To Mist or Not to Mist: Using Site-Specific Sensed Data to Evaluate Infrastructure Needs in a Vineyard

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Abstract.
This study explored the use of high-resolution site-specific data to understand how sensors can impact infrastructure purchases in a real-world precision agriculture growing operation. Since 2023, over 60 sensors have been deployed at Laurel Grove Wine Farm, a vineyard in Winchester, Virginia, recording temperature and humidity. The Sensor Collection and Remote Environment Care Reasoning Operation (SCARECRO) system has been employed to gather, clean and store the information from the field. Since the vineyard blocks were planted in spring 2024, growing infrastructure equipment has been added gradually, with an irrigation system installed one year later in 2025. The owners of Laurel Grove Wine Farm in this study were curious about the need for a mister to reduce heat stress in the vines during high temperature and high vapor pressure deficit (VPD) events in the vineyard. However, downy mildew has been noted in the vineyard in the last few years, and the mister is expected to increase the risk of vine infection to the diseases. The study used the site-specific sensor data to analyze the impact of high temperature stress, high vapor pressure deficit, and downy mildew infection risk factors together over the 2023, 2024, and 2025 growing seasons. Four heat stress levels were created based on temperature and VPD and applied to both growing areas. A what-if analysis was also performed combining the planned mister schedule during the heat stress events and the downy mildew infection model to determine possible risks associated with mister purchase and use. Ultimately, significant heat stress events at all levels were noted in the vineyard, especially in years 2024 and 2025, indicating the usefulness of canopy cooling intervention. However, several weeks in 2024 and 2025 saw high overlap with high humidity conditions and heat stress events, indicating the possibility of mister use creating downy mildew incidence conditions. The authors recommend purchasing a misting system with a high level of control for humidity. The study also explored the impact of individual sensors on the overall recommendations.

Keywords.
Heat stress, in-situ sensing, wireless sensor networks, downy mildew, vineyard management

Introduction

Heat stress is an important topic when it comes to vineyard management. Extreme heat events in a vineyard can cause issues with vine developmental stages (Venios et al., 2020) and overall berry quality (Hewitt et al., 2023).

Heat stress has been measured with regard to both temperature and VPD (measured in kPa), a metric relating to moisture potential in the air. High temperatures and high VPD both contribute to the heat stress of vines. In a 2025 study, Venios et al. noted the differences in heat stress tolerance between isohydric and anisohydric vine cultivars (the latter being less sensitive to high VPD stressors), defining moderate heat stress at 35 and severe heat stress at 40 degrees C. They considered a high VPD to be above 3 kPa, and noted differences between cultivar photosynthesis at different temperatures and high VPD (Venios et al., 2025).

A 2023 article also mentioned the threshold of 35 degrees C as important for limiting vine biological processes, and indicated water deficit as a more important limiting factor for vigor than temperature, even at the severe heat stress level (Keller, 2023).

One potential mitigation strategy for heat stress under high temperature and VPD conditions is the use of a vineyard mister, which can provide moisture to cool down the vineyard canopy either at regular intervals or triggered specifically by high temperature conditions. This strategy was used effectively in an Italian vineyard, with the system triggering automatically during moderate heat stress events at 35 degrees C (Valentini et al., 2025). However, one disadvantage of using a misting system is the potential to create conditions for downy mildew (*Plasmopara viticola*) infections, which are highly influenced by temperature, leaf wetness, and relative humidity (Kleb et al., 2022).

This study aimed to evaluate the tradeoffs of installing a canopy mister at Laurel Grove Wine Farm, a research partner and new vineyard located in Winchester, Virginia. Laurel Grove has incorporated high spatial and temporal resolution ground sensors in 2 of the growing areas (1 and 5) since 2023, collecting temperature and humidity data approximately every 5 minutes. Both heat stress events and downy mildew incidence have been observed in the growing areas since vines were planted in 2024. This study evaluates (1) the severity of the heat stress events, including whether such events warrant a mister intervention, and (2) the likelihood of increasing downy mildew optimal conditions by using a mister. The authors also seek to determine the value of ground-sensed information on farm infrastructure installation.

