Impact of Feeding Injury by Eastern Grape Leafhopper (Homoptera:Cicadellidae) on Yield and Juice Quality of Concord Grapes

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Productivity of Concord vines infested with endemic populations of Eastern grape leafhopper, *Erythroneura comes* Say, was compared with that of uninfested vines in three field experiments from 1990 to 1995. Responses of vines to infestation levels ranging from 100 to 577 leafhopper days and peak leafhopper densities ranging from two to 14 leafhopper nymphs per leaf varied. Mean crop weight in vines not treated with insecticides was reduced by up to 4.9 kg/vine compared to sprayed vines. Effects on productivity sometimes carried over to subsequent crop years, but response of yield components to injury varied. In the season of injury, berry weight was the yield component most strongly affected. In subsequent years, leafhopper injury reduced bud fruitfulness, as measured by the number of berries per cluster and clusters per retained node. Soluble solids, adjusted for crop weight, were significantly affected in only one cropping cycle (out of 22). Yield reductions were only weakly correlated with infestation levels, as measured by leafhopper days and leaf injury ratings. Availability of adequate soil moisture and vine reserves is hypothesized to be an important determinant of the impact of leafhopper injury on Concord productivity in northeastern North America.

KEY WORDS: *Erythroneura comes,* pest management, foliar injury, yield components, economic injury level

Eastern grape leafhopper, *Erythroneura comes* Say (Homoptera: Cicadellidae), is the principal foliar pest of Concord, *Vitis labruscana* Bailey, grapes in the Lake Erie region of New York, Pennsylvania, and Ontario (7,8,22). Other species of *Erythroneura*, primarily *E. bistrata* and *E. vitifex*, are also pests on *Vitis vinifera* L. and interspecific hybrid cultivars grown in the region (11). *Erythroneura* leafhoppers feed primarily in the leaf mesophyll layer on grapes (24), producing stippling that reduces the rate of photosynthesis in injured leaves. From the mid 1940s to the mid 1980s, *E. comes* was effectively suppressed by three calendar- and phenology-timed sprays applied to grapes to control grape berry moth, *Endopiza viteana* Clemens (21). Recent changes in pest management recommendations for grape berry moth, however, have reduced the number of insecticide sprays targeted at this pest by about 70% (13,25), with many vineyards receiving no insecticide sprays. As a result, management of leafhoppers is assuming new importance for growers reducing their insecticide inputs.

Establishing treatment thresholds based on knowledge of how injury affects yield is essential for developing integrated pest management recommendations. In irrigated production regions of the west, grapes have been shown to tolerate relatively high levels of leafhopper injury before vine productivity is affected (3). Few studies, however, have been done on native American grapes grown without irrigation under cool-season climate conditions in the Northeast. In the only recent study on Concord vines in the east, Jubb *et al.* (8) found no significant differences in crop weight under "low" and "high" leafhopper infestations, and significant reduction in soluble solids in only one year of the four-year study. Changes in pruning practices have led us to reevaluate the impact of *E. comes* on Concord vines. The previous study was done when vines were hand-pruned under the balanced-pruning principles set forth by Shaulis *et al.* (19). Since then, growers have increasingly adopted machine (15) and minimal pruning (2) in an effort to maximize production (15). Higher crop load in hedged vineyards can cause difficulty in ripening Concord grapes during cool, wet seasons in the Northeast (16), and undoubtedly places more stress on vines than was the case when vines were balance-pruned. We hypothesized that vines might be less tolerant of leafhopper injury under current pruning practices and cropping levels.

The objective of the present studies was to evaluate the impact of leafhopper injury on Concord vineyards under current production practices. We report herein results of three multi-year experiments measuring yield and juice quality of Concord grapes with and without endemic levels of leafhopper injury.

Materials and Methods

Yield and juice quality of grapes of Concord grape-

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Acknowledgment. We acknowledge T. Taft, Jr. and C. Cummings of the Vineyard Laboratory for providing technical assistance to complete these studies, and K. Hutchinson for allowing us to use his vineyard. T. J. Dennehy provided valuable guidance in initiating these studies. We thank R. Pool and N. Shaulis, whose reviews and comments improved this manuscript. This research was supported by the New York Wine and Grape Foundation, New York Grape Production Research Fund, The J. Kaplan Foundation, and the Lake Erie Regional Grape Research Fund.

Manuscript submitted for publication 7 October 1996.

vines with and without injury caused by eastern grape leafhopper, *E. comes* were measured in three field experiments from 1990 to 1995. Two experiments, (herein denoted VL1 and VL2), were conducted at the Vineyard Laboratory in Fredonia, New York. The third experiment (WW) took place in a commercial vineyard 5 km west of Fredonia.

VL1: Experimental plots were established in 1990 within a 0.5-ha block in which endemic populations of leafhoppers were allowed to develop without insecticide treatment. Mature Concord vines, with a planting density of 2.75 m between rows and 2.4 m between vines within rows, were used. Within the block, three different pruning treatments were established — minimal pruned (VL1-Min), balanced pruned (VL1-Bal), and 80 nodes per vine (VL1-80). Pruning blocks were laid out in adjacent three-row non-randomized blocks. Each pruning block was analyzed as a separate experiment, because lack of randomization of pruning treatments precludes joint analysis. In VL1-Min, vines were pruned to a fixed node number (80 nodes) in the first year of the experiment. In subsequent years, all canes extending below the low trellis wire were removed, and additional cuts were made between vines to maintain vine separation. From 1991 to 1994, the number of retained nodes per vine varied from 175 to 338. In the VL1-Bal block, vines were pruned to an established pruning formula (9), with 20 nodes plus 20 additional nodes retained per 0.45 kg cane prunings (range: 35 - 65 retained nodes per vine). The VL1-80 block was pruned to a constant node number of 80.

Within each pruning treatment, every fourth vine within each of three rows was chosen as a count vine. Two treatments, sprayed and unsprayed with insecticide, were established on alternate count vines. On the sprayed count vines, 2.5 kg/ha carbaryl (Sevin 80 WP, Rhone-Poulenc) was applied with a backpack sprayer monthly, beginning on 15 June. Individual vines were sprayed to runoff, using a total spray volume equivalent to 1870 L/ha (200 gal/acre). No insecticides were applied to other vines in the blocks. These monthly treatments effectively prevented leafhopper injury. Each treatment (sprayed or unsprayed) was replicated 15 times. In the VL1-Bal block, initial pruning weights in the sprayed treatment were higher than in the unsprayed treatment. For this reason, the three sprayed vines with the highest and the three unsprayed vines with the lowest initial pruning weight (in 1989) were excluded from the analysis to equalize initial vine size. This left 12 replicates per treatment in the VL1-Bal block. Population density of leafhopper nymphs, foliar injury ratings, and yield and soluble solid data (described below) were collected for each of the count vines. Aside from insecticide treatments, standard viticultural practices for ground cover, disease, and fertility management were followed in the blocks.

WW-150: A similar 0.5-ha block was established in 1991 in a mature commercial Concord vineyard near Fredonia New York. Vines (spaced at 2.4 m between vines and 2.75 m between rows) were hand-pruned to 150 nodes, to approximate crop loads typical of grower usage in western New York. This block was chosen because it had a history of early-season leafhopper injury. Within the 0.5-ha block, 30 sprayed and 30 unsprayed count vines were established. Every fourth vine within the block was a count vine, and sprayed and unsprayed count vines were alternated systematically within the block. Standard viticultural practices were used for ground cover, disease, and fertility management. Carbaryl (2.24 kg/ha) was applied monthly to the sprayed count vines with a backpack sprayer to prevent leafhopper injury from 1 June through 1 September. Population densities of leafhopper nymphs, foliar injury ratings, pruning weights, yield, and soluble solids were determined for each of the count vines.

