Botrytis Bunch Rot of Grapes: Influence of Trellis Type and Canopy Microclimate

S. D. Savage and M. A. Sall

Former graduate research assistant, presently assistant professor, Colorado State University, Orchard Mesa Research Center, 3168 B½ Road, Grand Junction 81503, and assistant professor, Department of Plant Pathology, University of California, Davis 95616, respectively.

Based on a portion of a Ph.D. thesis submitted by the first author.

The authors wish to express appreciation to Richard Nagaoka of Napa Valley Vineyard Company, and to Robert Steinhauer and James Frisinger of Beringer/Los Hermanos Vineyards for providing experimental sites and advice throughout the project.

Accepted for publication 11 June 1983.

ABSTRACT

Savage, S. D., and Sall, M. A. 1984. Botrytis bunch rot of grapes: Influence of trellis type and canopy microclimate. Phytopathology 74:65-70.

Grape clusters grown on vines trained to grow on a cross-arm style of trellis developed 47% ($P < 0.05$) more infection by *Botrytis cinerea* than vines trained to a two-wire vertical trellis in test plots under typical Napa Valley, California, summer drought conditions in 1981. To test the hypothesis that disease differences were related to canopy microclimate, temperature and moisture parameters were recorded within the two trellis regimes. Temperature and moisture measurements for vines maintained on the two trellis types were similar, particularly the duration of periods of low water vapor stress favorable to fungal development. Cluster temperature under the two regimes differed as much as 2 C, although this was relatively infrequent. Characteristic, subtle, diurnal temperature difference patterns between the two regimes were consistent. During each day, there were four distinct trend periods of differential temperature change between the two trellis types. Correlations of these trends with ambient wind speed measured 300 cm above ground level indicates the possibility of differential wind penetration of the canopy types.

Botrytis cinerea Pers. is a major fruit rot pathogen of grapes (*Vitis vinifera* L.) throughout the world. This pathogen causes bunch rot that substantially reduces grape quality, even under California summer drought conditions. The cultivars most seriously affected (Chenin blanc, Zinfandel, Riesling, and Sauvignon blanc) all have compact cluster development, and vineyards with high disease levels are often vegetatively vigorous. Some of these infections have been linked to colonization of senescent floral tissues by *Botrytis* as much as 4 mo prior to the appearance of visible signs and symptoms (13). Evidence for the importance of these "latent" infections in subsequent disease development is primarily circumstantial; in tests with certain cultivars, blossom period fungicide applications have not reduced disease (M. A. Sall, *unpublished*). Colonization of loose floral debris within clusters by *Botrytis* has been observed and hypothesized to play a role in further disease development (5). In addition, mechanical injuries to the berries during ripening and berry enlargement may also contribute to eventual disease expression. Direct spore germination and infection of ripe fruit can occur during sufficiently moist periods (14). In the absence of rain or dew formation on the fruit, this source of infection is minor unless limited fungal growth occurs during many short, intermittent wetting episodes (19). All of the infection modes discussed above or their later development are influenced by the microclimatic conditions within the grape canopy and cluster. Microclimate may affect the frequency and duration of growth-permissive periods for the pathogen as well as determine the frequency and severity of adverse conditions for fungal survival.

The incidence and severity of infection by *Botrytis* have been shown to be influenced by the style of trellis on which the grapes are grown (17) and it has been hypothesized that this influence is linked to microclimatic differences associated with the type of grape canopies formed on the two types of trellises.

Direct characterization of microclimates that influence fungal propagules in plant canopies is extremely limited by the lack of suitable instrumentation. Most sensor probes are much too large for the scale of the desired reading, and their bulk and expense do not allow adequate characterization of the extreme temporal and spatial variability in canopy microclimate parameters.

The effects of microclimate on disease progress have often been discussed by plant pathologists (3,8,15,20,21,23). The most extensive research in this area has been conducted on white mold of beans caused by *Sclerotinia* (= *Whetzelinia*) *sclerotiorum* as influenced by canopy architecture (4,24), row spacing (7), row orientation (11), and irrigation regime (24). White mold can be reduced in beans by using procedures that appear to modify the microclimate at the infection court. Microclimatic effects have been characterized to some extent for powdery mildew of lettuce (18) with respect to geographic gradients, Cercospora leaf spot of sugar beets (22) with respect to planting on raised beds or in basins, and tomato foliage diseases (16) with respect to irrigation regime.

