

Comparison of Active Thermography techniques for Copper Detection on Plants

Massimo Rippa^{*a}, Valerio Battaglia^b, Rossella Curcio^a, Michele Cermola^b, Ernesto Lahoz^b, Pasquale Mormile^a

^aInstitute of Applied Sciences and Intelligent Systems “E. Caianiello” of CNR, via Campi Flegrei 34, 80072 Pozzuoli (Na), Italy

^bCREA - Cereals and Industrial Crops Research Centre, via Torrino 2, 81100 Caserta, Italy

*m.rippa@isasi.cnr.it, phone +390818675334, <https://www.isasi.cnr.it/en/image-sensing-for-agricultural-cultural-heritage-and-ndt-applications/>

ABSTRACT

Active Thermography (AT) is a well-known non-contact and non-invasive imaging technique that in recent years it is gaining great interests in agriculture. It has been used to evaluate physical and physiological characteristics of plants such as: transpiration rates, heat capacity of the leaves, local water content, response to UV interaction and it fits well with emerging demands of the precision agriculture management strategy. According to this technique, the surface of the sample under investigation is stimulated using an external heat source and its thermal response is detected and recorded using infrared camera. Different strategies can be used for both the measurement protocol and for data analysis. Copper has been widely used in agriculture as a fungicide and bactericide for many decades. Applied on leaf, copper based fungicide (CBF) remains deposited and it is not absorbed into plant tissues, causing accumulation problems that needs to be monitored and controlled, also by using modern technologies. In this work, we test and compare different AT methods to detect and to monitor the presence of CBF on leaves. Our experimental results demonstrate that methodological approaches based on AT can be used to engineer effective remote tools to evaluate in real-time the presence of copper on plants, allowing a tentative of quantification and, therefore, to optimize its use in the agricultural practices.

Keywords: Active Thermography, Digital Agriculture, Precision Agriculture, Copper, Fungicide, Grapevine, Pulsed Thermography, Lock-in Thermography

1. INTRODUCTION

Remote sensing based on imaging techniques it is gaining in recent years great interests in agriculture to monitor and analyze crops of various kinds. Among them, Thermography is a well-known non-invasive and contact-less digital technique that represents an outstanding method applied in agriculture to perform qualitative or quantitative analysis.¹⁻⁶ Thermography has been used with both passive and active approaches in different agricultural application to evaluate physiological and physical characteristics of plants such as: heat capacity of the leaves, transpiration rates, local water content, water flow velocity and response to UV interaction.⁷⁻¹¹ This technique fits well with the precision agriculture requests, and it represents a reliable means of providing a both in situ and remote low-cost analysis.¹²⁻¹⁴ Copper based fungicide (CBF) are largely used in agronomical practice in order to control a wide range of diseases. Applied as a protective spray on plants, it remains deposited on leaf surfaces and it is not absorbed into plant tissues generating accumulation problems. Due to the its ecotoxicological profiles in the soil the use needs to be monitored, also by using novel technologies approaches, for the purpose of both better optimize the efficacy and minimize the amount of copper per season used. Different strategies to reduce and to optimize the use of CBF have been studied and tested at both industrial and research level¹⁵⁻¹⁷ but despite satisfying results from an agronomical point of view new approaches and techniques to optimize the use of CBF are required also considering the EU regulation concerning the maximum limits on CBF (EU Reg. n° 1981 of December 13th, 2018). According to Active Thermography (AT) approaches, the surface of the sample under investigation is heated using an external source and its thermal response is recorded using an

appropriate thermal camera. We have recently demonstrated the possibility of using this technique to monitor the presence of copper on plant leaves.¹⁸ In this work, we compare and discuss two different methods of AT to evaluate the persistence of the copper on grapevine plants. In particular, we analyzed the thermal response observed on grapevine leaf treated with CBF using the Pulsed Thermography (PT) and the Lock-in Thermography (LiT), comparing their results with the passive approach. Successively, we used one of these methods to monitor the copper persistence on plant leaves over a three-week period. Our achievements demonstrate that thermography can be an effective image sensing method to detect in real-time the presence of copper on plants, suitable for the development of remote sensing control systems.

