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Technical Feasibility Analysis of Advanced Monitoring with a Thermal Camera on an Unmanned Aerial Vehicle and Pressure Chamber for Water Status in Vineyards

Gonzalo Esteban-Sanchez [1,*], Carlos Campillo [2], David Uriarte [2] and Francisco J. Moral [3]

[1] Department of Agricultural and Forestry Engineering, School of Agricultural Engineering, Badajoz Campus, University of Extremadura, N-523, 06007 Badajoz, Spain
[2] Finca La Orden, Centre for Scientific and Technological Research of Extremadura (CICYTEX), Ctra. A-V, Km 372, 06187 Guadajira, Spain; carlos.campillo@juntaex.es (C.C.); david.uriarte@juntaex.es (D.U.)
[3] Department of Graphic Expression, School of Industrial Engineering, Badajoz Campus, University of Extremadura, Avenida de Elvas s/n, 06006 Badajoz, Spain; fjmoral@unex.es
* Correspondence: goestebans@unex.es

Abstract: Water is a limiting factor and to adopt the most appropriate agronomic strategy it is necessary to know the water status. The objective is (i) analysing of the influence of different agronomic treatments on canopy temperature in vineyards with a thermal camera on an unmanned aerial vehicle (UAV), (ii) analysing of the influence of different agronomic treatments on vineyard water potentials with a pressure chamber, (iii) advanced technical feasibility analysis of vineyard crop monitoring. The control treatment (T07) in cv. Grenache consisted of applying 30% of reference evapotranspiration (ET_o) with irrigation frequency every seven days and seven different treatments were proposed with different irrigation frequencies, pre-bud irrigation, and vine shoot distribution (T03, T15, T7A, T7V, T7P, T00, and T0P). As a result and in conclusion, the use of thermal cameras in UAVs and mid-day stem water potential allows differentiation between irrigated and unirrigated treatments, but no clear differences were shown between irrigation frequencies, pre-irrigation treatment, or vine shoot distribution. Comparing the thermal camera information in UAV and the stem water potential, certain patterns are identified with significant correlation values, the use of thermal cameras for the evaluation of plant water status is recommended, especially to obtain information in large areas.

Keywords: remote sensing technology; thermal camera; unmanned aerial vehicle (UAV); water status; temperature; pressure chamber; vineyard; agronomic treatments and irrigation frequencies; decision support systems

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1. Introduction

Water availability in the vineyard is a limiting factor for productivity in arid and semiarid zones and it is essential to improve water use efficiency [1,2]. Water availability in vineyards also affects sugar accumulation, and, with severe levels, it impairs wine quality [2,3]. The composition of the grapes for wine production depends on the water status of the vine during the growing season [4]. To adopt the most appropriate irrigation strategy for vines, it is essential to monitor the water status of the vines throughout the season [3,5,6]. Vegetative growth, yield, and berry composition are affected by the spatial heterogeneity of vineyards [7,8]. Water potential is the main indicator of vine water status, and some authors have established relationships between this indicator and berry compositional traits; however, these relationships differ between cultivars, regions, years, soil types, and management practices [3,9,10]. Furthermore, the results of a trial confirmed that unmanned aerial vehicles (UAVs) are a valuable tool for assessing spatial and temporal heterogeneity and monitoring vineyards with minimal operational cost [11]. The applications of thermal images with UAV in precision agriculture have been studied [12], demonstrating the potential of UAV thermal measurements in different applications, including as a fast and practical way to assess and estimate crop water status or stress [13–15]. Concerning water stress, it has been found that thermal images show a correlation between minor changes in water stress that are undetectable using the normalized difference vegetation index (NDVI) [16]. The crop water stress index (CWSI) calculated from canopy temperature has been found to correlate with plant physiological indicators in certain cases [17–21]. Nevertheless, the large-scale use of CWSI as an indicator to trigger irrigation has not been widely adopted over a full season for several reasons, among which is that the correlation between CWSI and water potential may differ between crop stages and cultivars [22]. Research is needed to accurately assess these relationships. It is well known that even short-term water deficits affect growth processes and induce stomatal closure, which reduces transpiration and consequently evaporative cooling, increasing leaf temperature [23]. This makes it interesting to evaluate existing techniques to determine the influence of agronomic decisions on the water status of the vineyard.

