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# The Use of Thermography Images in the Description of the Humidification Bulb in Soilless Culture

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**ABSTRACT**

Thermography is a tool used in many scientific disciplines, including agriculture. Determining the behavior of a nutritive solution in soilless culture containers using substrates is very important in order to establish the position of drippers, drainage holes, the use of humidification agents, and fertigation management in culture units. This paper describes the application of thermography to determine the humidification bulb in horticulture crops to rapidly diagnose the best way to advance fertigation in different horticultural substrates in soilless culture. Thermography was seen to be an excellent tool for evaluating the movement and distribution of the nutritive solution within the soilless culture container with different substrates.

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**KEYWORDS**
Fertigation; horticultural substrate; non-invasive monitoring; particle size substrate; thermography; thermometry; wetting agent

## Introduction

It is well known that infrared thermography is used in many aspects of science and technology (Grinzato, Cadelano, and Bison 2010), including agriculture (Inagaki and Nachit 2008; Jones et al. 2002; Krapez and Olioso 2011; Möller et al. 2007), plant physiology (Glenn 2012; Pearce and Fuller 2001), fertigation systems (Fernández-Bregón, Valera, and Urrestarazu 2013; Morales, Alvaro, and Urrestarazu 2014), or saline stress detection (Urrestarazu 2013a). As a technology, it can be used to monitor the efficiency of water resource use for in-field applications (Antonucci et al. 2011) or potted plants in a soilless culture (Urrestarazu 2013b).

Since the 1980s, soilless culture has expanded enormously (De Rijck and Schrevens, 1998). At that time, several kinds of substrates, both biodegradable and non-biodegradable, have been developed. It is estimated that in southeast Spain, there is a soilless surface of 5500 ha (13,590.80 acres) (Urrestarazu 2013a), with substrates including perlite and rockwool (approximately 1000 ha), sand (app. 700 ha), and coconut fiber, as well as other less common substrates and soilless culture systems (Urrestarazu 2013a).

The most commonly used soilless culture units are bag and slab, with a mean height between 7.5 and 20 cm (Urrestarazu 2004). The most popular fertigation systems are self-compensating and anti-draining drippers with microtube pick (Wamser et al. 2015).

Few studies have analyzed humidification bulbs. The flow patterns occurring in rockwool slabs under both laboratory and practical situations have been investigated using a pigmented nutrient solution (De Rijck and Schrevens 1998). The improvement in the spatial distribution of the fertigation in the cultivation unit in turn improves the production (Morales and Urrestarazu 2013; Urrestarazu et al. 2015). This increase in production is due to better use of the substrate unit volume causing improved availability of water and nutrients (Robinson 1994), which results in increased root growth. By occupying a greater volume, the roots

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can better access unevenly distributed physicochemical conditions, depending on the fertigation method (De Rijck and Schrevens 1998; Sonneveld and Voogt 1990).

The major advantage of infrared thermal imaging is the non-invasive, non-contact and non-destructive nature of the technique to determine the temperature distribution of any object or process of interest in a short period of time (Vadivambal and Jayas 2011)

There is a real need for sensitive, easy, economic, and robust techniques for detection of nutrient solution flow inside a soilless culture unit.

This paper investigates the potential of infrared thermography as a tool to monitor nutrient solution flux in soilless culture units, and the goal was to evaluate and determinate the capability as a useful, rapid and simple method for diagnosing speed flux, way and morphology of bulb humidification in comparison to other methods.

## Materials and methods

To evaluate the validity of thermography in soilless culture, there have been three very different experiments representing a broad range of among the wide range of possible cases in very different unit crop in hydroponic system.