2. MATERIALS AND METHODS

2.1 Thermographic measurements

Thermographic measurements were performed using a MWIR camera FLIR X6580 sc with a cooled indium antimonide (InSb) detector (FPA 640x512 pixels and NETD ~20 mK at 25 °C) mounting a 50 mm focal lens with spectral band 3.5-5 μm and IFOV 0.3 mrad. AT techniques were realized using a halogen lamp with tunable power as heat source. In all measurements, the thermal response achieved during and up to 120 s after heating was recorded with a frame rate of 5 Hz. In the case of PT test a thermal pulse of 20 seconds was used to heat each leaf investigated while, in the case of LiT, the leaves were heated using 3 cycles square wave modulated with a period $T = 40$ s (25×10^{-3} Hz). The measurements were performed with a room temperature of 25 °C and humidity of 55%. Figure 1 shows a schema of the experimental set-up used.

2.2 Plants: materials and treatments

Grapevine (*Vitis vinifera* L.) plants were used for the experiment. Grapevine seedlings of 'Aglanico amaro' (*V. vinifera* L.) variety were cultivated with two shoots for each plant, and each shoot had 8 leaves so that they developed 16 leaves. Each treatment consisted of 6 plants. Plants were grown in greenhouse in 15 cm pots filled with a pasteurized mixture of soil (zeoliter50) and sand (1:1, v:v). The mixture was pasteurized at 75 °C for 1 h on two consecutive days by autoclaving. All plants were kept at 25 °C with a 12-h photoperiod and watered as required. Treatments compared in the trials include: (i) plants treated with sterile distilled water (REF) and (ii) plants treated with CBF Airone extra (Gowan) containing 30% amount of copper (Cu). Plants were sprayed with the products using a glass atomizer and were kept in a greenhouse at 25 °C. They were sprayed once (using a glass atomizer) in order to test the persistence of CBF on leaves after a single application.

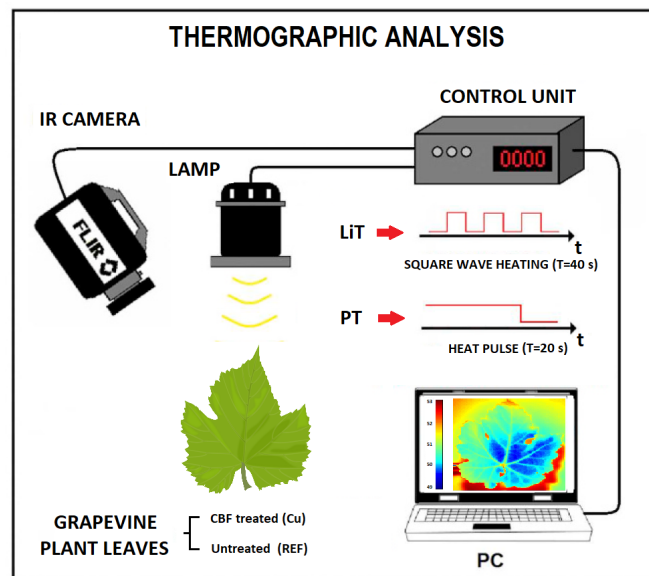


Figure 1. Schema of the experimental set-up used for thermographic measurements.

3. RESULTS AND DISCUSSION

We performed tests to compare different thermographic approaches in order to determine the most suitable one for monitoring the persistence of Cu on the leaf surface. We evaluated a passive approach and two different active approaches, the PT and the well-known LiT. As an example, in figure 2 are compared 4 images of a grapevine leaf treated with CBF representing: a) the passive thermal image achieved in natural environmental conditions, b) the map of the thermal recovery times (TRt) achieved with the PT analysis, while c) and d) are respectively the phase (Φ) and amplitude (A) maps obtained with the LiT technique.

