said that they would use them, and an additional 4.2 percent might use them. Lack of suitable software for use in the orchard business was the reason given by 53.8 percent of the growers for not having used personal computers. Also, 28.2 percent said that personal computers were not familiar enough to try, 23.1 percent said that they were too expensive, and 17.9 percent said that they were not needed.

Growers were asked to rank a list of on-farm personal computer applications according to what they used or would like to use. The most preferred use was accounting, followed by short-term farm management, long-term farm management, tax preparation, and mailing lists, respectively.

The limited use of a personal computer by growers was probably due to it being a somewhat costly new technology with limited orchard software available, and requiring training or considerable self study to master. Recent developments in software; such as MARKET MODEL (Willson, *et al.* 1987; Funt, *et al.* 1989), enable growers to analyze the crop yield and quality from packout records for a specific block, cultivar, or farm with the prices received, and the total fixed and variable costs incurred. The resulting enterprise budgets can be used to estimate profitability and evaluate options in both short-term and long-term planning (Osburn and Schneeberger, 1978).

Record Keeping: Only 14.6 percent of the growers had kept records of fruit quality while 62.5 percent had kept records of yields and 95.8 percent had kept chemical spray application records. More comprehensive yield and fruit quality packout records need to be collected by block for each cultivar and rootstock combination so that growers can perform thorough economic analyses. The "information gap" of which Norton (1982) refers is the discrepancy in information farmers need and what they actually receive. An important part of the "information gap" is probably due to growers not collecting and utilizing enough of their own unique, on-farm information.

Important Economic Loss Factors and Loss Estimates: The highest-ranked disease problem of tree fruit by far was apple scab, with 61.2 percent of 49 growers giving it their highest ranking. The next nine diseases in order of importance were powdery mildew, fire blight, flyspeck, collar rot, sooty blotch, peach canker, moldy core, black rot, and cedar rust. Fruit loss estimates from disease were 2.0 percent or less for 44.9 percent of the growers. The fruit loss estimates from disease ranged from less than 0.5 percent to a high of 25.0 percent.

The fruit loss from insects and mites fell in the range of 0.5-2.5 percent for 71.4 percent of the growers, while 18.4 percent and 10.2 percent of them reported fruit loss in the ranges of 2.6-5.0 percent and 5.1-50.0 percent, respectively. The three growers reporting the highest percent fruit damage from insects and mites, with damage of 21.0 percent, 25.0 percent, and 50.0 percent, respectively, listed San Jose scale (SJS), *Quadraspidiotus perniciosus* (Comstock), as the primary cause of fruit damage.

Problem Areas, Research Priorities, Goals and Threats to the Business: The most important problem areas were frost and freeze damage, lack of time, mite control, disease control, labor, pruning practice, deer control, insect control, weed control, water shortage, spray application, bird control, mowing, fruit drop and customers. Also suggested by the growers were the categories of chemical thinning, government regulation and overproduction. The importance of time constraints is exemplified by the high ranking given the time-consuming tasks of pruning and spray applications for control of mites, diseases and insects. Labor management is also time-consuming and maintaining the ideal number of workers can be a problem, especially when there is seasonal variability in the amount of labor needed. One of the reasons that insect control was only eighth in the ranking may be in the good level of control obtained.

The top six areas of the orchard business that growers were having the most problem doing properly were marketing, pruning, harvesting with emphasis on management of labor and timeliness, record keeping, total farm management, and disease control. More information was needed when dealing with these and the other problem areas according to 75.6 percent of the growers.

Growers were asked to rank research areas with one of three priority levels. Research on plant nutrition and growth regulation was given the highest priority. This coincides with the increased use of high-density plantings of dwarf and semi-dwarf trees. The next six areas of research in order of their priority were disease problems, pesticide mixes and rates, alternative non-chemical controls, better chemicals, monitoring and forecasting, and pesticide resistance. The high research priority given disease problems may be due to past losses by growers, which can occasionally be quite disastrous. While 89.8 percent of the growers had losses from disease in the 0.5-5.0 percent range, 10.2 percent had losses in the 5.1-25.0 percent range. Apple scab was the disease most responsible for the higher levels of loss reported. The high ranking given pesticide mixes and rates is probably driven by grower interest in being able to cut costs and still maintain quality. The selection of alternative, non-chemical controls as the fourth-ranked research priority demonstrates the growers' interest in reducing their dependence on chemical pest control.

When growers were asked what they need to remain competitive, the answer given by 35.4 percent of the growers was better fruit quality. It was noted by some that this was especially a problem on the older standard-size trees. The need for better cost efficiency was the next most common answer, given by 18.8 percent of the growers, followed by 8.3 percent needing higher yields or better packout of extra fancy fruit, or both, and 8.3 percent needing higher apple prices.

A list of growers' goals for the orchard ranked in order of importance were higher income, higher yield, keeping the acreage the same, more plantings of a desired combination of rootstock and cultivar, and more acres. Also suggested by the growers were the goals of having fewer acres, and producing more high-quality fruit. The third ranked goal of keeping the same acreage probably depends on growers increasing the total production of high-quality fruit by using high-density plantings. Also, some growers may not be willing to increase acreage because of the greater managerial load and increased capital outlay required.

Government regulation and taxes, overproduction, inflation (high production costs but low selling prices), difficulty in hiring good workers, and weather (winter injury and frost damage) were the five main grower perceived threats to the orchard business. The seeming unpredictability of the threats makes long-range planning very difficult for the grower. An increased flow of quality information to the grower, better information management, and advances in predictive capabilities are needed to overcome some of the uncertainties associated with these threats.

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Effects of Cultural Systems on the Horticultural Performance and Fruit Quality of Strawberries

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Introduction

In midwestern states, strawberries are produced primarily using the matted row cultural system (10). In this perennial system, dormant crowns are initially planted at wide spacings (*i.e.*, 45-75 cm within rows and ≈ 1 m between rows) on level bed surfaces. During the first season of growth, flower buds are removed to enhance root and runner production, and as daughter plants develop, they are allowed to root. Eventually a relatively dense "mat" of plants with a bed width of 30-45 cm is established. Fruit is produced during the second and subsequent seasons, and beds are contained and revitalized yearly using standard renovation practices (8). According to a recent survey, nearly 60 percent of Ohio strawberry growers use the traditional matted row cultural system exclusively (30).

Conversely, the success of high-density, annual strawberry production systems developed in California, Florida and North Carolina has fostered the adoption of some alternative system techniques for use in midwestern production fields. For instance, more than 25 percent of Ohio growers now establish their matted rows on raised bed surfaces (30). Raised bed surfaces are thought to be most advantageous when producing strawberries on heavy, poorly-aerated, poorly-drained and/or compacted soils, where excess moisture from uneven rainfall patterns or frost control irrigation applications often results in increased disease and/or physiological stress (12).

In addition, approximately 15 percent of Ohio growers have experimented with high-density production systems (30) such as the linear spaced row planting system and its successor, the ribbon row system (10,27,37). Both were described by Galletta and Bringhurst (10) as perennial, raised bed techniques involving narrow within- and between-row spacings (10 and 90 cm, respectively) with or without the use of plastic mulches. Proposed advantages of high density systems include the following: greater yields due to the "edge effect," which minimizes the shading of leaf surfaces, less vegetative and more reproductive growth per plant, increased crown branching, increased number of crowns/acre, increased fruit size, earliness, ease of picking, and greater percentage of ripe fruit picked (especially by pick-your-own customers) (4,5,11,12,14,27,29,33,37).

A small percentage of Ohio farmers (≈ 8 percent) have explored the benefits of plastic mulches used in conjunction with raised bed systems (30). Applying plastic mulches to the soil prior to planting supposedly improves plant water and nutrient status through better soil water retention and less nutrient leaching, moderates soil (bed) temperatures (warming or cooling effects are dependent on mulch color and environmental factors), improves weed control, enhances net photosynthesis, reduces insect and disease damage, reduces runnering, promotes crop earliness, increases fruit size, and renders the crop easier to pick (1,6,16,21,23,24,25,34).

Although adopting an entirely new cultural system is a complex task, which may require substantial inputs of time, money and effort (27), some growers who have converted to alternative systems for strawberry production have realized increased yields and other benefits (11,27,29,35,37). This study was initiated for two reasons: 1) to provide a base of information about alternative systems; and 2) to assess the benefits of using raised beds, plastic mulch and close spacing to culture strawberries perennially in a typical northeastern Ohio environment. The effects of cultural systems on plot establishment, subsequent growth and development of plants, yield and fruit quality were evaluated over three seasons.

Materials and Methods

This study was conducted at the Ohio Agricultural Research and Development Center on Wooster Silt Loam soil (fine-loamy, mixed, mesic Typic Fragiudalf) from 1988-1990. A split-split plot design in six replications was used with years as whole plots, cultural systems as primary (1°) subplots and cultivars as secondary (2°) subplots. Pre- and post-planting cultural practices recommended for Ohio strawberry growers (8) were followed throughout the experiment.

Irrigation for stand establishment, subsequent growth and frost control was supplied by overhead sprinklers. Soil moisture levels at a depth of 15 cm were monitored using a Watermark Moisture Meter (G.F. Larson Inc, Santa Barbara, CA), whereas soil (at 6 cm depth), crown and ambient temperatures were obtained using type T thermocouples (Omega Engineering Co., Stamford, CN) and recorded with a Campbell Scientific 21X data logger (Campbell Scientific Inc., Logan, Ut.). Temperatures were measured every 5 minutes, averaged internally and recorded as hourly readings.

To establish the experiment, east- to west-oriented beds (36 m × 1.22 m, 4/rep) were prepared to accommodate the following cultural systems: 1) MR-LB-NM=standard matted row, level beds without mulch; 2) RR-LB-PM=modified ribbon row, level beds covered with white plastic over black plastic mulch (separate sheets of polyethylene, 4 mil/sheet, Strout Plastics, Inc., Minneapolis, MN); 3) MR-RB-NM=modified matted row, raised beds without mulch; and 4) RR-RB-PM=modified ribbon row, raised beds (60 × 20 cm) covered with white over black plastic mulch. Each bed (cultural system) was quadrisected into 2^0 subplots; on 9 June 1988, subplots were planted with dormant 'Earliglow', 'Allstar', 'Sparkle' and 'Tristar' (early season, midseason, late season and dayneutral cultivars, respectively) strawberry nursery stock in single rows/bed at within-row spacings of 15 cm for modified ribbon and matted row systems and 60 cm for the standard, matted row control. Developing fruit was removed from all plots throughout the establishment year. Runners were periodically removed from mulched treatments (RR-RB-PM and RR-LB-PM), whereas daughter plants in unmulched treatments (MR-RB-NM and MR-LB-NM) were allowed to establish matted rows.

Plant growth (leaf number/plant and leaf area/leaflet) was monitored at intervals during the first season. Fully expanded leaves were counted on two randomly-chosen plants/plot; the central leaflet area of two fully expanded leaves/plant was also recorded using an LI-3000 leaf area meter (LI-COR Inc., Lincoln, NE). The impact of cultural system on net photosynthetic and transpiration rates of two 'Allstar' and 'Tristar' leaflets/2^0 subplot was assessed on 29 July and 15 Aug 1988 using an ADC Model LCA-2 portable infrared gas analyzer equipped with a 6.25 cm^2 Parkinson leaf chamber (Hoddesdon, England). On 1 Aug. 1988, photosynthetically active radiation (PAR) was measured in all 2^0 subplots of three replicates using an LI-191 SA line quantum sensor (1 m in length) coupled to an LI-1000 data logger (LI-COR Inc., Lincoln, NE). Measurements were taken from 30 cm above the canopy with the sensor facing the canopy to determine PAR levels reflected from bed and leaf surfaces, and from mid-canopy height with the sensor facing skyward to quantify PAR penetrating the canopy surface.

On 15 Nov. 1988, dormant plants were removed from the central 1 m of each 2^0 subplot and dry weights of plant parts obtained. A winter cover of straw ($\approx$20 cm thick) was applied to all plots on this date and removed 8 May 1989.

Total, marketable and cull yield data from two representative 3 m sections of each 2^0 subplot were recorded throughout the fruiting cycle of each cultivar. Fruit harvest commenced on 6 June 1989 and continued at semiweekly intervals until 7 July 1989; thereafter, 'Tristar' (dayneutral) was harvested at weekly intervals until 9 Sept. 1989. Fruit from the second harvest of each system/cultivar treatment combination were combined over replications, and representative samples of 10 fruit/treatment were evaluated for the following quality characteristics: wt/berry; soluble solid levels; skin strength and flesh firmness by the method of Ourecky and Bourne (18) using an Instron 1101 firmness tester (Instron Corp., Canton, MA) equipped with a 0.95 cm star punch (Dunkley Co., Kalamazoo, MI); and external color at three sites and internal color at two sites on each berry using a Minolta CR-100 chromameter (Minolta Corp, Meter Div., Ramsey, NJ). Raw color data was transformed according to Setser (31) and then reduced to a principle component (28). In addition, approximately 200 g of each treatment combination were frozen for titratable acidity analysis. At a later date, these samples were thawed and then pureed; duplicate 10 g of macerate were extracted with 90 ml of neutralized H_2O. The extracts were filtered through a qualitative grade filter paper (e.g., S/P Grade 361, Baxter Healthcare Corp., McGaw Park, IL); then, 25 ml aliquots of filtrate were titrated against 0.1 N NaOH to an endpoint of pH 8.1.

After the June 1989 harvest season, all plots of June-bearing cultivars were renovated without thinning, whereas everbearing 'Tristar' plots were not subjected to renovation. A winter cover of straw was maintained on all plots from 4 Dec 1989 to 16 April 1990. Fruit harvest was initiated on 25 May 1990 and continued at semiweekly intervals until 2 July 1990; harvest of 'Tristar' continued at weekly intervals until 18 Aug. 1990. Again, yield data were recorded throughout the fruiting season of each cultivar. Size and quality of 1990 fruit were determined as described above. Runner removal and renovation procedures were not practiced in the 1990 season in order to determine the effect of cultural system on plant growth. At experiment termination (3 Sept. 1990), plants were harvested from two 1 m sections of each 2⁰ subplot (two replications only); plant and crown numbers along with plant, crowns, leaf, root and runner dry wts were ascertained.

Analyses of variance for all temperature, plant development, fruit yield and fruit quality data were performed on an HP 3000 mainframe computer using an in-house statistical analysis program. Main effect and interactive means were separated using Duncan's Multiple Range test ($P \leq 0.05$).

Results and Discussion

Bed establishment and first season plant development: In general, the use of a mulched, modified ribbon row system appeared to enhance plot establishment and first season development. Improved canopy development in mulched, ribbon row plots was visually evident within one month of planting, and this distinction continued throughout the first season of growth (Fig. la-b). Initially, plants in these plots exhibited significantly greater central leaflet areas than those from plants in unmulched, matted plots. However, as the season progressed, the increased canopy surface area associated with mulched systems resulted from greater leaf number per plant rather than from larger individual leaflet size. At the end of the growing season, plants from mulched, ribbon row plots had a greater number of branched crowns, and had heavier crown and leaf dry wts than plants grown in unmulched systems (Table 1). Mulched ribbon row techniques also resulted in larger root systems, especially in 'Allstar' and 'Earliglow' (interactive means not shown). Other studies (6,23,25) described similar enhancements in establishment rates and/or in overall vegetative vigor (root, leaf and crown dry wts. and on leaf, crown and runner numbers, and shoot/root ratio) with the use of raised beds and/or polyethylene mulch. Enhanced vegetative vigor has also been associated with culture in high density systems (10,11,20).

Effects of mulch and bed height— The summer of 1988 was one of the hottest and driest seasons on record in northeastern Ohio (Figure 2a); ambient temperatures exceeded 32.2° C (90° F) on 20 of the first 45 days of the experiment (9 June 1988 to 23 July 1988). During this period, relative humidities were low and the monthly surface evaporation totals exceeded the average totals of the preceding 10 years by more than 40 percent (36).

As in other studies (1,16,23,24,34), the effect of plastic mulch on plant development may have been due in part to improved moisture retention (availability). In August, mulched plots within bed types were wetter than those without plastic mulch (Figure 3a), even though the fully-developed canopy in mulched, ribbon row systems could have resulted in a high transpiration loss/plot. Conversely, in unmulched plots, high temperatures and surface evaporation totals may have increased the relative importance of surface evaporation to the overall water balance of the plant-soil system. In August, unmulched plots were often near the 70-100 centibar range, which indicated the necessity of irrigation (Figure 3a).

Raised beds (mulch or no mulch) tended to be drier than level beds. These results were in agreement with two previous studies (12,20) reporting matric water potential to be more negative (drier) in raised than level beds. However, bed height did not appear to affect plant establishment (Table 1).