The goal of this study was to use available instrumentation to collect indirect evidence for trellis system-mediated microclimatic changes associated with observed differences in infection caused by *Botrytis cinerea.*

MATERIALS AND METHODS

Two commercial grape vineyards were used for intensive microclimate studies in 1981. The first, which is planted to cultivar Chenin blanc, is near Yountville, CA, in the southern end of the Napa Valley. The other, which is planted to cultivar Zinfandel, is located near St. Helena, CA, at the northern end of the valley. Both of these cultivars are particularly susceptible to bunch rot damage and both vineyards used in this study had a history of severe Botrytis damage. The Yountville Chenin blanc vineyard exhibited extremely vigorous growth. It is planted in east-west rows which are roughly perpendicular to the prevailing wind direction. The vines are spaced 2.44 m in rows spaced 3.66 m apart and are cordon-trained; thus, canes bearing fruit arise from short (two- to three-bud) spurs along a permanent, bilateral arm which runs along a trellis wire 110 cm from the ground. In the two-wire vertical trellis (TWV, Fig. 1) a second trellis wire runs above the spurs at the top of the grape stakes at a height of 160 cm. In the cross-arm trellis (XARM, Fig. 1) the single upper wire is replaced by two wires at the same height, which are supported at the ends of a 60-cm-long cross bar. These are the two most common trellis types used for premium wine grapes in California. The Zinfandel vines at St. Helena exhibited moderately vigorous growth, but never filled the rows as

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fully as the Chenin blanc vines at Yountville. At Yountville, the rows run north-south, nearly parallel to the direction of the prevailing winds. Vines are also spaced at 2.44 m in rows spaced at 3.66 m, are cordon-trained on both the TWV and XARM trellis types as described above.

Four replicates were established in the Yountville block, each consisting of six adjacent rows of each trellis type. Microclimate and disease measurements were made within sub-blocks, which were at least 100 m from the edge of the vineyard. Disease data were collected by periodic inspection of 20 clusters in each of five vines in the center of each unit. At the St. Helena site, five 3-row by 12-vine replicates were established for each trellis type and disease was rated on five vines in the center of each sub-block. Clusters were visually rated for the occurrence of *B. cinerea* and crop maturity was followed by removing berry samples through the season.

Microclimate data were collected with CR21 Microloggers (Campbell Scientific, Logan, UT 84321) of the standard one-scan-per-minute types. Most parameters were stored on cassette tape as 30-min averages.

Temperatures were measured with Fenwal model UUT 51J1 thermistors (obtained from Campbell Scientific as model 101). Relative humidity (RH) was measured with sulfonated polystyrene-type humidity sensors (Campbell Scientific, Logan, UT 84321). Free moisture was detected with wetness sensors (Wang Lab, Cincinnati, OH 45209; obtained from Campbell Scientific as model 731). Wind speed and direction were measured with MetOne model 014 anemometers and model 024 wind direction vanes (both from MetOne, Sunnyvale, CA 94087). Total solar radiation was measured with a pyranometer (Spectran Instruments, LaHabra, CA 90631).

Canopy conditions were measured at 110 cm above ground level and within the vine row. Three thermistors mounted 2 cm beneath radiation shields (3 mm of foam insulation covered with aluminum foil, 12 cm in diameter) were used to characterize canopy air temperature at this height in both trellis types. One humidity sensor and one wetness sensor were also placed in each trellis type at the 110-cm height.

Fruit surface temperature was measured by four thermistors inserted between berries to the central rachis of the cluster in each trellis type. These clusters were also ~110 cm from the ground.

Ambient conditions were measured at a height of 300 cm above ground level, directly above the vine row. Measurements at this height were made with a thermistor and a humidity probe mounted under a 20-cm-diameter radiation shield, a wetness sensor, the pyranometer, and the anemometer and wind-direction vane. The wind direction and speed data were summarized as a 30-min, eight-direction, wind speed rose.

The four microprocessors used to collect these data were synchronized with respect to the timing of their summary intervals. The raw field data were transferred to a Burroughs 7800 computer for which a group of ALGOL programs were developed to organize, reduce, compare, and display the data. Data were collected at each site in periodic 1- to 2-wk time blocks. Vapor pressure deficit and water vapor pressure were calculated from the recorded RH and temperature values by using a polynomial approximation of the saturated water vapor pressure ($e_{\mathrm{sat}} = 4.599586 + 0.32451\ T + 0.011998\ T^2 + 0.00012177\ T^3 + 0.0000041994\ T^4$, in which T = temperature and e_{sat} = the saturated water vapor pressure at temperature T). Data were presented as the average of values from redundant probes.