It has been shown that the higher the amount of irrigation applied, the higher the efficiency when the frequency of irrigation is reduced, when measured with a lysimeter [24]. Concerning temperature, the effect of irrigation was studied concerning vineyards without irrigation for seven days, with an infrared thermal camera on a quad bike, showing differences of two degrees between irrigated and non-irrigated vines [25]. Water potential was also studied, showing trends indicating that higher irrigation frequency implies a loss of efficiency under conditions of low water availability [26], encouraging further research on this topic. Regarding water potential, it was shown that leaf water potential measurements in vineyards should be replaced as a general rule by stem or pre-dawn water potential readings, as leaf potential is much less discriminating than the other two, and only operational constraints restricting its implementation could justify its use. The study concluded that there is a certain preference towards mid-morning stem water potential [27]. Water status studies have also been carried out with mid-day stem water potential at different irrigation rates, showing a less stressed stem water potential when vines were irrigated with a higher amount (0.50xevapotranspiration reference (ET_o)) compared to others that were irrigated with a lower amount (0.25xET_o) [28]. Stem water potential studies have also been carried out at different dates and times without obtaining significant differences in the water potentials measured at 6:00, but obtaining significant differences at midday solar (12:00 h); obtaining less stressed water potentials with irrigations of 0.20xET_o concerning dry irrigation; and less stressed water potentials with 0.40xET_o concerning 0.20xET_o [29]. In terms of comparative techniques, significant positive correlations of 0.81 have been found between temperature measurements taken from UAVs and from the ground [16]. Concerning UAV thermal camera measurements and water potential, negative significant correlation coefficients of -0.72 to -0.80 (0.28xET_o to 0.36xET_o) and -0.73 to -0.86 (0.18xET_o to 0.24xET_o) were found between leaf water potential between 14:00 and 17:00 and a ground-based FLIR thermal camera [30]. Significant negative correlations have also been found between stem water potential and thermal cameras on UAVs of -0.71 [16]. Although variations in the vapor pressure deficit can affect the cultivation temperature, it can also affect the temperature of the crop [21]. These significant correlation values suggest that canopy temperature measured on UAVs can be a simple and standardized indicator for rapid data collection over large areas of terrain [17], obtaining more representative surface data.

The influence of irrigation frequency and variety on production, vegetative development, and quality parameters has been investigated, obtaining little scope and little significant variation between frequencies, with different results depending on the vine variety and the year of cultivation, encouraging further research on this topic [31]. Nevertheless, no studies have been found that study irrigation frequency, pre-bud irrigation or shoot distribution with the above techniques. Taking this into account, we want to observe whether significant differences can be detected both with a thermal camera on a UAV and with mid-day stem water potential with different agronomic treatments, studying both non-irrigated plants and plants irrigated every seven days (0.30xET_o) in order to determine how to irrigate with the same quantities (0.30xET_o) every 15 days and every 3 days. We also want to evaluate if irrigation before pea growth affects the opening or closing of shoots. The objective of this article is to analyze the effect of different agronomic treatments on the canopy temperature of the vineyard with a thermal camera in UAVs, to analyze the effect of different agronomic treatments on the water potential of the vineyard stem measured with a pressure chamber, and also to analyze advanced techniques for crop monitoring by comparing both techniques.

