Microclimates of Grapevine Canopies Associated with Leaf Removal and Control of Botrytis Bunch Rot

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ABSTRACT

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Incidence and severity of Botrytis bunch rot are reduced significantly when leaves around grape clusters are removed. Disease reduction was found to be related to changes in microclimate brought about by this practice. Hourly measurements of temperature, atmospheric humidity, wind speed, and leaf wetness were made during the entire season in canopies of *Vitis vinifera* in which leaves had or had not been removed in 1986 and 1987. The contributions of these variables, individually and in combination, in distinguishing between canopy microclimates were evaluated by canonical discriminant analysis. Microclimates of these canopy types were not distinguished consistently by any single variable at three vineyards. Over the entire growing season, squared canonical correlations were less than 0.67 for any single variable. Microclimates were distinguished more completely when temperature, vapor pressure, wind speed, and leaf wetness were considered together. Squared canonical correlations generally were greater than 0.58. Of these variables wind speed was affected most by leaf removal. Average speeds in canopies in which leaves were removed were increased up to three or four times those in unaltered canopies. Microclimates of canopies were characterized and discriminated to greater extents as the period of sampling was decreased from the entire growing season to single days. Over the course of each day, canopy microclimates were distinguished most completely by wind speeds in the afternoon and evening. The impact of microclimate on bunch rot may be related to interactions between variables that were important in distinguishing canopies rather than any single variable alone.

Bunch rot is a serious disease of wine grapes (*Vitis vinifera* L.), caused by *Botrytis cinerea* Pers. In California, the disease becomes severe late in the season when grape berries are ripe and autumn rains occur. In the absence of precipitation, however, bunch rot may still be severe in the cooler, coastal valleys, which are subject to coastal fogs and cloud cover.

Savage and Sall (15,16) reported that incidence and severity of bunch rot were influenced by the trellis system on which grapes are grown. They hypothesized that differences in disease development are related to differences in microclimate within the canopies on each trellis system. Over the course of the growing season, they detected slight differences in microclimates of two trellis systems in terms of air and berry surface temperatures, as well as vapor pressure deficit.

Recently, Gubler et al (6) reported that bunch rot of grape could be controlled by removing leaves from nodes adjacent to grape clusters. Although increasing numbers of growers in California, Oregon, and elsewhere have begun using this procedure, little information is available to explain how the practice influences disease development. It is likely that changes in microclimate are brought about by removal of leaves. Such changes might influence disease development.

The epidemiology of bunch rot of grape is not well understood. Environmental conditions at various stages of epidemic development may influence final disease expression. Spores of *B. cinerea*, for example, require prolonged periods of free moisture on surfaces of grape berries in order to germinate and infect (11). These events are also influenced by temperature (11,12), atmospheric humidity (7,12), and nutrients exuded from plant tissues in this free water (8).

Most studies have focused on conditions that influence infection of mature grape berries. McClellan and Hewitt (10), however, showed that *B. cinerea* may infect grape flowers and remain latent in these tissues until grape berries begin to mature. Questions still exist as to the contribution of these two modes of infection to epidemic development. Because of these complexities, it is difficult to evaluate the influence of canopy microclimate on epidemic development in controlled experiments. Therefore, indirect approaches were used, in which microclimates of canopies with and without leaf removal were characterized and compared to each other and to development of bunch rot.

MATERIALS AND METHODS

In 1986 and 1987, microclimates of grapevine canopies were characterized in three California vineyards. One vineyard, which was planted with the grape cultivar Zinfandel, was located in Lake County. The other two vineyards, planted with the cultivar Chenin blanc, were located in Napa and Monterey counties. At all vineyards, the plants were spaced at 2.4 m within rows and 3.6 m between rows. The rows in the vineyards in Lake and Napa counties were perpendicular to the prevailing winds. The rows in Monterey County were parallel to the prevailing winds.

In each vineyard, vines were cordon-trained, spur-pruned, and grown on two-wire, vertical trellis systems. The cordons were supported by the bottom wire, and shoots that developed from spurs were supported, to some extent, by the higher wire. Generally, two shoots developed from each of 16 spurs per vine. Each shoot gave rise to two fruit clusters.

In the leaf removal treatment, leaves and lateral shoots were removed 2 wk after full bloom (at approximately day of year 155) from the node opposite each cluster and from the first nodes above and below clusters. Leaves were removed in this way from all shoots on each vine within the leaf removal treatment. This had the effect of creating a "window" at the level of the clusters. At the time of leaf removal, shoots were approximately 0.5 m long. Control vines were not altered from standard production practices. Four or five replicate plots of each treatment were established in a randomized complete block design at each vineyard. Each replicate plot consisted of 160 vines.