VL2-Min: In 1993, a new experiment with minimal-pruned vines was established at the Vineyard Laboratory in Fredonia, New York. We established this experiment because leafhopper population levels in the VL1-Min block (see results) were much lower than in adjacent VL1-80 and VL1-Bal blocks. The new minimal-pruned block (VL2-Min) was in a location which historically had higher leafhopper populations. The experiment was started in 1993, and continued through 1995. Treatments were established as previously described (pruning similar to VL1-Min), with the following exceptions. *(1)* Three spray treatments, (sprayed, threshold, and unsprayed) were established. The sprayed treatment received monthly applications of carbaryl (2.24 kg/ha) as previously described. In the threshold treatment, vines were to be sprayed when > 5 nymphs per leaf (determined by sampling in late July) were present. This threshold treatment was not sprayed in 1993 or 1994, and was, therefore, identical to the unsprayed treatment in those years. In 1995, a single application of carbaryl was made on 5 August to prevent late-season injury. *(2)* Treatments were randomly assigned to each of 29 blocks (9 vines per block, with 2 buffer vines between treatment vines) to adjust for variability in leafhopper infestation among blocks.

Leafhopper sampling: Population density of leafhopper nymphs was determined weekly from 1 June through 15 September by counting the number of leafhopper nymphs on leaves at nodes 3 through 7 (counting from the basal end of the shoot). The mean number of nymphs per leaf was then calculated for each sample date. From these data, cumulative leafhopper days were calculated for each vine by multiplying the number of leafhopper nymphs per leaf by the sampling interval (number of days between samples) and summing them over the entire growing season. This provides an index that integrates the amount of feeding and injury that is present over the course of the growing season.

Foliar injury ratings: Foliar injury was assessed by assigning injury severity ratings to leaves 3 to 7 of one randomly chosen shoot on each of the count vines. Five categories of leaf injury (visible stippling) were established and correlated with visual estimates of the percentage of leaf area injured. The five categories (% leaf area injured) are: 0 - no visible injury (0%); 1 - isolated stippling (1.4 ± 2.1%); 2 - feeding injury coalescing into lines concentrated near major leaf veins (8.6 ± 5.8%); 3 - veinal and interveinal stippling (31.8 ± 16.3%); and 4 - severe stippling with necrotic patches of leaf tissue (72.0 ± 16.4%). Reference injury photos were used for comparison with leaves on the count vines.

Viticultural data collection: Standard evaluations of cane pruning weight, yield, and juice quality were made. Pruning weight was determined at the start of each experiment, and yearly thereafter during the winter. At harvest, the number and weight of clusters per vine was recorded. Samples of two apical berries from 50 clusters of each count vine were weighed to determine average berry weight. Juice soluble solids (%) was obtained from expressed juice using a hand refractometer. Starting in 1992, the number of shoots per vine was counted in early June. Cluster weight, berries per cluster, yield per retained node, clusters per node, and shoots per retained node were then calculated.

Weather data: Daily minimum and maximum temperatures and rainfall data from 1990 to 1995 were collected at the vineyard laboratory in Fredonia, New York. Monthly cumulative degree-days after 1 April (base 10°C) and monthly rainfall (cm) were calculated. Cumulative deviations in temperature accumulations and rainfall for each year included in the three experiments are reported.

Within-shoot distribution of leafhopper nymphs: Nymph numbers on each leaf of five shoots on each of five vines was counted on 7 July, 2 August, and 14 September, 1994, on minimal-pruned and balanced-pruned vines at the Vineyard Laboratory in Fredonia, NY. Leaf injury ratings were also determined. Mean nymphal counts and injury ratings (±SEM) were calculated by leaf node for each pruning treatment.

Data analysis: For the VL1 experiment data were analyzed separately for each pruning level. For the VL1 and WW experiments, yield data from each year were analyzed separately as a completely randomized design. For each block and year, several yield and vine characteristics on the sprayed and unsprayed treatments were compared via t-tests. Tests were done on total yield (kg/vine), and on the yield components of clusters per vine, berries per cluster, and berry weight. Fruitfulness of buds were evaluated through tests comparing yield per node, clusters per retained node, and shoots per retained node (after 1992). Pruning weights and juice soluble solids were also compared. Because soluble solids are often inversely related to yield, differences in soluble solids at a particular cropping level might be masked by significant yield differences. Therefore soluble solids and yield relationships in sprayed and unsprayed vines were compared via two factor covariate analysis of variance with spray (categorical), yield (continuous), and spray × yield interaction. This analysis tested for differences in mean soluble solids values, as adjusted by yield.

The VL2 experiment was analyzed as a randomized complete block, with 29 blocks and three treatment factors (sprayed, unsprayed, spray on threshold). The two treatments with leafhopper injury (unsprayed, spray on threshold) were identical except in 1995, when a single spray was applied to the spray on threshold treatment. Following two factor ANOVA with block and treatment as the factors, single degree-of-freedom othogonal contrasts of sprayed *vs.* (unsprayed and threshold) and (unsprayed *vs.* threshold) were performed.

Power analysis: Several of the experimental blocks had consistent differences in mean yield that were not statistically different at the $\alpha = 0.05$ level. We performed additional analyses of total yield to determine the power of these experiments to detect differences at the $\alpha = 0.05$ level, given the existing variability among replicate vines. Two functions of power (the probability of attaining statistical significance at a given a level) were calculated. The first function is the least significant value of mean treatment differences, which is a function of sample size (18). This function was calculated for differences in mean yield among sprayed and unsprayed treatments, assuming sample sizes of 5, 15, and 30 vines per treatment. The second attribute is the least significant sample size, which is the number of replicates that would be necessary to detect differences, given the existing variance within treatments. This measure gives an indication of how robust the failure to detect statistical significance is to changes in sample size.

Results

Temperature and rainfall: Temperature and rainfall (Fig. 1) were both highly variable over the six growing seasons encompassed by these experiments. Unseasonably warm temperatures in May, and below-average rainfall throughout the season made 1991 a hot, dry growing season. This season was followed by an extremely cool, wet growing season in 1992. The years 1993 and 1995 were slightly warmer and drier than average, while 1990 and 1994 were slightly cooler and wetter than average.

VL1 leafhopper injury: Severity and timing of leafhopper injury, as indicated by leafhopper days and injury ratings, varied both among years and among blocks. Cumulative leafhopper days by 15 September ranged from 91 to 228, 187 to 588, and 165 to 576, in the VL1-Min, VL1-Bal, and VL1-80 blocks, respectively. Leafhopper days and injury ratings (Table 1) were similar in VL1-Bal and VL1-80 blocks. However, leafhopper days in VL1-Min were consistently lower than in the VL1-Bal and VL1-80 blocks in each year of the experiment, resulting in lower levels of leafhopper injury. Warm weather in May and June 1991 (Fig. 1) accelerated leafhopper development, leading to early and higher levels of leafhopper injury in 1991 (Table 1). Consistently lower injury levels and leafhopper days in the minimal-pruned vines may have affected results.

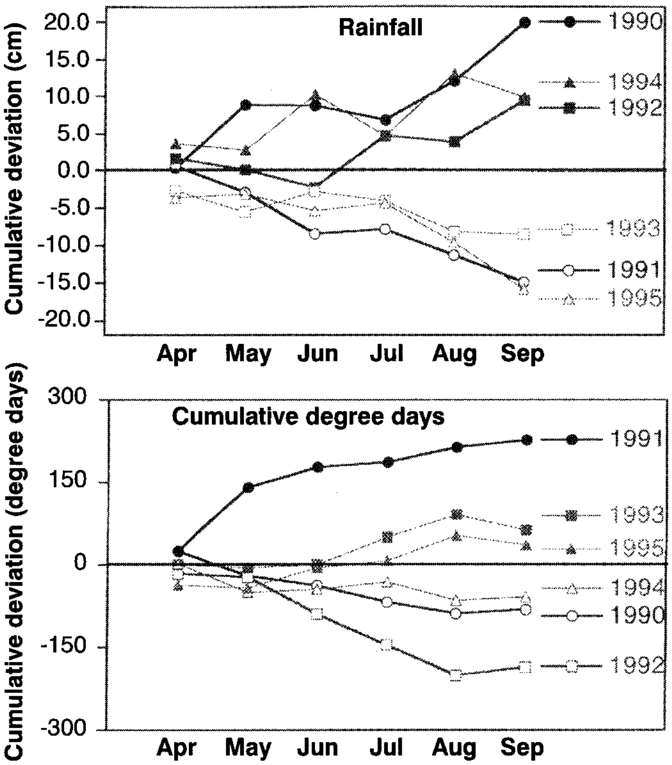

Fig. 1 (left). Monthly deviations from mean cumulative rainfall and growing degree-days (base 10°C) at Fredonia, New York, from 1990 to 1995.