### *Experiment units and nutrient solution*

The experiment was conducted in July 2011 at the University of Almería (Almería, Spain). Two airtight wooden boxes were made measuring 22 cm in height, 24 cm wide, and 6 cm deep. The front face of the boxes was covered with 2 mm thick high thermal transmission glass. The upper face was perforated with 2 $cm^2$ holes in order to aid the dissipation of the heat from the nutritive solution entering the box. A distribution system was installed in the center of the upper face to supply the nutritive solution at a flow rate of 8 mL $h^{-1}$, simulating a dripper with a similar flow rate. The total volume of nutritive solution distributed by each dripper was 200 ml. The interior of each box was filled with the corresponding culture substrate for each experiment up to a level of 2.5 cm from the supper face. Half way along the bottom face a 1 cm perforation was made to allow the outflow of any fluid not retained within the culture unit.

The nutritive solution was similar to that proposed for tomato by Sonneveld and Straver (1994) to reproduce standard fertigation conditions with the combination to safranin and wetting agent. In each experiment heat was applied using an orbital shaking thermostat to a temperature of 55°C.

### *Thermometric analysis*

The thermography images were recorded using a compact infrared camera, Fluke® TiS Thermal Imaging Scanner (Janesville, WI, USA), with a spectral infrared range of 7.3–13 µm, a temperature range of −40 to +120°C and an accuracy of ± 2%. The detector was a focal plane array – an uncooled microbolometer of 120 × 120 pixels – and the field of view was 20° with a minimal focus distance of 0.3 m. The temperature resolution was 0.01 °C at 30°C. Thermal measurements were obtained every 30 s from the start of the nutrient solution flow. For each experiment thermography images were recorded with the tested treatment and the specified control.

The camera used is supported by the software package SmartView 3.2™ Researcher Pro (Fluke Thermography, Plymouth, MN, USA). The range of the actual temperature and the false colors in the infrared images and photographs can be selected by the user (Figures 1–5). The upper limit was set at 55ºC, while the lower limit was the mean temperature of the substrate measured prior to the experiments using the same thermography camera, giving a reading of between 18 and 20°C.

The thermography images were taken every 30 seconds from the beginning of the fertigation process.