2. Materials and Methods

2.1. Description of the Experiment

The experiment was conducted during the 2022 growing seasons in a 1.2 hectares experimental vineyard of cv. Grenache (*Vitis vinifera* L.) grafted on 420A rootstock, located in Finca La Orden, Centre for Scientific and Technological Research of Extremadura (CICYTEX) in southwestern Spain. Regarding the beginning of the growing season, budbreak was on 21 March, flowering on 17 May, veraison on 26 July, and harvesting on 25 August. The climate of this location is semi-arid. The vines were 5 years old and trained as Royat bilateral cordons in a vertical trellis system. All vines were pruned in winter to eight spurs and two buds (16 buds per vine); in early spring, the number of shoots was manually adjusted to 16 per vine. The rows are oriented N–S and the distance between the rows and vines is 3.0 m and 1.4 m, respectively.

To obtain a wide range of possible water stress scenarios, seven different treatments were proposed and compared to a control treatment (T07). All of them have four replicates (blocks). The treatments differ as follows:

- T07, control treatment which consisted of applying 30% ET_o from pea size with irrigation frequency every seven days. ET_o was calculated from a meteorological station near (distance less than 1 km) to the test plot according to the Penman–Monteith method;
- T03, irrigation volume same as T07 but irrigation frequency every three days;
- T15, irrigation volume same as T07 but irrigation frequency is every fortnight;
- T7P, irrigation same as T07 in volume and frequency from pea size but with one irrigation up to field capacity before bud burst (March);
- T7A, irrigation same as T07 in volume and frequency from pea size, but with open canopy position (no vertical shoot-positioned);
- T7V, irrigation same as T07 in volume and frequency from pea size, but irrigation ceased in harvest (25th August);
- T00, rainfed treatment;
- T0P, rainfed treatment, but with one irrigation up to field capacity before bud burst (March).

2.2. Canopy Temperature Measurements

Thermal imaging was captured with a high-quality camera with radiometric correction suitable for a UAV using a DJI P4 drone with an integrated thermal camera, Vue Pro 640, 32 (FOV), 19 mm, 9 Hz. The thermal images were captured at solar noon (at the same time as the water status measurement with pressure chamber) with a ground sampling distance (GSD) of 3 cm/pixel; to achieve this GDS with the characteristics of the camera, images were taken at a flight altitude of 30 m and a pixel area of 10 cm^2. The interference of atmospheric conditions, camera movement (for blurred and out-of-focus images), and radiometric correction performed by the drone thermal camera was verified by measuring different control points (ground and plant) and calibration panels with different characteristics in the field with the apogee S411 thermometer. A calibration line was performed in the laboratory to verify the quality of the images obtained and the temperature values.

To process the thermal images obtained with the UAV, the PIX4D Mapper program was used. The thermal orthomosaic was processed using the QGIS 3.30.1 program to obtain the temperature values of the canopy zone in the different treatments. To obtain the specific temperature of the canopy, the "vector", "geoprocessing", and "buffer" tools were selected. After this, the buffer parameters were configured, selecting a linear buffer with a distance on both sides of 0.5 m to obtain information for 1 m of canopy. Once the buffer was created, the attribute table of the buffer layer was opened, a new field was added, and the field statistics tool was used to calculate the average temperature within each buffer; for this, "vector", "field statistics", and "average" in the statistics group were selected and run for the buffer layer. Once a temperature per row was obtained, the data were passed to Excel to facilitate grouping and classification for subsequent statistical processing. Three measures were taken per block, with four blocks per treatment, with a toal of eight treatments (T03, T07, T7A, T7V, T7P, T15, T00, and T0P).

2.3. Stem Water Potential

Stem water potential at midday was measured on the leaves of the shaded and lower side of the canopy close to the trunk. The leaves were wrapped in aluminum foil two hours before the time of measurement, with a pressure-chamber type Scholander (Soil Moisture Corp., Model 3500, Santa Barbara, CA, USA). The periodicity of the measurement was weekly, measuring one leaf per plant, in two plants per replicate (8 leaves per treatment).

Figure 1 shows the days on which the measurements were taken, as well as the different irrigation treatments. During the month in which the measurements were taken, there was no precipitation.