Many studies exist that examine downy mildew modeling with regard to environmental factors (Khatal et al., 2023; Kleb et al., 2022; Wade et al., 2025). However, to the authors' knowledge, combining heat stress and downy mildew what-if modeling with high spatiotemporal resolution ground sensor data to determine the potential risks of a mister installation is a novel contribution.

Methods

Data Collection

Data at Laurel Grove Wine Farm is collected on an ongoing basis using the SCARECRO system (Everett et al., 2023) and Data Gator sensor modules (Wells et al., 2024). Data is collected by iBeacon bBluetooth low energy (BLE) sensors (S5/S6 K6P, KKM, Guangdong, China) reporting approximately every 5 minutes. Because the sensors can be read by more than one collection module, data is filtered by a cloud service to obtain only 1 reading within a 5 minute interval before being stored in a database.

The sensors were first installed in spring 2023. However, because this is a real-world, long-term dataset, noise and uncertainty do exist. Not all sensors report consistently during the project and outages are present. The sensors themselves were replaced several times from 2023-2025 due to water damage, and a certain predisposition of the vineyard's livestock dogs to eat the sensor chassis. Analysis was conducted to assign sensors in approximately the same location to the same label, but there may be a few meters of difference between sensor locations year over year. The sensors were placed over two ridges in growing area 5 (forming an “X” pattern) and over one ridge in growing area 1. Figure 1 displays the geographic placement of the current S6 model of the beacon sensors across the two growing areas. Sensors are placed roughly 9 meters apart and at canopy height.

Figure 1 Placement of sensors across two growing areas: growing area 1 (left) and growing area 2 (right). Circles represent individual sensors

Most heat stress events occurred during the summer, when the solar-powered data collection system is more reliable, and reporting rates were stronger during these events of interest. Because of outages, the true number of heat stress events in the vineyard were likely underreported.

It should also be noted that the vines were first planted in spring of 2024, and data from 2023 will not reflect the microclimate impacts of the canopy vegetation. Because the vineyard is in its early growth stages, the microclimate of the sensed area was expected to change in 2024 and 2025.

Metric Creation

Data was pulled for all beacon sensors from March 1, 2022 to April 15, 2026. Insufficient data was present in years 2022 and 2026 (due to the early nature of the season for the latter) and was not included in this study. Data is stored in the database in Coordinated Universal Time (UTC) and was converted to Eastern Standard Time (EST) on download. Sensor data included temperature and relative humidity values. Temperature was converted from Fahrenheit to Celsius, and all temperature readings above 120 degrees were dropped to improve quality. Data was split into individual years. Saturation Vapor Pressure (SVP) was calculated according to Equation 1.

(1)
$$SVP = e^{\frac{17.27*T}{T+237.3}}$$

Where *T* is the temperature in Celsius.

Actual Vapor Pressure (AVP) was calculated according to Equation 2.

(2) $$AVP = \frac{RH}{100} * SVP$$

Where *RH* is relative humidity.

VPD was calculated as the difference between AVP and SVP according to Equation 3.

(3) $$VPD = AVP - SVP$$

The data was then resampled hourly (by sensor label) based on the maximum value of each column measure. In this case, the maximum value of temperature, humidity, and VPD represented the "worst-case" scenario for each hour.

Six metrics were created from the resampled data:

- Metric 1: Temp (C) >= 35
- Metric 2: Temp (C) >= 40
- Metric 3: Temp (C) >= 35 AND VPD >= 1.8
- Metric 4: Temp (C) >= 35 AND VPD >= 2.5
- Metric 5: Temp (C) >= 40 AND VPD >= 1.8
- Metric 6: Temp (C) >= 40 AND VPD >= 2.5

The 1.8 and 2.5 levels for VPD were chosen as thresholds for moderate and severe VPD distress, respectively. These threshold levels were determined by conversations with the partner vineyard domain expert and can also be found in certain industry heat stress models. The temperature thresholds were informed by Venios et al. (2025).