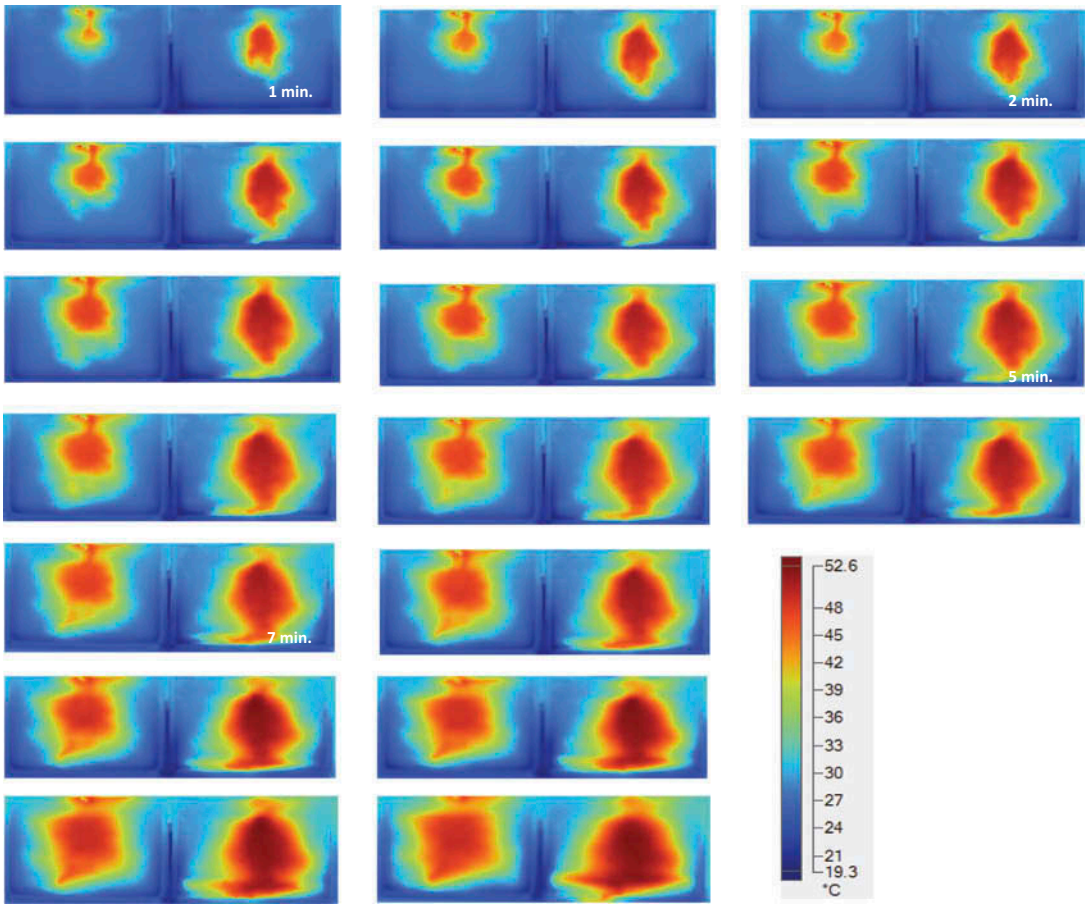


**Figure 1.** Thermography images of inside a soilless unit crop during a watering taken every 30 s. For the images on the left medium-course sand was used, while for the images on the right, coarse sand was used as substrate.

## *Treatment and experiments*

### *Experiment 1: with granulometry*

In this experiment, sand was used as substrate, and the control treatment used medium-coarse silica sand with a granulometry from 0.05 to 0.5 mm, while the evaluated treatment used coarse sand of 0.5–2 mm.

### *Experiment 2: wetting agent*

This experiment used Agroperl® B12 perlite. The control was the standard nutritive solution while the evaluated treatment consisted of the addition of 2 mg $L^{-1}$ of non-ionic surfactants of a commercial ether poly-ethylene-glycol nonil-phenol (Humectante Bayer), with 20% (w/v) active ingredient (Urrestarazu et al. 2008).

### *Experiment 3: fertigation application speed*

In this experiment, the control was the dripper system at 8 mL $h^{-1}$, while the evaluated treatment used a four-times slower flow rate for the supply of nutritive solution, using a devise similar to that described by Urrestarazu et al. (2015), so flux was at 2 mL $h^{-1}$, but volume was equal. The substrate used was the same as in experiment 2.

In this experiment, coconut fiber and perlite were used as substrate. The coconut fiber was from Pelemix® Ltd. (Pelemix Ltd., Israel) and its hydro-physical characteristics are described by Morales

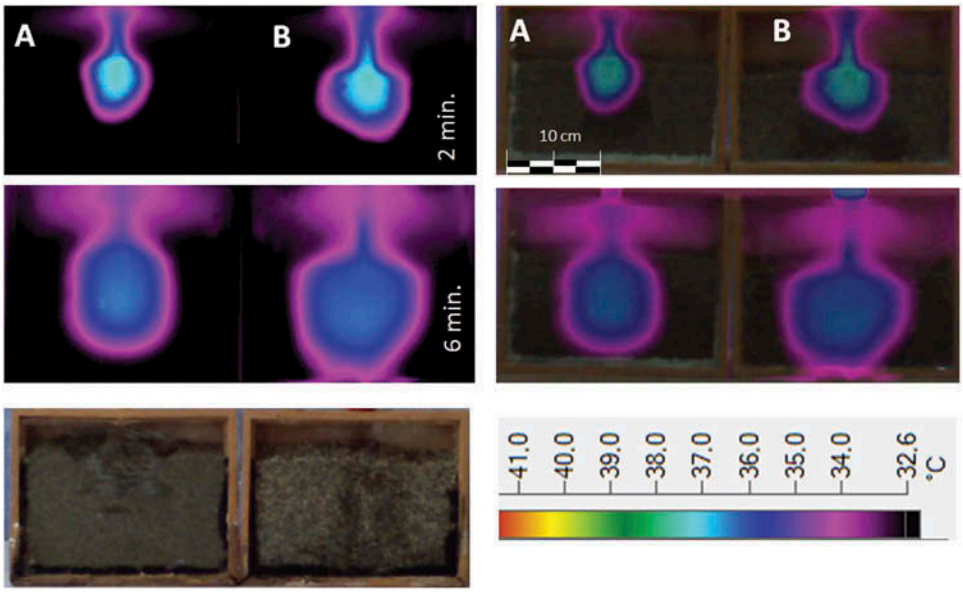


**Figure 2.** Thermography images of inside a soilless unit crop during a watering. Each row represents the compete thermography images at 100% (left) and combined in 50% with a photography image (right) as a function of fertigation time. The photography image below is for reference. A: Medium-coarse sand substrate. B: Coarse sand substrate.