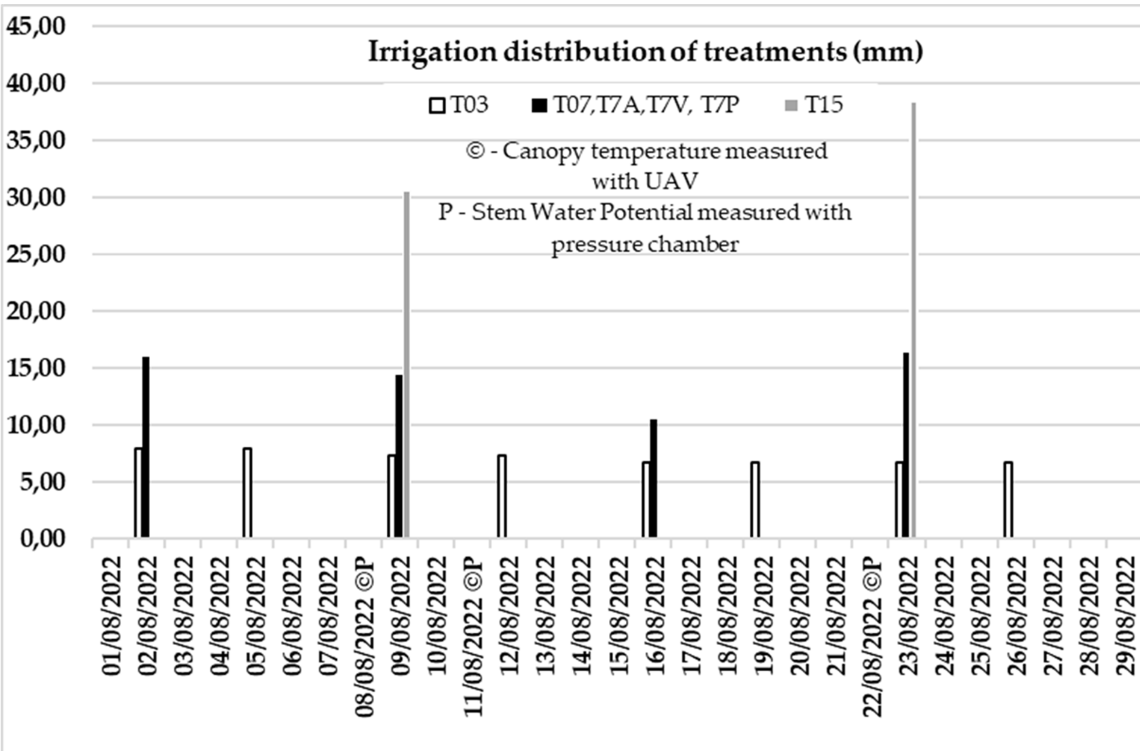

Figure 1. Distribution of irrigation frequency of the different treatments (T03, T07, T7A, T7V, T7P, T15) and days of measurement of canopy temperature with unmanned aerial vehicle (UAV) and stem water potential in the vineyard.

The measures were centralized in August, once the irrigation treatments were correctly established. The temperature measurements were made to coincide with the potential days to be able to compare them on three dates (F1, F2, and F3), which collected temperature and stem water potential information one day before a full fifteen-day irrigation cycle (F1, 8 August 2022), inside a complete fifteen-day irrigation cycle (F2, 11 August 2022) and at the end of a full fifteen-day watering cycle (F3, 22 August 2022).

2.4. Statistical Analysis

With the mean values obtained from the analyzed samples, a statistical study was carried out using the IBM SPSS Statistics 23.0 software for Windows 10 for the analysis of variance of repeated measures over time (ANOVA RM) (Tables 1 and 2), with a treatment factor with eight levels in four blocks for each treatment, measured on three different dates. In compliance with the previous assumptions, the significance of the interactions was analyzed; when the interaction was significant ($p < 0.05$), a post hoc test of comparison of means was carried out using the Tukey method. The results are shown as mean ± standard deviation with the corresponding letter obtained from the post hoc test of comparison of means by the Tukey method. For the evaluation of the advanced technique for crop monitoring, a Pearson correlation analysis between temperature and water potential within each treatment (Table 3) was also performed with IBM SPSS Statistics 23.0, taking into account the data on the three dates and also a Pearson correlation analysis of all stem water temperature and potential values within each date (Table 4).