Plastic mulch may have also enhanced plant establishment by moderating soil temperatures. For instance, for the period between 1 July and 15 August, mulched plots exhibited significantly lower average maximum and significantly higher average minimum soil (root) temperatures than their unmulched counterparts (Table 2). Water and nutrient assimilation rates, and ultimately, overall vegetative growth were reported to be optimal at root temperatures near 24° C (10,22,26). Since the temperature-buffered, mulched plots were more often maintained at or near this optimum temperature than plots without mulch, root growth and ultimately plant growth were enhanced. Several researchers have suggested the use of polyethylene mulch for increased soil warmth during critical development periods (16,23,24,25, 34). Alternatively, Galletta (9) and Fear and Nonnecke (6) discussed the potential benefit of polyethylene and straw mulches for reducing summer soil temperatures in dayneutral strawberry production fields. In the latter study, straw or white on black polyethylene mulches held root tempera-

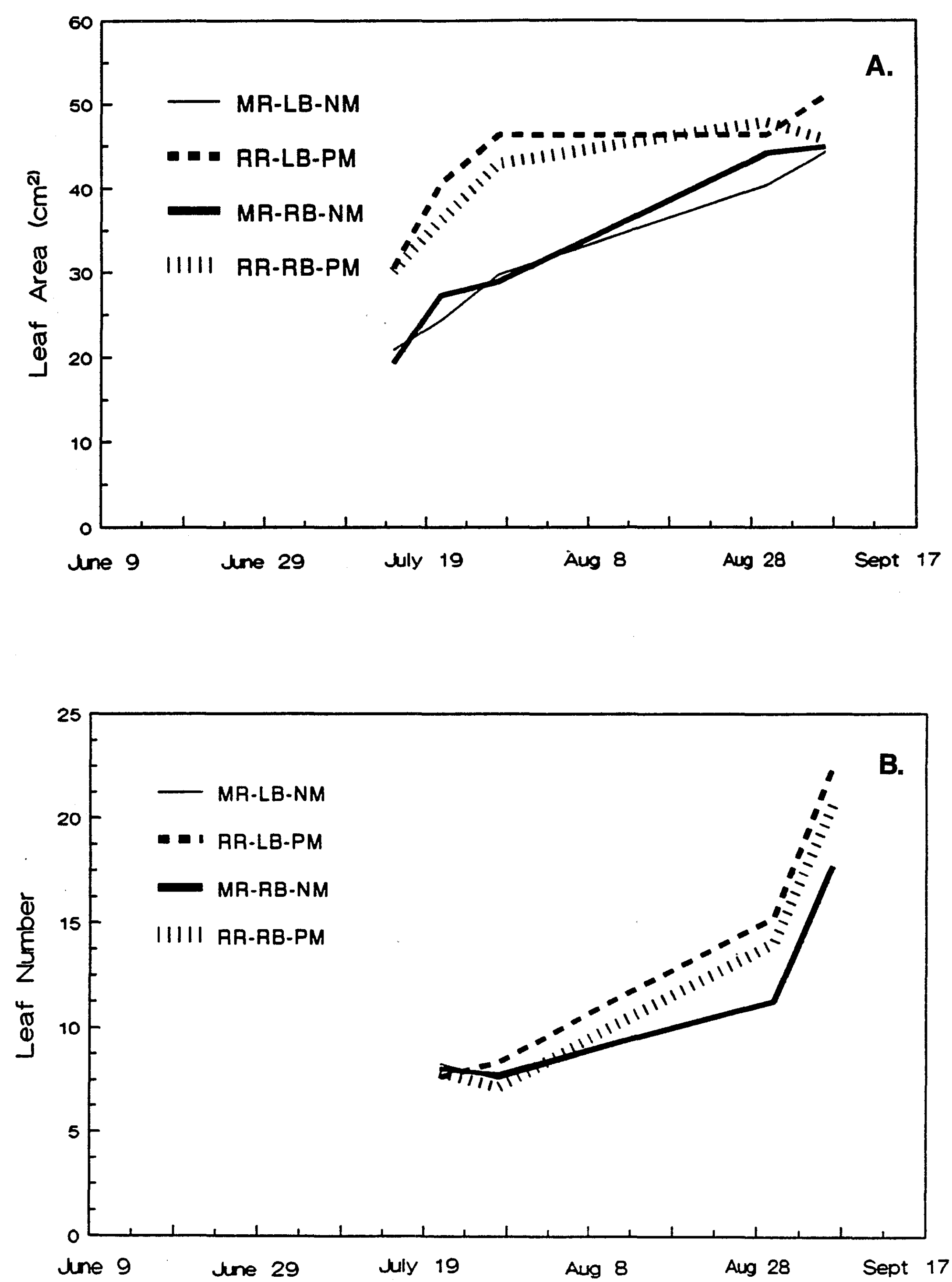

Figure 1. Canopy development within cultural systems during plant establishment and first season growth: (a) central leaflet areas; (b) leaves/crown.

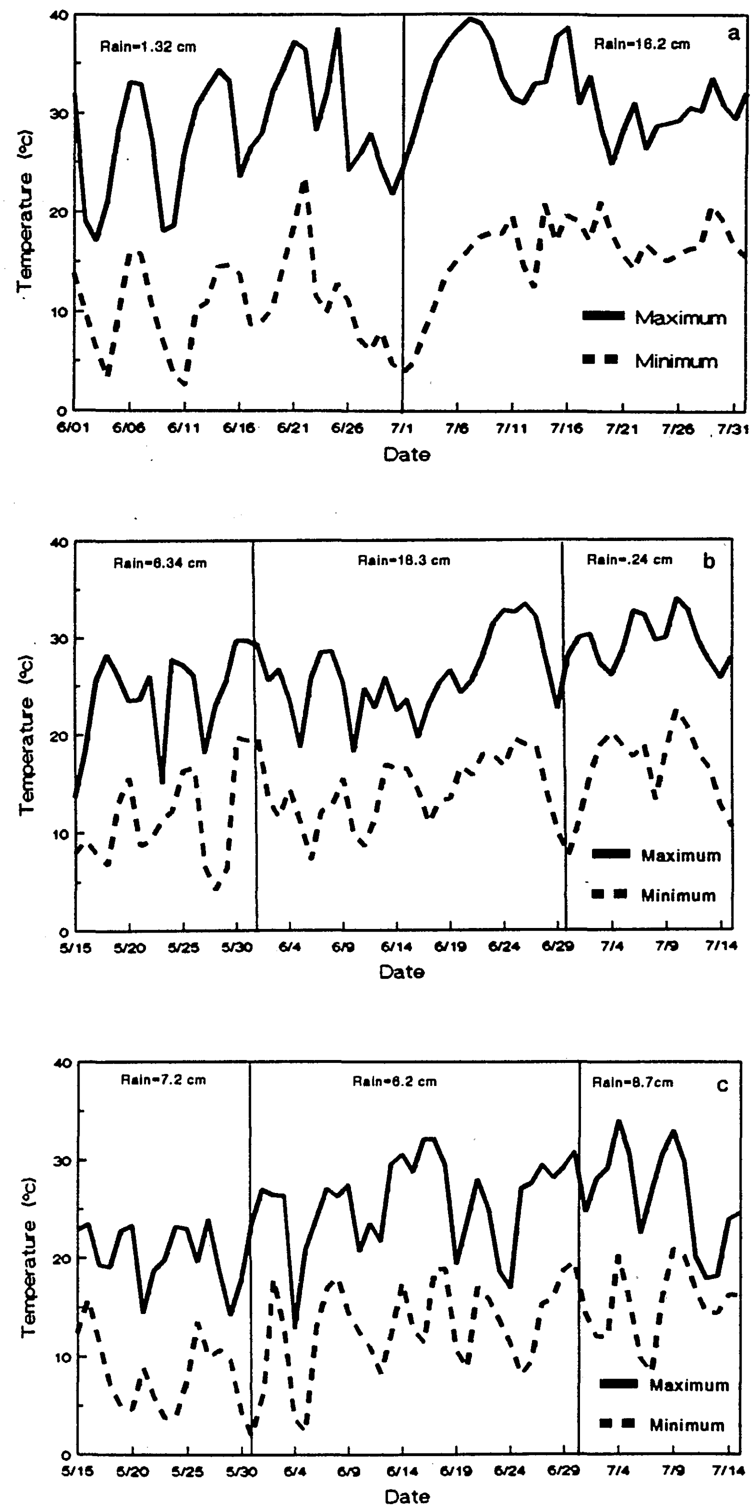

Figure 2. Ambient temperature maximums and minimums and rainfall patterns: (a) during plant establishment; (b) during second season fruit ripening and harvest; (c) during third season fruit ripening and harvest.

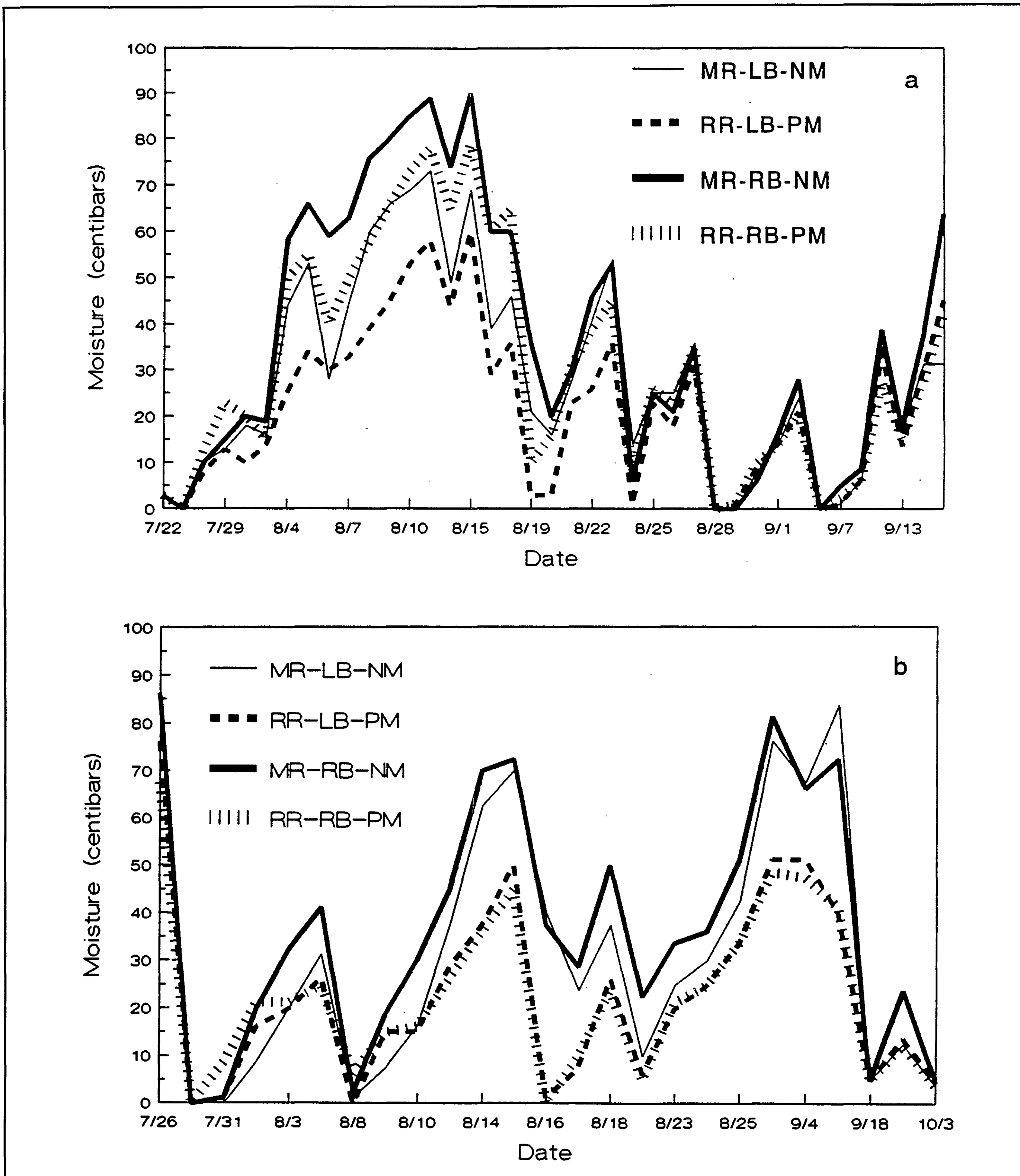

Figure 3. Soil moisture levels within cultural systems: (a) summer 1988; (b) summer 1989; higher soil moisture tension levels (centibars) indicate drier soils.

tures within the optimum range for fruiting while limiting runner (stolon) production, whereas clear and white plastic materials promoted vegetative growth.

The use of plastic mulch also affected environmental parameters in the above-ground portion of the plant. From 1 July to 15 August, the effect of mulch on crown maximum and minimum temperatures was similar to but even greater than its influence on soil temperatures (Table 2). During this period, the reduction in the maximum daily crown temperatures of mulch-grown plants over their unmulched counterparts may have resulted, in part, from increased shading provided by a greater canopy surface area (Figure 1a-b). However, the pattern of crown temperature moderation associated with mulched plots continued throughout the remainder of the season, even as canopies of all plots developed more fully and crowns were more universally shaded.

Table 1. Cultural system and cultivar means and interaction significance levels for crown, leaf and root development in strawberries following their first season of growth.

Effects and levels	Crown/ plant	Crown wt./plant (g)	Leaf wt./plant (g)	Root wt./plant (g)
		Main effect means[1]		
Cultural system (CS)				
MR-LB-NM[2]	2.4 b[3]	9.3 b	26.7 b	5.3 c
RR-LB-PM[4]	3.0 a	14.4 a	47.4 a	9.4 a
MR-RB-NM[5]	2.5 b	10.3 ab	32.7 b	7.4 b
RR-RB-PM[6]	2.9 a	15.2 a	47.9 a	11.1 a
Cultivar (CV)				
Allstar	2.1 a	11.3 b	42.7 a	9.7 a
Earliglow	2.3 bc	15.1 a	41.4 a	9.5 a
Sparkle	2.4 b	10.4 b	38.8 ab	7.0 b
Tristar	3.9 a	12.4 ab	31.4 b	7.0 b
		Interaction significance levels		
CS X CV	.NS[7]	.NS	.NS	0.03

[1]All wt./plant means expressed on a dry wt. basis.
[2]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[3]Mean separation within main effects by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[4]RR-LB-PM= modified ribbon row, level beds covered with white on black polyethylene mulch.
[5]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[6]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[7].NS=not significant at $P \leq 0.05$.

Some researchers (17,19) have suggested that the use of polyethylene mulches may increase photosynthetic efficiency and/or affect carbohydrate partitioning patterns by increasing photosynthetically-active radiation (PAR). For example, Himelrick (16) characterized white plastic as reflecting 80 percent of its incident sunlight back into the plant canopy. In this experiment, differences in reflected PAR among treatments appeared to be more closely associated with bed style (level or raised) than with the use of mulch (Table 3). However, it is doubtful that photosynthetic capacity was increased by the amount of light reflected by any of the cultural systems used, as it was far less than the level of incident sunlight (*i.e.*, background PAR values for full sunlight ≈1100 μmol s^{-1} m^{-2}). Light penetration tended to be greatest in unmulched plots as plants were less-developed, especially for the standard matted row (MR-LB-NM). Goulart and Funt (12) also reported an inverse relationship between PAR and plant spacing. Photosynthetic (Pn) and transpirational (Tr) rates of individual leaflets appeared to be unaffected by cultural system (Table 3), but the greater canopy surface area observed in mulched plots may have resulted in a higher overall production of photosynthate/crown and higher transpiration rates in RR-LB-PM and RR-RB-PM plots than in their unmulched counterparts. It is this overall effect that may have improved establishment and subsequent growth in mulched, ribbon row plots.

Effects of row style—In addition to a greater canopy surface area and presumed increase in available photosynthate/crown, the enhanced growth of individuals in mulched, ribbon row systems may have been influenced by the manner in which the increased photosynthates were partitioned. Periodic runner removal, a common practice for establishing and maintaining plants in this system, may have drastically altered the carbohydrate partitioning pattern within the plant, and the lack of stolons as sinks for photosynthate may have reserved energy for the growth of leaves, roots, crowns and flower bud initiation. Increased vegetative and

Table 2. Mean daily maximum and minimum crown and soil temperatures and temperature fluctuations during critical periods throughout the experiment.

Cultural systems	Max. crown temp. (°C)	Min. crown temp. (°C)	Crown temp. fluctuation (°C)	Max. soil temp. (°C)	Min. soil temp. (°C)	Soil temp. fluctuation (°C)
			1 July 1988—15 August 1988			
MR-LB-NM[1]	32.4 a[2]	19.6 b	12.8 a	28.5 a	21.3 b	7.2 a
RR-LB-PM[3]	28.6 b	21.2 a	7.4 b	25.7 c	22.7 a	3.0 c
MR-RB-NM[4]	32.4 a	19.9 b	12.5 a	28.8 a	21.5 b	7.3 a
RR-RB-PM[5]	27.7 b	21.8 a	5.9 c	27.3 b	22.9 a	4.4 b
			1 December 1988—28 February 1989 (coldest nights)[6]			
MR-LB-NM	0.3 a	−0.5 ab	0.8 bc	0.7 b	0.5 b	0.2 a
RR-LB-PM	0.0 ab	−1.4 c	1.4 a	1.3 a	1.0 a	0.2 a
MR-RB-NM	−0.3 b	−1.2 bc	1.0 b	0.2 c	0.0 c	0.2 a
RR-RB-PM	0.2 ab	−0.3 a	0.5 c	0.7 b	0.4 b	0.3 a
			1 December 1989—28 February 1990 (coldest nights)[7]			
MR-LB-NM	−2.3 c	−7.8 d	5.1 a	−0.7 ab	−1.2 ab	0.5 a
RR-LB-PM	−2.2 bc	−5.0 c	2.8 b	−0.1 a	−0.5 a	0.5 a
MR-RB-NM	−1.4 ab	−3.3 b	1.9 bc	−1.0 b	−3.5 b	1.1 a
RR-RB-PM	−0.8 a	−1.8 a	1.0 c	−0.7 ab	−2.1 ab	0.7 a

[1]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[2]Mean separation by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[3]RR-LB-PM=modified ribbon row, level beds covered with white on black polyethylene mulch.
[4]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[5]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[6]The twenty coldest night temperatures of the season occurred on 10,11,12,15,16,29,30 Dec. 1988, on 3,4,21 Jan. 1989 and on 4,6,7,8,9,18,23,24,25,28 Feb. 1989; mean maximum and minimum ambient temperatures on these days were −2.1°C (28.3°F) and −13.2°C (8.3°F), respectively.
[7]The twenty coldest night temperatures of the season occurred on 12,13,14,15,16,17,18,19,20,21,22,23,24,26,27 Dec. 1989 and on 20,21,24,25,26 Feb. 1990; mean maximum and minimum ambient temperatures on these days were −5.7°C (21.8°F) and −18.7°C (−1.7°F), respectively.

reproductive growth following runner removal in ribbon row systems was reported by others as well (10,11,20, 33). If such redirection of carbohydrates did occur, however its effect would have been greatest later in the season when plants were runnering profusely. Conversely, the mulch effects discussed above were perhaps most important early in the season prior to substantial canopy development.

Second and third season plant development:

Effects of mulch and bed height on winter damage—Statistical differences in maximum and minimum crown temperature on the 20 coldest nights during the winter of 1988-1989 could be attributed to growing system (Table 2). However, cultural system apparently had little effect on crown damage, as visual ratings for density/plot (data not shown) taken in the spring indicated all plots to have overwintered successfully. In support of this contention, system average minimum temperatures on cold nights were well above the critical temperature of −3.3° C (25° F), which has been reported to cause crown damage in many cultivars (3,10). Crown temperatures slightly below the critical level were recorded on only two occasions (12 and 13 Dec. 1988), and these readings were obtained simultaneously in both matted row (unmulched) systems. Minimum soil temperatures were also considered to be moderate (Table 2). However, within mulch treatments, the average minimum soil temperatures in raised beds was significantly colder than that determined for level beds, which supported earlier observations (15,20,23).