RESULTS

The incidence of *Botrytis* on 8 September 1981 at the Yountville site expressed as the percent of clusters infected at harvest, was 32.3% in the XARM trellis and 22.0% in the TWV trellis ($F = 5.13$, significantly different at $P < 0.05$). Expressed as the percentage of rot by weight, a common commercial measurement (17), the values are 5.47 and 2.85% for XARM and TWV trellises, respectively ($F = 12.7$, significantly different at $P < 0.01$). These disease incidence differences are comparable to those observed in previous years for grapes on the same two types of trellis (17). At the St. Helena site, fewer than 3% of the clusters became infected in either treatment in the 1981 season; however, the microclimate data will be presented for comparison.

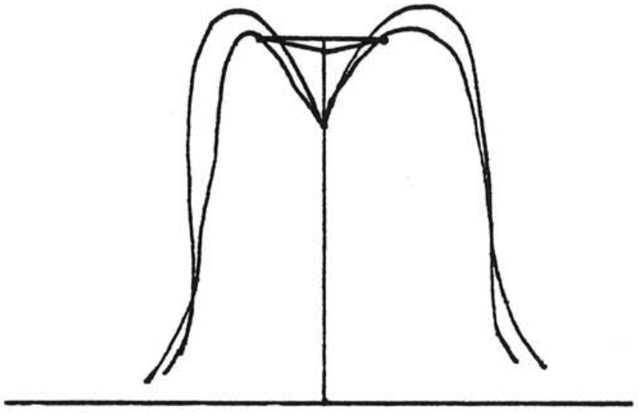
A measurement period of 16 days from 31 July to 19 August was chosen as a data set representative of conditions just prior to the period of rapid increase in observable infection by *B. cinerea* at the Yountville site. Between 12 and 26 August, the infection incidence in the cross-arm-trellised vines increased from 3 to 21%. For similar reasons a measurement period of 12 days (between 22 August and 2 September) was utilized at the St. Helena site. Canopy development (as indicated by following the growth of marked shoots) at both sites was essentially complete and the late-season leaf senescence had not begun when these measurements were made.

As indicated earlier, the prevailing wind at the Yountville site was from the south and southwest (81%), which is nearly perpendicular to the rows. The predominant wind direction at the St. Helena site (68%) was from the south and southeast, which is parallel to the rows.

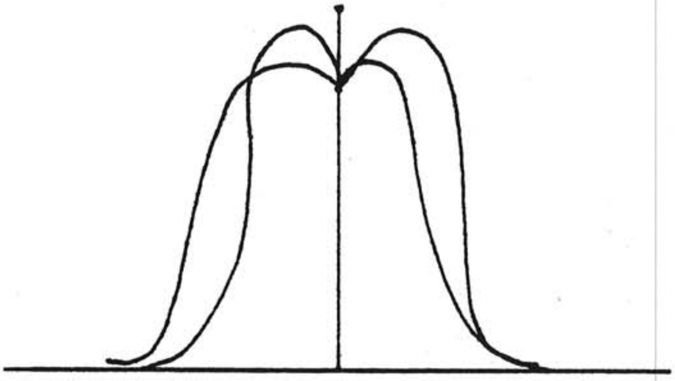
Dew formation within the grape canopy was not recorded by wetness sensors at either experimental location, although indications of dew were common at the 300-cm level.

Substantial canopy temperature differences were not detected between the two trellis types, XARM and TWV, during the measurement period (Fig. 2). Differences in measurable vapor pressure deficit were also minor (Fig. 2); however, the diurnal pattern of these minor differences was quite distinctive and consistent at both experimental sites.