3. Results and Discussion

3.1. Canopy Temperature

Table 1 shows the results obtained for the canopy temperature measured in a vineyard by a thermal camera in a UAV. The highest level of significance is the temperature by date, so the results of the existing significance between different treatments and between different dates are shown. Therefore, a comparison is shown between all the irrigation treatments carried out, and between the three dates analyzed.

Table 1. Canopy temperature (°C) measured in a vineyard by UAV on three dates (F1, F2 and F3). The values correspond to mean temperature ± standard deviation.

Irrigation Treatment	F1			F2			F3		
	Mean		Standard Deviation	Mean		Standard Deviation	Mean		Standard Deviation
T00	42.46 ^{a}	±	1.19	41.22 ^{ab}	±	0.75	38.15 ^{defg}	±	1.1
T0P	42.21 ^{a}	±	1.46	40.38 ^{abcd}	±	0.22	38.47 ^{cdef}	±	0.95
T03	41.33 ^{ab}	±	2.47	35.80 ^{fgh}	±	0.25	36.09 ^{fgh}	±	1.18
T7A	40.93 ^{abc}	±	1.36	36.30 ^{fgh}	±	0.07	36.61 ^{efgh}	±	0.53
T07	40.93 ^{abc}	±	1.97	36.20 ^{fgh}	±	0.68	36.51 ^{efgh}	±	0.98
T7V	41.45 ^{ab}	±	1.65	35.90 ^{fgh}	±	0.52	36.08 ^{fgh}	±	0.47
T7P	39.16 ^{bcde}	±	1.66	35.78 ^{gh}	±	0.65	36.15 ^{fgh}	±	1.17
T15	40.92 ^{abc}	±	1.43	34.57 ^{h}	±	0.69	36.88 ^{efgh}	±	0.97

$^{a–h}$ Values with superscripts with different letters are significant ($p < 0.05$).

First, comparing the treatments within each date, it can be observed that, in F1, there are significant differences between T7P concerning the T00 and T0P rainfed treatments. In F2, there are significant differences between T00 and T0P with the rest of the treatments. In F3, no significant differences are shown between treatments.

Second, comparing the three different dates within each treatment, T00 showed significant differences between F1 and F2 with F3; T0P showed significant differences between F1 and F3; and the rest of the treatments to which some irrigation treatment was applied (T03, T7A, T07, T7V, T7P, T15) showed significant differences between F1 with F2 and F3.

Canopy temperature differences of more than two degrees have been observed in unirrigated vines for seven days compared to irrigated vineyards [25]. In the present study, this is true in F2 where there are also significant differences of more than 2 °C between vines with and without irrigation. In F1 this is also true, but only between vines without irrigation and the T7P irrigation treatment; the difference between the two treatments is the most pronounced when comparing rainfed treatments with irrigated treatments that, in addition to control irrigation, had irrigation before sprouting to reach field capacity. However, when comparing irrigated vines with non-irrigated vines, no significant differences were found between vines watered every fifteen, seven, or three days, nor were there differences between vertically open or closed shoots.

When the frequency of irrigation is reduced, the greater the amount of irrigation applied according to needs, the greater the efficiency. Lower evaporation and greater transpiration [24,26] were obtained. Based on this, it can be assumed that higher transpiration leads to a lower canopy temperature. In this study, there were no significant differences between the frequencies of distribution of shoots when analyzing the thermal images, but significant differences were observed in F2 between treatments with irrigation and lower temperatures, and without irrigation, which had a higher temperature. This was also observed in F1, but only between rainfed conditions and higher temperatures, and T7P with lower temperatures.