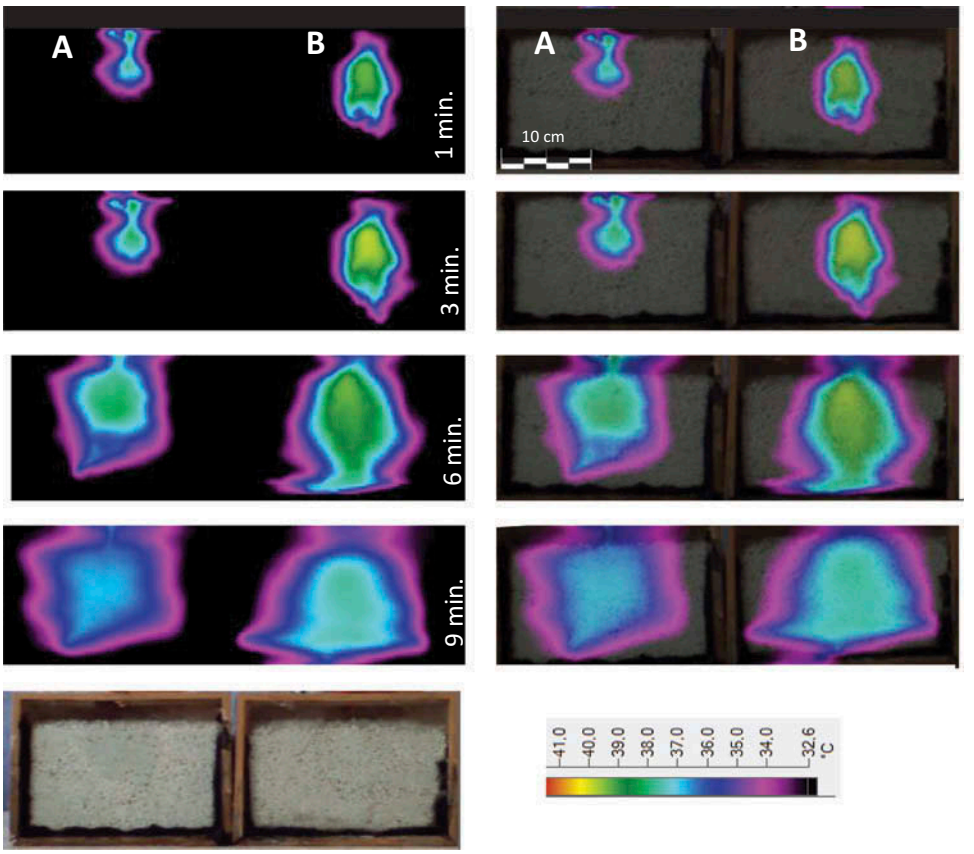


**Figure 3.** Thermography images of inside a soilless unit crop during a watering. Each row represents the compete thermography images at 100% (left) and combined in 50% with a photography image (right) as a function of fertigation time. The photography image below is for reference. A: Control fertigation treatment. B: fertigation with the addition of de 2 mg $L^{-1}$ wetting agent.