Disease assessments were made at the end of each growing season, at approximately day of year 250. Within every replicate plot, a group of five adjacent vines was selected for evaluation. All clusters were removed from each of these vines. Disease incidence was estimated as the percentage of clusters with rotted berries. Disease severity was estimated as the percentage of berries that were rotted in each diseased cluster. Disease incidence and severity within canopies with and without leaf removal were compared by *t*-tests with pooled variances.

At each vineyard a single vine within a replicate plot of control vines was selected for characterization of canopy microclimate in relation to canopy treatment. On one half of this vine, leaves were removed from around grape clusters as described for the leaf removal treatment. On the other half of the vine, leaves were left in position. Atmospheric temperatures and relative humidities were monitored with combination thermistor and sulfonated polystyrene humidity sensors (model 207, Campbell Scientific, Logan, UT). Aspirated psychrometers were not used to monitor humidity because these devices sampled volumes of air too large to represent the microscale of interest within grapevine canopies. Relative humidity sensors were calibrated with a sling psychrometer prior to placement in grapevine canopies. Sensors were evaluated for accuracy again at the end of the growing season. Leaf wetness was monitored with artificial-leaf electrical resistance sensors (Wang Lab, Cincinnati, OH), obtained from Campbell Scientific (model 237). Leaf wetness grids were calibrated on a scale of 0 to 10 according to procedures established by the manufacturer. As calibrated, 0 represented complete dryness, and 10 represented the presence of free water on the grid surface. Wind speeds were monitored with dual resistance temperature detector anemometers (series 690, Sierra Instruments Inc., Carmel Valley, CA). Power to operate the anemometers was provided by an external 18-V battery. Analog signals from all sensors were processed and recorded on a Campbell Scientific CR21X micrologger at each vineyard.

Two replicate sensors of each type were placed at cluster height within the canopy halves in which leaves had or had not been removed. The sensors were installed at the time that leaves were removed. The microloggers were programmed to record each microclimate variable, except wind speed, once per minute. Outputs were generated on the hour as the average, maximum, and minimum values of all of these variables during the previous 60 min and the number of consecutive minutes of complete leaf wetness and relative humidity greater than 95%. Complete leaf wetness was defined as a reading of 5.0 or greater.

The anemometers drained the external, rechargeable batteries rapidly when readings were made every minute. Therefore, wind speeds were recorded during a period of 5 min, once every 2 hr. During this 5-min period, wind speeds were measured once every 10 sec. Average, maximum, and minimum wind speeds were generated from these 30 readings. Vapor pressure and vapor pressure deficit were calculated from the recorded temperature and relative humidity, from the empirical equations

$$\mathrm{VAP} = 6.108(\mathrm{RH}/100)\exp[(17.27\mathrm{T})/(\mathrm{T}+237.3)]$$
$$\mathrm{VPD} = 6.108\exp[(17.27\mathrm{T})/(\mathrm{T}+237.3)](1-\mathrm{RH}/100)$$

in which VAP is vapor pressure (mbar), VPD is vapor pressure deficit (mbar), T is temperature (C), and RH is percent relative humidity (19). Microclimate measurements were made throughout the season until harvest. The final, condensed data set for each vineyard consisted of only even-hour measurements, because wind speeds were available only for those times. Data were analyzed with time series, canonical discriminant, and stepwise discriminant analyses.

The patterns of diurnal change of individual variables in canopies with and without leaf removal were compared by means of time series analysis (18). The periods between days of year 190 and 216 of the 1986 season at each vineyard were selected as typical examples of microclimatic conditions observed throughout the season within grapevine canopies. Time series analysis allowed comparisons to be made between sets of recorded values from the two canopies after accommodating for the high degree of autocorrelation between values within each set, which resulted from sequential measurements over time. For each microclimate variable, the cross-correlation between values recorded in canopies with and without leaf removal was estimated over a series of time shifts. One data set was maintained stationary as the other was shifted forward or backward for different time intervals or lags. Cross-correlations between the two data sets were evaluated for shifts through ±72 hr in steps of 1 hr for all variables except wind speed. Cross-correlations for wind speed were evaluated over this period of time in steps of 2 hr. Analyses were performed by the time series procedure within the BMDP statistical package (4). If patterns of change in the values of a variable over time in the two canopy types were the same, maximum cross-correlations would be expected to occur at a time shift of 0 hr. If values of a variable changed in one canopy in a different manner than in another, then maximum cross-correlation values would be observed at the time difference at which the two data sets again coincided in their patterns of change.

