DYNAMIC AGRIVOLTAICS, CLIMATE PROTECTION FOR GRAPEVINE DRIVEN BY ARTIFICIAL INTELLIGENCE

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Abstract:

Context and purpose of the study

The year-on-year rise in temperatures and the increase in extreme weather events due to climate change are already having an impact on agriculture. Among the perennial fruit species, grapevine is already negatively impacted by these events through an acceleration of its phenology, more damage from late frosts or through an increase in the sugar level of the berries (and therefore the alcoholic degree of the wine) and a decrease of acidity, impacting the wine quality. Sun'Agri, in partnership with INRAE, Chambre d'agriculture du Vaucluse, Chambre d'agriculture des Pyrénées-Orientales and IFV, developed a protection system based on dynamic agrivoltaics to protect grapevine. It consists of photovoltaic solar panels positioned above the crop, high enough not to impede the passage of agricultural machinery, and tiltable from +/- 90° to adjust the level of shading on the vineyard. These smart louvers, driven by artificial intelligence (physical models & plant growth models), are steered according to the plant's needs and provide real climate protection.

Material and methods

10 rows of ~40 plants of Grenache N. were monitored under two dynamic agrivoltaic systems in Piolenc (44°10'30.95''N 4°47'52.74''E) between 2019 and 2022. Microclimatic variables, phenology, dynamics of the grapevine water status and characterization of yield and quality (berry and vine) were measured. A large-scale dynamic agrivoltaic system of 4.5 ha in Tresserre (42°32'47.25''N 2°51'51.21''E) complements the response at a commercial level (including other grape varieties).

Results

Steering the panels throughout the season have demonstrated the system's ability to let light through during critical growth phases while providing maximum protection when needed to mitigate climate change effects. Shading reduces air temperature under the structure. Furthermore, shading also decreases evapotranspiration leading to a more comfortable plant water status with less irrigation under the panels than control. The active regulation of irradiation during the season not only avoids undesirable effects on clusters (shriveling) but also modifies the quality of the berries leading to a preservation of wine organoleptic properties.

Keywords: Grapevine, Climate Change, adaptation & mitigation, plant modelling.

1. Introduction

Climate change is expected to increase the occurrence of heatwaves. These extreme events can have a devastating effect on grapevine production. Vineyards sometimes are protected from heatwaves by refilling the rootzone as much as possible with irrigation water ahead of the forecasted heatwave (Hayman et al., 2012). However, climate change is also associated with drought and water shortages. Other solutions to maintain grapevine production in extreme climates are necessary. With this problem in mind, a new protection technique has been developed: agrivoltaic (AV) systems where photovoltaic solar panels are positioned above grapevine. A recent study indicates the potential of AV systems under hot and dry weather conditions (Ferrara et al., 2022). In Ferrara et al. (2022), the panels were fixed and shielded grapevine from the excessive brightness around midday. No study has reported grapevine responses under dynamic AV systems where the level of shading in the vineyards can be adjusted during the day and throughout the season. This study is based on dynamic AV systems developed by Sun'Agri to protect crops from climate change (Sourd et al., 2020). This solution is articulated around mono-axial trackers, usually oriented North-South, that can rotate panels in an angle of +/- 90° at any time. With this setting, panels can follow the course of the sun (solar tracking) or orient themselves parallel to the sun's beam (anti-tracking). Consequently, the system ensures the grapevines receive the full incoming light when necessary and protectively shade the plants when extreme weather conditions are forecasted. The objective of this study was to determine the effect of shading grapevines with photovoltaic panels during the periods of high evaporative demand (ca. all the afternoons from veraison until leaf senescence). Over four consecutive seasons (2019 to 2022), air temperature at the canopy level, crop reference evapotranspiration (ETo), amount of irrigation, predawn water potential, and visual observation of the canopy and berries were selected as indicators of grapevine performance of 'Grenache N' cultivated in an experimental dynamic AV vineyard of 600 m2. The results of this study will help to improve an existing algorithm by which the periods of shading are determined by artificial intelligence using environmental and plant indicators derived from sensors and crop models (Chopard et al., 2021). This algorithm is necessary to pilot commercial large-scale dynamic AV. A brief description of the algorithm and a large-scale dynamic AV system of 4.5 ha is included in the study to illustrate an example of a commercial dynamic AV park and how we expect to pilot the level of shading using artificial intelligence.