Fig. 3A presents 16 days of overlaid data that show the consistent diurnal pattern of cluster temperature difference between the two



CROSS ARM TRELLIS (XARM)



TWO WIRE VERTICAL (TWV)

Fig. 1. Diagram of the two vineyard trellis types compared in this study. View is down the row indicating trellis structure and approximate effect on canopy architecture at full cane growth.

trellis types at the Yountville site. In addition, the average diurnal pattern of rate of change in temperature for each trellis type is graphed (Fig. 3B). For convenience, these curves have been divided into four sectors which correspond to major trends in the temperature difference between the two regimes. Trends in temperature difference are labeled with roman numerals and the corresponding differences in temperature change rates are labeled with arabic numerals (Figs. 3A and B). (All indicated times are Pacific Standard Time.) Similar trends were observed at both sites and can be described as follows:

Trend I-1: After sunrise (approximately 0700 hours) on days without fog, as both cluster types were warming, the TWV clusters generally warmed more rapidly, particularly between 0900 and 1000 hours. As a result, XARM cluster temperatures were consistently lower than those in the TWV trellis during that period.

Trend II-2: Starting in midmorning and continuing until midafternoon, both cluster types continued to warm, although at a steadily decreasing rate. The decrease in the rate of warming began sooner in the TWV regime, leading to a reversal of the temperature relationship of the two canopies by midafternoon, ie, by 1300 hours, the XARM cluster temperatures were warmer than those in the TWV trellis.

Trend III-3: Starting at 1500–1600 hours and continuing to sunset, both cluster types ceased warming and then began to cool at an increasing rate. That trend was delayed or even reversed for a brief period around 1700 hours in the TWV trellis, resulting in cluster temperatures equal to or higher than those in the XARM trellis at that time. This effect was most pronounced at the Yountville site.

Trend IV-4: At sunset (2000 hours) clusters in both trellis types cooled rapidly; however, the cooling was more abrupt in the TWV trellis.

The relationship of ambient wind speed to the temperature deviations between the clusters at the two types of trellises was investigated in the following manner at Yountville (Fig. 4) and St. Helena (Fig. 5). Data sets for 8 days without morning fog were chosen at each of the experimental sites. Within each data set, the average wind speeds at 300 cm above ground level during each 30-min period of the day were correlated with the change in temperature during that same 30-min period in both the TWV (Figs. 4A and 5A) and XARM (Figs. 4B and 5B) trellises. In addition, the temperature difference between XARM and TWV clusters during each 30-min period was correlated with wind speed (Figs. 4C and 5C). These data are presented as the overlaid diurnal plots of the temperature parameters for the eight sample days with a bar graph of correlation coefficients below each plot to indicate the sign and magnitude of the correlations.

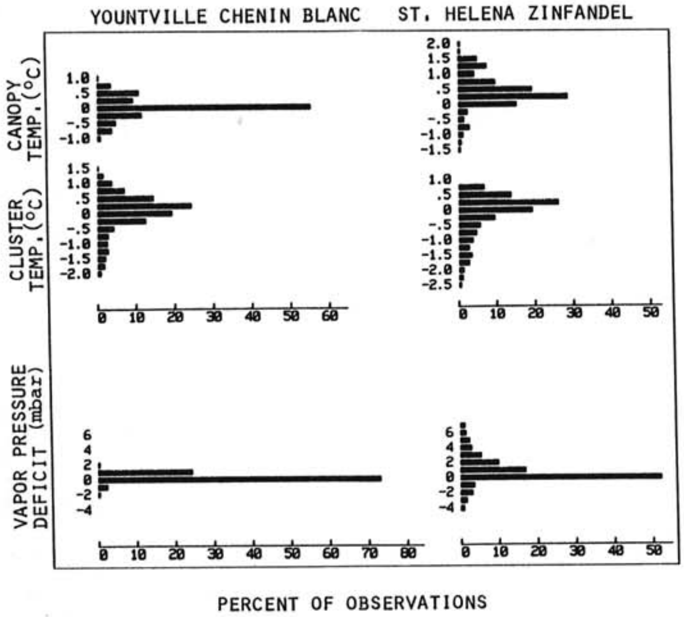


Fig. 2. Frequency distributions of the differences between temperature and moisture parameters measured within two trellis types (cross-arm [XARM] and two-wire vertical [TWV]) and each of two vineyards. Differences are expressed as XARM-TWV so that positive values indicate that the XARM measurement was warmer or dryer than that in the TWV trellis type. Observations represent 768 30-min averages recorded between 31 July and 19 August at the Yountville vineyard and 512 30-min averages between 22 August and 2 September at the St. Helena vineyard.