Microclimates of canopies with and without leaf removal were characterized and compared by means of canonical discriminant analysis. This multivariate procedure allowed for comparison of microclimates when one variable was examined alone or when many variables were evaluated simultaneously. Canonical discriminant analysis is a descriptive form of discriminant analysis (1). Analyses were performed by the use of the canonical discriminant and stepwise discriminant procedures of SAS (14). In the latter procedure, both forward and backward selections were made. Values of the significance level (*P*) to enter and exit were 0.15.

These discriminant procedures are used to determine the extent to which variables, within a set of available variables, contribute to the classification of subjects or observations into two groups, leaf removal and control. The extent to which the selected variables sort observations successfully into distinguishable groups is reflected by two statistics. The first of these is the Mahalanobis distance; the greater the value of this statistic, the greater the ease with which the defined groups can be discriminated. The second is the squared canonical correlation, which reflects the amount of variance within selected variables that is accounted for by classification of observations into defined groups. This latter statistic was used here to compare canopy differences.

Variables included in the discriminant analyses were average values of temperature, vapor pressure, vapor pressure deficit, wind speed, and leaf wetness taken from the even-numbered hours of each day. In some analyses maximum and minimum wind speeds also were included.

Analyses were run first with individual microclimatic variables. Subsequently, analyses were performed to allow for selection of the best group of variables for discrimination between canopy microclimates. As microclimatic readings were made sequentially over time, values of each variable within a canopy treatment were highly autocorrelated. Autocorrelation was reduced by transforming data prior to analysis. At each hour the values of a variable in the canopy with leaf removal and in the canopy without leaf removal were averaged together. The actual value recorded in each canopy was then subtracted from this mean. This gave a measure of the degree of difference in readings between the two canopy types. The values in the two canopies were equivalent but had opposite signs. These "centered" data were used in discriminant analyses.

Initial discriminant analyses were performed on data collected over the course of an entire growing season. Subsequent analyses, however, were performed on subsets of these original data. For example, beginning with the day on which treatments were imposed, data were grouped in 1- or 10-day intervals. Alternatively, subsets were established to contain all recorded values of variables from individual hours over the entire season, in such a manner that all readings at 0200 hr were considered as a data set, and so forth.

Evaluations also were made of the relative contribution of variables to distinguishing canopy microclimates over the course of each day. In these analyses each day was broken into three 8-hr periods. Variables were averaged over all hours within each of these periods to provide a single value for that period. This subset of data consisted of daily values of each variable for time periods 0–0600, 0800–1400, and 1600–2200 hr. These variables were then evaluated by stepwise discriminant procedures after transformation as described.

RESULTS

Similar results were obtained in 1986 and 1987. In the vineyards in Lake and Napa counties in 1986, disease incidence was significantly greater ($P < 0.05$) in canopies without leaf removal than in canopies with leaf removal (Table 1). Incidence ranged from 6.9 to 39.2%. Disease severity at each vineyard was significantly greater in canopies without leaf removal than in canopies with leaves removed. Severity ranged from 1.2 to 10.7%. Similar effects of leaf removal on disease were observed in 1987.

In all vineyards, temperature, vapor pressure, and vapor pressure deficit fluctuated in a diurnal manner (Figs. 1 and 2). Differences between values of these variables in canopies with and without leaf removal were very slight over the course of the season. Leaf wetness also fluctuated diurnally. Maximum values of wetness in both canopies were observed to be generally less than 1.0, and these occurred in the early morning. During and after irrigation events, however, values in both canopies often increased to near 10. Differences between values of leaf wetness in canopies with and without leaf removal were slight. No consistent differences in duration of leaf wetness were observed between canopy types.

The greatest changes brought about by removal of leaves within canopies were increases in wind speeds. Although patterns of change in wind speed over time were the same in each canopy type, the average wind speeds in canopies with leaf removal often were increased to three or four times those in canopies without leaf removal (Figs. 1 and 2).

Although the differences between values of most microclimate variables of the two canopies at a particular hour were slight, it could not be determined, by casual observation, whether the rates of change in values of variables over time were the same in each canopy. Time series analysis was used to evaluate and compare the patterns of change of variables in both types of canopies. As determined by this analysis, changes in each variable over time in canopies with leaf removal coincided closely with those in canopies without leaf removal (Table 2). Cross-correlations of each variable attained maximum values at a time shift of 0 hr. Values at this shift were greater than 0.76 and 0.51 in 1986 and 1987, respectively. Values declined with increasing lag through 12 hr. From shifts of 12 through 24 hr, cross-correlations increased to higher values as the series again overlapped at 24-hr intervals (Fig. 3).