VL1 yield components: In VL1-Bal (Table 2), total yield of sprayed vines was significantly greater than that of unsprayed vines in 1990, 1991, and 1992. Yield differences in the first year of the experiment (1990) were associated with fewer clusters per vine , and slightly fewer clusters per node and berries per cluster, resulting in lower crop weight per node. It is unlikely that leafhopper feeding in the first year of the experiment caused the reduction in clusters per vine and clusters per node, because these attributes were determined before leafhopper injury occurred. Thus these differences in yield components were probably associated with preexisting differences in vine condition. In 1991, yield was significantly lower in the unsprayed treatment, but no single yield component was significantly different. However, unsprayed vines had slightly (but not significantly) fewer nodes per vine and berries per cluster. In 1992, unsprayed vines had significantly fewer shoots per node and clusters per vine, and slightly fewer clusters per node. Notably, crop weight per retained node was not significantly lower in unsprayed vines from 1991 to 1994.

Table 1. Leafhopper density and leaf injury ratings in unsprayed Concord vines, at VL1, WW, and VL2 Experiments, 1990 - 1995.

		Peak Nymphal Density							
		First — brood —		Second — brood —		Leafhopper — days —		Injury rating	Percent injury
Site	Year	Date	Nymphs per leaf	Date	Nymphs per leaf	1 July	15 Sept.		
WW-150 Nodes	1991	14 June	5.5	26 July	3.6	113	250	2.3	20.4
	1992	23 July	1.4	2 Sept.	6.4	0	57	0.9	1.8
	1993	19 July	1.5	31 Aug.	2.9	0	109	1.5	6.0
	1994	12 July	1.9	7 Sept.	1.0	2	70	0.9	1.7
VL1-Minimal	1990	30 July	1.3	17 Sept.	6.6	1	184	—	—
	1991	23 June	3.5	11 Aug.	4.2	59	229	2.7	29.3
	1992	11 Aug.	2.1	—	—	0	97	1.2	3.2
	1993	20 July	1.2	7 Sept.	3.4	0	107	1.6	7.2
	1994	11 July	1.2	30 Aug.	1.6	3	90	0.8	1.6
VL1-Balanced	1990	30 July	0.9	17 Sept.	7.1	1	196	—	—
	1991	30 June	4.6	11 Aug.	13.8	62	577	3.2	43.5
	1992	5 Aug.	7	—	—	0	277	1.7	8.8
	1993	20 July	3	30 Aug.	15.7	0	448	2.3	18.7
	1994	11 July	1.9	7 Sept.	4.1	1	164	1.1	2.9
VL1-80 Node	1990	23 July	1.3	17 Sept.	8	1	274	—	—
	1991	17 June	3.5	25 Aug.	15.1	80	588	3.1	42.1
	1992	5 Aug.	5.1	—	—	1	228	1.8	9.8
	1993	20 July	1.9	30 Aug.	9.6	0	296	2.2	16.8
	1994	11 July	3.2	7 Sept.	4.4	3	187	1.2	3.2
VL2-Minimal (unsprayed)	1993	20 July	1.6	30 Aug.	5.3	0	177	1.8	10.0
	1994	25 July	2.3	7 Sept.	2.1	5	135	1.1	3.1
	1995	13 July	1.7	24 Aug.	2	21	101	0.9	1.9
VL2-Minimal (Threshold)[1]	1993	20 July	1.7	30 Aug.	5.9	0	189	1.7	9.5
	1994	25 July	1.9	7 Sept.	1.4	5	111	1.1	2.8
	1995	13 July	1.4	24 Aug.	—	16	40	0.4	1.6

[1] Sprayed 5 August 1995. Not sprayed in 1993 or 1994.

Table 2. Yield Components of Concord vines with and without *E. comes* Injury from VL1 experiment, 1990-1994.