Based on spring plant density/plot scores, plants cultured under all systems sustained far greater cold injury during the 1989-1990 winter

Table 3. Cultural system and cultivar means and interaction significance levels for photosynthetically-active radiation levels, net photosynthesis and transpiration rates in strawberry canopies during their establishment season.

Effects and levels	PAR (μ mol s^{-1} m^{-2})[1] Above canopy	PAR Mid-canopy	Pn (mg CO_2 dm^{-2} hr^{-1}) 29 July	Pn 15 Aug	Tr (g H_2O dm^{-2} hr^{-1}) 29 July	Tr 15 Aug
			Main effect means			
Cultural systems (CS)						
MR-LB-NM[2]	80.3 a[3]	887.9 a	20.7 a	22.3 a	3.85 a	2.29 a
RR-LB-PM[4]	78.4 a	446.4 a	22.5 a	22.1 a	4.23 a	2.45 a
MR-RB-NM[5]	43.8 b	667.4 a	22.6 a	22.3 a	3.78 a	2.46 a
RR-RB-PM[6]	59.6 ab	521.1 a	22.1 a	20.5 a	4.01 a	2.26 a
Cultivar (CV)						
Allstar	75.6 a	655.4 a	20.8 b	20.4 b	3.96 a	2.44 a
Earliglow	61.7 a	588.6 a	.ND[7]	.ND	.ND	.ND
Sparkle	62.8 a	652.2 a	.ND	.ND	.ND	.ND
Tristar	62.2 a	626.7 a	23.1 a	23.1 a	3.98 a	2.28 a
			Interaction significance levels			
CS X CV	.NS[8]	.NS	.NS	0.04	.NS	.NS

[1]Light measurements taken on 1 August with sensor at two locations: from 30 cm above canopy with sensor facing canopy to determine PAR levels reflected from bed and leaf surfaces, and from mid canopy height with sensor facing skyward to quantify PAR penetrating the canopy surface.
[2]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[3]Mean separation within main effects by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[4]RR-LB-PM= modified ribbon row, level beds covered with white on black polyethylene mulch.
[5]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[6]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[7]ND=not determined.
[8]NS=not significant at $P \leq 0.05$.

season than they had in the winter of 1988-1989. Outright loss of plants appeared to be greatest among mulched, ribbon row treatments, especially those plots with level beds (RR-LB-PM). One RR-LB-PM/'Tristar' replicate was lost entirely. The mean minimum ambient temperatures of the coldest 20 nights [−18.7°C (−1.7°F)] was 5.5 degrees colder than corresponding temperatures experienced in 1988; the coldest hourly temperature of the year [−29.0°C (−20°F), 22 Dec. 1989] was 12 degrees colder than the coldest hourly temperature of 1988. Although it was not evaluated directly, some sublethal crown damage presumably occurred as mean minimum crown temperatures in all cultural systems equalled or exceeded the critical temperature of −3.3°C on at least five nights throughout the season. Cultural system maximums and minimums were statistically different; minimum crown temperatures in unmulched plots were colder than those in mulched plots and alternately, crown temperature minimums in level beds were colder than those in raised beds (Table 2). These results seemed anomalous when compared to the distribution of damaged plots witnessed the following spring. However, several of the coldest nights in December 1989 and especially in February 1990 were preceded by periods with relatively high winds (36). During these periods, the straw winter cover often shifted, exposing or nearly exposing some crowns directly to ambient conditions until the straw could be manually repositioned. Polyethylene mulched plots seemed especially vulnerable to temporary loss of winter cover. Therefore, crown damage or death throughout the field may have resulted more directly from the effects of exposure rather than from cultural system effects per se. Wetherell (37) cautioned that in some cases, maintaining mulch cover on raised beds may also be difficult. Mean soil temperature maximums and minimums were also lower than they were in the previous season: within mulch treatments, minimum raised bed soil temperatures were lower than those recorded in level beds, again supporting the work of others (15, 23).

Effects of mulch and bed height on summer moisture retention—In contrast to 1988, the summer of 1989 was relatively cool (Figure 2a-b), and during the June harvest, the precipitation level at Wooster was nearly double that of the average for the preceding 80 years (36). During midsummer, soil moisture levels were again substantially higher in ribbon row systems with polyethylene mulch than in matted row systems lacking mulch. The effect of mulch on 1989 soil moisture levels was more dramatic in 1989 than it was in 1988, but in contrast, the effect of raised bed systems on soil moisture was not nearly as pronounced as it was in the previous season (Figure 3a-b). Normally, increased moisture retention is considered to be a positive attribute of a cultural system, although in June 1989, when precipitation levels were higher than normal, the increased drainage offered by raised beds and/or increased surface evaporation in unmulched plots may have been beneficial.

Effects of cultural system on plant development in established plots—Regardless of bed style (level vs. raised), plant development after three seasons of growth differed significantly in matted row vs. ribbon row plots for all development parameters studied except leaf wt/plant (Table 4). In matted rows where runners were allowed to peg, the number of plants/plot was 3-5 times greater than it was in ribbon row systems that underwent periodic runner removal. The plants remaining in mulched, ribbon row treatments were essentially large, three-year-old mother plants with extensively branched crowns and well-developed root systems. These plants tended to produce greater leaf wt/plant, and when allowed to runner in their third year, developed more runners than their matted row counterparts. In contrast, plants remaining in unmulched, matted rows were a mixture of mother plants and younger plants that had resulted from the pegging of runners in the summers of 1988-1990. Other researchers have noted similar differences in crown and leaf development patterns for plants cultured under ribbon row or matted row systems (11,20), with the increased vegetative growth in the former attributed to runner removal (11). Cultural system-mediated developmental differences were considered to regulate reproductive parameters at the time of floral bud initiation (fall), and thus, the yield potential of individuals within systems (33).

The effects of year, cultural system and cultivar on yield parameters: The economic return from planting season yields has been extolled as a means to offset the higher cost of nursery stock for high-density, ribbon row plantings (10). However, in this experiment, flowers were removed from all treatments during the planting year because the nursery stock was set in early June, approximately three weeks later than recommended (8,10), and because the avoidance of fruiting stress during plant establishment under extremely adverse environmental conditions was deemed necessary. In addition, Popenoe and Swartz (20) found planting year fruit to be too sparse and too small for an economic harvest.

Marketable yield per 3 m plot was similar in both harvest years and differences in cultivar performance followed well-established patterns for 'Allstar', 'Earliglow', 'Sparkle' and 'Tristar' based on research and production experience (Table 5). However a significant CV × YR interaction suggested that cultivars responded differently to 1989 and 1990 environments with respect to yield (Figure 4a). The marketable yield of 'Allstar' was adversely affected by the cool wet conditions experienced during the 1989 harvest season whereas 'Tristar' suffered significant yield reductions in 1990, presumably as a result of extensive winter damage.

Although growers have reported ribbon row yields as high as 34,746 kg/ha (31,000 lbs/ acre) (11), researchers in the Midwest and Northeast have generally found matted row culture to be the more productive of the two systems (2,4,12,13,15,21,35). In this study, mulched, ribbon row plots also exhibited lower marketable yields than their unmulched matted row counterparts (Table 5). As third season marketable yields per plant were not statistically different among cultural systems, the low yields associated with ribbon rows may have been due, in part, to their narrow bed width resulting in a reduced number of plants per plot (Table 4).

Admittedly, in a commercially-established ribbon row planting, the narrow bed width would allow for less spacing between rows than that used for matted row culture. Hancock (13) envisioned that successful ribbon row systems would require approximately 50 percent more rows than their matted row counterparts. However, in this experiment, the discrepancy in yield between row types was even greater: one would have had to double the number [*i.e.*, decrease the between row spacing to approximately

Table 4. Cultural system and cultivar means and interaction significance levels for plant, crown, leaf, root and runner development in strawberries following their third season of growth.

Effects and levels	Plants/ plot[1]	Crown plant	Crown wt./plant (g)	Leaf wt./plant (g)	Root wt./plant (g)	Runners/ plant	Runner wt./plant (g)
			Main effect means[1]				
Cultural system (CS)							
MR-LB-NM[3]	38.9 a[4]	2.5 b	8.0 b	12.9 a	2.3 b	1.5 c	1.9 c
RR-LB-PM[5]	7.0 c	6.0 a	22.3 a	37.2 a	5.5 a	8.8 a	9.1 a
MR-RB-NM[6]	26.5 ab	3.1 b	12.2 b	17.9 a	2.1 b	2.2 bc	2.1 c
RR-RB-PM[7]	9.9 bc	5.2 a	19.6 a	36.9 a	4.1 ab	6.1 ab	5.3 b
Cultivar (CV)							
Allstar	21.1 a	3.2 b	9.0 b	17.5 a	2.8 b	4.9 a	4.9 a
Earliglow	23.7 a	3.8 b	13.1 b	26.8 a	3.3 b	7.3 a	5.4 a
Sparkle	28.1 a	4.4 ab	11.2 b	33.0 a	2.6 b	5.4 a	3.2 a
Tristar	9.4 b	5.4 a	29.0 a	27.4 a	5.3 a	1.0 b	4.9 a
			Interaction significance levels				
CS X CV	.NS[8]	.NS	.NS	.NS	.NS	.NS	.NS

[1]plot=2 m
[2]All wt./plant means expressed on a dry wt. basis.
[3]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[4]Mean separation within main effects by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[5]RR-LB-PM=modified ribbon row, level beds covered with white on black polyethylene mulch.
[6]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[7]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[8].NS=not significant at $P \leq 0.05$.

50 cm (20 in)] in order to obtain yields equal to those of the matted row systems. The implementation of such a system would have been impractical as it would most likely have resulted in a canopy surface that covered the entire field, substantial inter-row competition for sunlight and other detrimental effects of overcrowding. Alternately, one might have reduced the within-row spacing by one-half [to 7-8 cm (≈ 3 in). However, Durner and Poling (5) maintained that very close within-row spacings in ribbon row systems did not increase crown number sufficiently enough to offset poor crown productivity due to over crowding.

Even though plant spacings within ribbon rows in this experiment were purposely chosen to avoid overcrowding, third season marketable yields per crown in both ribbon row treatments were significantly lower than those exhibited by their matted row cultured counterparts (Table 5). The low productivity/crown in ribbon row plots may have resulted from the following: winter injury to exposed crowns; from stress caused by intraplant competition between branched crowns during the preceding autumn when reproductive variables such as inflorescence, flower and berry numbers were being established (33); and from the use of cultivars not suited to this method of culture. Successful high density plantings in areas such as California, Florida and North Carolina are based upon cultivars specifically developed to suit this cultural technique (10). Moreover, midwestern cultivars have been found to respond differently to ribbon row culture. Wetherell (27) mentioned the suitability of 'Raritan' for raised bed, high density plantings. Hancock and coworkers (14) found 'Guardian' yields to be similar under ribbon row and matted row culture, but 'Midway' yields were significantly increased using the matted row system. In addition, Durner and Poling (5) demonstrated differences among six cultivars for yield and crown productivity in response to plant spacing. Successful ribbon row culture was thought to require cultivars that are less vigorous vegetatively, channel a greater portion of their water, nutrients,

Table 5. Year, cultural system and cultivar means and interaction significance levels for yield and berry weights of strawberries during their second and third season of growth.

Effects and levels	Second and third season yields[1] Marketable yield/plot[3] (g)	Culls/ plot (%)	Marketable yield/plant (g)	Third season yields[2] Marketable yield/crown (g)	Berry wt.[4] (g)
			Main effect means		
Year (YR)					
1989	2502 a[5]	33.3 a	.NA[6]	.NA	12.4 b
1990	2350 a	26.2 b	96.5	26.1	14.9 a
Cultural system (CS)					
MR-LB-NM[7]	3625 a	27.4 b	82.4 a	31.0 a	14.8 a
RR-LB-PM[8]	1431 c	32.6 a	99.9 a	17.5 b	13.0 b
MR-RB-NM[9]	3156 b	29.4 b	108.7 a	36.9 a	15.0 a
RR-RB-PM[10]	1490 c	29.5 b	95.1 a	19.1 b	11.9 c
Cultivar (CV)					
Allstar	2393 b	33.0 b	101.2 a	34.3 a	15.0 b
Earliglow	1709 c	22.9 c	44.6 b	15.6 c	17.1 a
Sparkle	3070 a	25.0 c	116.4 a	31.1 ab	12.9 c
Tristar	2531 b	38.2 a	123.9 a	23.4 bc	9.7 d
			Interaction significance levels		
CS X YR	0.002	0.020	.NA	.NA	.NS[11]
CV X YR	<0.001	<0.001	.NA	.NA	<0.001
CV X CS	.NS	0.002	.NS	.NS	.NS
CV X CS X YR	<0.001	.NS	.NA	.NA	0.001

[1]For YR means, n=192; for CS and CV means n=96.
[2]For YR means, n=64; for CS and CV means, n=16.
[3]plot=3 m.
[4]Mean of 20 berries at second harvest of each cultural system X cultivar combination; field replications pooled.
[5]Mean separation within main effects by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[6].NA=not applicable.
[7]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[8]RR-LB-PM=modified ribbon row, level beds covered with white on black polyethylene mulch.
[9]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[10]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[11].NS=not sigificant at $P \leq 0.05$.

carbohydrates and other components to competing crowns, and exhibit a higher production per unit vegetative growth (5,20,27). Contrarily, ribbon row-enhanced vegetative growth was evident in the cultivars studied herein. Popenoe and Swartz (20) argued that the vegetative vigor of cultivars like 'Allstar' must be controlled horticulturally before they can be successfully planted in ribbon rows.

Among matted row systems, level beds (MR-LB-NM) outyielded those cultured on raised beds (MR-RB-NM) in 1989 (Table 5, Figure 4b), even though raised beds offered increased drainage during the unusually wet June. Under more favorable weather conditions in 1990, the yield of raised bed, matted row plots increased significantly whereas the yields of all others decreased; increased yields of 'Allstar' and 'Sparkle' were primarily responsible for this effect (three-way interactive means not shown). Among mulched, ribbon row systems, bed height seemed to have no influence on yield (Table 5, Figure 4b). Renquist and coworkers (23) reported that the combined effects of raised beds and polyethylene mulch on yield increased production five-fold over the Oregon state average. However, under midwestern and northeastern conditions, some researchers have observed raised beds to outyield level beds (11), some have reported the converse to be true (3,15), whereas still others found no differences in yield between level and raised beds (4,5,12,20).

Cull percentages were higher in 1989 than in 1990 (Table 5), because unusually high rainfall patterns in the former season resulted in canopies and fruit which were in nearly continual contact with moisture. The incidence of fruit rots, primarily from gray mold (*Botrytis cinerea*), were somewhat elevated in 1989, but high populations of garden slugs (*Arion subfuscus*) favored by wet canopies and overcast days caused the most severe fruit damage, especially to 'Allstar' berries (Figure 4c). 'Tristar' plots exhibited high cull percentages in both years (Table 5, Figure 4c), as a large portion of its fruit were undersized, especially during late summer harvests. Unlike those of other cultivars, 'Tristar' cull rates increased in 1990, presumably due to the effect of increased winter injury on fruit weight. Apparently, the reported benefits of ribbon rows (29) and mulch (16) in reducing fruit rots

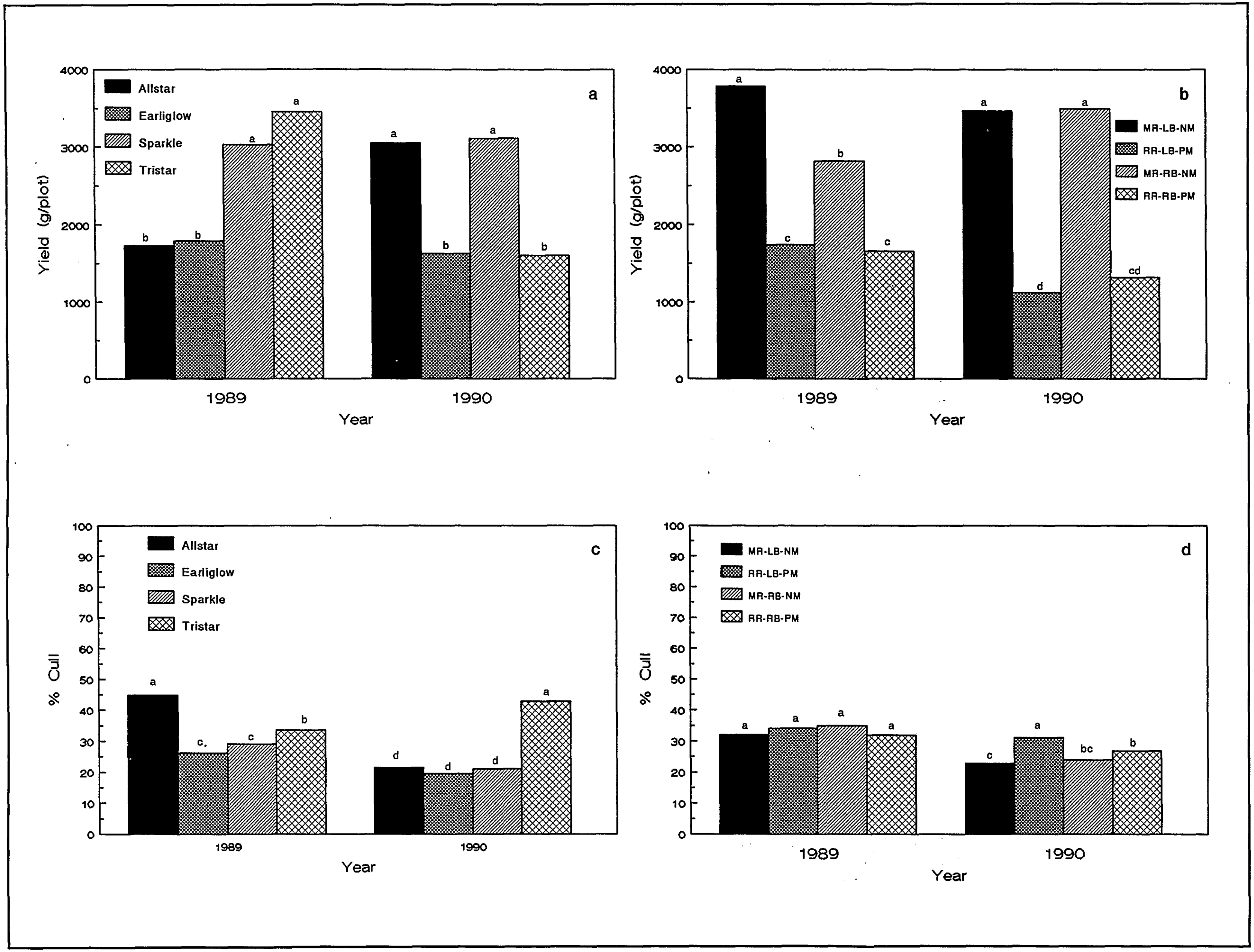

Figure 4. Interactive yield parameter means for years, cultivars and cultural systems: (a) YR X CV for marketable yield; (b) YR X CS for marketable yield; (c) YR X CV for % culls; (d) YR X CS for % culls.