No single variable discriminated consistently between canopies with leaf removal and canopies without leaf removal in all vineyards (Table 3). The maximum value of the squared canonical correlation coefficient in 1986 was 0.56, in association with average hourly vapor pressure in the vineyard in Lake County. The maximum canonical correlation in 1987 was 0.67, in association with average wind speed in the vineyard in Napa County. Differences in canopy microclimates at the other vineyards were less apparent in terms of these variables.

Canopy microclimates were distinguished most completely by a group of variables including average hourly temperature, vapor pressure, wind speed, and leaf wetness, as well as maximum and

TABLE 1. Effect of leaf removal on incidence and severity of Botrytis bunch rot during 1986

Vineyard location[a]	Treatment	Incidence[b,c]	Severity[d,e]
Lake County	Leaf removal	6.9 (1.9)	1.2 (6.5)
	Control	24.9 (5.4)	10.7 (2.5)
Monterey County	Leaf removal	29.4 (5.4)	2.0 (0.3)
	Control	33.7 (2.4)	3.4 (0.4)
Napa County	Leaf removal	12.4 (2.3)	1.3 (0.3)
	Control	39.2 (8.2)	4.6 (1.0)

[a] The Lake County vineyard was planted with the cultivar Zinfandel. Vineyards in Napa and Monterey counties were planted with the cultivar Chenin blanc.

[b] Incidence is estimated as the percentage of clusters with rotted berries. Standard errors are in parentheses.

[c] In vineyards in Lake and Napa counties, leaf removal significantly reduced disease incidence, in comparison with control vines, as determined by *t*-tests with pooled variances ($P < 0.05$).

[d] Severity is estimated as the percentage of rotted berries per diseased cluster. Standard errors are in parentheses.

[e] In each vineyard, leaf removal significantly reduced disease severity, in comparison with control vines, as determined by *t*-tests with pooled variances ($P < 0.05$).

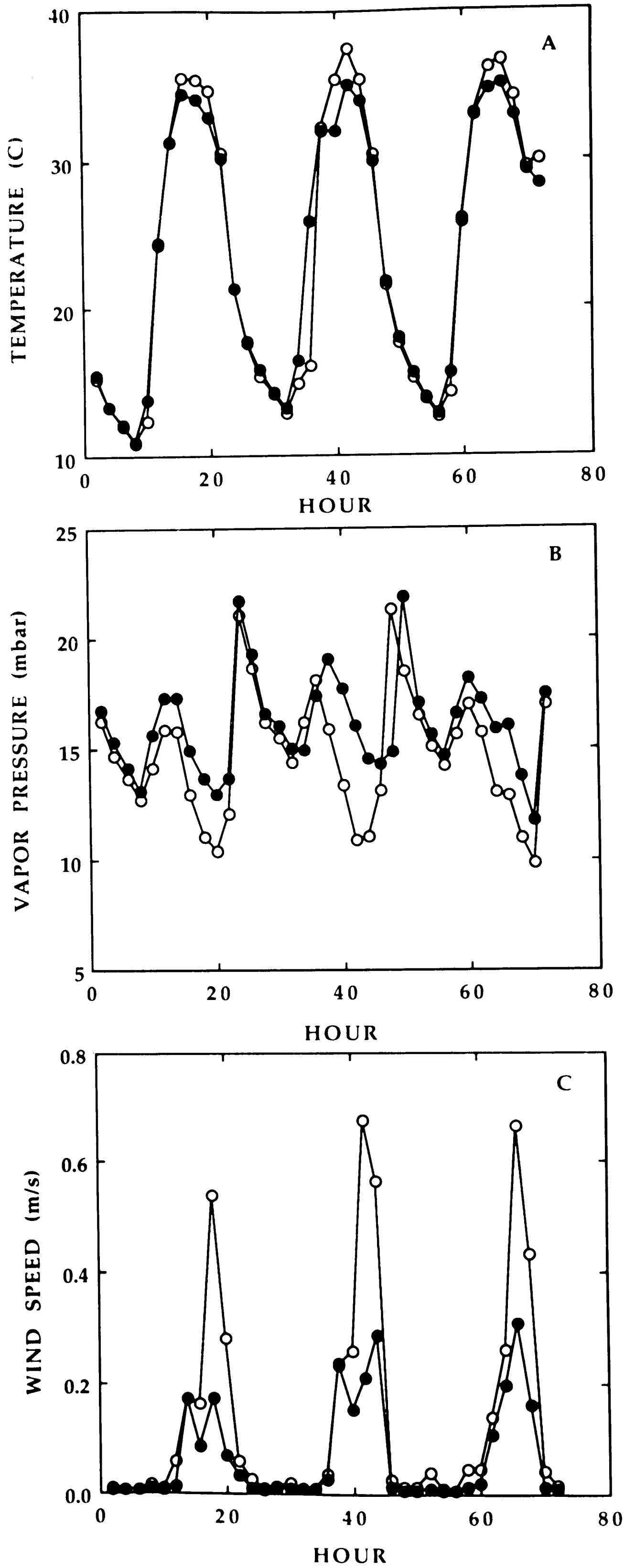

Fig. 1. Typical fluctuations of temperature (**A**), vapor pressure (**B**), and wind speed (**C**) in grapevine canopies with leaf removal (○) and without leaf removal (●) during a randomly selected 72-hr period (days of year 214 to 216) at the vineyard in Lake County during 1986.