All metrics were resampled daily per sensor; the total hour counts for each metric and the maximum value of the metric were kept. The number of hours where the relative humidity was above 60% during the hours of a given metric being active (and not during other periods) was also reported on a daily basis. These thresholds were informed by the partner vineyard to indicate high humidity events, which factors into the downy mildew modeling.

Heat Stress Analysis

Heat stress events were divided into 4 possible levels:

- **Level 1: Possible Temperature Stress** (Metric 1, [temperature >= 35 degrees C])
- **Level 2: Possible Heat Stress** (Metric 3, [temperature >= 35 degrees C AND VPD >= 1.8])
- **Level 3: Heat Stress** (Metric 2 or Metric 4, [temperature >= 40 degrees C] OR [temperature >= 35 degrees C AND VPD > = 2.5]
- **Level 4: Severe Heat Stress:** (Metric 5 or Metric 6, [temperature >= 40 C AND VPD >= 1.8] OR [temperature >= 40 degrees C AND VPD >= 2.5].

The levels are not exclusive of one another and the criteria becomes gradually harder to reach with the exception of level 4, discussed below. The levels were chosen based on the recommendations from the partner vineyard, as well as studies by Venios et al. (2025) and Keller (2023).

For levels 1-3, an "event" was not noted unless the level metrics were observed for at least 3 hours/day over the course of at least 3 days, due to the ability of the vineyard to recover from short-term heat stress events. However, for level 4 events, only 3 hours of the metric observation needed to occur over the course of 1 day to be considered an "event", due to the increased severity of these conditions (Venios et al., 2020). Thus, a level 3 event would never have more total hours than a level 1 event, but a level 4 event could.

For each year, growing area, and heat stress level, the following are tracked:

- Event Start (Date)
- Event End (Date)
- Event Duration (Number of days in a row)
- Maximum Hours noted for the level (continuous, one sensor)
- Number of Sensors reporting the metric

Downy Mildew Incidence Modeling

In addition to heat stress events, the possibility of downy mildew occurrence by using a mister intervention was considered. While this would be difficult to model precisely, it is assumed for this study that a mister with basic temperature thresholds would follow the same schedule as the one set out Valentini et al. (2025).

This mister would be triggered by temperatures above 35 degrees C and would not activate more than 3 times per hour, according to their control schema. During the heat stress level observation events, the number of hours of humidity above 60% is tracked (these precisely correspond in time with the observed heat stress levels, and are not aggregated separately). As a "worst-case" scenario, it was assumed that that any event where the maximum hours above 60% humidity that corresponded within 3 hours of the maximum hours of the heat stress level occurred had an additional "wetness risk". This assumes that the high humidity overlap with mister operation could cause vine leaves to remain wet in spite of elevated temperatures. Assuming that downy mildew needs 8 hours of leaf wetness (approximately 1 day) (Khatal et al., 2023), a risk of downy mildew was modeled for any event with a duration above 8 hours and the presence of the "wetness risk" factor.

Results

Heat Stress Events

The results for growing area 1 by year are located in Tables 1-2 (2023 and 2024). The 2025 results were too expansive to display here but are summarized.

metric	event_start	event_end	Event duration days	Max hours at metric	Num sensors
level_1	2023-07-05	2023-07-07	3	4	13
level_1	2023-07-13	2023-07-16	4	6	9
level_1	2023-07-25	2023-07-29	5	7	11
level_2	2023-07-05	2023-07-07	3	4	12
level_2	2023-07-13	2023-07-15	3	6	8

level_2	2023-07-25	2023-07-29	5	7	10
level_3	2023-07-05	2023-07-07	3	4	12
level_3	2023-07-13	2023-07-15	3	6	8
level_3	2023-07-25	2023-07-29	5	7	10