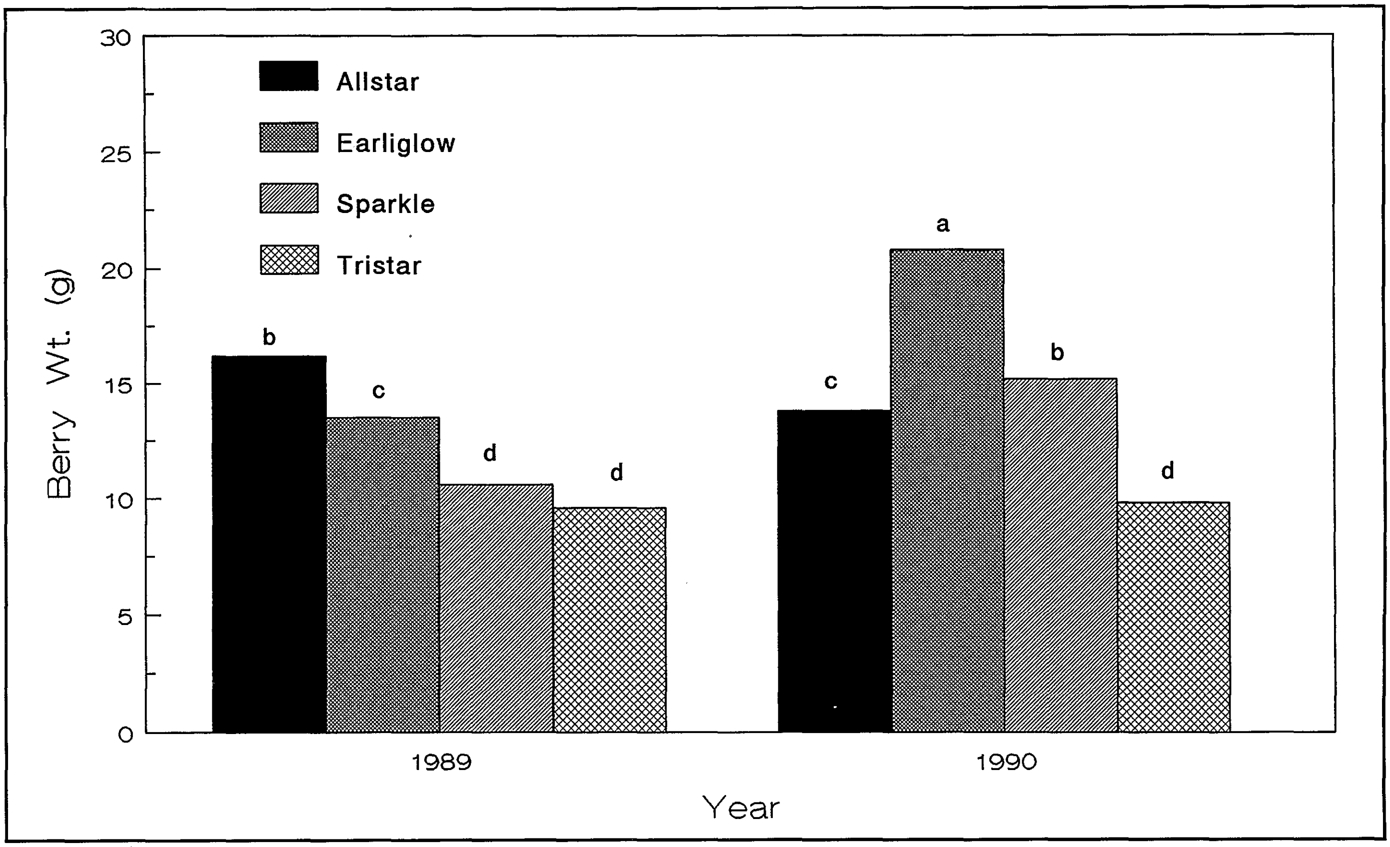

Figure 5. Interactive YR X CV means for berry wt.

and/or insect damage were not realized in 1989 as cull percentages were similar in all cultural systems. Moreover, in 1990, the percentage of cull fruit tended to be greatest in mulched, ribbon row plots (Figure 4d). The effect of winter injury on fruit size may have also precipitated this effect.

Over all treatments, berry weights were greater in 1990 than in 1989 (Table 5), primarily resulting from increased fruit size in 'Earliglow' and 'Sparkle' plots (Figure 5). In both harvest seasons, fruit harvested from matted row plots were larger than those from their ribbon row counterparts. Berry size in mulched ribbon row plots may have been reduced in 1989 by excessive soil moisture levels, and in 1990 by winter damage. In short, reduced fruit weight low crown productivity and low plant densities in ribbon row plots all contribute to low marketable yield associated with the ribbon row system. Among mulched, ribbon row plots, berry size was greater in level beds than in raised beds, which is in agreement with previously reported data (3,12,15).

The effects of year, cultural system and cultivar on fruit quality:

Seasonal effects on fruit quality— The environmental conditions that characterized the late spring and early summer of 1990 (Figure 2c, *i.e.*, relatively dry days and cool nights) were thought to optimize fruit quality. Conversely, inadequate sunlight and/or excessive rainfall have been shown to retard fruit development and ripening, and to reduce fruit firmness, color, soluble solids, glucose and fructose content, ascorbic acid (Vitamin C) content and flavor and to maintain high levels of fruit acidity (32). Accordingly, except for 'Earliglow' fruit (interactive means not shown), berries harvested during the cloudy, wet 1989 season (Figure 2b) displayed reduced soluble solid levels and higher titratable acidity values than those harvested in 1990 (Table 6). The nearly continual presence of moisture on fruit surfaces resulted presumably in a rain-damaged epidermis that caused fruit to soften more extensively. The integrity of 'Earliglow' and 'Sparkle' fruit were perhaps most damaged by the cool, wet conditions of 1989. However, 'Allstar' fruit did not ripen sufficiently to soften in 1989, and it was this interaction that artifactually elevated the 1989 average fruit firmness value above that recorded for 1990. Environmental differences between years apparently had little effect on the internal color of the fruit whereas, surprisingly, 1989 fruit displayed darker exterior (surface) colors than those harvested in 1990. All cultivars exhibited this trend although 'Allstar' exhibited greatest discrepancy in color between years. The cloudy weather experienced in 1989 should have limited the supply of photosynthate available to the ripening fruit and thus retarded the development of the anthocyanin pigments responsible for the strawberry's red color. However, rainfall, especially during the latter portion of the harvest season, has been shown to increase the incidence of mechanical damage (32), which may have caused fruit surfaces to darken in 1989.

Fruit quality as affected by cultural system and cultivar—The relative performance of cultivars was similar to industry-wide expectations for these genotypes (Table 6). In both years, soluble solid levels were higher in mulched, ribbon row plots. The size, vegetative vigor and reduced fruit load on plants in these plots perhaps resulted in a greater supply of photosynthate available to ripening fruit. Titratable acidity values appeared to be more closely aligned with bed height treatments, as fruit harvested from raised beds were less acidic than those obtained from level beds. However, the CS X CV interaction (means not shown) was highly complex, with the acidity levels of 'Earliglow' fruit high in mulched, ribbon row systems, those of 'Sparkle' high in flat beds, those of 'Tristar' low in RR-RB-PM plots only, and those of 'Allstar' fruit being essentially unaffected by system. Apparently, cultural systems did not affect skin toughness. Except for 'Tristar' fruit (interactive means not shown), flesh tended to be softer in fruit harvested from mulched, ribbon row plots. Moreover, the fruit from mulched, ribbon row plots was darker in color than fruit from their unmulched counterparts. Cultural system patterns for flesh firmness and external fruit color may have resulted from differences in the physiological status and photosynthate availability in ribbon row vs. matted row plants. However, differences in soil and/or canopy temperatures mediated by the use of mulch and the reduced diurnal temperature fluctuation in mulched plots may have also influenced fruit ripening processes.

Conclusions and Grower's Summary

A small but increasing portion of Ohio's strawberry growers are experimenting with the use of unconventional cultural techniques for the production of strawberries, which include the use of raised beds, polyethylene mulch and/or high density (ribbon row) plant spacings. This study examined the effects of these system components on Ohio-grown strawberries to provide a base of information from which to develop cultural recommendations. The salient results include the following:

1) In the hot, dry summer of 1988, plant establishment and first season vegetative growth were enhanced in mulched, ribbon row systems regardless of bed height. Mulch apparently improved growing conditions early in the establishment phase by stabilizing fluctuations in temperature and moisture. Cultural system had little effect on the apparent photosynthetic and/or transpiration rates of individual leaves, but the improved canopy development in mulched, ribbon row plants presumably increased the total amount of photosynthate/plant available for additional growth. The establishment and growth was additionally enhanced by runner removal in ribbon row systems, which may have redirected photosynthates to crown, leaf and root development.

2) Crown temperatures were lower in unmulched plots than mulched plots and lower in level beds than raised beds during the severe winter of 1989-1990. However, the most extensive winter damage was observed in mulched, ribbon row systems, due primarily to the wind's temporary displacement of the straw cover from the slick polyethylene surfaces.

3) Soil moisture levels during the summer were higher in mulched plots than they were in unmulched plots. Normally, increased moisture retention levels would be advantageous, but during the inordinately wet conditions of the 1989 harvest season increased moisture levels in mulched plots were thought to have negatively impacted strawberry growth, yield and fruit quality.

4) The culture of plants in the ribbon row system resulted in large individuals with extensive branch crown and root systems. However, in this study, the increased vegetative vigor of these individuals failed to enhance individual crown productivity

Table 6. Year, cultural system and cultivar means and interaction significance levels for fruit quality parameters of strawberries during their second and third season of growth.

Effects and levels	Skin toughness (g)	Flesh firmness (g)	Soluble solids (%)	Titratable acidity (%)	External color[1]	Internal color[1]
			Main effect means			
Year (YR)						
1989	253 b[2]	548 a	7.7 b	0.87 a	−0.86 b	0.07 a
1990	282 a	490 b	8.7 a	0.74 b	0.86 a	−0.07 a
Cultural system (CS)						
MR-LB-NM[3]	264 a	547 a	8.0 c	0.81 ab	0.37 a	0.13 a
RR-LB-PM[4]	262 a	475 b	8.4 b	0.83 a	−0.11 c	−0.04 a
MR-RB-NM[5]	271 a	548 a	7.9 c	0.77 b	0.12 b	−0.01 a
RR-RB-PM[6]	274 a	506 ab	8.7 a	0.79 b	−0.38 c	−0.08 a
Cultivar (CV)						
Allstar	316 a	600 a	8.5 a	0.67 d	1.16 a	1.15 a
Earliglow	312 a	565 ab	8.4 a	0.86 b	−0.28 b	−0.26 c
Sparkle	159 c	355 c	7.9 c	0.75 c	−0.63 c	0.26 b
Tristar	284 b	558 b	8.1 b	0.92 a	−0.25 b	−1.15 d
			Interaction significance levels			
CS X YR	.NS[7]	.NS	0.026	.NS	.NS	⟨0.001
CV X YR	⟨0.001	⟨0.001	⟨0.001	⟨0.012	⟨0.001	⟨0.001
CV X CS	.NS	⟨0.001	.NS	⟨0.001	.NS	.NS
CV X CS X YR	0.006	⟨0.001	⟨0.001	.NS	0.002	⟨0.001

[1]Principle component of L, hue angle (θ) and saturation index; negative values indicate darker colored fruit.
[2]Mean separation within main effects by Duncan's multiple range test at $P \leq 0.05$; means with similar postscripts are not significantly different.
[3]MR-LB-NM=standard matted row, level beds without polyethylene mulch.
[4]RR-LB-PM=modified ribbon row, level beds covered with white on black polyethylene mulch.
[5]MR-RB-NM=modified matted row, raised beds without polyethylene mulch.
[6]RR-RB-PM=modified ribbon row, raised beds covered with white on black polyethylene mulch.
[7].NS=not significant at $P \leq 0.05$.

(yield/crown) and/or berry weight. The vegetative behavior of these individuals, when coupled with the reduced numbers of crowns/unit area associated with this cultural system, resulted in low marketable yields. High-density plantings in other areas of the country rely upon cultivars that have been developed to exhibit a high level of crown productivity/unit of vegetative growth. Popenoe and Swartz (20) maintained that like cultivars would have to be developed for the Midwest or Northeast before growers would consistently benefit from the use of ribbon row systems.

Even though some growers report increased yields and other benefits from the use of mulch, raised bed and/or ribbon row culture, research at various locations throughout the Midwest and Northeast has routinely failed to demonstrate these system components as horticulturally advantageous for perennial strawberry production (2,4,12,13,15,21,35). An economic analysis by Funt (7) maintained that, holding all other variables constant, an Ohio June-bearing strawberry grower using a typical ribbon row management strategy involving high-density production of ribbon rows on fumigated raised beds would have to nearly double yields over a four-year period to achieve the same rate of return on investment as matted row culture. Even in North Carolina, where the yields of mulched, ribbon rows were favorable, Durner and Poling (5) questioned whether the advantages of the ribbon row system were substantial enough to offset the additional planting and labor costs for derunnering. Neither of these economic assessments considered the use of polyethylene mulches; however, when used over several seasons as in the present study, even UV-stabilized polyethylene will sustain damages (punctures, tears, etc.) that require time, labor and materials to repair.

5) In this study, the use of mulch did not apparently reduce the incidence of fungal rots, one of the presumed advantages of this system (29); however, as expected, mulched plots were preferred by the harvesting crew for ease of picking. Fruit quality was affected by the cultural systems used in this study, but the effects of these differences on consumer acceptability have yet to be determined.

As stated earlier, adopting an entirely new cultural system requires substantial inputs of time, money and effort (27), and since horticultural performance of the conventional matted row was superior to all others in this study, there is little presented in the above data to warrant a conversion of Ohio plantings to ribbon rows and/or raised beds, with or without plastic mulch. However, each grower is faced with a unique economic and environmental situation, and therefore, whether conventional or alternative, each should select the best system for his/her needs based on available cultivars, production goals and site restrictions (14). Moreover, future development of cultivars suited specifically to high density plantings, annual culture, raised beds and/or polyethylene mulch may strengthen the advantages of adopting these alternative systems for strawberry production.

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Performance of New or Uncommon Strawberry Cultivars Grown Under Ohio Cultural Conditions

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Introduction

The continued development, testing and adoption of new strawberry cultivars is perhaps the most efficient strategy to maintain an edge against the ever-changing challenges faced by growers, and therefore, is essential to the industry's sustained viability (8). Within the last decade, strawberry breeders have released several cultivars with improved yield, fruit size and quality characteristics (2,4,8,17,21), wide adaptability (4,17), winter hardiness (17) and pest resistance (4,8,14,17) which have gained wide acceptance among growers. These and other cultivar characteristics have a direct and significant impact on profit, which makes cultivar choice one of the most important management decisions for a strawberry producer.

Cultivar characteristics thought to affect profitability include the following: earliness of ripening, length of season, yield, size, adaptability to a wide range of growing conditions and pest resistance. Berries from early-ripening cultivars often demand a higher market return, whereas maintaining a mixture of cultivars with complementary ripening periods (i.e., early, mid and late season cultivars) can extend the fruiting season to meet continuing market demands. Larger berries pick faster, reducing harvest labor cost. Adaptability to regions far beyond those of their originally intended use have assured the success of cultivars such as 'Chandler', the California industry standard which has been profitably-grown not only in its home state, but also in Florida, in North Carolina and internationally (1,2,4,12). Moreover, increased restrictions in the use and/or availability of pesticides fostered by environmental and consumer safety issues has and will continue to necessitate the development of disease-and insect-resistant cultivars (14).

New (released after 1980) and/or uncommon (developed in and for regions outside the Midwest, and therefore, not typically grown in Ohio) cultivars can best be evaluated for these and other strawberry fruit and plant characteristics under controlled, replicated cultivar trials, and to this end, cultivar performance evaluations have remained an important component of OSU/OARDC's strawberry research and extension program. Data from cultivar trials conducted at Wooster traditionally have provided Ohio growers with information on yield stability and other performance parameters (5). Accordingly, growers have relied upon this information to aid in their selection of cultivars for trial plantings under individual climatic, production and marketing systems. New releases that offer an advantage over existing cultivars are adopted quickly, gaining wide acceptance throughout the region. For instance, 'Earliglow', listed as being planted for trial in a 1978 Ohio survey (3), has supplanted all others as Ohio's most popular cultivar (20) and has become an industry standard, with widespread plantings throughout all regions east of the U.S. Great Plains (11,12). Likewise, according to a 1990 survey (20), 11 of the 24 strawberry cultivars released by nine breeding programs since 1979 are currently grown in Ohio, with 'Allstar', 'Honeoye', 'Lester' and 'Lateglow' being adopted by 10 or more Ohio growers.

The number of improved cultivars recently released, the willingness of Ohio growers to adopt them if advantageous, and the potential for discovery of useful, uncommon cultivars heretofore not considered as adapted to Ohio conditions were prime motivations for conducting the current study. This article therefore seeks to provide Ohio growers with yield and size data on new and/or uncommon cultivars to aid growers in their choice-of-cultivar decisions.

Materials and Methods

Standard cultivars, as well as new and/or uncommon cultivars included in this study, are listed by region of adaptation in Table 1 along with their release dates, release sites and prominent disease-resistance characteristics. The trial was established during the spring of 1989 using a randomized complete block design with 5 replications of 22 cultivars. Plots 12 feet long were planted with nursery stock placed 2 ft. apart with 4 ft.

Table 1. Region of adaptation, release date, release site, and significant characteristics of 22 standard, recently-released and/or novel strawberry cultivars.