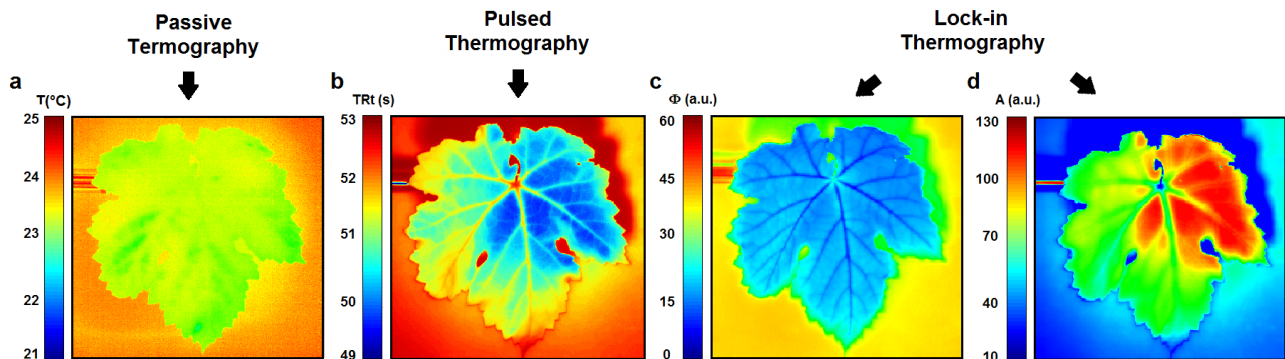


Figure 2. Comparison of thermographic techniques to detect the presence of copper residue on a grapevine plant leaf: a) passive thermal image, b) map of the thermal recovery times (TRt), c) phase (Φ) and d) amplitude (A) maps achieved with the LiT technique.

As clearly visible from the figure 2a, the thermal map of the leaf achieved with the passive thermography does not show appreciable pattern associable with the presence of Cu. As expected, under natural environmental conditions, the fungicide thermalizes with the leaf surface thus making it impossible to detect it with this approach. In the case of PT, spatial map of the TRt of the leaves was calculated using a home-made MATLAB code (R2019b, Math-Works) analyzing the temporal trend of the temperature from the frames acquired. TRt associated to each pixel of the map is defined as the time that it spent to recovery the 80% of the induced thermal gap by the heating pulse. The 80% threshold represents the value that, in our experimental measurements, allows to achieve a higher resolution of the temporal data. In figure 2b the areas of the leaves mainly characterized by the presence of Cu are well visible and characterized by lowest TRt values (blue color). This is due to the different thermal and optical properties of the metal residue (lower emissivity and higher conductivity) respect the leaf surface that produces a faster thermal response.

In the case of LiT, from recorded data, phase and amplitude maps were calculated using the software IRTA (DES). The phase map in figure 2c gives a clear view of the morphological structure of the leaf but no information relating to the presence of Cu on the surface. As well known, the phase parameter is related to the propagation time of the thermal wave inside the sample under investigation and it is independent of local optical and infrared surface features (as for example the emissivity).^{19,20} Therefore, this intrinsic characteristic of the phase makes it impossible to detect the Cu, the presence of that mainly alters the thermo-optical phenomena concerning the leaf surface. Differently, the amplitude map in figure 2d is strictly dependent on the surface thermo-optical parameters (such as diffusivity and emissivity) and hence it allows to see the presence of the metal residue in a similar way as the TRt map (figure 2b).

We observe that despite this last interesting result obtained with the LiT, PT technique is certainly easier to implement, also in view of using the proposed method in field or for the realization of a prototype monitoring system. In fact, in the LiT technique there is the necessity to monitor the exact time dependence between the output signal and the modulated heating and this requires dedicated hardware to control and to set the lamps. Moreover, other technical parameters as the period of the thermal wave and the recording frame rate must be set accurately. These technical complications are very reduced in the case of the PT technique that, when it provides results comparable to those of LiT, makes it preferable for its simple use. For these reasons, we choose to test the PT as method to monitor the persistence of CBF on grapevine leaves for a period of three weeks.