2. Material and methods

Plant material - Two grapevine dynamic agrivoltaic systems (AV) were constructed by Sun'Agri in the South of France. An experimental AV system in Piolenc (44°10'30.95''N, 4°47'52.74''E) to perform fundamental research and a demonstration AV system in Tresserre (42°32'47.25''N, 2°51'51.21''E) to serve as extension activities for growers (Sun'Agri, 2023). The experimental AV system of Piolenc was constructed in beginning of 2019 over a mature 'Grenache N' vineyard planted in 2000. The whole vineyard was divided in two AV replicates of 300 m^2 each and a control plot of 340 m^2 without solar panels. The maximum amount of electricity the system can produce under ideal conditions is 70 kW peak. The AV site of Tresserre was put into operation in beginning of 2018. Three cultivars ('Grenache blanc', 'Chardonnay' and 'Marselan') were planted just after the completion of the structure. The AV vineyard consists of 4.5 ha for the AV divided in three replicates for each cultivar and 3 ha for the control. The maximum amount of electricity the system can produce under ideal conditions is 2.1 MW peak. All experimental results have been measured in Piolenc, while the demonstration AV system in Tresserre is mentioned in this study only for the perspectives of work. To determine if AV can improve the grapevine growing conditions if they are shaded during periods with high evaporative demand, this study focuses on a modality that was shaded in the afternoon from budbreak until leaf senescence over four consecutive season (2019-2022). Both AV and control modalities consist of five rows of 40 plants but only the middle one was used for physical measurements. Irrigation was managed separately for the AV and control plants to maintain an optimal predawn water potential.

Plant measurements - To evaluate the capacity of protection of the AV system from heatwaves and drought, the following variables were determined during the whole season for each experimental year at Piolenc: air temperature from a weather station (HMP155, Vaisala, Germany) installed at the border of the vineyard, air temperature at the canopy level, irradiance reaching the plants, crop reference evapotranspiration (ETo), amount of irrigation and predawn water potential. During summer, visual observation of the canopy and cluster were performed to assess the impact of heatwaves. Air temperature around the grapevines was measured continuously during the whole-season with thermo-hygrometers placed inside radiation shields for control and AV vines. One sensor (CS215, Campbell scientific, USA) was placed close to the canopy of one grapevine at around 0.8 m height. Irradiance was measured using PAR sensors located just above the canopy in each modality (PAR Quantum sensors, Skye, UK). The Penman-Monteith method was used to estimate ETo for AV and control plants considering the incoming irradiance as the most relevant variable. The amount of irrigation was recorded with manual water meters for the AV and control plot. Predawn water potential was measured between five and twelve times during the season (one measurement every three weeks) using a pressure chamber (PMS 600, PMS instrument company, USA). Measurements were performed on 6 vines for control and 6 vines for AV located in the central row following the recommendations of Turner and Long (1980).

Statistical analysis – A Wilcoxon test was used to compare the distribution of predawn water potential over the whole season for the control and AV vines using the python scipy library (ver. 1.10.0, https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.wilcoxon.html). A threshold of p-value of 0.05 was used to determine statistical difference between treatments.

3. Results and discussion

3.1. *Air temperature at the canopy level during heatwaves*

AV systems alter how heat is absorbed, stored, and released (Barron-Gafford et al., 2019), affecting air temperature surrounding the crops. In this study, the air temperature of vines in a dynamic AV system that shaded the vines during the days with heatwaves was lower than in control vines (Fig. 1). These results agree with other AV studies (Barron-Gafford et al., 2019; Juillion et al., 2022), indicating the potential of AV system to maintain crops under a less stressful environment. In our study, a 2°C reduction was measured on average when the dynamic AV system was positioned in solar tracking position (maximal plant shading, see 'tr' in Fig. 1), while the reduction was only 0.5°C when panels were anti-tracking (see 'atr' in Fig. 1). This small reduction may result either from the effect of the structure itself or the position of the weather station in the canopy. Ferrara et al. (2022) reported that using fixed shading to protect plants from dry environments may be associated with a decrease in yield. However, it is interesting to note that air temperature responds to sudden modifications of incident light (Fig. 1). Therefore, while a compromise between heatwave protection and yield must be found when shading the crops, steering solar panels based on specific air temperature thresholds may help protect vines from heatwaves only when necessary.