Table 1 Heat Stress Events (Levels 1-4) for growing area 1 in 2023. These events include the event start and end date, duration in days, maximum observed hours at the level, and number of reporting sensors.

metric	event_start	event_end	Event duration days	Max hours at metric	Num sensors
level_1	2024-06-16	2024-06-26	11	11	37
level_1	2024-07-02	2024-07-10	9	11	37
level_1	2024-07-12	2024-07-17	6	11	37
level_1	2024-07-27	2024-08-02	7	8	37
level_1	2024-08-04	2024-08-07	4	10	36
level_1	2024-08-23	2024-08-29	7	8	35
level_2	2024-06-17	2024-06-26	10	11	37
level_2	2024-07-02	2024-07-10	9	11	37
level_2	2024-07-13	2024-07-17	5	11	37
level_2	2024-07-27	2024-08-02	7	8	37
level_2	2024-08-04	2024-08-07	4	10	36
level_2	2024-08-23	2024-08-29	7	8	35
level_3	2024-06-17	2024-06-23	7	11	37
level_3	2024-07-03	2024-07-10	8	11	37
level_3	2024-07-13	2024-07-17	5	11	37
level_3	2024-07-27	2024-08-02	7	8	37

level_3	2024-08-04	2024-08-07	4	10	36
level_3	2024-08-23	2024-08-29	7	8	35
level_4	2024-04-16	2024-04-16	1	3	1
level_4	2024-06-17	2024-06-17	1	3	1
level_4	2024-06-21	2024-06-22	2	5	8
level_4	2024-07-05	2024-07-09	5	6	4
level_4	2024-07-13	2024-07-17	5	8	36
level_4	2024-07-28	2024-07-28	1	3	1
level_4	2024-08-02	2024-08-02	1	3	1
level_4	2024-08-05	2024-08-06	2	7	1

Table 2 Heat stress events (levels 1-4) for growing area 1 in 2024.

In 2023, the growing area had 3 level 1, 2, and 3 heat stress events, all with an average duration of about 4 days which averaged a maximum of about 6 hours of incidence/day. The worst event was lasted 5 days, with a maximum of 7 hours of stress per day. It had no level 4 events.

In 2024, the growing area had 6 level 1 events, averaging about a week of duration and an average maximum stress hours of 10/day. The worst level 1 event lasted 11 days with a maximum 11 hours of stress per day. Level 2 events were similar, except the worst duration lasted 10 days. There were 6 level 3 events, lasting about 6 days on average with average maximum stress hours of 10/day. The worst level 3 event lasted 8 hours with a maximum of 11 hours of stress per day. 2024 also noted 8 level 4 events, lasting about 2 days on average, with nearly 5 hours of average maximum stress. The worst event lasted 5 days with a maximum of 8 stress hours per day.

In 2025, the growing area had 11 level 1 events, averaging about 8 days and an average maximum stress hours of 8/day. The worst level 1 event lasted 20 days with a maximum 11 hours of stress per day. There were 12 level 2 events, lasting on average 6 days with 8 average maximum stress hours per day. The worst lasted 16 days with a maximum 11 hours of stress per day. There were 13 level 3 events, lasting just under 6 days on average with average maximum stress hours of 8/day. The worst level 3 event lasted 16 days with a maximum of 9 hours of stress per day. 2025 had 15 level 4 events, lasting about 3 days on average, with about 5 hours of average maximum stress. The worst event lasted 8 days with a maximum of 8 stress hours per day.