Significant differences can be observed between rainfed and irrigated treatments; however, no significant differences are observed between different irrigation frequencies or distribution of shoots, which may also be influenced by the spatial variability of the plot. This implies the importance of properly setting up the measurement points and blocks, as was observed in a study in which water potential was measured remotely from thermal images, obtaining special variability between irrigation treatments [21]. No studies have been found that analyze irrigation frequencies or pre-bud irrigation, as well as shoot-like distributions in canopy temperature, but we have found in terms of vine wood productions or grape quality parameters depending on the frequency of irrigation and vineyard variety. Specifically, the variety analyzed in this cv. Grenache study obtained a slightly higher but not significant productive value in T07 than in T03 or T15, and slightly higher but not significant pruning wood values in T07 than in T03, and higher values than in T15. Regarding total soluble solids, there were no identified trends. Concerning pH, the wort did not offer a defined response, with little variation of values shown between the various treatments. Concerning total acidity, the greatest difference found was between T15, which was greater than T03 in one of the years without being significant. Concerning tartaric acid, the greatest difference observed was between T15 which was a year higher, and T03, which was lower without being significant. With regard to malic acid, the greatest numerical difference was between the T07 treatment, which was higher, and T15, which was lower without being significant. With regard to potassium concentrations, no significant trend was identified either. Finally, with regard to total polyphenols in cv. Grenache, the T15 treatment was higher, and T07 was lower, without maintaining a significant trend. However, the production and quality parameters analyzed were shown to have little scope and were not very significant, varying moderately according to the variety or year, which encourages further study in this line of research [31].

3.2. Stem Water Potential at Midday

Table 2 shows the results obtained with the pressure chamber for stem water potential at midday in a vineyard. Among the significances analyzed, the one with the highest level is that of the temperature by date; thus the results of the existing significance between different treatments and between different dates are shown. Therefore, a comparison is shown between all the irrigation treatments carried out and between the three dates analyzed.

Table 2. Stem water potential at midday (MPa) was measured in a vineyard with a pressure chamber on three dates (F1, F2, and F3). The values correspond to mean water potential ± standard deviation.

Irrigation Treatment	F1			F2			F3		
	Mean		Standard Deviation	Mean		Standard Deviation	Mean		Standard Deviation
T00	-1.80^{a}	±	0.10	-1.82^{a}	±	0.10	-1.93^{a}	±	0.16
T0P	-1.85^{a}	±	0.06	-1.78^{a}	±	0.07	-1.86^{a}	±	0.19
T03	-1.42^{b}	±	0.11	-1.42^{b}	±	0.14	-1.34^{bc}	±	0.09

Table 2. *Cont.*

Irrigation Treatment	F1			F2			F3		
	Mean		Standard Deviation	Mean		Standard Deviation	Mean		Standard Deviation
T7A	-1.37^{b}	±	0.14	-1.33^{bc}	±	0.15	-1.23^{bc}	±	0.04
T07	-1.26^{bc}	±	0.27	-1.31^{bc}	±	0.15	-1.23^{bc}	±	0.09
T7V	-1.36^{bc}	±	0.15	-1.21^{bc}	±	0.18	-1.30^{bc}	±	0.06
T7P	-1.29^{bc}	±	0.32	-1.21^{bc}	±	0.08	-1.24^{bc}	±	0.17
T15	-1.40^{b}	±	0.16	-1.04^{c}	±	0.16	-1.32^{bc}	±	0.16

$^{a–c}$ Values with superscripts with different letters are significant ($p < 0.05$).

First, comparing the different treatments within each date, F1 and F3 only show significant differences between the T00 and T0P rainfed treatments concerning the treatments that apply irrigation (T03, T7A, T07, T7V, T7P, T15). In F2, there are also significant differences between T00 and T0P and the rest of the treatments, but there are also significant differences between T3 and T15, in which the water potential was more negative and therefore the plants were more stressed in T3 than in T15.

Second, comparing the three different dates within each treatment, the only significant differences were shown between F1 and F2 at T15; in the rest of the treatments no significant differences were shown between the dates.