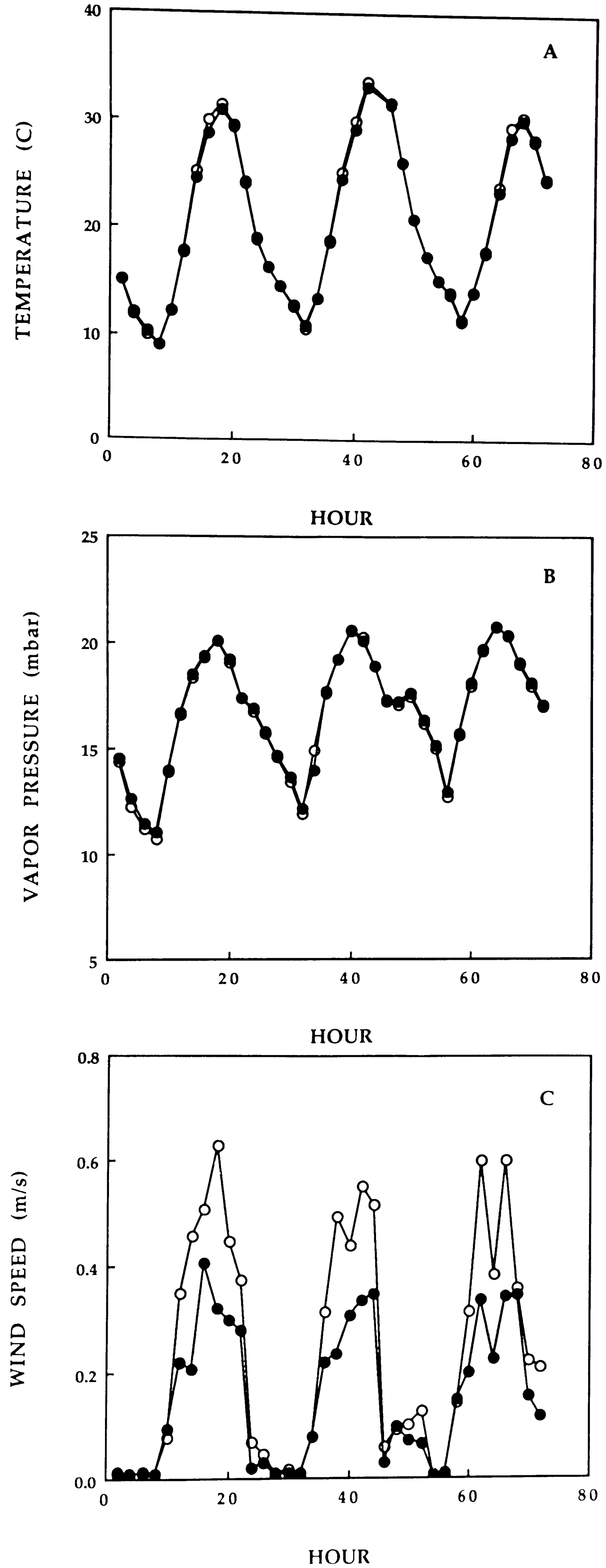

Fig. 2. Typical fluctuations of temperature (**A**), vapor pressure (**B**), and wind speed (**C**) in grapevine canopies with leaf removal (o) and without leaf removal (●) during a randomly selected 72-hr period (days of year 214 to 216) at the vineyard in Napa County during 1986.