		Balanced Pruned (VL1-Bal) Mean ± SEM				80 Node (VL1-80) Mean ± SEM				Minimal Pruned (VL1-Min) Mean ± SEM			
Attribute	Year	Sprayed	Unsprayed	t^1	*P*	Sprayed	Unsprayed	t^2	*P*	Sprayed	Unsprayed	t^2	*P*
Yield (kg/vine)	1990	4.6 ± 0.4	3.2 ± 0.3	2.79	0.01	10.6 ± 0.4	9.6 ± 0.7	1.42	0.16	9.2 ± 0.5	10.0 ± 0.6	1.01	0.32
	1991	15.9 ± 0.9	13.2 ± 0.9	2.11	0.05	17.2 ± 0.9	15.7 ± 0.5	1.45	0.16	21.3 ± 1.2	20.6 ± 1.2	0.40	0.69
	1992	17.2 ± 0.8	13.9 ± 1.0	2.59	0.02	18.9 ± 1.1	16.8 ± 0.9	1.49	0.15	18.9 ± 0.9	18.7 ± 1.1	0.13	0.90
	1993	10.8 ± 0.8	9.3 ± 0.6	1.50	0.14	10.0 ± 0.4	9.2 ± 0.4	1.49	.015	16.8± 0.8	16.1 ± 0.9	0.56	0.58
	1994	14.9 ± 1.3	13.4 ± 0.7	1.07	0.29	16.1 ± 0.7	15.9 ± 0.5	0.24	0.81	23.5 ± 1.3	24.8 ± 1.0	0.77	0.45
Clusters per vine	1990	61 ± 5	49 ± 3	2.23	0.03	140 ± 5	130 ± 7	1.12	0.27	124 ± 6	131 ± 6	0.78	0.46
	1991	149 ± 12	129 ± 10	1.22	0.23	169 ± 6	164 ± 5	0.68	0.50	421 ± 21	406 ± 21	0.13	0.90
	1992	175 ± 9	141 ± 13	2.17	0.04	210 ± 8	189 ± 9	1.78	0.08	345 ± 19	341 ± 28	0.13	0.90
	1993	128 ± 10	122 ± 10	0.47	0.64	135 ± 4	132 ± 4	0.54	0.59	421 ± 21	392 ± 24	0.90	0.38
	1994	156 ± 11	150 ± 10	0.40	0.69	175 ± 6	173 ± 5	0.25	0.80	478 ± 27	528 ± 24	1.37	0.18
Berries per cluster	1990	22.3 ± 1.0	19.5 ± 1.2	1.80	0.09	23.0 ± 0.5	23.5 ± 1.0	0.39	0.70	23.9 ± 0.5	24.5 ± 0.6	0.85	0.40
	1991	38.6 ± 2.0	35.9 ± 1.2	1.13	0.27	37.3 ± 1.1	36.4 ± 1.4	0.54	0.59	24.8 ± 0.7	25.5 ± 1.5	0.45	0.65
	1992	34.7 ± 1.0	34.6 ± 1.5	0.03	0.97	33.0 ± 1.0	31.9 ± 0.8	0.84	0.41	23.4 ± 0.7	22.8 ± 0.7	0.60	0.55
	1993	28.0 ± 0.9	26.8 ± 0.8	0.95	0.35	25.3 ± 0.7	24.5 ± 0.6	0.90	0.37	17.1 ± 0.3	17.8 ± 0.6	1.02	0.3
	1994	29.5 ± 0.7	28.0 ± 1.1	1.23	0.23	27.9 ± 0.5	29.3 ± 0.8	1.40	0.17	18.4 ± 0.4	18.1 ± 0.4	0.54	0.59
Berry weight (g)	1990	3.36 ± 0.05	3.25 ± 0.06	1.38	0.18	3.3 ± 0.05	3.1 ± 0.04	2.68	0.01	3.1 ± 0.06	3.1 ± 0.04	0.32	0.75
	1991	2.88 ± 0.05	2.87 ± 0.06	0.14	0.89	2.7 ± 0.06	2.7 ± 0.05	0.76	0.45	2.0 ± 0.04	2.1 ± 0.04	0.40	0.69
	1992	2.85 ± 0.05	2.91 ± 0.06	0.75	0.46	2.7 ± 0.04	2.8 ± 0.04	0.79	0.45	2.4 ± 0.05	2.5 ± 0.08	0.16	0.87
	1993	3.04 ± 0.08	2.92 ± 0.06	1.23	0.22	2.9 ± 0.04	2.8 ± 0.05	1.37	0.18	2.3 ± 0.06	2.3 ± 0.04	0.26	0.80
	1994	3.22 ± 0.04	3.25 ± 0.05	0.47	0.64	3.3 ± 0.05	3.2 ± 0.05	1.59	0.12	2.7 ± 0.05	2.6 ± 0.04	1.03	0.31
Nodes per vine	1990	40.0 ± 2.3	38.5 ± 2.1	0.48	0.63	80	77.6	—	—	78.3 ± 1.4	78.2 ± 0.8	—	—
	1991	70.0 ± 4.3	62.5 ± 5.5	1.07	0.29	80	80	—	—	255.5 ± 9.8	242.5 ± 12.4	0.81	0.42
	1992	56.2 ± 1.3	51.3 ± 4.4	1.04	0.31	80	80	—	—	175.9 ± 9.9	188.1 ± 10.2	0.85	0.40
	1993	67.8 ± 4.3	64.8 ± 5.2	0.44	0.66	80	80	—	—	330.5 ± 13.8	329.5 ± 20.2	0.03	0.97
	1994	59.3 ± 2.8	63.0 ± 4.6	0.69	0.49	80	80	—	—	318.8 ± 16.2	338.1 ±16.1	0.84	0.40
Yield per node (g)	1990	119.6 ± 12.3	85.3 ± 9.14	2.24	0.03	132.6 ± 4.5	122.2 ± 7.7	1.16	0.25	117.0 ± 5.1	127.0 ± 6.8	1.18	0.25
	1991	231.2 ± 11.3	220.1 ± 15.9	0.57	0.57	214.7 ± 10.7	196.4 ± 6.8	1.45	0.16	83.7 ± 4.8	85.5 ± 4.5	0.28	0.79
	1992	306.5 ± 12.4	279.7 ± 18.3	1.21	0.24	235.6 ± 13.5	209.9 ± 10.7	1.49	0.15	109.0 ± 4.2	100.2 ± 4.6	1.41	0.17
	1993	158.7 ± 5.8	147.4 ± 7.5	1.19	0.24	124.7 ± 5.0	114.4 ± 4.8	1.49	0.15	51.0 ± 1.7	50.0 ± 2.9	0.31	0.76
	1994	251.3 ± 17.7	218.0 ± 11.2	1.58	0.13	200.7 ± 9.2	198.1 ± 5.6	0.21	0.81	73.6 ± 3.0	74.2 ± 3.6	0.11	0.91
Clusters per node	1990	1.56 ± 0.11	1.32 ± 0.09	1.66	0.11	1.75 ± 0.07	1.67 ± 0.08	0.78	0.44	1.58 ± 0.06	1.67 ± 0.06	0.95	0.35
	1991	2.11 ± 0.11	2.12 ± 0.11	0.05	0.96	2.12 ± 0.07	2.05 ± 0.07	0.67	0.50	1.66 ± 0.07	1.70 ± 0.10	0.39	0.10
	1992	3.12 ± 0.13	2.78 ± 0.14	1.79	0.08	2.63 ± 0.10	2.37 ± 0.11	1.78	0.09	1.98 ± 0.08	1.81 ± 0.11	1.21	0.22
	1993	1.89 ± 0.09	1.89 ± 0.08	0.06	0.95	1.68 ± 0.05	1.65 ± 0.05	0.54	0.60	1.28 ± 0.04	1.21 ± 0.05	1.09	0.29
	1994	2.63 ± 0.16	2.41 ± 0.11	1.13	0.27	2.19 ± 0.07	2.17 ± 0.06	0.25	0.81	1.50 ± 0.05	1.58 ± 0.07	0.93	0.36
Shoots per node	1990	—	—			—	—			—	—		
	1991	—	—			—	—			—	—		
	1992	1.50 ± 0.04	1.34 ± 0.06	2.40	0.02	1.28 ± 0.03	1.08 ± 0.04	3.94	<0.001	1.46 ± 0.08	1.41 ± 0.07	0.53	0.61
	1993	0.96 ± 0.04	1.01 ± 0.04	0.80	0.43	0.94 ± 0.02	0.93 ± 0.03	0.05	0.95	0.93 ± 0.04	0.98 ± 0.07	0.62	0.54
	1994	0.89 ± 0.05	0.90 ± 0.04	0.07	0.94	0.88 ± 0.01	0.91 ± 0.03	1.15	0.25	0.95 ± 0.04	0.94 ± 0.04	0.19	0.87
Pruning weight (kg)	1989	0.91 ± 0.05	0.86 ± 0.05	0.48	0.63	0.82 ± 0.09	0.86 ± 0.09	0.05	0.96	0.91 ± 0.09	0.91 ± 0.05	0.21	0..83
	1990	1.59 ± 0.09	1.45 ± 0.14	0.73	0.47	1.23 ± 0.09	1.18 ± 0.09	0.44	0.66	1.09 ± 0.09	1.09 ± 0.09	0.20	0.84
	1991	1.27 ± 0.05	1.18 ± 0.09	1.04	0.31	1.23 ± 0.14	1.09 ± 0.09	0.98	0.33	0.32 ± 0.05	0.45 ± 0.09	1.56	0.13
	1992	1.55 ± 0.09	1.45 ± 0.14	0.47	0.63	1.36 ± 0.09	1.05 ± 0.09	2.70	0.01	0.36 ± 0.05	0.45 ± 0.05	1.40	0.17
	1993	1.36 ± 0.05	1.45 ± 0.09	0.69	0.50	1.27 ± 0.09	1.23 ± 0.09	0.48	0.64	0.32 ± 0.05	0.41 ± 0.05	1.33	0.19
	1994	1.82 ± 0.09	1.55 ± 0.09	1.14	0.25	1.59 ± 0.14	1.45 ± 0.14	0.73	0.47	0.36 ± 0.05	0.32 ± 0.05	0.55	0.59

[1] Two-tailed *t*-test, *n* =12, *df* = 22 [2] Two-tailed *t*-test, *n* =15, *df* = 28

In VL1-80, mean yields between 1990 and 1993 ranged from 0.9 to 2 kg/vine lower in the unsprayed vines than in the sprayed vines, however they were not significantly different ($0.1 < p < 0.2$) at the $\alpha = 0.05$ level. Following the dry 1991 season, there were significantly fewer shoots per vine in the unsprayed than in the sprayed treatment in 1992, and a slight reduction in clusters per node. Grown pruning weight in the unsprayed treatment was significantly lower in 1992. In 1994, yields, and yield components of unsprayed and sprayed vines were similar.

In the minimal-pruned VL1-Min block, sprayed and unsprayed vines performed equally well. There were no significant differences in either total yield, yield components, pruning weights, or juice soluble solids in any year of the experiment.

WW-150 leafhopper injury: Leafhopper-days ranged from 259 in 1991 to 75 in 1994 (Table 1). Early onset of leafhopper population development in 1991 led to accumulation of >100 leafhopper days by 30 June - more than half of the total leafhopper days accumulated over the growing season. Following the hot, dry 1991 growing season, leafhopper injury was low. Leafhopper days were under 100 in 1992, 1993, and 1994, and estimated total foliar injury was less than 5%. Compared to the VL1-Bal and VL1-80 blocks, fewer leafhopper days were accumulated at WW-150. However, leafhopper days accumulated were in a similar range as those of VL1-Min.