The results for growing area 5 by year are located in Tables 3 and 4 The 2025 results were too expansive to display here but are summarized.

metric	event_start	event_end	Event duration days	Max hours at metric	Num sensors
level_1	2023-07-05	2023-07-08	4	4	4

level_1	2023-07-11	2023-07-13	3	5	5
level_1	2023-07-18	2023-07-20	3	5	4
level_1	2023-07-23	2023-07-29	7	7	8
level_1	2023-08-24	2023-08-26	3	7	7
level_1	2023-09-04	2023-09-06	3	4	1
level_2	2023-07-05	2023-07-08	4	4	4
level_2	2023-07-11	2023-07-13	3	5	5
level_2	2023-07-18	2023-07-20	3	5	4
level_2	2023-07-23	2023-07-29	7	7	8
level_2	2023-08-24	2023-08-26	3	7	7
level_3	2023-07-05	2023-07-07	3	4	4
level_3	2023-07-11	2023-07-13	3	5	5
level_3	2023-07-18	2023-07-20	3	5	4
level_3	2023-07-23	2023-07-29	7	7	8
level_3	2023-08-24	2023-08-26	3	7	7

Table 3 Heat stress events (levels 1-4) for growing area 5 in 2023. These events include the event start and end date, duration in days, maximum observed hours at the level, and number of reporting sensors.

metric	event_start	event_end	Event duration days	Max hours at metric	Num sensors
level_1	2024-06-17	2024-06-23	7	11	36
level_1	2024-07-03	2024-07-11	9	11	39
level_1	2024-07-13	2024-07-19	7	11	40
level_1	2024-07-26	2024-08-02	8	9	33

level_1	2024-08-04	2024-08-06	3	8	28
level_1	2024-08-25	2024-08-29	5	8	28
level_2	2024-06-17	2024-06-23	7	11	36
level_2	2024-07-03	2024-07-11	9	11	39
level_2	2024-07-13	2024-07-19	7	11	40
level_2	2024-07-27	2024-08-02	7	9	33
level_2	2024-08-04	2024-08-06	3	8	27
level_2	2024-08-27	2024-08-29	3	8	27
level_3	2024-06-17	2024-06-23	7	11	36
level_3	2024-07-03	2024-07-11	9	11	39
level_3	2024-07-13	2024-07-19	7	11	40
level_3	2024-07-26	2024-08-02	8	8	33
level_3	2024-08-04	2024-08-06	3	8	28
level_3	2024-08-27	2024-08-29	3	8	27
level_4	2024-06-21	2024-06-22	2	4	2
level_4	2024-07-05	2024-07-05	1	3	2
level_4	2024-07-14	2024-07-16	3	7	34
level_4	2024-07-27	2024-07-30	4	6	1
level_4	2024-08-28	2024-08-28	1	4	1

Table 4 Heat stress events (levels 1-4) for growing area 5 in 2024.

In 2023, the growing area had 6 level 1 and 5 level 2 and 3 heat stress events, all with an average duration of about 4 days which averaged a maximum of about 5 hours of incidence/day. The worst event in all cases lasted 7 days, with a maximum of 7 hours of stress per day. It had no level 4 events.

In 2024, the growing area had 6 level 1, 2, and 3 events, averaging about 6 hours of duration and an average maximum stress hours of 9/day. The worst level 1-3 events lasted 9 days with a maximum 11 hours of stress per day. 2024 had 5 level 4 events, lasting about 2 days on average, with nearly 5 hours of average maximum stress. The worst event lasted 4 days with a maximum of 7 stress hours per day.

In 2025, the growing area had 11 level 1 events, averaging about 5 days and an average maximum stress hours of 7/day. The worst level 1 event lasted 8 days with an maximum 9 hours of stress per day. There were 9 level 2 events, lasting on average 5 days with 7 average maximum stress hours per day. The worst lasted 8 days with a maximum 9 hours of stress per day. There were 7 level 3 events, lasting just over 4 days on average with average maximum stress hours of about 7/day. The worst level 3 event lasted 6 days with a maximum of 9 hours of stress per day. 2025 had 12 level 4 events, lasting just under 2 days on average, with about 4 hours of average maximum stress. The worst event lasted 6 days with a maximum of 6 stress hours per day.