No studies have been found that analyze the water potential of the stem as a function of the frequency of irrigation in vineyards. The mid-day leaf water potential was studied, but no significant differences were found between irrigation frequencies of once a week and once every two weeks [21]. As mentioned above, when the frequency of irrigation is reduced and a greater amount of irrigation is applied according to needs, the efficiency is greater and lower evaporation and greater transpiration rates are obtained [24,26]. Given this, a plant that is not watered should present greater stress than a watered one. In addition, a plant that is watered with a lower frequency of watering and with a greater amount of water should present a lower stress. When stress through water potential is analyzed in this study, the above hypotheses are true in F1, F2, and F3 because the non-irrigated treatment always presented a more negative and significant water potential than the irrigated treatments. In addition, in F2 it was also true that at a lower frequency and higher amount of watering at T15, a lower stress and a less negative potential significantly than at a higher frequency with a lower amount of watering at T3. With respect to the amount of irrigation, it was observed that when a greater amount of irrigation, within the needs of the area, was applied, a better water status was achieved [28]. In the present study, a better water status was also observed among areas that were irrigated concerning and not irrigated on all dates. When evaluating a specific day of the irrigation period in F2, the plants that had a higher daily dose in T15 presented a better water status and significantly less negative potential, than those in T3 when a lower daily dose was applied. These results also correspond to studies of the stem water potential on different dates, where on three out of four dates there was a water potential in the most stressed stems with lower irrigation amounts [29]. In this trial, with stem water potential at midday, significant differences were found between rainfed treatments and easy irrigation and also, on one of the dates, between a higher and lower frequency of irrigation. No differences were observed between open or closed shoots or between pre-irrigation or control irrigation.

3.3. Evaluation of Advanced Technique for Crop Monitoring

The evaluation of the advanced crop monitoring technique showed that, first, according to the results shown in Tables 1 and 2 comparing both techniques within each date with the thermal camera, significant differences were shown between the T00 and T0P rainfed treatments in F1, but only with T7P and with stem water potential with pressure chamber between the T00 and T0P rainfed treatments with the other treatments that applied irrigation (T03, T7A, T07, T7V, T7P, T15). In F2 with the thermal camera, significant differences were identified between the T00 and T0P rainfed treatments and the rest of the treatments that applied irrigation (T03, T7A, T07, T7V, T7P, T15). With the stem water potential with the pressure chamber, a significant difference between T3 and T15 was also identified. In F3, no significant differences were identified between treatments with a thermal camera, and with stem water potential with pressure chamber, differences between the T00 and T0P rainfed treatments and the rest of the treatments (T03, T7A, T07, T7V, T7P, T15) were observed.

Comparing both techniques within each treatment, no significant differences between dates were noted in the pressure chamber measurements of stem water potential, except for T15, where significant differences between F1 and F2 were seen. In temperature measurements with the thermal camera for all treatments, differences between F1 and F2 and F3 were seen, except for the rainfed treatments, where T00 shows significant differences between F1 and F2 with F3. T0P showed significant differences between F1 and F3.

In addition to showing the comparison between the significant differences between Tables 1 and 2, for a better comparison analysis between the two techniques, Tables 3 and 4 show the results of the correlation analysis performed between the temperature values measured with a thermal camera on an UAV and water potential values measured with a pressure chamber camera.

Table 3. Pearson's correlation coefficient (r) between canopy temperature measured with a thermal camera on a UAV and stem water potential measured at midday with a pressure chamber in the different irrigation treatments.

Treatment	Pearson Correlation Coefficient (r)
T3	−0.29 n.s.
T7	0.03 n.s.
T7A	−0.43 *
T7P	−0.41 *
T7V	−0.55 **
T15	−0.67 ***
T00	0.41 *
T0P	0.07 n.s.

n.s.—no sig. differences; *, **, ***—sig. differences at $p < 0.05$, 0.01 and 0.001, respectively.

As shown in Table 3, the treatments with a lower and higher frequency of irrigation (T7A, T7P, T7V, and T15) have a mean negative significant correlation. However, T7 and T3 did not present a significant correlation when analyzing each frequency separately with data from the three dates. For the rainfed treatments, T0P did not show a significant correlation and T00 showed a mean positive significant correlation.