WW-150 yield components: Total yield (kg/vine) was significantly lower in the unsprayed compared to sprayed vines in 1991, 1992, and 1993 (Table 3). Yield components responsible for lower yield varied among years. In 1991, yield reduction was associated with lower berry weight in the unsprayed vines. In 1992 many yield components were affected. Unsprayed vines had significantly fewer clusters per vine, fewer berries per cluster, and lower berry weight. On a per node-basis, yield was also lower, due to reduced fruitfulness of buds as indicated by fewer clusters per node, and fewer shoots per node. In 1993, berry weights were similar in both treatments, but berries per cluster and clusters per vine were still lower in unsprayed vines. Bud fruitfulness, as indicated by the number of clusters per node, was also lower. In 1994, however, no significant differences were observed, except in the number of shoots per node. Soluble solids, although numerically lower in 1991, were not significantly different, either before or after adjustment for yield differences (Table 5).

VL2-Min leafhopper injury: Leafhopper days in the unsprayed and threshold treatments (Table 1) were similar in 1993 (177-193) and 1994 (135-111). In 1995, however, a mid season spray was applied to the threshold experiment on 4 August. As a result, leafhopper days averaged 100 (untreated) and 40 (spray on threshold), respectively. Mean injury ratings were also similar in 1993 and 1994. However in 1995, injury rating in the spray on threshold treatment averaged 0.43, about half of the 0.91 rating in the unsprayed treatment.

Table 3. Yield Components of Concord vines with and without *E. comes* injury from WW-150 Experiment, 1990-1994.

Attribute	Year	Mean (± SEM) Sprayed	Unsprayed	t [1]	P
Yield (kg/vine)	1991	14.1 ± 0.4	12.7 ± 0.5	2.21	0.03
	1992	10.5 ± 0.6	8.2 ± 0.7	2.47	0.01
	1993	7.5 ± 0.3	6.1 ± 0.3	3.48	0.001
	1994	12.9 ± 0.4	12.7 ± 0.6	0.34	0.73
Clusters per vine	1991	235 ± 5	228 ± 6	0.87	0.39
	1992	186 ± 9	146 ± 10	2.83	0.006
	1993	145 ± 6	126 ± 6	2.22	0.03
	1994	241 ± 7	227 ± 10	1.12	0.26
Berries per cluster	1991	27.2 ± 0.4	26.8 ± 0.7	0.54	0.58
	1992	21.9 ± 0.6	20.0 ± 0.5	2.51	0.015
	1993	18.1 ± 0.4	16.5 ± 0.4	3.02	0.003
	1994	18.7 ± 0.3	19.2 ± 0.4	1.06	0.29
Berry weight (g)	1991	2.2 ± 0.04	2.1 ± 0.04	1.88	0.06
	1992	2.6 ± 0.04	2.8 ± 0.03	3.68	<0.001
	1993	2.9 ± 0.04	2.9 ± 0.03	0.56	0.58
	1994	2.9 ± 0.02	2.9 ± 0.03	0.25	0.80
Nodes per vine[2]	1991	147.5±1.4	149.2 ± 0.8	—	—
	1992	144.0±2.4	138.5 ± 3.6	—	—
	1993	147.5±1.8	149.0 ± 1.0	—	—
	1994	144.5±2.8	143.8 ± 2.4	—	—
Yield per node (g)	1991	95.4 ± 2.6	85.2 ± 3.1	2.51	0.01
	1992	72.1 ± 3.8	58.0 ± 4.3	2.45	0.017
	1993	51.0 ± 2.0	40.6 ± 2.2	3.48	0.001
	1994	90.4 ± 3.4	87.7 ± 3.9	0.53	0.60
Clusters per node	1991	1.60 ± 0.03	1.53 ± 0.04	1.25	0.22
	1992	1.28 ± 0.06	1.03 ± 0.06	2.88	0.006
	1993	0.98 ± 0.04	0.84 ± 0.04	2.43	0.01
	1994	1.68 ± 0.06	1.58 ± 0.06	1.28	0.20
Shoots per node	1991	—	—	—	—
	1992	1.05 ± 0.03	0.97 ± 0.03	2.09	0.04
	1993	0.72 ± 0.03	0.71 ± 0.03	0.34	0.74
	1994	0.99 ± 0.03	0.89 ± 0.03	2.37	0.02
Pruning weight (kg)	1990	0.44 ± 0.02	0.41 ± 0.03	0.57	0.56
	1991	0.13 ± 0.01	0.13 ± 0.01	0.08	0.94
	1992	0.30 ± 0.02	0.28 ± 0.02	0.75	0.45
	1993	0.16 ± 0.01	0.17 ± 0.01	0.27	0.78
	1994	0.35 ± 0.03	0.34 ± 0.04	0.07	0.94

[1] Two-tailed t-test, n =30, df = 59.

[2] Vines pruned to 150 nodes.

VL2-Min yield components: Yields of the sprayed and two unsprayed treatments were marginally different ($0.05 < p < 0.10$) in 1993 and 1994, ranging between 1 and 2 kg/vine lower than the sprayed treatments (Table 4). In 1995, however, yield was significantly lower (3 to 5 kg/vine) in threshold and unsprayed treatments compared to sprayed vines. In 1993, sprayed vines had slightly higher yield/node associated with higher berry weight than the unsprayed and threshold treatments. In 1994, berry weight, yield per node, and the number of clusters per node were all significantly higher in the sprayed vs. two unsprayed treatments. In 1995, yield differences were wider, ranging from 13.7 kg/vine (sprayed) to 10.6 kg/vine (unsprayed) to 8.8 kg/vine (spray on threshold). In spite of the mid-season spray applied to the threshold treatment, resulting in a 50% reduction in leafhopper days, yield was marginally lower ($p = 0.09$) in the threshold

Table 4. Yield components of Concord vines with and without *E. comes* injury from VL2 Experiment, 1990-1994.

		Mean ± SEM			Sprayed *vs.* thresh. & unsprayed		Threshold *vs.* unsprayed	
Attribute	**Year**	**Sprayed**	**Unsprayed**	**Threshold**	***t***	***P***	***t***	***P***
Yield (kg/vine)	1993	10.8 ± 0.4	9.8 ± 0.5	9.7 ± 0.6	1.66	0.09	0.11	0.91
	1994	23.0 ± 0.9	21.0 ± 0.9	21.1 ± 0.9	1.81	0.07	0.11	0.91
	1995	13.8 ± 0.7	10.6 ± 0.7	8.8 ± 0.7	4.53	<0.001	1.73	0.09
Clusters per vine	1993	106 ± 2	106 ± 2	104 ± 2	0.46	0.64	0.82	0.41
	1994	439 ± 17	422 ± 17	427 ± 17	0.70	0.48	0.21	0.83
	1995	315 ± 15	251 ± 13	205 ± 14	5.13	<0.001	2.31	0.02
Berries per cluster	1993	38.2 ± 1.4	35.4 ± 1.9	36.1 ± 2.3	1.06	0.29	0.23	0.81
	1994	20.3 ± 0.4	20.6 ± 0.4	20.6 ± 0.6	0.56	0.57	0.02	0.98
	1995	18.0 ± 0.4	17.0 ± 0.5	16.7 ± 0.5	2.04	0.04	0.46	0.64
Berry weight (g)	1993	2.7 ± 0.0	2.6 ± 0.0	2.6 ± 0.0	1.47	0.14	0.14	0.88
	1994	2.6 ± 0.0	2.4 ± 0.0	2.4 ± 0.0	3.77	0.003	0.12	0.90
	1995	2.4 ± 0.0	2.4 ± 0.0	2.6 ± 0.0	1.69	0.09	2.20	0.03
Nodes per vine	1993	120	120	120	—	—	—	—
	1994	288 ± 13	299 ± 12	295 ± 14	0.59	0.85	0.56	0.83
	1995	277 ± 10	227 ± 7	224 ± 11	4.50	<0.001	0.26	0.80
Yield per node (g)	1993	90.3 ± 3.7	81.8 ± 4.5	81.1 ± 4.9	1.66	0.10	0.12	0.91
	1994	82.0 ± 2.9	71.8 ± 3.2	73.9 ± 3.3	2.37	0.02	0.48	0.63
	1995	49.6 ± 2.1	45.8 ± 2.6	39.3 ± 2.2	2.48	0.01	1.97	0.05
Clusters per node	1993	0.88 ± 0.01	0.88 ± 0.02	0.86 ± 0.02	0.46	0.64	0.84	0.40
	1994	1.54 ± 0.03	1.42 ± 0.04	1.47 ± 0.04	2.20	0.03	0.05	0.97
	1995	1.14 ± 0.04	1.09 ± 0.04	0.92 ± 0.04	2.57	0.01	2.91	0.004
Shoots per node	1993	1.52 ± 0.04	1.44 ± 0.05	1.36 ± 0.07	1.75	0.08	1.07	0.28
	1994	1.08 ± 0.03	1.04 ± 0.03	1.05 ± 0.03	1.09	0.0.28	0.30	0.77
	1995	0.91 ± 0.03	1.00 ± 0.04	0.89 ± 0.04	0.72	0.47	2.20	0.03
Leafhopper days	1993	11 ± 2	177 ± 22	190 ± 21	8.09	<0.001	0.52	0.61
	1994	6 ± 1	135 ± 14	111 ± 13	9.46	<0.001	1.71	0.08
	1995	0 ± 0	101 ± 12	40 ± 7	7.67	<0.001	5.88	<0.00
Injury Rating	1993	0.65 ± 0.05	1.77 ± 0.09	1.74 ± 0.08	12.47	<0.001	0.27	0.79
	1994	0.16 ± 0.05	1.14 ± 0.08	1.09 ± 0.07	11.72	<0.001	0.51	0.61
	1995	0.03 ± 0.01	0.91 ± 0.08	0.43 ± 0.06	8.92	<0.001	5.83	<0.001
Pruning weight (kg)	1993	0.64 ± 0.05	0.64 ± 0.06	0.60 ± 0.06	0.27	0.78	0.45	0.66
	1994	0.77 ± 0.08	0.60 ± 0.07	0.68 ± 0.09	1.37	0.70	0.70	0.49
	1995	0.39 ± 0.04	0.34 ± 0.05	0.33 ± 0.04	1.13	0.26	0.20	0.84