Regions of Adaptation	Cultivar	Release date	Release site	Disease resistance characteristics[1] RS[2]	VW[3]	LSc[4]	LSp[5]	PM[6]	V[7]
North Central, Northeast and Mid-Atlantic	Allstar	1981	Beltsville, MD	R[8]	R	R-S	R-S	R-S	—
	Crimson King	1981	Monticello, MN	S	S	R	S	VS	—
	Earliglow	1975	Beltsville, MD	R	R	R-S	S	S	U
	Gilbert	1982	Madison, WI	—	—	R	—	—	—
	Honeoye	1979	Geneva, NY	S	S	S	R	R	—
	Lateglow	1988	Beltsville, MD	R	VR	R-S	VS	VS	—
	Lester	1986	Beltsville, MD	R	S	R-S	R-S	VS	—
	Raritan	1968	New Brunswick, NJ	S	S	S	S	—	U
	Redchief	1968	Beltsville, MD	R	R	R	S	R	U
Mid Central and Mid-South	Arking	1981	Fayetteville, AR	R	—	R-S	R	R	—
	Cardinal	1978	Fayetteville, AR	S	S	R	R	—	U
Central and Eastern Canada	Blomidon	1984	Kentville, NS	S	VS	R	S	VR	—
	Bounty	1972	Kentville, NS	—	—	—	—	—	—
	Cornwallis	1985	Kentville, NS	R	S	R	S	R-S	—
	Glooscap	1983	Kentville, NS	S	—	R	VR	VS	—
	Kent	1981	Kentville, NS	S	S	R-S	VS	R	—
	Micmac	1978	Kentville, NS	—	—	—	—	—	—
	Redcoat	1957	Ottawa, ON	S	S	R	R-S	R-S	U
Pacific Northwest	Sumas	1987	Vancouver, BC	R	—	—	S	S	—
	Totem	1962	Vancouver, BC	R	U	U	U	—	T
California	Oso Grande	1987	Davis, CA	—	—	—	—	—	—

[1]Primary reference for disease ratings is Luby (16), secondary references include Craig *et al.* (6), Moore (17) and Scott *et al.* (21).
[2]RS=Red Stele (*Phytophthora fragariae* Hickman).
[3]VW=Verticillium wilt (*Verticillium albo-atrum Reinke & Berth*).
[4]LSc=Leaf scorch [*Diplocarpon earliana* (Ell. & Ev.) Wolf].
[5]LSp=Leaf spot [*Mycosphearella fragariae* (Tul.) Lindau, Ramularia tulasnei Sacc.].
[6]PM=Powdery mildew [*Sphaerotheca macularis* (Wallr. ex Fries) Jacz. f. sp.fragariae].
[7]V=Virus
[8]Key to ratings is as follows:
R=Resistant (in the case of RS, resistant to at least one race.)
S=Susceptible
R-S=Variable response in different trials
—=Not listed in sources cited
VR or VS=Very resistant or very susceptible, respectively
U=Unknown
T=Tolerant

between rows. Flowers were removed during the planting year, plants were maintained in a 2 ft. wide matted row, and 3-5 in. of straw mulch was applied during late November of each year. Pesticides were applied according to standard Extension Service recommendations (9). Frost protection and supplemental irrigation were provided by overhead sprinklers.

Data was collected during 1990 and 1991. Yield was determined at each harvest by weighing marketable and cull berries from each plot; cull ratios were calculated by expressing the cull weight as a percentage of the total (marketable+cull) yield. The comparative yield distribution of each cultivar was characterized using two expressions adapted from those suggested by Khanizadeh and Fanous (15): 1) the "index of earliness," IE, which considers the initial harvest date, duration of harvest (no. of days fruiting) and proportion of crop load at each pick; and 2) an "index of concentration," IC, which compares the actual proportion of crop load at each picking with a reference proportion of equal crop loads among pickings. (Note: High IE values denote early yielding cultivars and high IC values denote cultivars exhibiting a concentrated ripening pattern.) The use of the IC and IE formulae are illustrated in Figure 1. Fruit size was determined by weighing 25 berries from each plot during its second harvest. Data was then statistically analyzed as a "split-plot in time" with harvest season representing whole units and cultivars within years representing sub-units. Marketable yield/acre, cull ratio, average berry size, IE and IC means for each cultivar by year combination were separated into significance groups using Duncan's Multiple Range Tests (P=0.05).

1990 Harvest of 'Raritan' - Replicate 4

Dates: June 4-28, Total (marketable+cull) yield=10,021 g

Day	1	4	8	11	15	18	22	25
Harvest completed (%)	4	16	32	44	60	72	88	100
Yield/harvest (g)	0	854	1500	2770	1202	2602	1075	0
Yield/harvest (%)	0	8.5	15.0	27.6	12.0	26.1	10.7	0

1990 Index of Earliness for 'Raritan'- Replicate 4

$$I.E. = \sum_{i=1}^{n} (Yi/Di)$$

i=1,2, . . . n and n=number of harvests
Yi=percent of total yield at i^{th} harvest for 'Raritan'
Di=percent of harvest period (days) completed for all cultivars

$$I.E. = \frac{0.0}{4.0} + \frac{8.5}{16.0} + \frac{15.0}{32.0} + \frac{27.6}{44.0} + \frac{12.0}{60.0} + \frac{26.1}{72.0} + \frac{10.7}{88.0} + \frac{0.0}{100.0} = 2.31$$

1990 Index of Concentration for 'Raritan'-Replicate 4

$$I.C. = \frac{\sum_{i=1}^{n} (Yi - Y)^2/n}{n}$$

i=1,2, . . . n and n=number of harvests
Yi= percent of total yield at i^{th} harvest for 'Raritan'
Di=percent of harvest period (days) completed for all cultivars

$$I.C. = \frac{\dfrac{(0.0-12.5)^2+(8.5-12.5)^2+(15.0-12.5)^2+(27.6-12.5)^2+(12.0-12.5)^2+(26.1-12.5)^2+(10.7-12.5)^2+(0.0-12.5)^2}{8}}{8} = 1.21$$

Figure 1. Sample calculations of earliness and concentration indices (I.E. and I.C.).

Results and Discussion

Harvest season effects: The harvest season (year) had a highly significant effect on general crop performance for all parameters studied, except IE and berry weight (Table 2). Contrary to what might be expected from the second cropping cycle of a strawberry planting, cultivars generally exhibited significantly lower marketable yields (31.7 percent reduction), higher cull ratios (47.5 percent increase), and higher ICs (more than 150 percent increase) in 1991 than they did in 1990, their maiden cropping season. Although some variation in performance can be expected to occur as plantings decline (23), the relatively young age of plots in this trial suggests that significant differences in performance between harvest seasons reported herein were caused primarily by seasonal differences in the environment. Climatic factors (temperature, humidity, light intensity levels, etc.) were quite dissimilar in 1990 and 1991, with 1991 being considerably warmer and drier than the previous year (Figure 2a,b). Comparatively high day/night temperatures in the spring of 1991 (15 April—20 May) resulted in the early emergence of inflorescences and subsequent compression of all developmental phases through fruit maturation. Moreover, 1991 was unusually warm during the harvest season, with a diurnal average temperature 4° F higher and an average maximum temperature 6° F higher than those experienced in the previous season. OARDC weather records show 5 days during the 1991 fruiting season on which the maximum temperature exceeded 90° F, whereas berries ripening in 1990 did not experience conditions above this temperature. As a result of these

Table 2. Comparison of annual performance means obtained from strawberry cultivars grown at Wooster, OH.

Year	I.E.[1]	I.C.[2]	Marketable yield (lbs./acre)	Cull ratio[3] (%)	Berry weight (g)
1990	2.59 a[4]	1.77 b	12,828 a	20.2 b	12.4 a
1991	2.85 a	4.67 a	8751 b	29.8 a	12.8 a

[1]I.E.=index of earliness (larger values indicate earlier yield).
[2]IC=index of concentration (larger values indicate more concentrated ripening patterns).
[3]Cull ratio=cull weight expressed as a percentage of total yield.
[4]Between year means with similar postscripts are not significantly different at P=0.05.

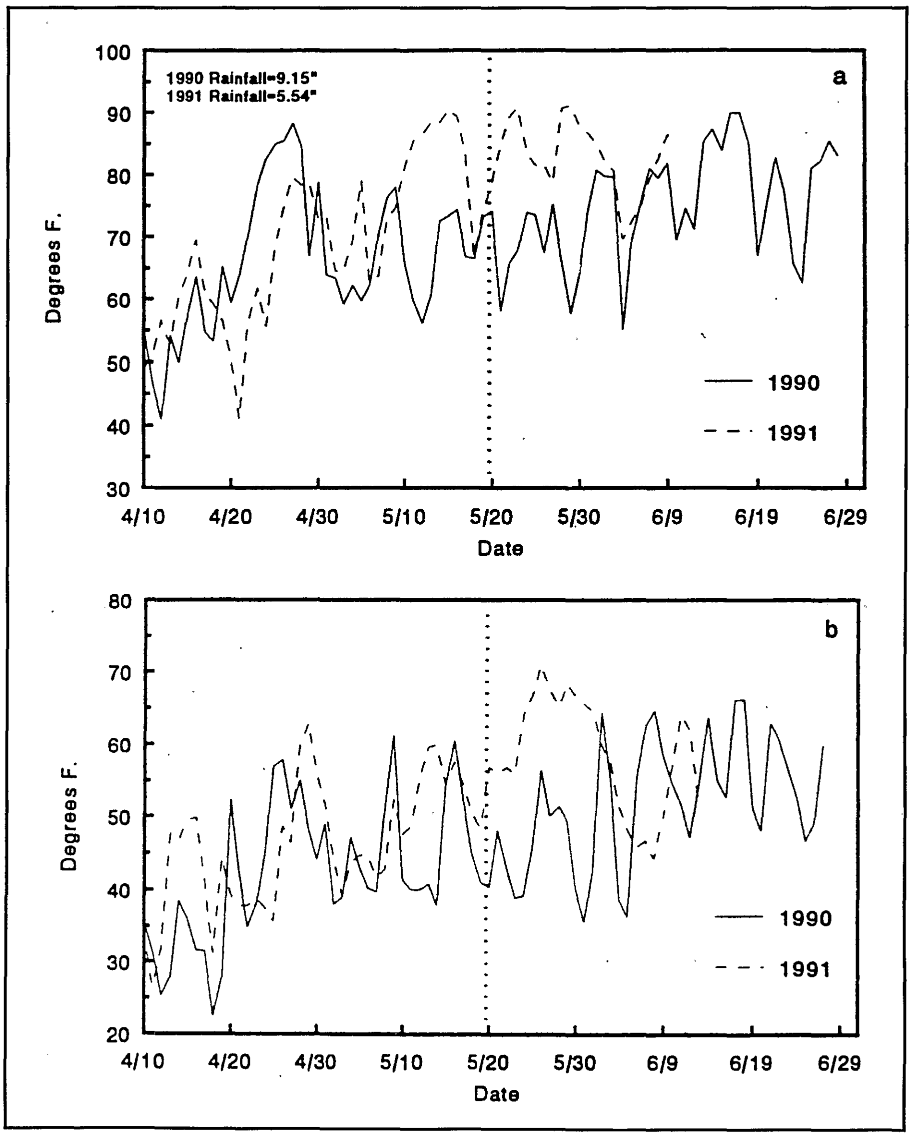

Figure 2. Diurnal maximum (a) and minimum (b) ambient temperatures (°F) during the flowering and fruit development and fruit maturation periods of strawberry in 1990 and 1991.

unusually warm temperatures, the 1991 harvest commenced approximately 5 days earlier and was considerably shorter in duration (13 days long) than would be expected for a "normal" cropping season as evidenced by higher ICs overall (Table 2).

The environmental stress-induced losses in marketable yield for the 1991 strawberry crop resulted, in part, from increased cullage of berries that ripened faster than they could be harvested (Table 2). However, because increased cull ratios could not account totally for the loss in 1991 marketable yield, a portion of this loss was suspected to be conditioned by a decrease in the total number of berries formed. Pollen formation and pistillate (female) flower receptivity have been reported previously to be adversely affected by temperature stress (10). Cultural factors such as nutritional status or winter damage also may have influenced seasonal variation in marketable yields, but evidence for the influence of these factors was not visually apparent. Finally, since the summer and fall of 1990 have been described as the wettest seasons on record in the Wooster area, an overabundance of soil moisture coupled with reduced light intensity resulting from cloud cover may have diminished the strawberry plants' ability to form flower buds.

Cultivar and interactive effects: Cultivar (genetic) differences were evident for all performance parameters studied (Tables 3-5). Significant cultivar by year interactions indicated that cultivars responded differently, either in magnitude or direction, to the environmental stresses presumably imposed during the second cropping season.

Earliness—Ripening patterns for midwestern cultivars were not ostensibly different than those reported by

Table 3. Cultivar X year interactions for earliness and concentration indices of 22 strawberry cultivars grown at Wooster, Ohio.

Cultivar	I.E.[1] 1990		1991		I.C.[2] 1990		1991	
Allstar	1.83 i-m[3]	(16)[4]	1.61 k-m	(16)	1.74 j-l	(11)	4.54 d-g	(9)
Arking	1.65 j-m	(20)	1.38 l-m	(21)	1.84 j-l	(9)	3.94 e-g	(17)
Blomidon	1.75 i-m	(18)	1.77 i-m	(15)	1.88 j-l	(7)	7.07 a	(2)
Bounty	1.87 h-m	(15)	1.57 k-m	(17)	2.20 i-k	(3)	7.25 a	(1)
Cardinal	2.24 g-m	(11)	3.06 e-h	(7)	1.73 j-l	(12)	5.18 c-d	(6)
Cornwallis	3.91 d-e	(3)	5.33 a-c	(4)	1.73 j-l	(13)	4.37 d-g	(13)
Crimson King	3.17 f-g	(6)	5.50 a-b	(2)	1.77 j-l	(10)	4.37 d-g	(12)
Earliglow	6.10 a	(1)	5.35 a-c	(3)	1.63 j-l	(16)	4.84 c-e	(7)
Gilbert	1.88 h-m	(14)	1.54 k-m	(18)	1.53 j-l	(18)	5.58 b-c	(4)
Glooscap	1.93 h-m	(12)	2.29 g-m	(13)	2.49 i-j	(1)	3.60 g-h	(21)
Honeoye	4.34 c-d	(2)	2.43 f-m	(11)	1.39 k-l	(20)	4.29 d-g	(16)
Kent	2.54 f-l	(9)	1.90 h-m	(14)	1.64 j-l	(15)	4.61 d-f	(8)
Lateglow	1.67 i-m	(19)	1.48 k-m	(19)	1.91 j-l	(6)	3.64 g-h	(20)
Lester	2.83 e-j	(7)	4.50 b-d	(5)	1.44 k-l	(19)	4.35 d-g	(15)
Micmac	1.62 j-m	(22)	1.31 m	(22)	1.55 j-l	(17)	4.52 d-g	(10)
Oso Grande	1.63 j-m	(21)	2.42 f-m	(12)	1.84 j-l	(8)	3.75 f-h	(19)
Raritan	2.42 f-m	(10)	4.36 c-d	(6)	1.20 l	(22)	2.90 h-i	(22)
Redchief	1.90 h-m	(13)	2.64 f-k	(9)	2.30 i-k	(2)	5.22 c-d	(5)
Redcoat	3.54 d-f	(5)	2.47 f-m	(10)	2.07 i-l	(4)	4.42 d-g	(11)
Sumas	2.61 f-k	(8)	2.87 e-i	(8)	1.34 k-l	(21)	3.85 f-g	(18)
Totem	1.76 i-n	(17)	1.46 k-m	(20)	1.96 j-l	(5)	6.19 b	(3)
Veestar	3.77 d-e	(4)	5.55 a-b	(1)	1.72 j-l	(14)	4.35 d-g	(14)

[1]I.E=index of earliness (larger values indicate earlier yield).
[2]I.C.=index of concentration (larger values indicate more concentrated ripening patterns).
[3]Within and between year means with similar postscripts are not significantly different at P=0.05; i-m=i,j,k,l,m.
[4]Yearly rank.

Table 4. Cultivar X year interactions for marketable yields and cull ratios harvested from 22 strawberry cultivars grown at Wooster, Ohio.

	Marketable yield (lbs./acre)		Cull ratio (%)[1]	
Cultivar	1990	1991	1990	1991
Allstar	10,835. d-k[2] (15)[3]	8,843. g-n (12)	19.2 i-o (13)	34.9 a-e (7)
Arking	15,012. b-d (8)	11,044. d-k (5)	17.9 j-o (15)	17.8 j-o (22)
Blomidon	7,798. j-n (21)	4,772. n (21)	28.1 b-j (2)	38.9 a-b (4)
Bounty	10,733. d-l (16)	6,674. k-n (17)	33.7 a-g (1)	39.1 a-b (3)
Cardinal	13,242. c-h (11)	4,474. n (22)	16.1 k-o (18)	30.3 a-i (11)
Cornwallis	11,804. d-j (13)	9,529. f-m (8)	18.2 j-o (14)	23.1 f-o (18)
Crimson King	15,195. a-d (5)	6,908. k-n (18)	24.2 e-n (4)	40.3 a (1)
Earliglow	9,694. e-m (18)	6,630. k-n (22)	14.3 m-o (20)	20.5 h-o (20)
Gilbert	15,168. a-d (7)	8,002. j-n (14)	20.9 h-o (9)	39.4 a-b (2)
Glooscap	18,461. a-b (2)	13,614. c-f (1)	23.8 e-o (5)	25.9 e-m (14)
Honeoye	19,522. a (1)	13,028. c-i (2)	12.6 n-o (21)	24.2 e-n (16)
Kent	15,230 a-d (4)	9,440. f-m (9)	23.6 e-o (6)	37.4 a-d (6)
Lateglow	9,775. e-m (17)	6,947. k-n (15)	20.1 h-o (11)	23.6 e-o (17)
Lester	17,162. a-c (3)	11,028. d-k (6)	12.2 o (22)	27.6 c-k (12)
Micmac	11,697. d-j (14)	11,168. d-k (4)	23.0 f-o (7)	19.6 i-o (21)
Oso Grande	8,698. h-n (20)	6,093. l-n (19)	21.7 h-o (8)	25.3 e-m (15)
Raritan	12,935. c-i (12)	9,050. f-n (10)	15.3 l-o (19)	26.3 d-l (13)
Redchief	9,675. e-m (19)	12,295. d-j (3)	24.4 e-n (3)	22.4 g-o (19)
Redcoat	13,546. c-g (10)	10,331. e-l (7)	19.9 i-o (12)	33.5 a-g (9)
Sumas	15,181. a-d (6)	8,432. i-n (13)	16.5 j-o (17)	38.5 a-c (5)
Totem	6,584. k-n (22)	5,232. m-n (20)	17.7 j-o (16)	31.7 a-h (10)
Veestar	14,266. b-e (9)	8,988. f-n (11)	20.6 h-o (10)	34.4 a-f (8)

[1]Cull ratio=cull weight expressed as a percentage of total yield.
[2]Within and between year means with similar postscripts are not significantly different at P=0.05; d-k=d,e,f,g,h,i,j,k.
[3]Yearly rank.

other authors (Table 3) (10,17,22). When data from both years was considered, 'Cornwallis', 'Crimson King', 'Earliglow' and 'Veestar' emerged as early-season cultivars. 'Earliglow', the benchmark cultivar characterizing the early-fruiting habit (11), exhibited an IE that was significantly higher (earlier) than all other cultivars of this group in 1990, but in 1991, these differences were not significant. 'Micmac' exhibited the lowest (latest) IE during both seasons. 'Blomidon', 'Bounty', perhaps 'Gilbert', 'Lateglow' and the uncommon cultivars 'Arking', 'Oso Grande' and 'Totem' were also considered to be late-fruiting cultivars. In general, cultivar ripening patterns were similar in 1990 and 1991 (Tables 2 and 3), but early-season cultivars 'Cornwallis', 'Crimson King', 'Veestar' and mid-season cultivars 'Lester' and 'Raritan' ripened earlier (*i.e.*, exhibited significantly higher IEs) in 1991 than in 1990. In contrast, 'Honeoye,' regarded as an early season cultivar in 1990, exhibited a midseason yield pattern 1991.