Downy Mildew Incidence Modeling

Table 5 lists the events in the growing areas where high humidity during the heat stress event hours could potentially cause leaf wetness and conditions. Only results from 2024 are displayed due to the expansive nature of the results. While the temperatures during these events would likely be too hot to maintain the survival of downy mildew (Kleb et al., 2022), persistent leaf wetness during these times (for example, as the temperature drops overnight) could potentially cause issues. There were no noted downy mildew risk events in 2023 in either growing area. Because these events are presented by risk level, many dates overlap, and the true number of risk events is less than the number of rows in the table.

year	Growing area	metric	event_start	event_end	Event duration days	Num sensors	Wetness risk	Mildew risk
2024	1	level_1	2024-06-16	2024-06-26	11	37	1	1
2024	1	level_1	2024-07-12	2024-07-17	6	37	1	1
2024	1	level_1	2024-07-27	2024-08-02	7	37	1	1
2024	1	level_2	2024-06-17	2024-06-26	10	37	1	1
2024	1	level_2	2024-07-13	2024-07-17	5	37	1	1
2024	1	level_2	2024-07-27	2024-08-02	7	37	1	1
2024	5	level_1	2024-07-26	2024-08-02	8	33	1	1
2024	5	level_1	2024-08-04	2024-08-06	3	28	1	1
2024	5	level_1	2024-08-25	2024-08-29	5	28	1	1
2024	5	level_2	2024-07-27	2024-08-02	7	33	1	1
2025	5	level_1	2025-06-22	2025-06-26	5	9	1	1
2025	5	level_1	2025-08-14	2025-08-17	4	6	1	1
2025	5	level_2	2025-06-22	2025-06-26	5	8	1	1

2025	5	level_2	2025-08-14	2025-08-17	4	6	1	1

Table 5 Heat stress events with possible downy mildew conditions for both growing areas in 2024. The events in this table occur at the same time as high humidity conditions.

Discussion

There were a significant number of heat stress events in 2023, 2024, and 2025 across both growing areas of the vineyard. 2023 had less overall data collection due to issues with the initial system installation, but 2024 and 2025 noted multiple heat stress events during the summers at various levels of temperature and VPD. The length and severity of the heat stress events support the need for cooling infrastructure interventions in the vineyard. In many cases, the heat stress events weren't tied to one particular sub-microclimate in the field, as many sensors reported the same conditions.

A misting system which activates on temperature is one potential solution to the issue. However, in 2024 and 2025, several weeks of heat stress events co-occurred with elevated humidity levels which may cause leaf wetness and therefore downy mildew conditions. These primarily occurred with level 1 and level 2 events, and the vineyard may be sufficiently heat tolerant to avoid using the misting systems under these conditions. However, level 3 and level 4 heat stress events would likely necessitate intervention. In 2025, there were 6 separate events at heat stress level 3 with high humidity co-occurrence from early June to mid-August. These risk factors highlight the potential need for additional controls on the mister; especially the ability to hold off cycles or reduce spray times.

The number of sensors reporting heat stress events for individual areas in both growing areas was higher than expected. This potentially suggests less sensors could be used to effectively capture microclimate effects important to vineyard management. However, very extreme events (level 4 heat stress) were noted by fewer sensors spatially, increasing the ability for very granular management under extreme conditions. The beacon sensors were relatively inexpensive (approximately $10-$20 each, depending on the model number).

Figure 3 displays the sensors reporting a level 3 heat stress event in growing area 1 during July 2024. Most sensors across the growing area record multiple hours of this heat stress event. Figure 4, in contrast, displays a level 4 heat stress event in growing area 1 during June 2025. This event is sparser and more concentrated on the northern end of the growing area.