DISCUSSION

There have been several studies dealing with cultural modifications to influence canopy microclimate for various purposes (1,4,12,16,22,24). The alterations of temperature and moisture regime produced by cultural practices in most of these cases have been relatively small. Large, but brief, differences can be observed during overhead sprinkling (1,4,12,16,24). In systems in which the potential role of microclimate in disease was of concern, most workers have concluded that the temperature and humidity alterations observed were not alone sufficient to explain the

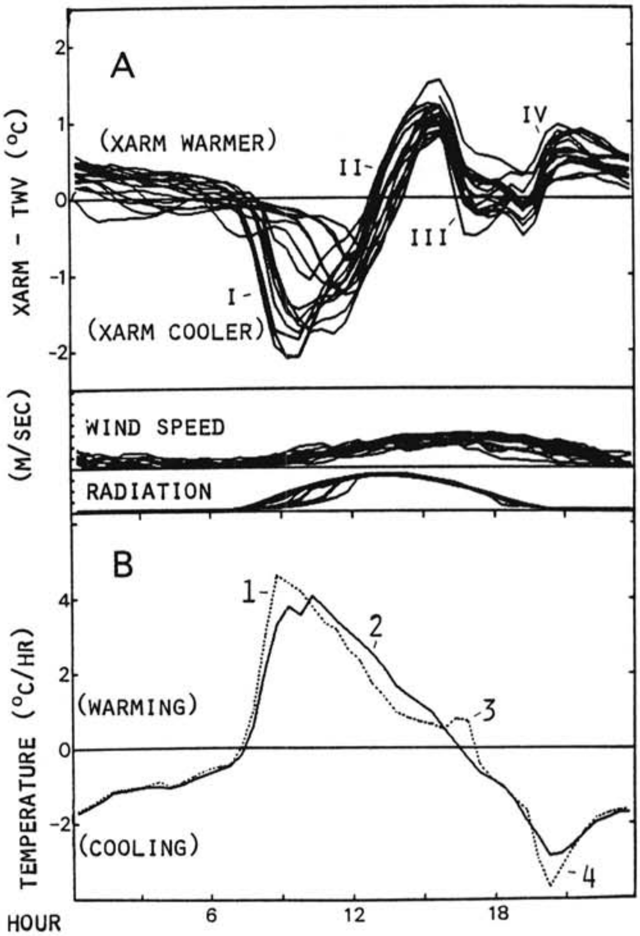


Fig. 3. Diurnal patterns in microclimate parameters at a cultivar Chenin blanc vineyard near Yountville, CA, from 31 July through 19 August in 1981. **A,** The difference between temperatures in the two trellis types (XARM − TWV) with patterns for all 16 days overlaid. **B,** The 16-day average rate of cluster temperature change in XARM(——) and in TWV(----)trellis systems. Overlaid curves representing data for wind speed and solar radiation at 300 cm above ground level are also presented. Arabic numerals indicate four trend periods of differential temperature change between trellis types and Roman numerals indicate the corresponding trends in temperature difference between the trellis types.