TABLE 2. Cross-correlations at time shift of 0 hr between microclimate variables in grapevine canopies in which leaves were removed from around clusters and variables in canopies without leaf removal

Year	Variable	Cross-correlation coefficients Lake County	 Monterey County	 Napa County
1986	Temperature	0.99	0.99	0.99
	Vapor pressure	0.96	0.99	0.99
	Vapor pressure deficit	0.99	0.99	0.99
	Leaf wetness	0.99	0.79	0.82
	Average wind speed	0.91	0.93	0.82
	Maximum wind speed	0.85	0.85	0.76
	Minimum wind speed	0.83	0.86	0.85
1987	Temperature	0.99	0.99	0.99
	Vapor pressure	0.99	0.99	0.99
	Vapor pressure deficit	0.99	0.99	0.99
	Leaf wetness	0.78	0.71	0.51
	Average wind speed	0.88	0.87	0.90
	Maximum wind speed	0.84	0.62	0.81
	Minimum wind speed	0.75	0.81	0.56

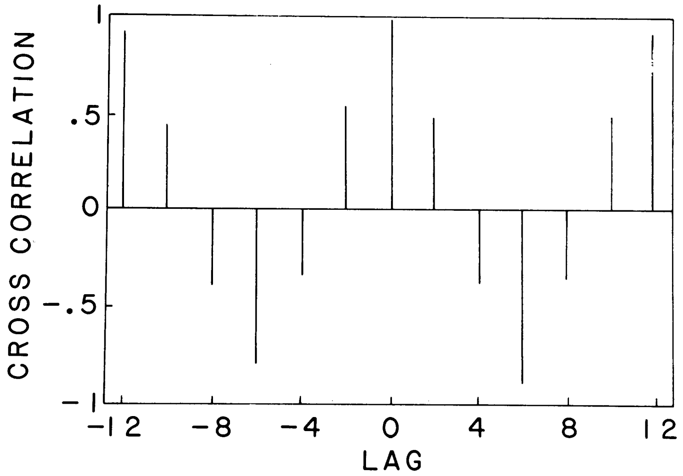

Fig. 3. Typical cross-correlations between temperature in canopies with leaf removal and temperature in canopies without leaf removal over a range of time lags between days of year 190 and 216 at the vineyard in Lake County during 1986. One lag is equivalent to 2 hr.

TABLE 3. Relationship between individual microclimate variables and discrimination between canopies in which leaves were removed from around clusters and canopies without leaf removal

Year	Variable[a]	Squared canonical correlation coefficients Lake County	 Monterey County	 Napa County
1986	Temperature	0.02	0.02	0.16
	Vapor pressure	0.56	0.06	0.23
	Vapor pressure deficit	0.26	0.04	0.30
	Average wind speed	0.30	0.17	0.30
	Leaf wetness	0.30	0.12	0.31
	Maximum wind speed	0.38	0.45	0.29
	Minimum wind speed	0.05	0.35	0.14
1987	Temperature	0.01	0.02	0.01
	Vapor pressure	0.18	0.07	0.38
	Vapor pressure deficit	0.06	0.06	0.09
	Average wind speed	0.13	0.54	0.67
	Leaf wetness	0.09	0.01	0.08
	Maximum wind speed	0.14	0.65	0.60
	Minimum wind speed	0.21	0.15	0.41

[a] Average hourly values of each variable when used as the only variable in canonical discriminant analysis. Data included in analyses are from the entire season.

TABLE 4. Relative cumulative contributions of variables selected to optimally characterize and discriminate between microclimates of canopies in which leaves were removed from around clusters and those of canopies without leaf removal

	Lake County		Monterey County		Napa County	
Year	Variable	SCC[a]	Variable	SCC	Variable	SCC
1986	Vapor pressure	0.56	Maximum wind speed	0.45	Average wind speed	0.30
	Temperature	0.63	Minimum wind speed	0.77	Vapor pressure	0.43
	Maximum wind speed	0.68	Vapor pressure	0.78	Leaf wetness	0.51
	Minimum wind speed	0.69	Leaf wetness	0.79	Temperature	0.58
	Leaf wetness	0.69[b]	Temperature	0.79	Minimum wind speed	0.58
	Average wind speed	0.69	Average wind speed	0.79	Maximum wind speed	0.58
1987	Minimum wind speed	0.21	Maximum wind speed	0.65	Average wind speed	0.67
	Maximum wind speed	0.32	Vapor pressure	0.68	Vapor pressure	0.69
	Vapor pressure	0.41	Leaf wetness	0.68	Maximum wind speed	0.71
	Leaf wetness	0.46	Temperature	0.68	Minimum wind speed	0.74
	Temperature	0.48	Minimum wind speed	0.68	Leaf wetness	0.75
	Average wind speed	0.49			Temperature	0.75

[a] SCC = cumulative squared canonical correlation coefficient estimated from canonical discriminant analyses using data from the entire season.

[b] Variable included adds less than 0.005 to the cumulative squared canonical correlation.