Yield concentration—The concentrating effect of the warm dry weather on yield duration (*i.e.*, the interval between the first and last harvest dates) was clearly evident in the significantly elevated ICs exhibited by all cultivars in 1991 (Tables 2 and 3). During this season, many cultivars were completely harvested in two or three pickings. 'Blomidon', 'Bounty and 'Totem' exemplified cultivars that ripened most of their fruit simultaneously, whereas 'Glooscap', 'Lateglow' and 'Raritan' appeared to be least affected by the environmental extremes of this season. 'Raritan' also displayed the lowest IC of all cultivars in 1990, but this value was significantly different only from those of 'Bounty', 'Glooscap' and 'Redchief' in that year. The apparent lack of differences among cultivars for yield concentration in 1990 was presumably due to the high degree of variability found among cultivars in the subsequent season, and was therefore considered an artifact of statistical analysis. The variation in yield concentration among cultivars exhibited in 1990 was typical of that to be expected during an "average" Ohio season. Therefore, the rank order of ICs displayed in 1990 should be a reliable indicator of average performance to be used when choosing cultivars that meet specific production requirements such as a prolonged fruiting season or its opposite, concentrated fruit ripening.

Table 5. Cultivar X year interactions for fruit weights exhibited by 22 strawberry cultivars grown at Wooster, Ohio.

Cultivar	Fruit weight (g/berry) 1990	1991	Mean
Allstar	15.6 b-f[1] (4)[2]	14.2 c-i (7)	14.9 (6)
Arking	14.4 c-i (6)	17.3 a-c (1)	15.9 (4)
Blomidon	9.4 k-p (18.5)	9.3 m-p (20.5)	9.4 (21)
Bounty	8.2 n-p (20)	11.7 g-n (14.5)	10.0 (18)
Cardinal	10.1 j-p (17)	12.3 f-m (13)	11.2 (14.5)
Cornwallis	12.6 e-m (8.5)	13.2 d-l (10)	12.9 (10.5)
Crimson King	10.9 h-o (14.5)	14.9 c-g (5)	12.9 (10.5)
Earliglow	12.6 e-m (8.5)	7.5 o-p (22)	10.1 (16.5)
Gilbert	11.6 g-n (12)	14.5 c-h (6)	13.1 (8)
Glooscap	11.4 g-n (13)	13.1 e-m (11)	12.3 (13)
Honeoye	18.8 a-b (2.5)	10.6 i-p (18)	14.7 (7)
Kent	19.2 a (1)	13.3 d-k (9)	16.3 (2)
Lateglow	10.9 h-o (14.5)	11.5 g-n (16)	11.2 (14.5)
Lester	18.8 a-b (2.5)	16.3 a-e (4)	17.6 (1)
Micmac	10.8 h-o (16)	9.3 m-p (20.5)	10.1 (16.5)
Oso Grande	13.0 e-m (7)	16.9 a-d (2.5)	15.0 (5)
Raritan	12.3 f-m (10)	13.6 c-j (8)	13.0 (9)
Redchief	7.0 p (22)	11.7 g-n (14.5)	9.4 (21)
Redcoat	12.2 f-m (11)	12.8 f-m (12)	12.5 (12)
Sumas	15.2 b-g (5)	16.9 a-d (2.5)	16.1 (3)
Totem	8.0 n-p (21)	11.4 g-n (17)	9.7 (19)
Veestar	9.4 k-p (18.5)	9.4 k-p (19)	9.4 (21)

[1]Within and between year means with similar postscripts are not significantly different at P=0.05; b-f=b,c,d,e,f.
[2]Yearly rank.

Marketable yield—All 22 cultivars studied exhibited some reduction in 1991 marketable yields over levels established in the previous season, but only nine cultivars experienced reductions that were substantial enough to be considered statistically significant (Table 4). 'Cardinal' and 'Crimson King', perhaps, best exemplify this group by sustaining considerable losses in actual marketable yield (55-66 percent) and in cultivar ranking for this trait. In contrast, Micmac exhibited remarkable yield stability over both seasons. Typically, stable cultivars will be outyielded by their high-performance counterparts when environmental stress levels are low. However, when stress occurs, high performance cultivars are most greatly affected and thus, the comparative status of the stable cultivar is improved. Micmac's rankings among cultivars for marketable yield, 14th in 1990 (non-stress) and fourth in 1991 (stress), suggest that it is a particularly stable cultivar. 'Honeoye', an industry standard, and 'Glooscap,' a mid- to late-season cultivar, ranked first and second in both 1990 and 1991 marketable yields, averaging 16,275 and 15,656 lbs./acre, respectively, during this two-year study (Table 4). Historically, 'Honeoye' has been the most consistent producer in cultivar trials at Wooster (5) and appears to be one of the most widely adapted cultivars produced in eastern and central growing regions of North America (4,5,12,13,16,17). Consistently high yields recorded in Ohio (5,21), in other midwestern states (13,17), in selected areas of the mid-south region (*e.g.*, Kentucky) and in eastern Canada (12,16) have made this cultivar a standard inter-regionally. Remarkably, 'Honeoye' has even exhibited some yield potential and adaptation to a saline soil (pH 8.0) in western Colorado (19). Similarly, 'Glooscap' may also exhibit wide adaptation to a number of production environments. Comparable to its performance herein, 'Glooscap' yielded exceptionally well in Minnesota trials (17), maintaining a "top" ranking annually during a three-year study. 'Lester' was ranked third and fourth in marketable yields during its first and second cropping season, respectively, whereas 'Gilbert' displayed a commendable marketable yield during the first year of study, but appeared to be adversely susceptible to environmental stresses experienced in the 1991 season.

Although it has performed well in other areas (4,17), 'Blomidon' did not appear to be adapted to Ohio conditions (Table 3). However, as fruit harvested from this cultivar did not resemble either its type description (6) or that obtained from 'Blomidon' in another OARDC planting, an error in cultivar identification was suspected. Therefore, additional tests will be necessary to accurately determine the potential of this cultivar for Ohio growers. Marketable yields exhibited by the new cultivars 'Cornwallis' and 'Lateglow' were not outstanding in either year of the study. However, because of their resistance to some foliar and root fungal pathogens, winter hardiness in the former case and superior fruit quality characteristics in the latter case, these cultivars deserve further consideration by Ohio growers.

In general, cultivars developed for western growing regions exhibited relatively poor marketable yields in this trial (Table 3). 'Oso Grande', a new California cultivar released as a complement to 'Chandler', failed to produce as well as 'Chandler' under Ohio conditions (data not shown). For marketable yield, 'Oso Grande' ranked in the lower 15 percent of all cultivars in both years of the present study. Likewise, 'Totem', an industry standard in the Pacific Northwest, also performed poorly, accumulating the lowest average marketable yield of all cultivars examined herein. 'Sumas', released from the BC breeding program in 1987, has gained some acceptance over 'Totem' in colder areas of that region for its earliness, hardiness and yield superiority (4). 'Sumas' has also outyielded 'Totem' when grown in Ohio and, under the moderate temperatures experienced in the maiden season of this trial, 'Sumas' ranked sixth in marketable yield. 'Arking' also performed surprisingly well under Ohio growing conditions, particularly in the 1990 season. The marketable yield of this southern-adapted release from the Arkansas breeding program ranked eighth among yields of all cultivars harvested in 1990; the yield of 'Arking' was not statistically different from that of 'Honeoye' in 1991 or from the yield of 'Glooscap' in either year.

Cull ratio—Inherent differences among cultivars had a highly significant effect on the proportion of their respective total yields assessed as unmarketable (Table 4). Moreover, these cultivar differences appeared to be amplified under the stressful environment of 1991, as shown by the highly significant cultivar x year effect and by the increased number of statistical differences among cultivar means realized in the second harvest season (Table 4). In contrast, in 1990, 'Blomidon' and 'Bounty' exhibited the only cull ratios that were significantly different from the lowest cull ratio reported during the study, that of the 1990-harvested 'Lester'.

Among new and/or western-adapted cultivars examined, the cull ratios of 'Blomidon' (1990 and 1991, see caveat stated above) 'Gilbert' (1991), 'Sumas' (1991) and 'Totem' (1991) were not significantly different from that of 1991-harvested 'Crimson King', the highest cull ratio recorded in the study. High cull ratios in 'Crimson King' were attributable, in part, to its production of fasciated primary fruit that contained central cavities open to infestation by insects or infection by pathogens. High cull ratios found for the other four cultivars resulted predominantly from the production and/or over maturation of soft fruit predisposed to fungal degradation, especially during the 1991 season. In contrast, southern-adapted 'Arking' and the recently-released 'Cornwallis' and 'Lateglow' consistently exhibited low cull ratios that were not significantly different than those of 'Earliglow', which serves as a standard of excellence for fruit quality characteristics among cultivars commonly grown in Ohio (20).

Fruit weight—As mentioned above, the average berry weights of cultivars was relatively constant between harvest seasons (Tables 2 and 5). However, berry weights of 'Earliglow' and 'Honeoye' were significantly larger in 1990, whereas 'Crimson King', 'Kent', 'Oso Grande' and 'Redchief' produced significantly larger berries in 1991. Among midwestern cultivars, 'Allstar', 'Honeoye', 'Kent' and the newly released 'Lester' ranked among the top cultivars in average berry weight over both seasons. These cultivars also showed some superiority in berry weight in Minnesota and Quebec trials (16,17), and Ohio growers who have evaluated these cultivars under production listed large size as one of their perceived strengths (20). The superior average fruit weights of these cultivars, all of which have been released within the last 15 years, supported the authors' previous contention that berry weights have been increased substantially over time through successful breeding efforts (21). In contrast, the new cultivar 'Lateglow' produced large primary berries in this trial, but apparently berry size decreased among secondary and tertiary fruit, resulting in its moderate ranking for this trait. 'Glooscap' also displayed an average fruit weight that was intermediate among cultivars, suggesting that this newly-released cultivar owes its high-yielding characteristic to berry number rather than berry size. Uncommon cultivars 'Sumas', 'Arking' and 'Oso Grande', noted elsewhere for their large size (1,7,18), also exhibited average berry weights that were ranked third, fourth and fifth, respectively, among the cultivars studied. 'Totem''s lack of adaptation to midwestern conditions was confirmed not only by low yield but by an uncharacteristically low average berry weight as well.

Conclusions

Among midwestern-adapted cultivars in this trial, the most consistent performers in the trial were 'Honeoye' and 'Lester', both placing within the top five cultivars for marketable yield, low percent cull and size. 'Honeoye' has gained wide acceptance among Ohio growers (20) and it has been praised not only for its consistently high yield and wide adaptability, but also for its hardiness, size, appearance and shelf life (4,17). However, this cultivar has been rated poorly for its susceptibility to root diseases and occasionally for poor flavor. The new 'Lester' deserves further consideration for planting in Ohio due to its consistent performance in several areas, improved disease resistance, excellent fruit quality and improved shelf-life (4,17, unpublished data). However, in early commercial trials, 'Lester' has been criticized by Ohio growers for yield decline in third and fourth year of fruiting (20). The high-yielding new cultivar 'Glooscap' also is also recommended by the data herein for limited trial by Ohio growers. Although its yield performance was intermediate in this study, 'Allstar' is likely to remain a prominent cultivar in Ohio due to its reported high yield under certain conditions, firmness, size, flavor, disease resistance and shelf life (20). Conversely, 'Allstar' has been criticized by Ohio growers for its erratic performance and poor color. The recent survey of Ohio strawbery growers (20) did not show the uncommon cultivar 'Arking' as being grown in Ohio, yet it was one of the best performers in this cultivar trial, combining high yield with good flavor, large size, low percent cullage and superior disease resistance (5,18). 'Arking' was the only uncommon cultivar studied which showed promise under Ohio conditions, recommending it for trial by Ohio growers desiring a mid- to late-season berry.

In Ohio's mixed marketing system, fruit quality and disease resistance assume a position of importance equal to or even exceeding that of yield when choice of cultivar decisions are made (4,17,20). To this end, even though its yield performance was disappointing in this and other trials (17), 'Earliglow' deserves continued support of Ohio growers because of its earliness, superior fruit quality, and varietal identification by consumers, especially "pick-your-own" customers (11,20). Likewise, 'Lateglow' has been praised for its resistance to all major root diseases (including Verticillium wilt) and its unique, "mellow" flavor (4,17, unpublished data).

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A Comparison of Spray Drift Deposited on Ground and Airborne Spray Collectors and on Soybean Plants

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Abstract

Soybean plants and collectors to measure ground and airborne spray deposits were placed downwind from a row of semi-dwarf apple trees sprayed with an orchard air sprayer. Water with a fluorescent tracer was sprayed on the row of trees during three spray passes with the Myers A36 sprayer on April 30, 1990. Collector locations were from 0 to 800 ft. from the tree row. At distances beyond 35 ft. from the sprayed tree row, deposits on soybean leaves were found to be greater than deposits on plastic ground targets. Soybean leaves collected about the same amount of spray as airborne-spray targets, even though the leaves were closer to the ground. Fluorescent droplet residue spots on the top and bottom leaf surfaces were counted. For a given increase in distance from the tree row, number of spray droplets varied about the same as fluorescence of the tracer washed from the leaves.

Introduction

To determine spray drift out of an orchard, drift droplets or particles are collected on a target and amount of spray deposit measured. Some studies have used pesticide and artificial targets or collectors. Riley and Wiesner (1990) measured off-target spray losses resulting from applying pesticide on 20-ft. tall trees with an air assisted sprayer. Ground deposits and airborne deposits up to 36 ft. elevation were measured. They found that deposits decreased rapidly with increased distance downwind.

Tracers such as fluorescent materials are used to avoid exposure of both the environment and workers to pesticides. Fox *et al.* (1990a, 1990b, 1993) used fluorescent tracers and collectors to measure airborne and ground deposits downwind from dwarf apple trees sprayed with an orchard air sprayer. They found ground deposits decreased rapidly beyond 35 ft. from the sprayed tree row.

Salyani and Cromwell (1991) used a fluorescent tracer to compare ground and airborne deposits resulting from spraying an orange grove with an orchard air sprayer (72 and 5434 gpa), a fixed wing aircraft, (13.4 gpa) and a helicopter (17 gpa). Averaged over all downwind locations, the highest airborne deposit and the least ground deposit were produced by the orchard sprayer applying the low application rate, but there were not significant differences between drift from aerial and ground spraying. They also found that, in all cases, the greatest amount of drift resulted from applications to the last one or two rows on the downwind edge of the grove.

Fluorescent tracers have also been used to measure spray deposits on leaf surfaces (Herrington *et al.*, 1985; Cross, 1988; Cowell *et al.*, 1988); and also for the quantitative analysis of spray deposits on plants (Lawson and Uk, 1978).

Objective

The objective of the work described here was to test the hypothesis that spray drift deposits on soybean plants, downwind from an orchard, are more similar to deposits on airborne spray than ground collectors.