We monitored three leaves of both treated with CBF (Cu) and untreated (REF) plants evaluating the TRt maps. In Figure 3a we report the results relative to the TRt values versus the days measured for the grapevine leaves monitored. In the graphs, each point represents the average TRt calculated on the whole area of the three leaves analyzed. Error bars were calculated as the standard deviation of the experimental evaluations realized. REFs (red squares) show TRt values quite constant in time. The low observable variability is mainly due to the increase in both area size and leaf thickness over the observation period. In the case of Cu (blue circles), the TRt calculated at time t_0 are about 19 s lower than those measured for REFs plants. Successively, they increase monotonically over the 21 days of monitoring due to the reduction of the presence of CBF on the leaves surface, converging toward to those of the REFs after three weeks of monitoring. The data obtained therefore highlight the possibility of monitoring the persistence of copper by relating it to the TRt parameter. Furthermore, assuming that the ratio $(TRt(REF)-TRt(Cu))/(TRt_0(REF)-TRt_0(Cu))$ is in linear relationship with the quantity of copper present on the leaf, the proposed method can allow an attempt to quantify the percentage of copper present on the plant as represented in figure 3b.

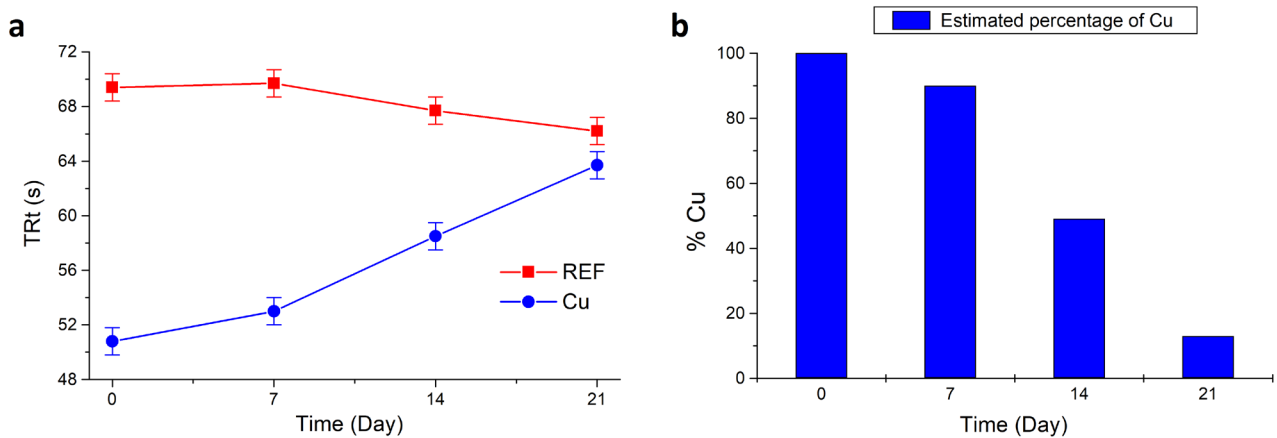


Figure 3. PT analysis performed on grapevine plant leaves: a) TRt estimation on both untreated (REF, red squares) and treated leaves with CBF (Cu, blue circles), b) Percentage of Cu on leaves estimated during the monitoring time.

4. CONCLUSIONS

In this work we compared and analyzed different thermographic methods to detect the presence of CBF on treated grapevine leaves. Successively, using the PT approach, we monitored the persistence of CBF on plant leaves for a period of three weeks. Our achievements demonstrate how thermographic techniques can be used to monitor the persistence of the copper on plant leaves allowing also a tentative of quantification. Tools of analysis based on this strategy can be used to realize remote sensing systems useful for an optimized use of copper allowing to reduce the number of treatments and hence to develop a more sustainable agronomic practice.

ACKNOWLEDGEMENTS

This work was supported by DI.BIO Project “Riduzione di input di ordine extra-aziendale per la Difesa delle coltivazioni BIOlogiche”-WP 5 “Strategie alternative all’uso del Rame in viticoltura in funzione dei cambiamenti climatici” – CUPROSUP funded by the Ministry of Policies Agricultural, Food and Forestry (Mipaaf) of Italy.

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