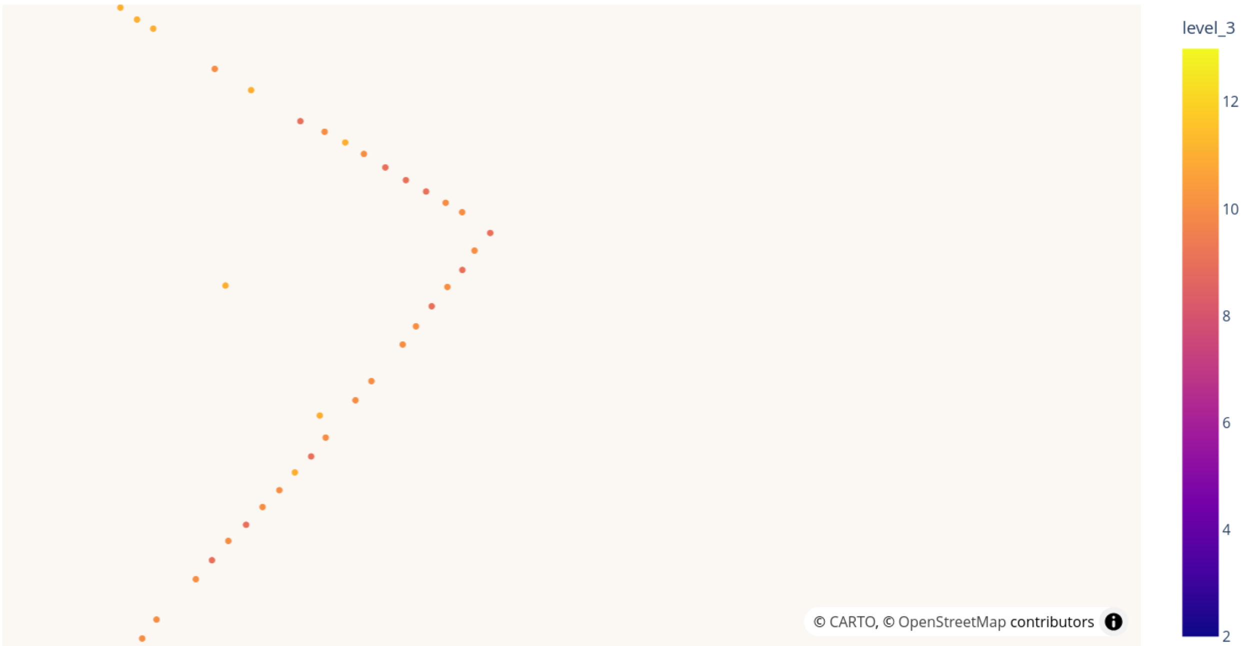

Figure 2 A level 3 heat event in July 2024 for growing area 1. The entire growing area reports the level 3 conditions by sensor

Figure 3 A level 4 heat event in June 2025 for growing area 1. For this level of extreme heat stress, the northern end of the growing area is the only reporting region by sensor.

The study was not without limitations. To begin, the data collection rate was inconsistent across years, and the number of true heat stress events may be underreported. Additionally, the modeling of the downy mildew was subject to several assumptions of relative humidity relationship to leaf wetness. However, the authors consider these assumptions a reasonable estimate of "worst-case" scenarios for downy mildew incidence.

A dashboard was created using the open-source Grafana software for monitoring real-time temperature across all sensors present in growing areas 1 and 5. Future work for the study includes adding better thresholds for the different heat stress levels and incorporating forecast alerts for heat stress and downy mildew conditions. Figure 4 displays a view of the dashboard.