Materials and Methods

Experiments were conducted in a plot of semi-dwarf apple trees of mixed varieties on Malling 26 rootstock, trained as a central leader and pruned to maintain a height of 10 to 13 ft. The distance between rows was 20 ft. and tree spacing within rows was 12 ft. The trees were planted at the Ohio Agricultural Research and Development Center (OARDC) in 1968 and the foliage formed a dense hedge-row in each block as shown in Figure 1. The trees were just finishing bloom and foliage was about 50 percent developed. Additional experiments with full foliage were

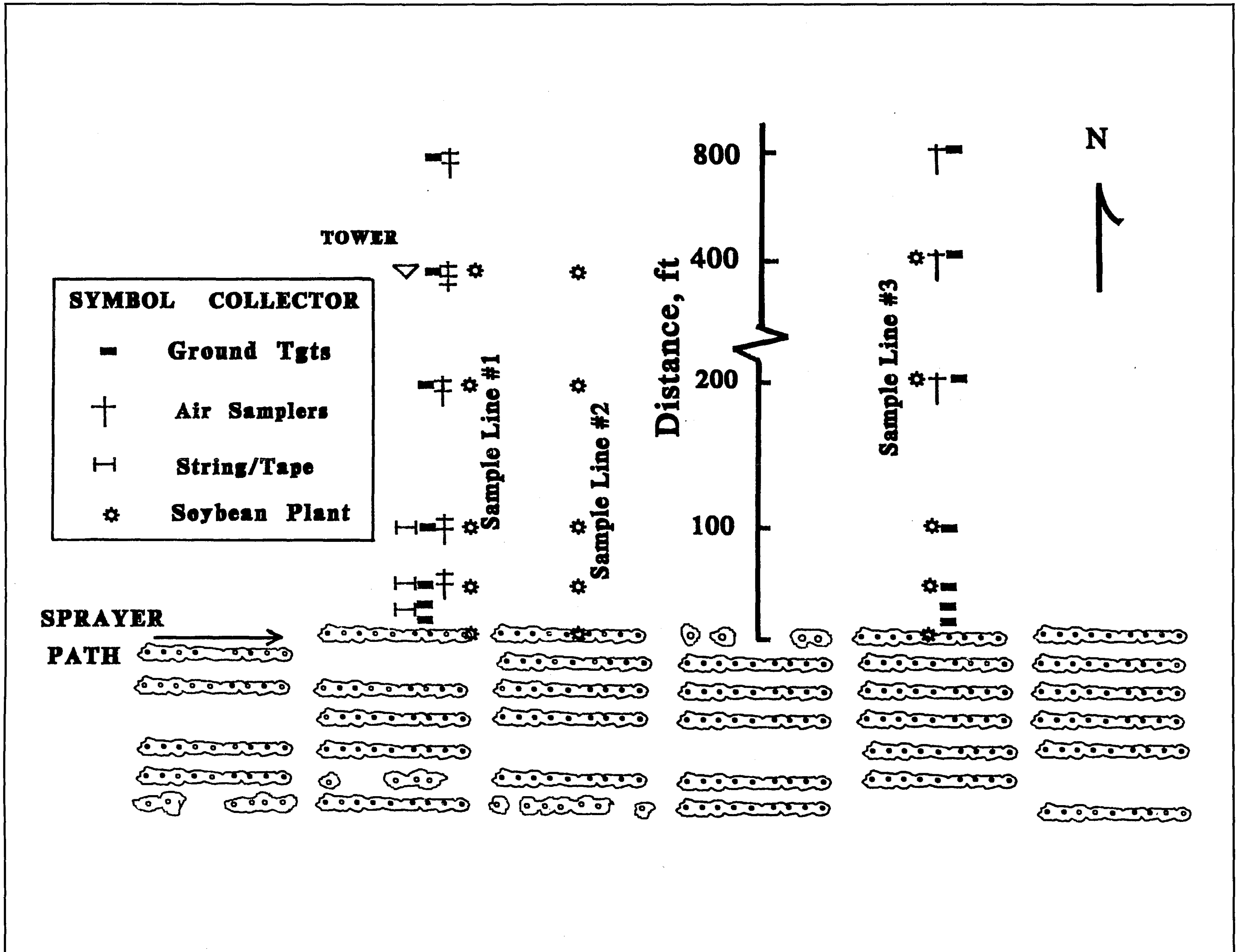

Figure 1. Drawing of experimental spray site showing tree and collector locations.

planned, but no day with a suitable, southerly wind direction occurred between 15 June and 1 August, when S. Hussein returned to Egypt.

Figure 1 is a drawing of the orchard and the region north of the orchard where the weather tower and sample collectors were located. The land sloped downward at about a 2 percent grade from south to north. The field around the collectors was planted to grass and corn strips; the corn plants were about 3 in. tall on April 30, 1990.

The outside, north row was sprayed using a Myers A36 orchard air sprayer traveling from west to east at 3 mph. The sprayer had seven Spraying Systems Co. D4-25 nozzles per side and was operated at 130 psi. The sprayer would have applied 50 gal/a if both sides were used, but only nozzles on the left side of the sprayer were used during the experiments.

The water-soluble fluorescent tracer, Tinopal, was used at concentrations of 260 μg/ml. Tank mix samples were analyzed to obtain actual dye concentration applied.

For each experiment, collectors were put into position and the tree row was sprayed. Ten minutes were allowed for the spray to dry, then collectors were removed and clean collectors were put in place for the next experiment.

A bivane anemometer at 30 ft. elevation on the instrument tower was used to record wind speed and direction at one minute intervals.

Two sample lines of ground collectors were used north of the sprayed tree row (Fig.1). Ground collectors were 8 × 8 in. rigid plastic sheets; four sheets were mounted on cross brackets at each location. On both lines, collectors were located at 10, 30, 50, 100, 200, 400 and 800 ft. from the sprayed tree row. The plastic sheets were collected and stored in zip-lock freezer bags after each sprayer pass. Distilled water was used to wash the fluorescent tracer from the plastic targets and bags for analysis.

String and plastic tape collectors for airborne-spray were located on racks at 25, 50 and 100 ft. from the tree row on sample line 1. Collectors were 6.6 ft. long, parallel to the tree row, and were mounted at elevations of 1.6 (string) and 3.3 (tape) ft. Collectors were also mounted higher on the racks, but results above 3.3 ft. were not used in this study. On sample line 1, high-volume air samplers with cellulose filters were located at 50, 100, 200, 400 and 800 ft. from the tree row at elevations of 3.3 and 9.8 ft. Only results from samplers at 3.3 ft. were used in this study. On sample line 2, samplers were at 200, 400 and 800 ft. at an elevation of 9.8 ft.

Soybean plants (12-16 in. high) were grown in 12 in. pots (2 plants per pot). In the field, the plants were placed at 0, 50, 100, 200 and 400 ft. along sample lines 1, 2 and 3. Deposits were measured by washing two leaf disks (1.31 in) per plant with water to remove the Tinopal. A Turner Model 112 fluorometer was used to measure fluorescence of wash samples. Calibration and wash procedures are given in detail in Fox, *et al.*(1990b).

Three leaves from each sample soybean plant exposed to spray drift were placed under an ultraviolet light and images of the top and bottom were recorded on video tape. The number of droplets on the top and bottom of each leaf was counted and droplets per square cm calculated. Leaves from plants at the tree row were covered with so many overlapping droplets that droplet counts could not be made and therefore are not reported.

Results and Discussion

Ground deposits: Spray pass times and weather conditions for these experiments are reported in Table 1. For all three spray passes, the wind speed at the 30 ft. elevation was less than 6 mph from the southwesterly direction. The trees were just finishing bloom and foliage was about 50 percent developed.

Graphs in Figures 2, 3 and 4 use a "log-log" scale to show deposit versus distance. Measured data shown are mean values of all samples at each distance from the tree row, *i.e.*, averages of three passes and 1, 2 or 3 sample lines. Error bars show the standard deviation of samples.

Deposits washed from plastic ground collectors and soybean leaf disks at several locations downwind from the sprayed apple row are plotted in Figure 2. Deposits per unit area of collector surface were about the same out to 50 ft., but beyond 50 ft., deposits on soybean leaves were much greater than on ground targets. The difference in deposits collected increased with increasing distance from the tree row. Large ground deposits near the tree row are probably due to large spray droplets that follow nearly a ballistic trajectory from the sprayer to the ground. The small deposit on ground targets at long distances from the tree row is likely due to the size of spray droplets still airborne at these distances. By the time droplets travel beyond 50 ft., large droplets have fallen to the ground and smaller droplets have evaporated to 50 μm diameter or less in size. These tiny droplets settle slowly and are easily

Table 1. Summary of atmospheric conditions for April 30, 1990, drift studies.

Sky conditions	Time	Air temp °F	Relative humidity %	Wind[1] vel mph	Wind[1] dir deg
Clear & sunny	1512	77	36	3.8	242
Clear & sunny	1553	80	29	5.6	201
Clear & sunny	1625	81	28	5.8	234

[1]Wind measured with bivane anemometer at 10 m elevation.

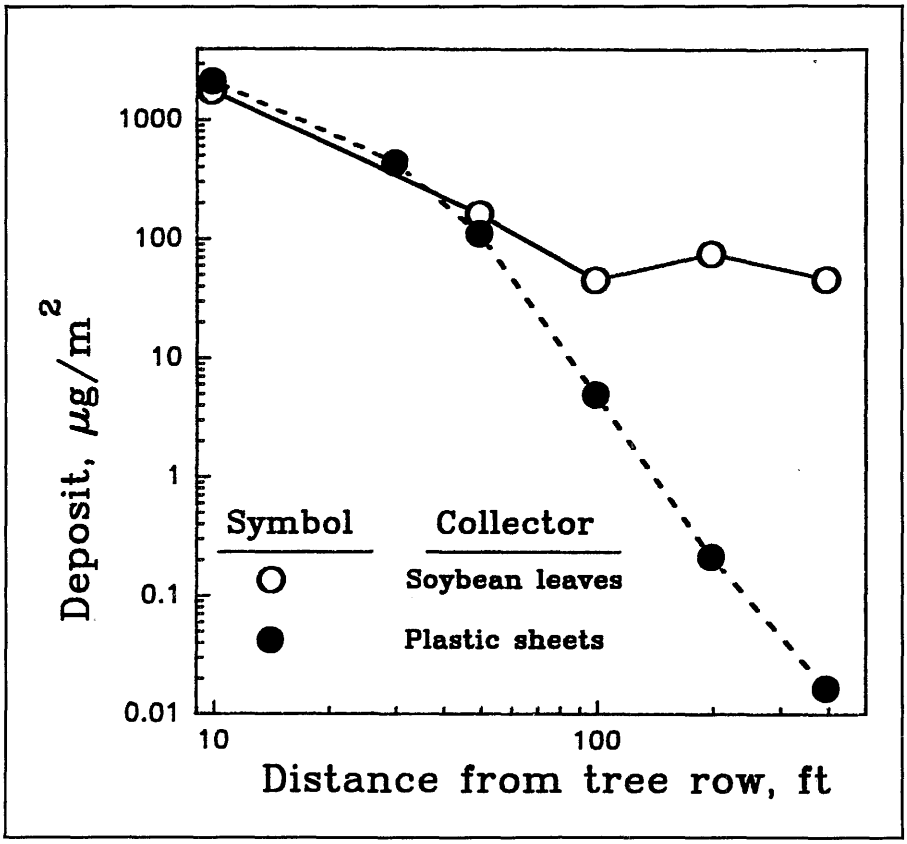

Figure 2. Comparison of spray deposits on ground collectors and on soybean leaves at several locations downwind from a row of sprayed apple trees.

carried long distances by wind currents. As the wind carries these small droplets along, they can be collected at greater rate on vertical than horizontal surfaces, especially on very small objects such as string fibers or hairs on plant leaves.

Airborne-spray deposits: In Figure 3, deposits on soybean leaves are compared with airborne-spray collectors. From 50 to 200 ft. the sampler filters collected the most spray deposit; this has been the case for almost all drift experiments conducted at OARDC. The sampler has a blower that draws air containing droplets through the filter, neutralizing natural air currents that tend to carry droplets or residue of droplets around other types of collectors. Therefore, droplets in the air are collected on the filter. The soybean leaves collected about the same amount of spray ($\mu g/m^2$) as the air-sampler filter at the 400 ft. location. However, the area washed (disk size) was much less for leaves than for other collectors, so measured leaf deposits were nearer the lower detectable level of the fluorometer and were likely to be less accurate. Deposits on leaves (per unit area) were greater than on plastic tape and less than deposits on string at 50 ft. but greater than deposits on string at the 100 ft. location. Differences in deposits are due to the collection efficiency of each collector. Collection efficiencies are affected by droplet size, air (and droplet) velocity, and size and shape of the collector.

Based on Figure 2 and Figure 3, the amount of residue collected on soybean leaves was closer to residue collected on airborne-spray than ground collectors. Fox *et al.* (1993) reported that sampler filters at elevations of 3.3 and 9.8 ft. collected about the same amount of spray. Because soybean plants were close to the ground, usually less than 16 in. tall, it had been hypothesized that they would collect less spray than airborne-spray collectors at higher elevations, but these data seem to contradict that hypothesis.

Spray deposits washed from leaves were verified by counting fluorescent droplet residue spots on the top and bottom of sample leaves. Figure 4 shows that, for a given change in distance, residue deposits measured by fluorescence changed approximately the same as the number of droplets on the top and bottom leaf surfaces. This appears logical because droplets collected at a given distance far downwind are probably nearly the same size. Droplet counts were about equal on both leaf surfaces. Note that droplet count is plotted against an arbitrary scale on the right hand side of the graph; this scale could be changed to raise or lower the droplet count data points with respect to the fluorescence data. This plot verifies the trend of decreased deposit with increased distance. Therefore, soybean plants seem to collect spray residue more like airborne-spray collectors than ground collectors.

Summary and Conclusions

Spray deposits on ground and airborne-spray collectors were compared to deposits on soybean plants placed downwind from the outside row of a semi-dwarf apple orchard. Fluorescent tracer deposit was measured out to 800 ft. from the tree row. Wind speeds at the 30 ft. elevation were less than 6 mph on the day experiments were conducted.

Deposits on soybean leaves beyond 35 ft. from the sprayed tree row were found to be greater than deposits on plastic targets placed on the ground. Soybean leaves collected about the same amount of spray as airborne-spray targets, even though the leaves were closer to the ground.

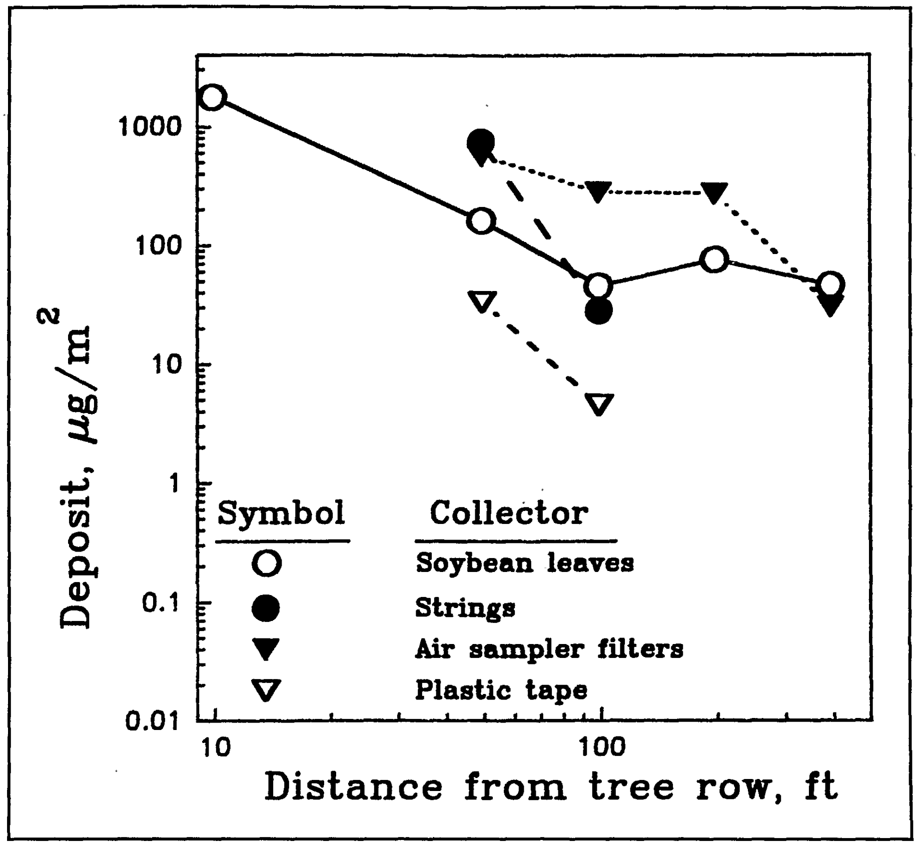

Figure 3. Comparison of airborne spray deposits on string, plastic tape, high-volume sampler filters, and soybean leaves at several locations downwind from a row of sprayed apple trees.

Acknowledgements

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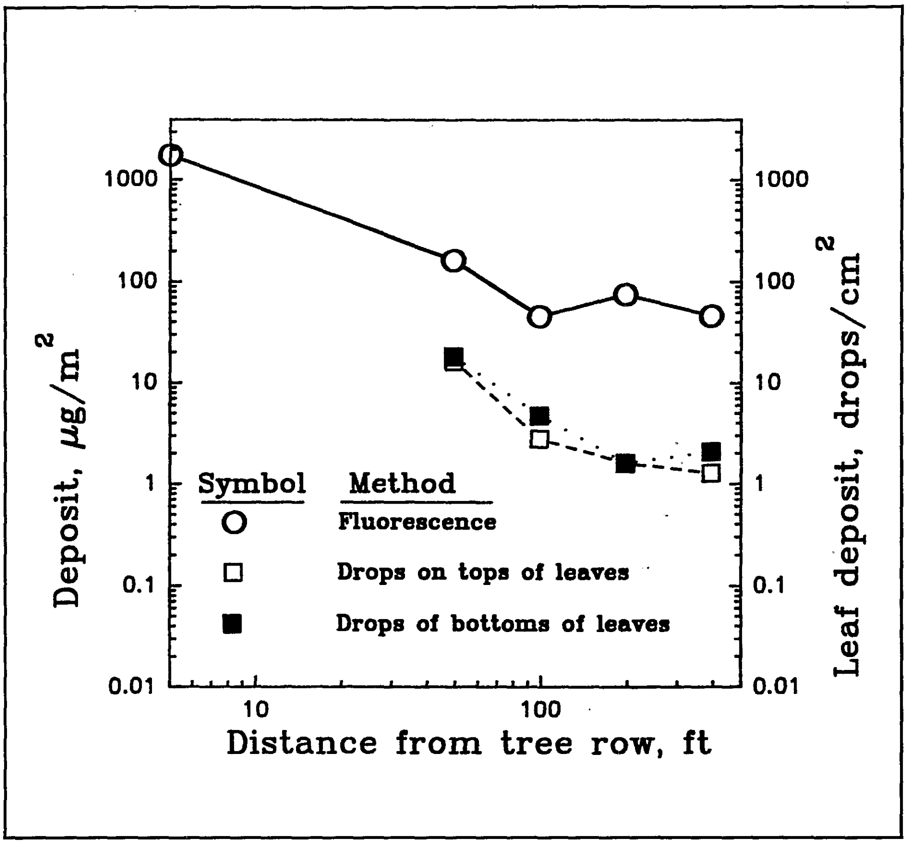

Figure 4. Comparison of spray deposits washed from soybean leaves to the number of fluorescent-droplet residue spots on the top and bottom of leaves.

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Experimental vs. Computer-Predicted Air Velocities for a Cross-Flow Sprayer

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Abstract

Air velocity profiles were measured along the axial centerline of a two-unit, cross-flow fan orchard sprayer. Profiles were measured at 13 distances from 2 inches to 20 ft. from the outlet, at the elevation of the centerline of the bottom fan. Velocities were measured for a fan speed of 1476 rpm and for the top fan vertical and inclined 20° from vertical.

Maximum velocities along the axial centerline agreed with measured values predicted by plane jet models. For the top fan inclined, air velocities increased 10 percent to 25 percent between 6 and 12 ft. from the outlet. Beyond 15 ft. from the outlet, the inclined top fan appeared to deflect the top of the bottom jet toward the ground.