treatment compared to the unsprayed treatment. Yield differences among treatments were associated with fewer clusters per vine, and fewer berries per cluster. Bud fruitfulness (yield per node and clusters per node) was also significantly reduced. Pruning weights did not vary significantly in any year among treatments.

Juice soluble solids: Covariate analysis of yield/soluble solids relationships in all experiments indicated that juice soluble solids, adjusted for yield, were not significantly lowered by leafhopper feeding (Table 5). In most years except 1991, yield was a highly significant ($p < 0.001$) correlate of juice soluble solids. Spray treatment was only significant ($p = 0.03$) at VL2-Min in 1995, where soluble solids in the unsprayed treatments were higher than those in the sprayed treatment. However, at VL2-Min in 1993 and 1994, the slope of the yield/Brix line, as indicated by the significant spray × yield interaction term, was significantly different, indicating that Brix readings were lower in high-yielding unsprayed vines than in high-yielding sprayed vines. This suggests that leafhopper injury reduced the rate of soluble solids accumulation most in vines with the heaviest cropping levels.

Power analysis: Analysis of the power to detect significant differences in mean yield at the $\alpha = 0.05$ level (Table 6) indicated that an increase in sample size in some of the blocks would have resulted in statistical significance. This was most apparent in the Vl1-80 block, where mean yield ranged from 0.8 to 1.5 kg/vine lower in the unsprayed treatment. At the sample size used ($N = 15$), mean yield differences were nearly equivalent to the calculated least significant value. Calculated least significant sample size values ranged from 27 to 30, indicating that sample sizes equivalent to those in the WW-150 experiment may have detected significant differences. In contrast, sample sizes rang-

Table 5. Tests of significance for impact of spray treatment, yield, and their interaction on juice soluble solids accumulations at VL1, WW, and VL2.

		Juice Soluble Solids (±SEM)		Effect: Spray treatment		Effect: Yield		Effect: Spray × Yield interaction	
Experiment	Year	Sprayed	Unsprayed	*F*	*P*	*F*	*P*	*F*	*P*
VL1-Bal	1990	16.2 ± 0.1	16.4 ± 0.1	0.01	0.91	0.06	0.80	0.09	0.76
	1991	16.9 ± 0.5	17.5 ± 0.4	1.60	0.21	2.90	0.09	1.76	0.19
	1992	16.7 ± 0.2	17.1 ± 0.2	1.31	0.26	24.03	<0.001	0.71	0.4
	1993	17.3 ± 0.1	17.2 ± 0.1	0.01	0.94	17.3	0.003	0.58	0.45
	1994	17.4 ± 0.2	17.5 ± 0.2	1.04	0.31	2.45	0.13	0.94	0.34
VL1-80	1990	15.7 ± 0.2	15.5 ± 0.2	0.07	0.79	3.65	0.07	0.01	0.98
	1991	16.9 ± 0.3	16.1 ± 0.3	0.04	0.82	0.72	0.40	0.09	0.92
	1992	15.8 ± 0.2	15.7 ± 0.2	2.58	0.11	14.84	<0.001	3.665	0.07
	1993	17.5 ± 0.1	17.4 ± 0.1	0.58	0.45	8.7	0.007	0.26	0.61
	1994	17.5 ± 0.2	16.7 ± 0.4	0.28	0.60	1.35	0.26	0.59	0.45
VL1-Min	1990	15.5 ± 0.2	15.4 ± 0.2	0.01	0.94	1.07	0.31	0.01	0.95
	1991	13.8 ± 0.3	13.3 ± 0.3	0.87	0.36	9.0	0.006	0.37	0.55
	1992	14.1 ± 0.3	14.0 ± 0.4	0.05	0.82	23.7	<0.001	0.02	0.89
	1993	15.5 ± 0.2	15.4 ± 0.1	4.2	0.05	0.98	0.33	4.03	0.05
	1994	14.4 ± 0.3	13.6 ± 0.2	0.53	0.43	8.6	0.007	0.21	0.65
WW-150 node	1991	13.0 ± 0.1	12.7 ± 0.1	0.39	0.53	0.31	0.58	0.14	0.71
	1992	15.5 ± 0.2	16.0 ± 0.2	3.04	0.08	99.6	<0.001	1.56	0.11
	1993	15.9 ± 0.1	15.9 ± 0.1	2.19	0.14	19.6	<0.001	1.19	0.28
	1994	15.8 ± 0.2	15.7 ± 0.2	1.19	0.47	13.4	<0.001	0.36	0.55
VL2-Min[1]	1993	16.8 ± 0.0	16.7 ± 0.0[1]	1.91	0.17	7.91	0.006	3.85	0.05
	1994	14.0 ± 0.2	13.3 ± 0.2	1.21	0.27	7.58	0.007	3.71	0.06
	1995	15.8 ± 0.2	16.3 ± 0.2	4.79	0.03	49.4	<0.001	5.50	0.02

[1] Data from unsprayed and threshold treatments pooled.

ing from $N = 95$ to 3406 would have been required in the VL1-Min block for statistical significance at the $\alpha = 0.05$ level, indicating that our finding of no differences in yield or other attributes at VL1-Min was not due to inadequate sample size. Averaged over all 22 individual blocks, yields were 1.4 kg/vine lower in the unsprayed vines than in sprayed vines, while the least significant value averaged 0.7, 1.1, and 2.1 for sample sizes of 30, 15, and 5, respectively.

Within-shoot distribution of leafhoppers: Leafhopper nymphs, and injury were concentrated at the basal nodes of the shoots (Fig. 2) early in the growing season. On 7 July, nymphal density was highest at node 3, and injury ratings were very low. By 2 August, nymphal populations were concentrated at nodes 3-9 and significant injury was present. By 15 September, injury ratings and nymphal populations were evenly distributed among shoot nodes.

Discussion

These experiments are the first to provide documentation that feeding by relatively low levels of eastern grape leafhopper can have significant effects on productivity of Concord vines. These effects occurred both in the year of infestation and in subsequent years. In spite of relatively low levels of leafhopper injury (generally < 10% of foliage injured), injured vines (in some years and experiments) showed reduced total yield. In years in which significant injury occurred, berry size was the main component affected. This is consistent with results of defoliation studies, showing reduced cluster weight due to defoliation at veraison (1,9,14). However, in subsequent years of these experiments, vines with leafhopper injury showing yield reductions also had fewer clusters per vine, fewer berries per cluster, and buds with lower fruitfulness, as measured by the number of clusters and shoots per retained node.