3.2. *Crop reference evapotranspiration, amount of irrigation and predawn water potential*

As reported in other AV experiments in kiwi (Jiang et al., 2022), apple (Juillion et al., 2022), and grapevine (Ferrara et al., 2022), 'Grenache N' grown under the shade of dynamic AV system improved its plant water relations (Table 1). While ETo for control vines was between 790 and 902 mm, the values in the AV modality was between 518 and 579 mm. That was associated with a reduction in the irrigation needs of AV grapevines (Table 1), confirming that AV systems can save a great amount of irrigation water. Besides the reduction of irrigation for AV vines, the amount of water in the soil, expressed as predawn water potential, was still higher in comparison with control plants (Table 1). It was difficult to keep the exact same predawn water potential between control and AV plants as reported in other field experiments (Jiang et al., 2022). Therefore, we think that the water saving of about 37 to 62% reported in this study is conservative and higher savings could be observed in different systems.

3.3. *Visual observation of the canopy and cluster*

The summer of 2022 was characterized by hot and dry conditions in Piolenc as well as most part of the western Europe (Copernicus, 2022). Negative visual symptoms in the canopy and the berries were observed in control vines while the canopy and berries of AV grapevines remained intact (Fig. 2). We did not quantify the damage in this study, but as an example, in another study with 'Cabernet Sauvignon', 25% of the clusters were damaged when the vineyard suffered a 4-day heat wave 21 days before harvest (Martínez-Lüscher et al., 2020). We still need to establish a link between heatwaves, yield and quality in future analyses for 'Grenache N' to quantify the exact impact of heatwaves in grapevine production and the full capacity of protection of the AV systems.

3.4. *Climate protection for grapevine driven by artificial intelligence*

The results included in the previous sections indicate the need to steer the panels differently throughout the season according to environmental conditions and plant needs. A conceptual algorithm is presented in Figure 3. The solar panels are oriented using information collected from environmental and plant sensors. Variables that are difficult to evaluate continuously in the field such as predawn water potential can be estimated by crop models and used to take decisions (Chopard et al., 2021). This solution is currently evaluated in the commercial field experiment situated in Tresserre, as described in section 2.1. Experimental research like the one presented in this study allows to refine the algorithm with specific environmental and plant thresholds. The main objective of all this research program is to be able to implement the best shading strategies in any commercial large-scale vineyards and help grapevine growers mitigate the effects of climate change on their crops.

4. Conclusions

Grenache N grapevines shaded during the afternoon between budbreak and leaf senescence over four seasons with a dynamic AV system were exposed to a less stressful environment due to a reduction of air temperature around the canopy during heatwaves (reduction of about 2 °C on average and until 5 °C for extreme events). ETo was significantly reduced mainly due to a reduction in the irradiance level reaching the vines. A reduction of about 65% in ETo was consistently reported over the four seasons. As a direct consequence, irrigation needs were reduced between 37% to 62% depending on the climatic conditions of the season. Besides this reduction of irrigation, AV vines had a better predawn water potential than control vines in three experimental years, indicating soil water conservation. This reduction is particularly relevant with the coming water shortage alongside climate change which will induce drastic reduction in the possibility of irrigation in the near future, as already observed in the South of France. Another positive consequence of shading vines during the afternoon is related with the avoidance of leaf damage and grape sunburn although that was only visually observed in 2022. Further research will focus on the quantification of this damage using all the cultivars grown under the dynamic AV in Piolenc and Tresserre. The results of this study can justify steering the orientation of solar panels to protect plants from heatwaves. The management of the shading level throughout the season will become a new horticultural practice. This could be an extremely difficult task for vine growers. Shading interacts with multiple factors driving the physiological and agronomical responses of the plants. Therefore, as implemented in Tresserre, we propose to use an artificial intelligence to pilot the orientation of solar panels using environmental and plant indicators derived from both sensors and crop models.

5. Acknowledgments

This work is part of the R&D project “Sun’Agri3”, supported by the PIA 2 (Programme d’investissement d’avenir), under the ADEME Grant Agreement number 1782C0103.