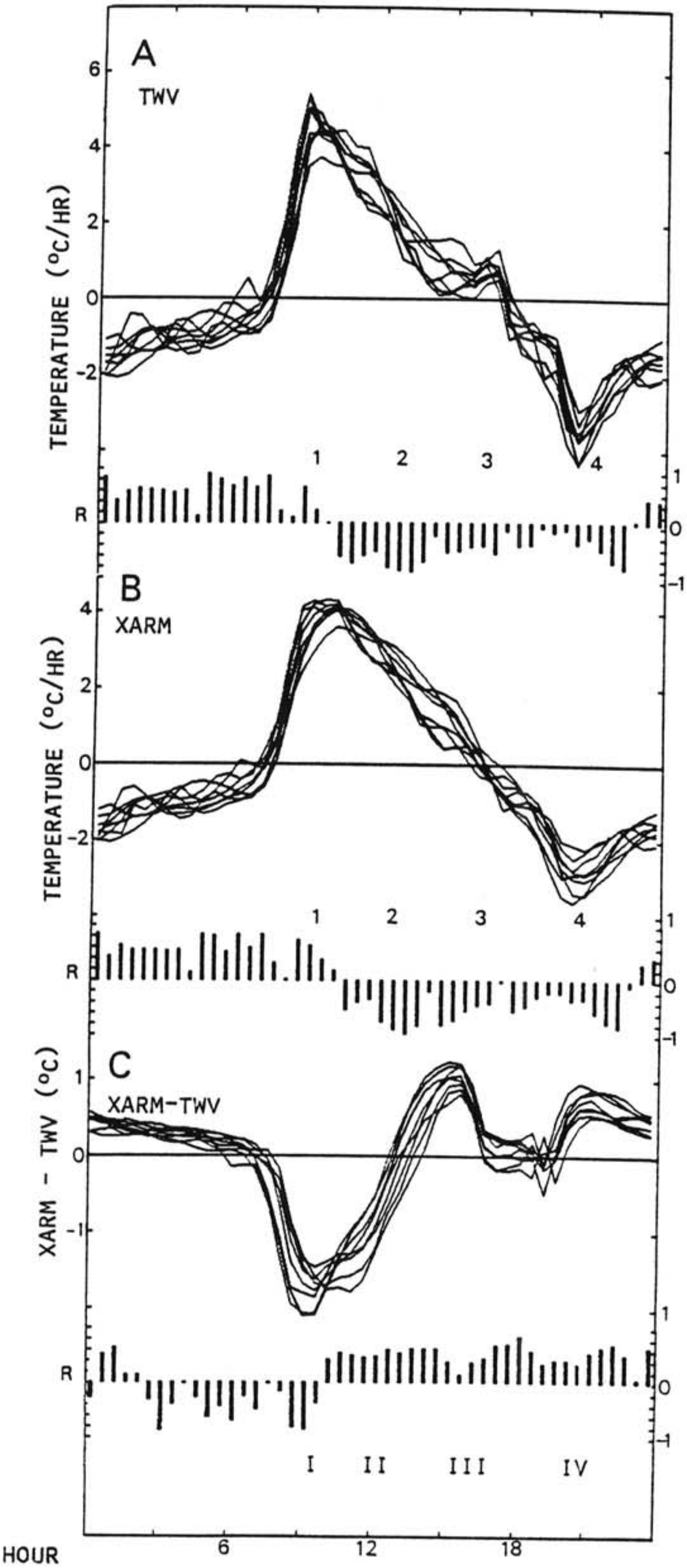


Fig. 4. Overlaid diurnal microclimate patterns at a cultivar Chenin blanc vineyard near Yountville, CA, for 8 days without morning fog between 31 July and 19 August in 1981. **A,** Temperature change in clusters in the two-wire vertical (TWV) trellis. **B,** Temperature change in cluster in the cross-arm (XARM) trellis. **C,** The difference in temperature between the clusters in the two trellis types. Presented beneath each temperature parameter are correlation coefficients of that parameter with the wind speed at 300 cm averaged during each 30-min period of the day. Numerals indicate differential trends in the trellis types as indicated in Fig. 2.