The clearest example of carry-over effects is illustrated by data from WW-150. In this experiment, leafhopper injury in the hot, dry 1991 growing season occurred early and was coupled with water stress. Both sprayed and unsprayed vines in this experiment were wilting during the day by mid July. In subsequent years, leafhopper injury was low (between 1% and 6 %, Table 1). In 1991, yield differences were largely due to reduced berry weight. In 1992 and 1993, however, infested vines had fewer clusters per vine, berries per cluster, and lower yield per node. By 1994, infested vines had recovered from the severe injury in 1991 that was coupled with drought stress, and there were no significant differences in yield components.

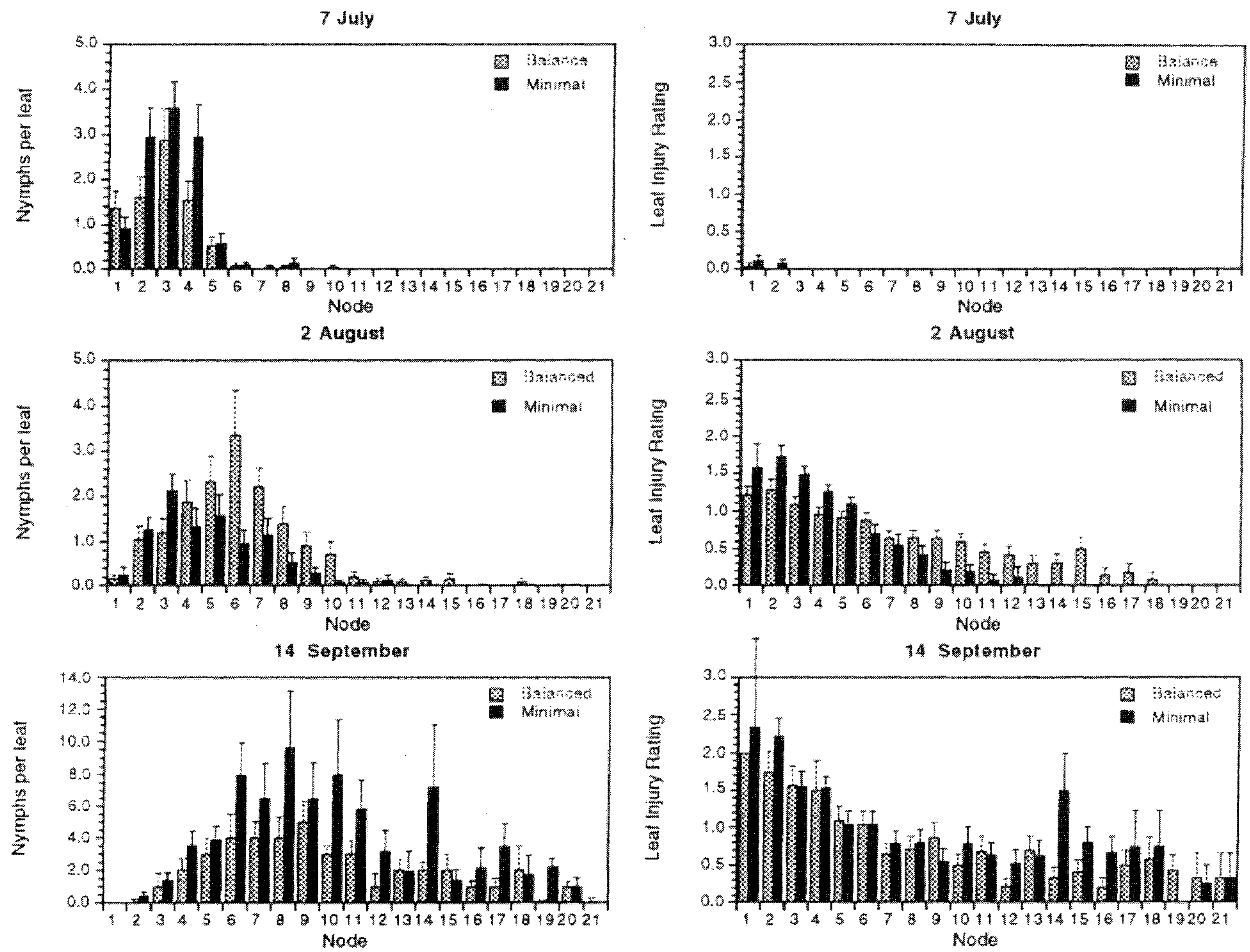

Fig. 2. Density of *E. comes* nymphs and mean injury rating by leaf node in minimal-pruned and balanced-pruned Concord vines on 7 July, 2 August, and 15 September 1994.

Data from the three pruning blocks at VL1 showed varying effects. No significant differences were seen in VL1-Min, in spite of higher crop levels. At VL1-Bal, yield in the unsprayed treatment was lower than that of the sprayed vines. Initial numbers of clusters per vine and berries per cluster were significantly lower in the unsprayed treatment before the experiment started, indicating that despite the high cumulative leafhopper days in this block (Table 1), yield differences probably reflected preexisting differences in vine size. In this block, yield differences were largely associated with lower numbers of clusters per vine in the unsprayed treatment (Table 2). On a per node basis, however, yields of the sprayed and unsprayed vines were equivalent. In VL1-80, yields were consistently lower, but not significantly so.

In the final experiment, VL2, productivity of unsprayed, minimally-pruned vines was significantly reduced, despite relatively low leafhopper injury, as quantified by leafhopper days (range 40 to 177, Table 1) and estimated percent foliar injury (1% to 10%; Table 1). Elimination of leafhopper feeding after early August in the 'threshold' treatment in 1995 did not reduce the impact of leafhopper feeding on productivity.

Adjusted for yield, juice soluble solids were not significantly reduced by leafhopper feeding in any of the 22 cropping cycles encompassed by these experiments.

Our results contrast with those of earlier studies. Single-year studies early in the century (4,7,22,23) cited reductions in soluble solids as the main impact of *E. comes* injury. More recently, a four-year study by Jubb *et al.* (8) failed to detect any consistent effects of *E. comes* injury on yield and juice characteristics on balanced-pruned Concord vines. Several possible reasons for the disparity between results of our study and previous studies exist.

First, the experiment of Jubb *et al.* (8) may have not had enough replicates ($N = 5$) to statistically separate yield differences of the magnitude detected in our studies. In contrast, our experiments had 15 to 30 replicates per treatment. Treatment means in the 1981 and 1982 seasons of Jubb *et al.* (8) were 1.1 to 2.0 kg/vine lower for the vines with leafhopper injury than in uninjured vines, and yield per node was 20 to 45 g less for the 'high' infestation level than the sprayed control in 1981 and 1982, respectively. These ranges of yield and bud fruitfulness reduction associated with leafhopper in-

Table 6. Power Analysis of total yield from VL1, WW, and VL2 Experiments.

Block	*N*	Year	Observed yield difference (sprayed-unsprayed) (kg/vine)	Least significant value for given *n* (kg/vine) — (α = 0.05) —			Least significant sample size (α = 0.05)
				5	15	30	
VL1-80	15	1990	1.1	1.5	0.8	0.5	30
		1991	1.0	2.0	1.0	0.7	29
		1992	1.5	2.8	1.4	1.0	27
		1993	0.8	1.1	0.6	0.4	27
		1994	0.2	1.7	0.8	0.6	1020
VL1-Min	15	1990	-0.7	1.5	0.8	0.5	56
		1991	0.7	3.4	1.8	1.2	306
		1992	0.2	2.8	1.4	1.0	3406
		1993	0.7	2.4	1.2	0.9	183
		1994	-1.3	3.3	1.7	1.2	95
VL1-Bal	15	1990	1.4	0.9	0.5	0.3	8
		1991	2.7	2.3	1.2	0.8	12
		1992	3.3	2.3	1.2	0.8	8
		1993	1.5	1.7	0.8	0.6	21
		1994	1.5	2.5	1.3	0.9	41
WW-150	30	1991	1.4	1.1	0.6	0.4	25
		1992	2.3	1.7	0.8	0.6	25
		1993	1.4	0.8	0.4	0.3	13
		1994	0.2	1.4	0.7	0.5	967
VL2-Min	29	1993	1.0	1.9	1.0	0.7	54
		1995	3.1	2.9	1.5	1.0	13
Average			1.2	2.1	1.1	0.7	

jury are similar to those found in our experiments. Power analysis of our experiments indicated that between 15 and 30 replicates per treatment would have been necessary to detect significant differences at the $\alpha = 0.05$ level (Table 6).