TABLE 5. Discrimination between canopies in which leaves were removed from around clusters and canopies without leaf removal in 1986, associated with a group of variables including temperature, vapor pressure, wind speed, and leaf wetness[a]

	Squared canonical correlation coefficients[c]		
Time period of analysis[b]	Lake County	Monterey County	Napa County
Full season	0.69	0.79	0.58
10-day intervals[d]	0.90 (0.53)	0.90 (0.74)	0.88 (0.45)
1-day intervals[d]	0.99 (0.88)	0.99 (0.53)	0.99 (0.55)
Hourly[e]	0.96 (0.85)	0.96 (0.86)	0.89 (0.50)

[a] Variables were considered simultaneously and included average hourly values of temperature, vapor pressure, wind speed, and leaf wetness and maximum and minimum hourly values of wind speed.

[b] Period of time for which data were included in analyses.

[c] Values not in parentheses are maximum values and values inside parentheses are minimum values of the squared canonical correlation for subsets of data grouped by 1- or 10-day intervals or by hour over the season.

[d] Analyses were of subsets of data grouped by 1- or 10-day intervals beginning at the time when canopy treatments were imposed.

[e] Analyses were conducted for the set of values at individual hours collected over the entire season.

minimum hourly wind speeds (Table 4). For example, in analyses of 1986 data, 69, 79, and 58% of the variation in recorded data were accounted for by classification of the canopies into the two treatments at Lake, Monterey, and Napa counties, respectively.

This group of variables discriminated between canopies to even greater extents as the sets of data were analyzed over shortened time intervals (Table 5). Values of squared canonical correlations increased as the time period of data collection was reduced. For example, in the vineyard at Lake County in 1986, the maximum values of squared canonical correlations were 0.69, 0.90, and 0.99 for data collected over the entire season, at 10-day intervals, and at 1-day intervals, respectively. Similar maximum values were observed in the other vineyards. The minimum squared canonical correlation observed was 0.45 during a 10-day interval of data collection in the vineyard at Napa County. Maximum values of squared canonical correlation for data collected by individual hour also were greater than the full-season values.

The most important variable for distinguishing canopy microclimates over any particular interval of time varied (Table 4). However, wind speed or vapor pressure generally was selected as the dominant variable over temperature or leaf wetness. Temperature and leaf wetness contributed little to an explanation of differences in canopy microclimates.

Over the course of each day, wind speeds in the afternoon (0800–1400 hr) and evening (1600–2200 hr) were the variables of greatest importance in distinguishing canopy microclimates at most vineyards (Table 6). In particular, maximum and minimum wind speeds during these periods were important. Wind speeds in the morning (0–0600 hr) were important in distinguishing canopies only in the vineyard at Lake County in 1987. Other variables, including vapor pressure, vapor pressure deficit, leaf wetness, and temperature, increased squared canonical correlations only slightly beyond those associated with wind speeds. These variables were not associated consistently with any specific time of day.

DISCUSSION

As in earlier studies, removal of leaves around grape clusters reduced bunch rot development (6). However, only slight differences were observed between values of certain individual microclimate variables in canopies with and without leaf removal. The most noticeable differences in values generally occurred either late in the afternoon or early in the morning. Factors such as temperature, atmospheric humidity, and leaf wetness have been monitored previously within or around plant canopies (2,3,9,16,17,21,22). Slight changes in such factors have been observed in association with modifications of irrigation practice, plant spacing, and cultivar utilization. In most cases the slight changes in temperature and atmospheric humidity brought about by modifications of cultural practices were not sufficient to bring about reductions in disease.

Savage observed only slight differences in temperature and vapor pressure deficit within grapevine canopies trained on two different trellis systems (16). Differences between these variables in relation to the trellis system were more evident in terms of the rate of change in their values over the course of each day. In the present study, differences in patterns of change of variables in canopies with and without leaf removal were not evident; maximum and minimum values of a variable in the two canopies were attained during the same hour. These analyses were performed, however, with data collected every 1 or 2 hr. Differences in rates of change that occurred over shorter time periods than this were unlikely to influence significantly the development of disease.

No consistent differences were observed between canopy types in terms of leaf wetness duration. In canopies with and without leaf removal, leaf wetness durations generally were much less than 10 hr. Durations of this length occurred only during irrigation events. Leaf wetness durations were considerably less than the minimum of 12 to 24 hr of free moisture reported as a requirement for germination of conidia of *B. cinerea* and infection of grape berries (11). The leaf wetness grids used in these experiments were located within canopies at the height of clusters and therefore quantified appearance of free moisture in this region. Dew may have formed on surfaces of berries to a different extent than on the metallic grids, as the surface temperature of these instruments may have differed from that of the berries. Even finer levels of measurement will be required in order to examine conditions at the level of the

TABLE 6. Relative cumulative contributions of variables selected to optimally characterize diurnal differences between microclimates of canopies in which leaves were removed from around clusters and those of canopies without leaf removal