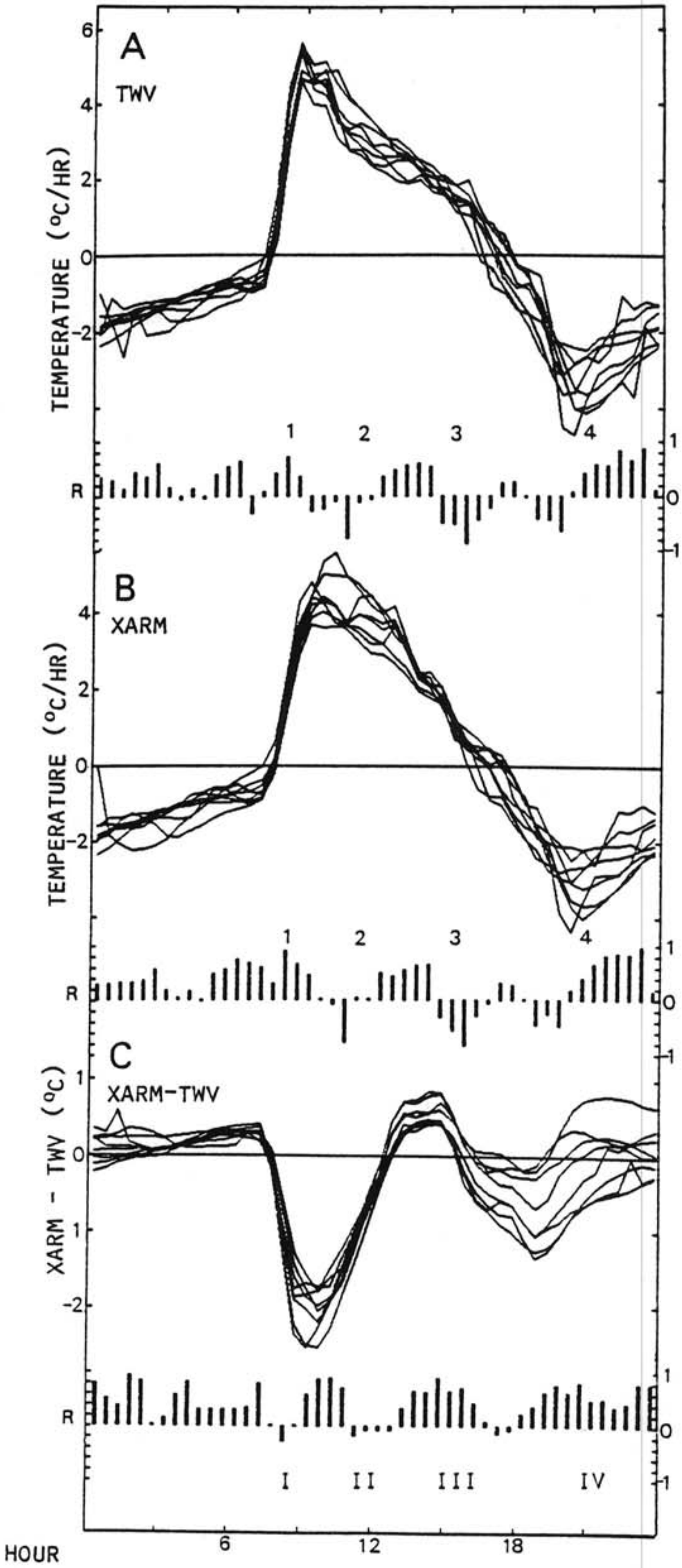


Fig. 5. Overlaid diurnal microclimate patterns at a cultivar Zinfandel vineyard near St. Helena, CA, for 8 days without morning fog between 22 August and 2 September in 1981. **A,** Temperature change in clusters in the two-wire vertical (TWV) trellis. **B,** Temperature change in clusters in the cross-arm (XARM) trellis. **C,** The difference in temperature between the clusters in the two trellis types. Presented beneath each temperature parameter are correlation coefficients of that parameter with the wind speed at 300 cm averaged during each 30-min period of the day. Numerals indicate differential trends in the trellis types as indicted in Fig. 2.

associated disease phenomena. Even though Blad et al (4) and Wiess et al (24) found only occasional 3–4 C differences between bean plants with different canopy architecture, white rot incidence in the irrigation and canopy type treatments differed by three- to nine-fold and nine- to 25-fold, respectively. They concluded that a combination of maximum temperature and dew period differences of 30–60 min per night resulted in the observed disease differences. Schnathorst (18) considered the differences between the microclimates at upper and lower leaf levels of unirrigated lettuce plants insufficient to explain the higher incidence of powdery mildew on the lower leaves. He concluded that the mediating factor in the observed disease difference was physiological rather than microclimatological. Rotem and Cohen (16) concluded that 1–2 C differences in monthly average temperature and 3–5% in average relative humidity could not account for differences in tomato foliage diseases under furrow and overhead irrigation.

The results of the present study are similar to the previous ones in that only relatively subtle differences in temperature or moisture regime are associated with the change in trellis type and a change in disease severity. For instance, the frequency and duration of periods of low water vapor stress that permit growth of *Botrytis* (9) are similar in the two trellis types. The small differences in temperature between the two regimes would not appear to account for disease differences. Since it was not possible to measure the humidity of the air within the clusters, it is possible that there were important trellis-related differences in moisture regimes which were not detected. With respect to periods of very low vapor pressure deficit favorable for fungal growth, only during the transition period at sunrise would there be permissive conditions for growth in one regime and not in the other. Based on internal cluster temperature measurements, that transition is quite rapid—the warming rate is 2–4 C/hr.

A serious limitation of the humidity measurements made in this experiment was the inability to detect the conditions within the clusters during the day when there was substantial air movement. In addition, short-term fluctuations either at that or at any other location could not be detected due to the sluggish response of the probe and to the 30-min averaging of the data.