Table 4. Pearson's correlation coefficient (r) between canopy temperature measured with a thermal camera on an UAV and stem water potential measured at midday with a pressure chamber on three different measurement dates.

Date	Pearson Correlation Coefficient (r)
F1	−0.51 ***
F2	−0.88 ***
F3	−0.63 ***

*** sig. differences at $p < 0.001$.

The results of Table 4 show that on the three dates, taking into account all the treatments together within each date, the correlation between temperature measured with a thermal camera on the UAV and the stem water potential at midday was between −0.51 and −0.88, and was therefore significant, negative, and considerably strong.

The results between temperature and stem water potential of T7A, T7P, T7V, and T15 coincide with another rainfed study of the correlation between stem water potential at midday with a pressure chamber and temperature with a thermal camera on a UAV, in which a coefficient of determination of 0.50 was obtained and therefore a negative significant correlation coefficient of −0.71. In this study, the same correlation coefficient of stem water potential with canopy temperature–ambient temperature was also shown, as well as with CWSI [16]. This may indicate that, even though variations in the vapor pressure deficit (VPD) of the air can affect the evaporative cooling of the canopy and thus the canopy temperature [21], the canopy temperature can be a quick and simple indicator of the water status of the plant, which could be obtained both airborne with UAVs, as well as with thermal camera from the ground, since coefficients of determination of 0.65 were found, indicating significant positive correlations of 0.81 between both techniques for obtaining the canopy temperature [16].

The results of T7A, T7P, T7V, and T15 also coincide with results seen in other studies. In this case, with the values of water potential of leaves measured between 14:00 and 17:00 h and the temperature from a terrestrial thermal camera showing that irrigation had been applied but that different frequencies were not present, with one of between 0.28 and 0.36 ET_o, a significant correlation coefficient of −0.72 to −0.80 was obtained. With an irrigation of 0.18 to 0.24 ET_o, a significant correlation coefficient between −0.73 to −0.86 was obtained [30]. The results also coincide with measured correlation results of remotely measured water potential with mid-day water potential, taking into account the optimal stage and time of measurement [21]. The results emphasize the value of canopy temperature as a relevant explanatory variable of the physiological state of the grapevine, despite being a simpler and more normalized thermal indicator [17].

4. Conclusions

The use of UAVs with thermal cameras to analyze the influence of different agronomic treatments in the canopy temperature did not allow for a differentiation of significant differences between irrigation frequencies, nor between vertically closed or open shoots. However, it did allow for differences between rainfed treatments and irrigation on one of the dates, and between rainfed and control irrigation treatments with a pre-irrigation before sprouting, to be observed.

The use of stem water potential measured at midday to analyze the influence on the different treatments agronomic studies did not make it possible to differentiate between vineyards with open or closed shoots. No differentiation between pre-irrigation treatments and controlled irrigation treatments was observed. However, it was possible to differentiate between rainfed treatments and irrigation treatments; to identify a difference in one of the dates between frequencies; and to find vineyards that were less stressed at a lower frequency with a greater amount of water in each irrigation.

Regarding the feasibility analysis of the advanced technique comparing the thermal camera information on the UAV and the stem water potential, the stem water potential technique has provided information according to what was expected, showing significant differences in the three dates between the rainfed and irrigated treatments. The technique was able to distinguish differences between frequencies. In the case of the thermal camera on the UAV, on one of the three dates (F2), the same differences were observed as those in the potential measurements between the rainfed and irrigated treatments. In F1, a difference was noted between the rainfed and one of the irrigation treatments; however, in F3, no significant differences were identified between the rainfed and irrigation treatments. Nevertheless, certain patterns were identified with the thermal camera on the UAV, and significant correlation values were found in the correlation data obtained. Therefore, the use of thermal cameras for the evaluation of plant water status is recommended, especially to obtain information in large areas quickly, as these can be measured more frequently.

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