	Lake County			Monterey County			Napa County		
Year	Variable	Period[a]	SCC[b]	Variable	Period	SCC	Variable	Period	SCC
1986	Maximum wind speed	3	0.24	Maximum wind speed	2	0.25	Maximum wind speed	3	0.71
	Minimum wind speed	2	0.42	Minimum wind speed	3	0.30	Minimum wind speed	2	0.82
	Maximum wind speed	2	0.50	Leaf wetness	1	0.37	Vapor pressure	1	0.84
	Vapor pressure deficit	3	0.56	Vapor pressure deficit	1	0.43	Minimum wind speed	3	0.85
	Leaf wetness	3	0.60	Average wind speed	3	0.44	Average wind speed	3	0.86
1987	Minimum wind speed	1	0.84	Average wind speed	2	0.75	Maximum wind speed	3	0.61
	Temperature	1	0.89	Maximum wind speed	3	0.81	Vapor pressure	2	0.73
	Leaf wetness	1	0.94	Minimum wind speed	1	0.84	Maximum wind speed	1	0.82
	Vapor pressure	1	0.96	Maximum wind speed	2	0.89	Vapor pressure deficit	2	0.85

[a] Time periods include 1 = 0–0600 hr; 2 = 0800–1400 hr; 3 = 1600–2200 hr.

[b] SCC = cumulative squared canonical correlation coefficient estimated from canonical discriminant analysis.

cluster itself.

Wind speed was the microclimatic factor affected most strongly by leaf removal. Within each day wind speeds in the afternoon and evening were particularly important in distinguishing canopy microclimates. Average wind speeds in canopies with leaf removal were, at times, more than three or four times greater than those observed in canopies without leaf removal. When all recorded microclimatic factors were considered simultaneously, wind speed was the factor of greatest importance in distinguishing canopy microclimates in most vineyards. The nonuniform distribution of foliage and canopy structure would be expected to create turbulence and to prohibit constant rates of air flow around grape clusters. Hourly average wind speed within canopies may therefore not accurately reflect patterns of air movement. The importance of maximum and minimum wind speeds in analyses characterizing canopy microclimates at various vineyards supports this.

Maximum and minimum wind speeds were particularly important in characterizing canopy microclimates in Monterey County. Vine rows at this site were parallel to the prevailing winds. The lesser importance of these variables at sites where vine rows were perpendicular to the prevailing winds suggests that row orientation affects the ability of wind to penetrate grapevine canopies.

This study represents only the second time that wind speeds have been quantified within grapevine canopies. An earlier report (13) described the construction of a sensor to measure wind speed. Velocities measured in grapevine canopies over the course of 1 day were less than 1.0 m/sec (13). Similar speeds were observed in canopies at all vineyards in the present investigation. Prior to these two studies, only cup and propeller anemometers were used for measurement of wind speed within vineyards. These instruments were used to quantify wind speeds above and between vine rows but not within canopies themselves (23,24). The resistance temperature detector anemometers used in this study had very small dimensions, had no significant zero drift, and had no moving parts. These instruments therefore were not hindered in their operation by contact with plant parts and did not require recalibration over the course of the season.

That maximum differences in canopy microclimates were obtained when several microclimatic variables were evaluated simultaneously reflects the situation in the field, where changes in vapor pressure, wind speed, temperature, and leaf wetness occur simultaneously. These variables, when considered together, distinguished canopy microclimates more clearly as the time interval of analysis decreased from the entire season down to a single day. Within these shorter time intervals, there were less likely to be complicating influences of macroclimate changes. There also would be less influence of change in canopy structure resulting from plant growth and development.

No obvious relationships between any of the several variables that distinguished canopy microclimates and disease development were observed. The influences of microclimatic factors on pathogen or host plant behavior might not be related to the behavior of any particular factor; rather, such influences may reflect interactions between two or more of these factors.

Thomas et al (20) found that certain aspects of the biology of *B. cinerea* are influenced significantly by the evaporative potential of the atmosphere around infected grape berries. Evaporative potential refers to the capacity of the atmosphere to evaporate water and to contribute to the creation of moisture stress within plant tissues or within cells of microorganisms present on plant surfaces. Evaporative potentials in those growth chamber studies and under ambient conditions in field experiments were shown to be influenced very strongly by atmospheric humidity and wind speed (5,20). In the present investigation, humidities in canopies with and without leaf removal were similar. In contrast, wind speeds were increased greatly by leaf removal. The importance of wind in grapevine canopies may be related to its influence on evaporative potential.

The role of evaporative potential as an environmental factor of importance in the development of Botrytis bunch rot of grapes bears further examination. Evaluation of this factor could provide insight into how canopy manipulations bring about small changes in microclimatic conditions and yet significantly reduce disease development.

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