Although the magnitudes of the measurable deviations between trellis types were small, a detailed examination of those deviations is fruitful. Clearly, the consistent pattern of temperature change observed (Figs. 3A and B, 4A and B) reflects the dynamics of radiant energy balance through the day. The differences between trellis types in their response to this input could be due to differences in the distribution of radiation within the canopies or to differences in the advective and convective exchange of energy based on canopy structure. Since either radiation or air movement differences could be of consequence in disease development, evidence of such differences is sought in the correlations of temperature and wind presented in Figs. 3 and 4. The ambient wind speed parameter was used in this analysis since actual canopy wind movement was below the threshold of the available instrumentation.

During the post-sunrise period (Trend I–Figs. 4 and 5) the rate of cluster warming in both trellis types was positively correlated with wind speed, suggesting that the importation of warm, canopy surface air to the cool canopy interior was facilitated by general air movement. During that period the TWV clusters warmed more rapidly, and the resulting XARM-TWV temperature difference was greatest at higher wind speeds (Figs. 4C and 5C). Enhanced warming to TWV trellis clusters attributable to greater radiation penetration to those clusters at that time would be expected to be diminished by enhanced air exchange, and this is not indicated in the wind speed correlations. However, those correlations are consistent with a more efficient importation of warm air to the TWV canopy at a given wind speed.

Later in the day (Trend II), with increasing radiation load, the rate of cluster warming is negatively correlated with wind speed in both trellis types (Figs. 4A and B, 5A and B) although only for a short period at the St. Helena site. Presumably, in such instances, the heat load of the fruit is being ameliorated by evaporation and convection, which are enhanced by wind movement. During this period, the extent to which the XARM cluster temperatures change and exceed those of the TWV is positively correlated with ambient wind speed (Figs. 4C and 5C). Again, if a greater radiation load on the XARM clusters is involved in this trend, increasing wind-driven exchange should diminish the difference. If relatively more efficient wind exchange in the TWV canopy occurs, then the observed enhancement of the effect at higher wind speeds would be expected. Similar arguments concerning the possible role of wind exchange in the more rapid cooling of TWV clusters at sunset (Trend IV) can be made; however, the correlations during that period are weaker.

The late afternoon trend (Trend III), when the TWV trellis clusters either warm more rapidly or fail to cool to the extent that occurs in the XARM trellis, exhibits essentially the same correlations with wind speed as the earlier Trend II. The rate of cluster warming is still negatively correlated with wind speed (Figs. 4A and B, 5A and B) while the relative temperature elevation of the TWV clusters is slightest at higher wind speeds (Figs. 4C and 5C). Therefore, this pattern would be consistent with a greater radiation penetration to the TWV trellis clusters at that particular sun angle.

The data at the St. Helena vineyard site exhibit two periods in the afternoon (1200–1400 hours and 1700–1800 hours) when wind speed is positively correlated with cluster warming or slower cooling in both canopy types (Fig. 5A and B). This relationship was not observed at the Yountville location. These correlations are consistent with the advective importation of hot air into the canopies in the afternoon and this factor may be related to the extremely low disease incidence at the St. Helena site. Large areas of open ground are adjacent to the St. Helena vineyard, while the Yountville vineyard is bordered by additional vineyards.

As previously mentioned, it is doubtful that the minor temperature differences observed between the XARM and TWV grape trellis regimes are sufficient to explain the disease differences that consistently have been observed between the two systems. The relationship of these temperature differences to wind speed suggests that the TWV trellis canopy is more easily penetrated by winds, favoring mixing with ambient air, and that during one period of the day it appears that the TWV canopy is penetrated to a greater extent by solar radiation. The ramifications of air fluxes and solar irradiances of this scale on the developing pathogen within grape clusters can only be surmised due to the present inability to directly measure those parameters. Even so, it can be hypothesized that this pathogen, developing in the absence of free moisture, may be able to grow in the protected, internal cluster environment, and that even minor microclimatic differences of air movement and radiation may influence its ability to survive and progress. Minor changes in air movement or light penetration in a grape cluster could alter the water vapor status at boundary layers in which fungal thalli exist prior to or during infection. *B. cinerea* (9,14,19) and other fungi as well (2,6,10) are known to be capable of growth at slightly subsaturated humidities and to be capable of renewed growth following intervening dry periods. Adaptations of this nature are undoubtedly important in the success of many pathogens in xeric environments; unfortunately, our knowledge of the role of the sequence and variation of temperature and moisture stresses in pathogen survival is still extremely limited.

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