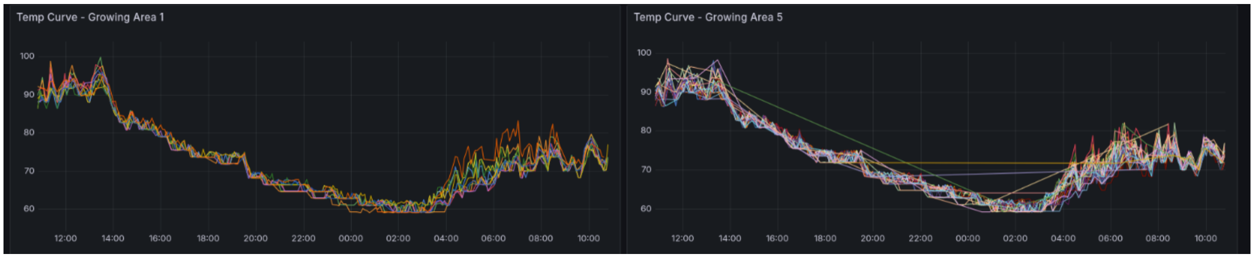

Figure 4 Temperature curves, by sensor, displayed in an interactive Grafana dashboard for growing areas 1 and 5

Conclusion

This study analyzed heat stress events in 2 growing areas at 4 levels of potential vine impact across the 2023, 2024, and 2025 growing seasons. In all seasons and growing areas, significant heat stress events were observed, indicating the value of a system for cooling the canopy. However, several heat stress events occurred with high relative humidity, indicating the possibility for downy mildew conditions. Ultimately, a misting system with a high level of control (including the ability to reduce cycles or shut off during high humidity conditions) is recommended to best manage extreme events in the vineyard.

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References

Everett, M., Wells, G., & Shovic, J. (2023). The SCARECRO system: open-source design for precision agriculture adoption gaps. In *Precision agriculture'23* (pp. 415-421). Wageningen Academic.

Hewitt, S., Hernández-Montes, E., Dhingra, A., & Keller, M. (2023). Impact of heat stress, water stress, and their combined effects on the metabolism and transcriptome of grape berries. *Scientific Reports*, 13(1), 9907.

Keller, M. (2023). Climate change impacts on vineyards in warm and dry areas: Challenges and opportunities: From the ASEV Climate Change Symposium Part 1–Viticulture. *American journal of enology and viticulture*, 74(2).

Khatal, M. P., Narute, T. K., Sonawane, R. B., & Bhalerao, V. K. (2023). Effect of weather parameters on the growth and development of downy mildew of grape caused by Plasmopara viticola. *Journal of Agrometeorology*, 25(4), 610-612.

Kleb, M., Merkt, N., & Zörb, C. (2022). New aspects of in situ measurements for downy mildew forecasting. *Plants*, 11(14), 1807.

Valentini, G., Allegro, G., Pastore, C., Zanini, A., Moffa, A., Gottardi, D., ... & Filippetti, I. (2025). An Automatic Cooling System to Cope with the Thermal–Radiative Stresses in the Pignoletto White Grape. *Horticulturae*, 11(9), 1128.

Venios, X., Banilas, G., Beris, E., Biniari, K., & Korkas, E. (2025). Physiological Efficiency and Adaptability of Greek Indigenous Grapevine Cultivars Under Heat Stress and Elevated CO2: Insights into Photosynthetic Dynamics. *Plants*, 14(16), 2518.

Venios, X., Korkas, E., Nisiotou, A., & Banilas, G. (2020). Grapevine responses to heat stress and global warming. *Plants*, 9(12), 1754.

Wade, C. R., Check, J. C., Chilvers, M. I., & Dong, Y. (2025). Monitoring leaf wetness dynamics in corn and soybean fields using an IoT (Internet of Things)-based monitoring system. *Smart Agricultural Technology*, 11, 100919.

Wells, G., Everett, M., & Shovic, J. (2024). Data Gator: a Provision-less Network Solution for Collecting Data from Wired and Wireless Sensors. *Proceedings of the 16th International Conference on Precision Agriculture*, 21-24 July 2024, Manhattan, Kansas, United States.