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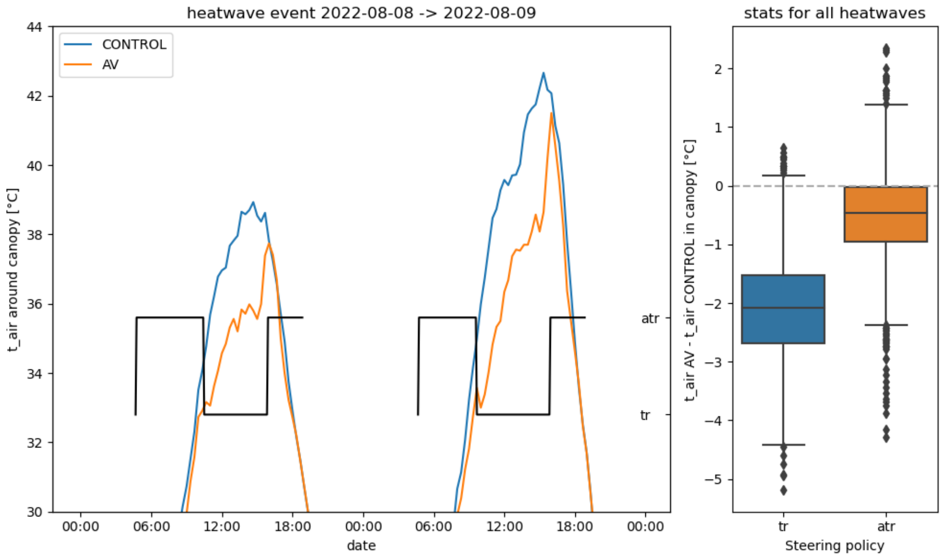

Figure 1:(left) Evolution of air temperature around canopy for two example days of heatwave, the black line refers to the steering policy of panels at that time, **(right)** statistical difference of air temperature around canopies (AVD – CONTROL) for all heatwaves for the two steering policies.

Figure 2: Visual aspect of canopies and clusters after strong heatwaves in 2022, (above) CONTROL (below) dynamic AV; left 2 photos during veraison (2022/07/29) & right during harvest (2022/09/06).

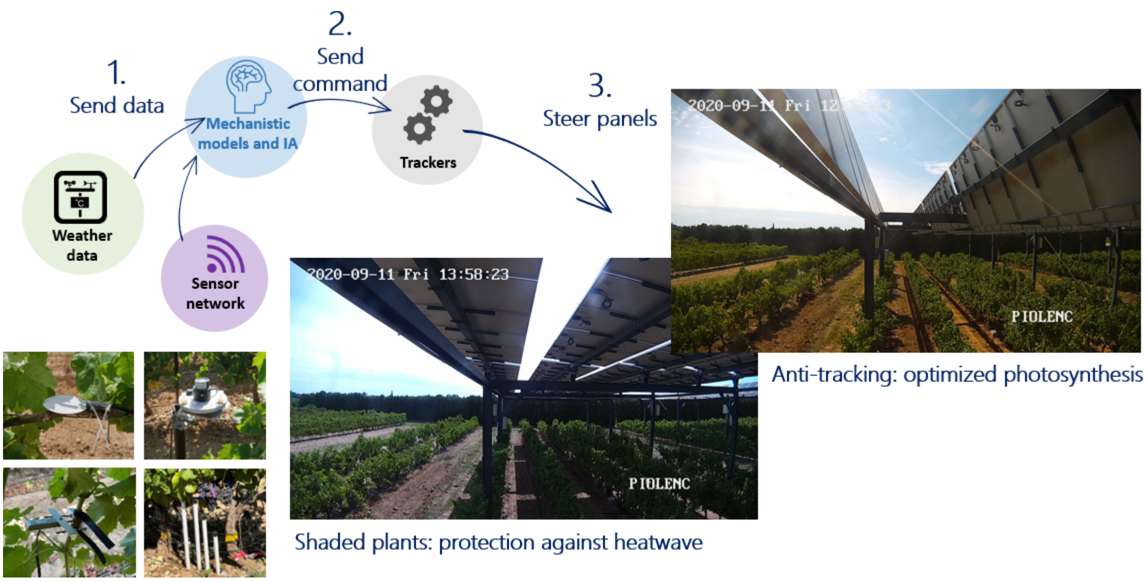

Figure 3: Schematic representation of the use of artificial intelligence to combine information from sensors and mechanistic models to steer panels.

Table 1: Reference evapotranspiration and irrigation

season	ETo CONTROL [mm]	ETo AV [mm] ([% control])	irrig CONTROL [mm]	irrig AV [mm] ([% control])	Water saving (%)	pvalue (predawn water potential higher than)
2019	869	569 (65%)	63	40 (64%)	37%	0.031
2020	851	568 (67%)	64	26 (40%)	59%	0.097

2021	790	518 (66%)	127	48 (37%)	62%	0.016
2022	902	579 (64%)	136	81 (59%)	40%	0.020

Computed ETo from micro-weather variables in each modality. Amount of irrigation applied in each modality. Pvalue of one-sided Wilcoxon test that both CONTROL and AV predawn water potentials follow the same distribution.