Another factor that differed in our experiments was pruning practices. Jubb *et al.*'s (8) experiment was balanced pruned (30 +10), while blocks in our experiments showing significant yield differences were pruned to a constant 80 nodes (VL1-80), 150 nodes (WW-150), or minimal pruned (VL2-Min), with bud numbers ranging from 200 to 400 per vine. Notably, balanced-pruned vines showed significant yield differences, but bud fruitfulness was reduced only in 1992. Yields in all of the experiments averaged 15 kg/vine (range: 3.0 to 23.0 kg/vine), while yields in the previous experiment ranged from 4.6 to 11.4 kg/vine (8). High crop load that placed more physiological stress on vines probably contributed to the yield differences we observed.

Although leafhopper days were correlated with mean injury rating, neither leafhopper days nor peak nymphal density were good predictors of the impact of *E. comes* feeding. Apparently, the response to absolute levels of leafhopper feeding varied among years and experiments. For example, 250 leafhopper days were sufficient to cause yield reduction in 1991, 1992, and 1993 at WW-150, but no significant differences were observed with similar amounts of feeding in the same years at VL1-Min (Table 1). In the same manner, leafhopper days ranging from 91 to 228 from 1991 to 1994 at VL1-Min were not associated with yield reduction, but similar amounts of feeding in an adjacent block in the VL2 experiment in 1993 to 1995 (range 100 - 177 leafhopper days) were associated with significant and widening differences in yield by the end of the experiment. Clearly, stress factors other than leafhopper injury may have modified vine response to the injury.

Temperature accumulations and rainfall varied greatly among years, and probably had a major effect on response of the vines to leafhopper injury. The 1991 and 1992 growing seasons represented extremely sunny, hot (1991) and cloudy, cool (1992) deviations from long-term averages (Fig. 1) for the Lake Erie region. These temperature extremes affected both vine development and leafhopper phenology. Ample sunlight in 1991 increased bud fruitfulness in 1992, leading to heavy cropping and inability to ripen the 1992 crop. This combination of heavy crop and poor weather in 1992 led to lowered bud fruitfulness and region-wide crop reduction in 1993. High temperatures early in 1991 also accelerated *E. comes* development by 3 weeks in 1991 (Table 1), lengthening the amount of time that leaf injury was present, and allowing development of a full second brood (10).

A consequence of variable weather conditions was variability in vine water relations, which probably had important effects. Three of the six years encompassed by these experiments (1991, 1993, and 1995) were extremely dry (Fig. 1). At WW-150 in 1991, with deep, gravelly, and well drained soil, moisture stress was visible by mid-July (vines were wilting during the day), leading to low soluble solids accumulations (12.7 to 13.0) despite ideal temperatures for accumulating soluble solids. Impact of this water stress was also seen in the reduction in clusters per retained node from 1991 to 1992. In contrast, VL1-Bal showed higher soluble solids accumulations at a similar crop load (16.9 to 17.5 °Brix, Table 2), and all VL1 blocks had a numerical increase in clusters per retained node in 1992. This suggests that vines at WW-150 were under more extreme water stress than those at VL1, and thus may have suffered more severe effects from the additional stress imposed by leafhopper injury. The VL2 experiment spanned two dry years (1993 and 1995), and started out with extremely low bud fruitfulness (<1 cluster per node in all treatments). Subsequently, in 1994 and 1995, the number of clusters per node remained lower in the unsprayed treatments (Table 4).

Most interesting was the strong effect that leafhopper feeding had on bud fruitfulness, with injured vines having fewer clusters per node, and fewer berries per cluster. Leafhopper feeding produces cumulative injury that generally becomes apparent in vineyards only after mid July. This late onset of injury (>1 month after bloom) suggests that leafhopper injury should have the strongest effect on accumulation of soluble solids. A concurrent study testing effects of late season epizootics of powdery mildew from 1991 to 1994 (D. Gadoury, Cornell University, pers. comm.) showed that injury affected soluble solids, but had no effect on yield. However, our results indicate that leafhopper injury in Concord grapes also affects development of inflorescence primordia. Cluster initiation for the next season is thought to begin in Concord grapes about 6 d before bloom (17), with growth continuing for about 1 month after bloom (generally mid-July) (20). After this period, photosynthate is allocated first to berry growth, then to berry ripening until harvest (17). Apparently, early-season leafhopper injury, though generally affecting a small proportion of foliar area by mid-season, is capable of significantly reducing bud fruitfulness.

The intensity of this effect may be related to within-shoot distribution of leafhoppers. Early in the season, oviposition by *E. comes* adults and subsequent nymphal feeding is concentrated in the first 5 basal nodes (Fig. 2). Only after the beginning of the second brood in August is leafhopper feeding more evenly distributed throughout the shoot. Thus injury is concentrated in the fruiting zone. Recent studies of leaf removal in Vinifera grapes (5) have shown that leaf removal at the basal nodes can affect subsequent bud fruitfulness. Leafhopper injury is most severe at these nodes.

Our studies demonstrated that even relatively low levels of leafhopper injury can have significant economic effects on Concord productivity. Single-year reductions in yield ranging from 1 to 3 kg/vine would represent economic losses ranging from $100 to $600 per ha at current prices. Furthermore, the significant reduction in bud fruitfulness we observed demonstrates that effects of leafhopper injury on productivity can carry over to subsequent cropping years. Our data also suggest that the impact is greatest when leafhopper injury is combined with inadequate water availability and possibly increased crop loads associated with mechanical pruning.

Integrated pest management programs stressing the use of treatment thresholds have been increasingly adopted by grape growers in New York and Pennsylvania. A provisional treatment threshold of 5 leafhopper nymphs per leaf has been recommended, along with a recommendation to use a mid-season scouting session to evaluate the need for controlling leafhoppers in early August (13). Results of this study suggest that significant yield reduction can occur at densities as low as 2 nymphs per leaf in dry years (Table 1). Furthermore, in hot, dry years the most significant injury probably occurs earlier in the growing season. Thus in years when leafhopper feeding is severe enough to cause economic losses, early treatment may be necessary. While surveys in untreated vineyards have demonstrated that the incidence of economically-significant leafhopper populations in viticultural regions of NY and Pennsylvania is low (12), the treatment thresholds should be more conservative. Growers should be particularly concerned about leafhopper injury in dry years, when inadequate soil moisture intensifies the impact of leafhopper injury.

These results underscore major differences that exist among cool-season viticultural regions in the Northeast and irrigated production areas of the West. Defoliation experiments in California showed that vines could tolerate a loss of 20% of foliar area without affecting yield or maturity (3). As a result, treatment thresholds of 10 to 20 leafhopper nymphs per leaf were developed for *E. elegantula* and *E. variabilis* (6). Apparently, vines in the Northeast, where growing seasons are shorter and water availability is not typically controlled through irrigation, have a much lower tolerance for leafhopper injury, or other foliar injury that reduces photosynthetic capacity.

Jubb *et al.* (8) concluded that improved cultural practices, which increased average yield from 4.5 kg/vine in 1900 to 6.6 kg/vine in 1975 lessened the impact of leafhopper injury on Concord productivity. Since then, changes in production practices, most notably the widespread adoption of mechanical pruning, have raised yields of some growers to the range of 10 to 18 kg/vine. Maintaining adequate juice quality (soluble solids) and productivity under these conditions means that less excess photosynthetic capacity exists than under earlier production practices. Our results suggest that leafhopper injury, although affecting a relatively small proportion of total leaf area, can have a strong and significant impact under current cultural practices.

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