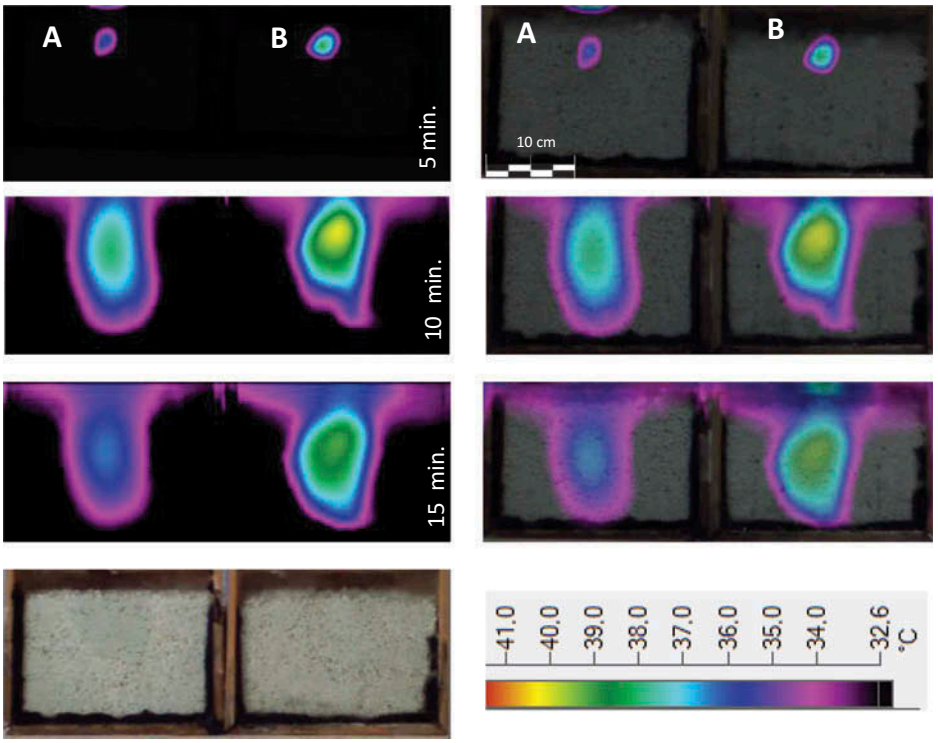


**Figure 4.** Thermography images of inside a soilless unit crop during a watering. Each row represents the compete thermography images at 100% (left) and combined in 50% with a photography image (right) as a function of fertigation time. The photography image below is for reference. A: The fertigation control with a standard flow rate (2 l/h). B: The same fertigation with a four times slower flow rate.

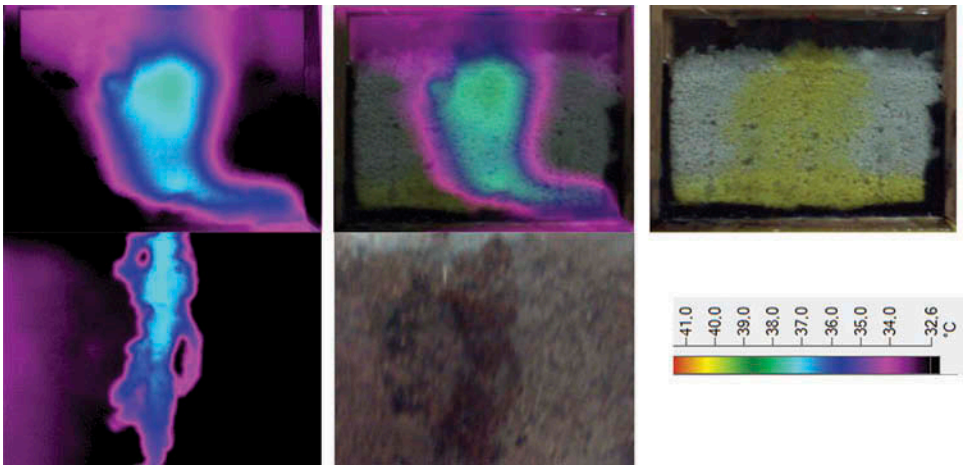


**Figure 5.** Thermography images of inside a soilless unit crop during a watering. The upper row represents the compete thermography images in perlite substrate at 100% (left) and combined in 50% with a photography image (middle). The photography image is for reference. The nutritive solution stained with safranin can be seen. Below: preferred channel in coconut fiber. Bottom-right: reference image.