Introduction

In the last few years, sprayers using cross-flow fans have become available in the U.S. and Europe. The air jet from these sprayers is directed horizontally or, in some cases, even downward, whereas traditional orchard air sprayers direct their air jets upward through the tree. Van Ee *et al.* (1985) have reported improved uniformity of deposition within fruit trees from using a cross-flow fan sprayer. Whitney and Salyani (1991) compared a cross-flow fan sprayer with a conventional sprayer and reported increased total deposit with the conventional sprayer, but somewhat more uniform deposition over grapefruit trees with the cross-flow fan sprayer. Randall (1971) used a plane jet model to predict air velocities produced by three types of orchard air sprayers. Brazee *et al.* (1981) and Fox *et al.* (1980) developed a computer model to predict the velocity field produced by a fan jet (traditional orchard air sprayer) and their measurements using two commercial sprayers agreed with the model. Svensson (1991) used a sprayer equipped with two cross-flow fans in experiments on spray deposits in dwarf apple trees. He found that an inclined top fan (air jet aimed downward) improved deposition on the far side of the tree compared to spraying with both fans vertical.

The objective of this study was to test the hypothesis that the air velocity field produced by a two-fan, cross-flow fan sprayer can be represented by a standard mathematical (computer) plane jet model.

Methods and Materials

The experiments were conducted in the Agricultural Engineering Building at the Ohio Agricultural Research and Development Center (OARDC), Wooster. Horizontal air velocity profiles were measured across the air jet produced by two cross-flow fans. The fans, driven by hydraulic motors, were made by Gebr. HOLDER GmdH. & Co., Metzinger, Germany, and were mounted on a three-point hitch chassis built in the laboratory. Both fans were operated at 1476 rpm. Two fan positions were used: 1) both fans vertical and 2) the top fan inclined 20° from vertical. This latter configuration directed air from the top fan downward toward the jet from the bottom fan. Figures 1a and 1b are photographs of the sprayer in operation with the fans in both positions. Figure 2 is a drawing of the cross-flow fans; the measurement elevation is shown. Air velocities were measured while a traversing mechanism moved a hot-film sensor at 3.7 ft./min, a distance of 17 inches across the center line of the air jet. The anemometer signals were recorded on FM magnetic tape and analyzed later; each record was 22 seconds long. The hot-film sensor was calibrated before the experiments using a Model 1125 calibrator (TSI, St. Paul, MN). The calibration was also verified after the experiments were completed.

Air velocity profiles were measured at the following locations:

I. 52 in. above the floor
   A. Both fans vertical
      1. Profiles measured at positions 1-13 (distances from the sprayer outlet to the measurement positions are given in Table 1).
   B. Top fan inclined 20°
      1. Profiles measured at positions 6-13

From each 22-second taped record, approximately 1,950 velocity measurements were acquired. Groups of 10 samples were averaged to obtain velocities at 195 points across each of the 21 profiles. To further smooth the data, a 5-point running average of these 195 velocity points to determine was used for the maximum velocity for each profile.

The plane jet model used to simulate air velocities produced by cross-flow fans require initial values for the jet outlet width (3 3/8 in. for the cross-flow fan) and outlet air velocity. The mean of three measured velocities nearest the outlet was used as the initial jet velocity.

The plane jet model used to simulate air velocities produced by a cross-flow fan was described by Randall, 1971. Computer code for the model was written as part of the research reported by Brazee *et al.*, 1981.

Results

Figure 3 is a plot of the maximum velocity in the air jet as distance from the jet outlet increases. The solid line represents velocities calculated by using a computer program (model) of the plane-jet theory. The open circles represent measured velocities at a fan speed of 1476 rpm. The measured values agree with values predicted by the plane jet model.

Figure 3 shows that jet velocity decreased quickly as distance increased beyond 2 to 3 fan-outlet widths (7 to 12 in.). As distance increased, velocity continued to decrease, but at a slower rate.

Figure 4 shows air velocities when the top fan was inclined downward 20°. Velocities predicted by the model of the vertical fans are shown for comparison. The main effect of the inclined fan, relative to both fans vertical, is a slight increase in velocity between 6 and 12 ft. from the outlet and a decrease in velocity beyond 15 ft. At positions beyond 15 ft., the inclined top fan appears to reduce the height of the combined jets from the two jets to less than the height of the bottom jet alone. Therefore, with this fan configuration, spray particles should be entrained into the atmospheric flow at much lower elevations and should settle to the ground quicker.

Figure 5 shows plots of axial velocities predicted by models of fan (conventional orchard air sprayer) and plane (cross-flow fan sprayer) jets with the same outlet width and outlet air velocities. The jet produced by the cross flow fan maintains its velocity for a much greater distance than does the conventional sprayer jet. Beyond 6 ft. from the outlet, air velocities at the center of the cross-flow fan jet are more than twice the velocities of the conventional orchard sprayer jet.

Table 1. Distance from cross-flow fan outlet to the air velocity measurement positions

Position no.[1]	Distance from fan outlet ft (m)	Position no.	Distance from fan outlet ft (m)
1	0.16 (0.05)	8	4.9 (1.5)
2	0.33 (0.10)	9	6.6 (2)
3	0.49 (0.15)	10	9.8 (3)
4	0.66 (0.20)	11	13.1 (4)
5	0.82 (0.25)	12	16.4 (5)
6	1.60 (0.5)	13	19.7 (6)
7	3.30 (1.0)		

[1]All air velocity profiles were measured at 52 in. above the floor.

Summary and Conclusions

Maximum air velocities, measured along the axial centerline of a two-unit cross-flow fan orchard sprayer, agreed with air velocities predicted by a plane jet model. When the top fan was inclined 20° downward, air velocities at the centerline of the lower fan were increased 10 percent to 25 percent at distances of 6 to 12 ft. from the fan outlet, then decreased beyond 15 ft. In the inclined 20° configuration, the bottom jet was deflected downward, which would likely reduce penetration of the jet into the atmosphere. However, when the top fan is inclined, the height of trees that can be covered by the sprayer is reduced. Only air velocities for a stationary sprayer were measured in this study. When the sprayer is pulled through an orchard, wind and travel speed will affect the air jet and actual velocities will be less than for a stationary jet.

Because the plane jet model accurately predicted the air velocity field, it should be possible to model droplet dispersion from sprayers of this type. Beyond 6 ft. from the outlet, model predicted air velocities for a cross-flow fan jet were more than twice air velocities in a conventional orchard sprayer jet with an equal outlet velocity.

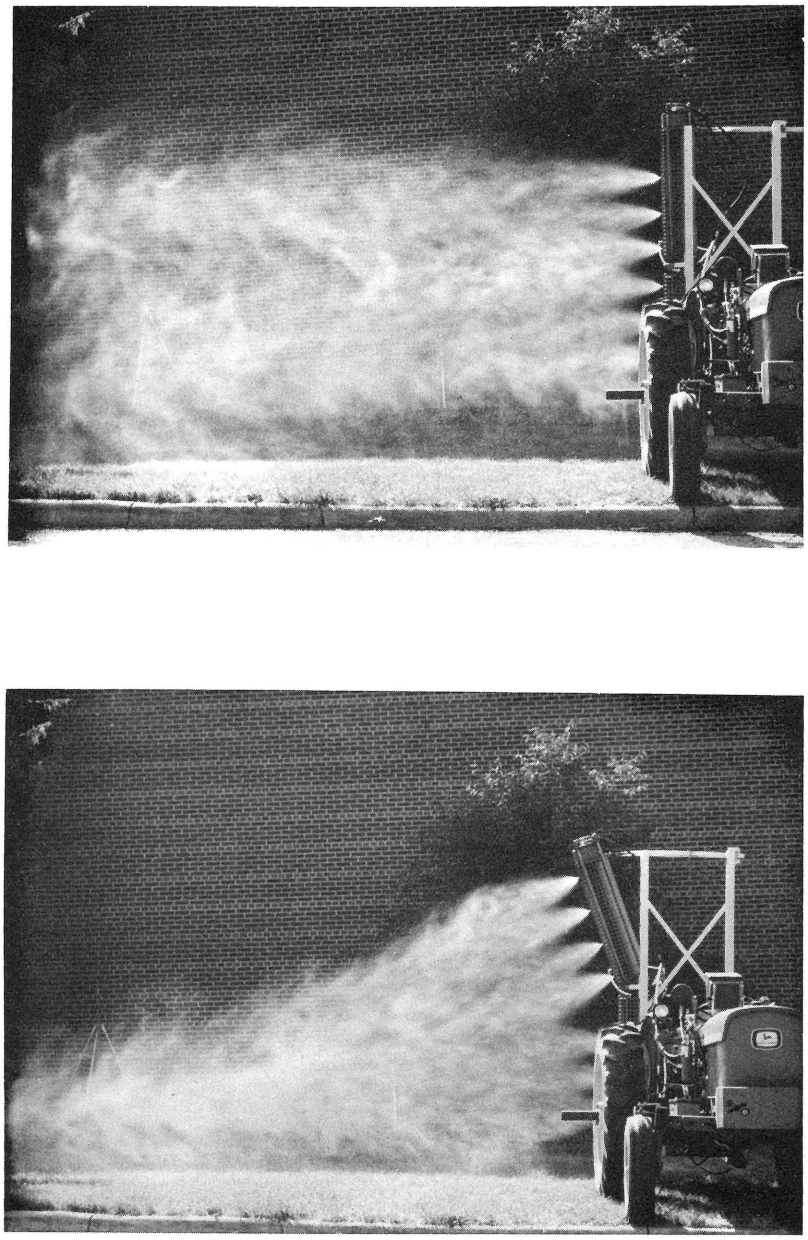

Figure 1. Photographs of a cross-flow fan sprayer in operation with: (a) both fans vertical, and (b) top fan inclined 20^{0} from vertical.

Acknowledgment

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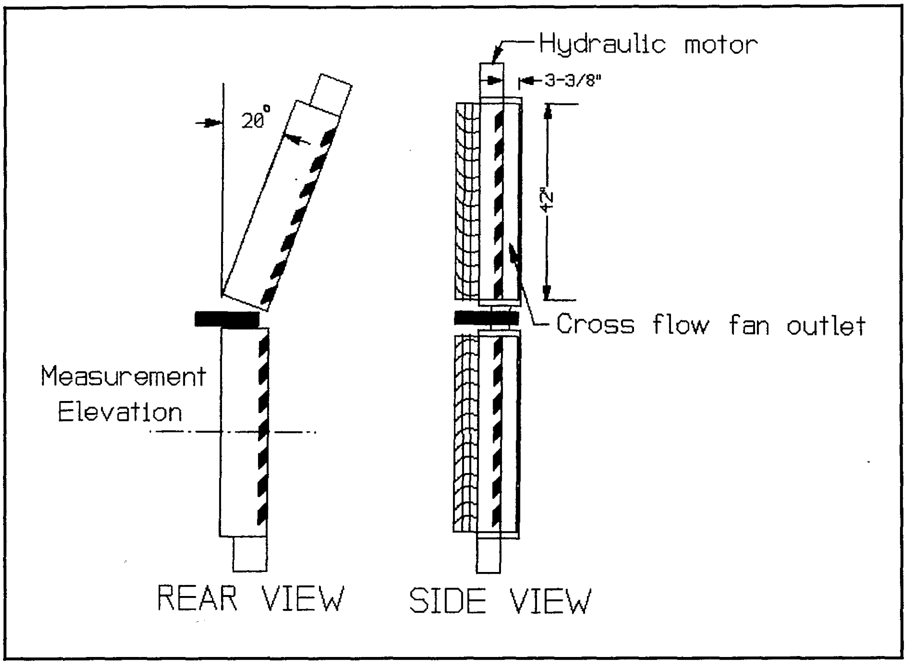

Figure 2. Drawing of two-unit cross-flow fan sprayer; the rear view shows the top fan inclined 20° and the measurement elevation; side view shows the fan outlet size for the top fan in the vertical position.

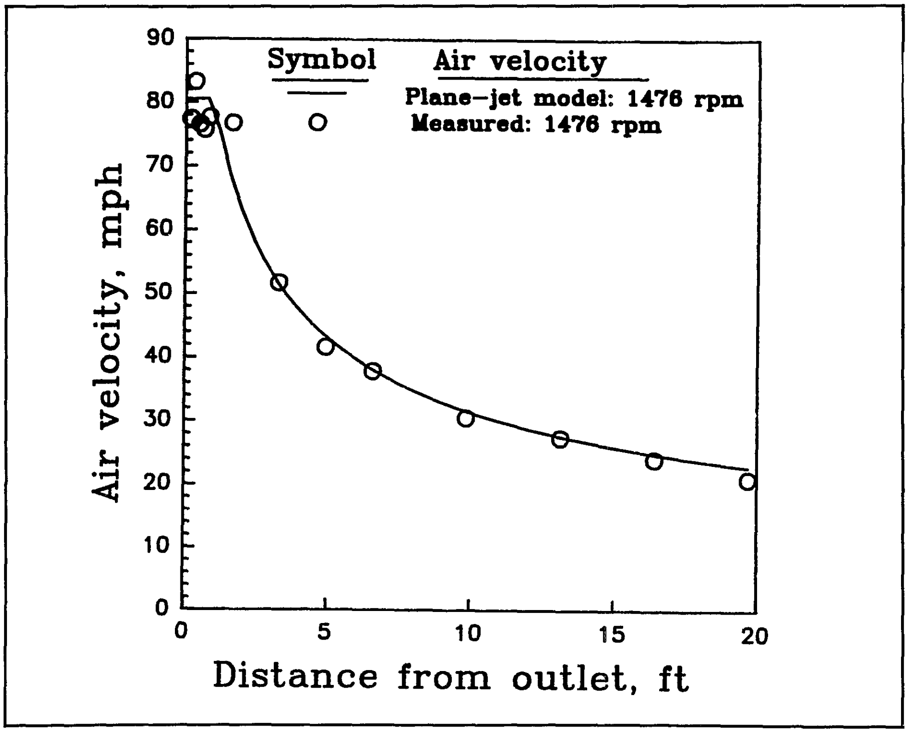

Figure 3. Maximum measured velocities compared with maximum velocities predicted by plane-jet model along the axial centerline of the jet. The top fan was vertical and velocities were measured 52 in above floor.

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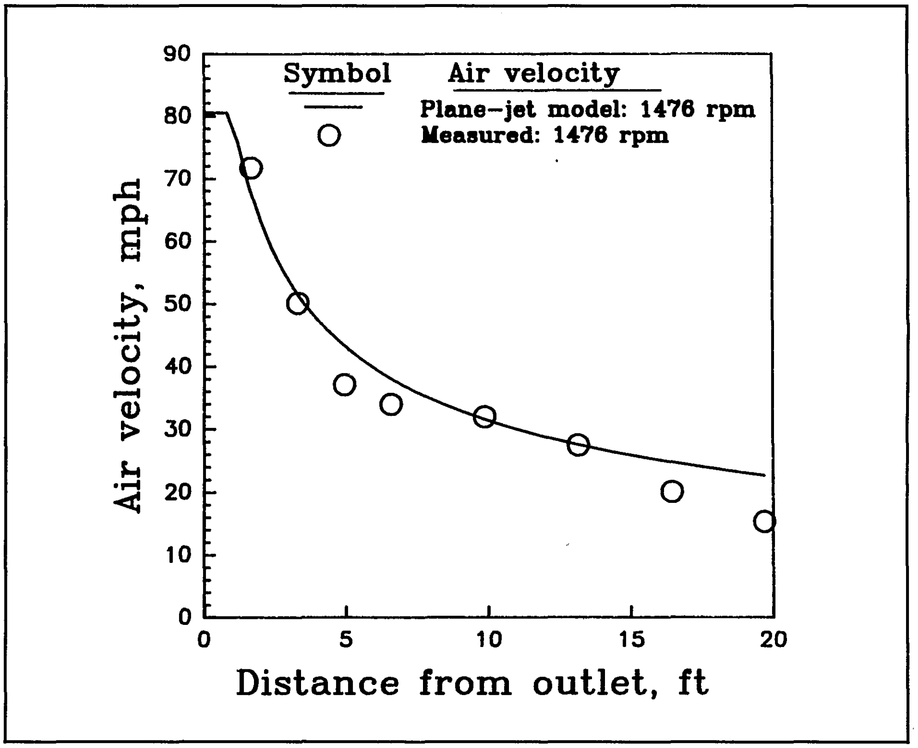

Figure 4. Maximum measured velocities along the axial centerline of the jet. The top fan was inclined 20°.

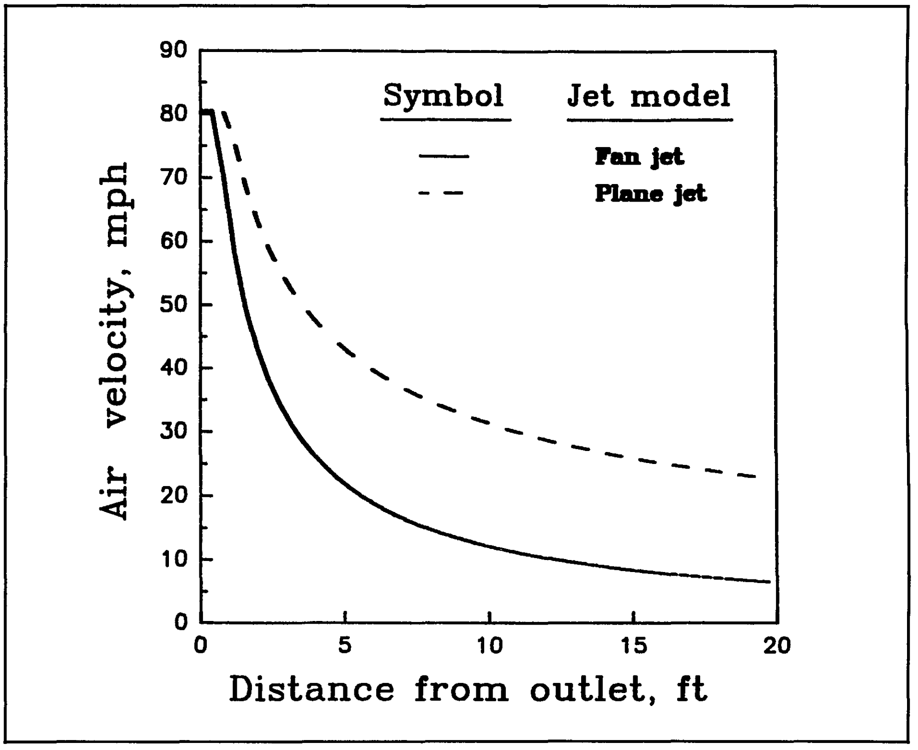

Figure 5. Predicted axial air velocities for fan (conventional orchard sprayer) and plane (cross-flow fan sprayer) jet models.

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