Table 1. Effect of the different particle granulometry, presence of wetting agent, and applied speed in the nutrient solution on the vertical hydraulic penetration rate (%, bigger size vs smaller size) and width of humidification bulb at a height of 7 cm from the base of the culture unit after 200 mL of the standard nutrient solution.

| | | Final humidification bulb mean width (cm) | | | | | |
|---|---|---|---|---|---|---|---|
| Vertical speed % | | Wetting agent[a] | | Sand particle size | | L $h^{-1}$ [a] | |
| With wetting agent[a] | Size particle[b] | Without | With | Medium-coarse | Coarse | 2 | 8 |
| 13.56*** | 24.41*** | 14.67 | 16.03** | 10.61 | 11.89* | 10.66 | 8.32** |

*, ** and *** significant difference $P$ at 0.05, 0.01 and 0.001 by Tukey test, respectively.
Data are means of three replicates. [a]Perlite substrate used. [b]Sand substrate used.

and Urrestarazu (2013). In order to favor the appearance of the preferred channel, a proportion of 10% (v/v) of 1–5 mm long fibers were added. The perlite used was the same as that of experiment 3. All experiments were carried out in triplicate.

### *Experimental design and statistical analysis*

Three replicates were used for each measurement. The data were analyzed using the Tukey test to separate the means using Microsoft Office Excel 2007 (Microsoft Corportation, Pullman, WA).

## Results and discussion

### *Granulometry experiment*

Figure 2 and Table 1 show how the increase in fertigation volume occurs more rapidly with the coarser sand. There is a negative correlation between vertical penetration of the nutritive solution and the width of the humidification bulb. However, this was 12% more with the coarser sand. The utility of fertigation flow monitoring by thermography is similar to the validity founded by De Rijck and Schrevens (1998) using pigmentation of the nutritive solution in rockwool slab.

### *Wetting agent experiment*

Figure 3 shows how the vertical penetration rate is higher when the fertigation contains wetting agent. The increased vertical penetration seen in this study may explain some results obtained by Urrestarazu et al. (2008). However, though the vertical penetration rate was 24% more, the width of the humidification bulb around the middle was 9% more when using the wetting agent.

### *Applied fertigation speed experiment*

Figure 4 shows the thermography images in relation to the applied fertigation speed. The width of the humidification bulb at the top was 20% more when the flow rate was four times higher. The higher fertigation distribution in the substrate on the surface of the container is considered a positive element that gives increased root distribution on the surface of the culture unit and thus improves productivity (Morales and Urrestarazu 2013). Despite more cooling due to the different time over which the same amount of nutritive solution was supplied, the thermography images were able to discern the volume occupied by the fertigation fluid for both treatments.

### *Experiment to see flux and preferred channel*

Figure 5 shows the difference identified by the thermography images compared to photography images using pigmented fertigation. The photograph shows the base of the container marked by the yellow color, indicating that there was flow throughout the lower part of the unit, while the thermography image shows the preferred direction of the flow in real time with greater accuracy

than the safranin pigmented Moreover, the lower image in Figure 5, also show details of the preferred channels that can be created although its diameter is very small (<1 cm).

## Conclusions

The thermography technique was able to discern the behavior and geometry of the fertigation flow distribution from the dripper for all test cases.

As a general conclusion, thermography coupled with adequate software clearly could be useful for identifying the movement of the nutritive solution flow in the container by non-destructive testing and remote sensing. Similar results were reported to identify the uniformity of fertigation as diagnosed by infrared thermography under soilless culture (Fernández-Bregón, Valera, and Urrestarazu 2013), or early detection of plant stress by reflectance in narrow wavebands within 690–700 nm and its ratio with near-infrared (Carter and Miller 1994), or hydric (Urrestarazu 2013b) and salinity stress (Urrestarazu 2013a). With regard to plant diseases (Oerke et al. 2006) reported changes in temperature of infected leaves allowed discrimination between healthy and infected areas in thermograms.

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