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Canopy temperature for peach tree at various soil water contents

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Abstract

Canopy temperature measurements with infrared thermometry have been extensively studied as a means of assessing plant water status for field and row crops. Achieving high quality peach fruit depends on the ability to maintain mild to moderate levels of water stress in the crop during the growing season. The paper examined the spatial distribution of tree canopy temperature (Tc) using thermal images in a peach orchard for irrigation scheduling. The variation of Tc was investigated in three irrigation regime treatments (factor A) that produced various soil moisture content (SMC) values, three cardinal points (factor B): South, North and East-West aspects combined, and five up-down vertical position measurements (factor C: upper, middle upper, middle, middle lower and lower) across the tree canopy thermal images. It was found that Tc was significantly influenced by the irrigation regime. Cardinal point showed a significant Tc difference between South on the one hand and the other aspects. The vertical position within canopy image did not significantly influence Tc.

Keywords: Thermal imagery, leaf and air temperature, cardinal points, drip irrigation.

Introduction

Tree canopy temperature is one indicator of water stress. The mechanism is that the closure of stomata induced by water deficits causes an increase in canopy temperature because of a lower transpiration cooling. On a clear day, plant canopies well supplied with water are cooler than the surrounding air by several degrees (Idso et al., 1981). Jones (1999) recommended the use of reference surfaces in measurements concerning thermal images and stomatal conductance. Thermal images are widely used in recent years in relation with irrigation scheduling in both horticultural crops and agricultural crops. Thermal imagery is a viable alternative to point measurements, since the canopy temperature of the whole field can be measured at once and a map of the plant water status distribution in the field can be produced (Cohen et al., 2005). In the same manner, Grant et al. (2007) have shown that the traditional methods of measuring stomatal conductance using porometers or infrared gas analyzers only give point measurements while being time-consuming and labor-intensive. One of the advantages of using thermal imaging systems is that it allows rapid and non-invasive collection of data, integrated over the areas of individual leaves or areas of canopies, thus revealing spatial heterogeneity within or between leaves. Average temperatures over several leaves per canopy may be expected to reduce the impact of variation in leaf angles. More recently, Grant et al. (2010)

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have also reported that thermography can detect variations between treatments even at times when not identified by porometry due to the many influencing characteristics. Variability in temperatures between plants in the same management treatment has been noted to increase with stress, probably as a result of variation in soil properties and root depth (Gardner et al., 1981).

Leaf orientation and canopy geometry represented by row orientation, row spacing and plant height interact with environmental factors and stomatal conductance to determine the temperature of the plant canopy (Boissard et al., 1990). Zia et al. (2012) have revealed a high correlation between stomatal conductance (gs) and crop water stress index (CWSI), depending on the phenological stage of the crop, as well as between yield and CWSI at different growth stages, indicating that thermography can predict yield.

Thomson et al. (2012) published a review of pertinent issues involved in using thermal methods for sensing canopy temperature and demonstrated the effect of altitude on thermal imaging; most of the successful work in this area, as these authors showed, has been accomplished in arid, semiarid, or Mediterranean climates, where large differences between canopy and air temperature permitted adequate sensitivity for water management. Other authors recently dealing with thermal imaging were: Cohen et al. (2012), who studied aerial thermal images, Wheaton et al. (2011), who recently reported data on the use of thermal imagery to detect water stress in vineyards, Meron et al. (2010), who reported that mapping crop water status was necessary to match irrigation quantities to site-specific crop water demands, and the use of remote thermal sensing could provide such maps in sufficient detail and in a timely way.

The objective of this paper is to examine the spatial distribution of canopy temperature in peach tree orchards using thermal images taken from all cardinal points for various irrigation regimes and soil water content values.

Material and Methods

The experiment was performed in the summer of 2012, at the Research Station for Fruit Growing Constanta, Romania, in the village of Agigea located on the Black Sea coast line, at the latitude of 44º 05' North and longitude of 28º 37' East, with an average altitude of 30 m. The peach tree (*Prunus persica* (L) Batsch) has been selected for this study because it is representative for this region. The orchard was planted in the spring of 2009, with the 'Cardinal' variety grafted on franc rootstock in a 4 m x 3 m layout. The studied plots comprised three adjacent fruit tree rows with the central row containing six trees for various measurements and observations. The canopy shape was a spindle bush and the soil management system was clean cultivation both between tree rows and in the row. Tree canopies are flattened in the row to allow traffic, and canopy volumes occupy all the space in the row.

The climate conditions at the semi-arid experimental site are characterized by a mean annual temperature (Ta) of 11.4°C and a mean annual precipitation (P) of 382 mm (Paltineanu et al., 2007), not uniformly distributed across the year. The soil is a Calcaro-Calcic Chernozem (**World Reference Base for Soil Resources, 2006) with a loamy texture and alkaline pH, a proper soil structure and high fertility in topsoil (0-60 cm), while the non-structured subsoil (60 – 100 cm depth) lies over a thick loess deposit. Land slope is between 1.0 and 3% and soil bulk density around 1.20 g cm^{-3}. Details of the site ecological conditions are given in the accompanying paper (Paltineanu et al., 2014).

The variation of canopy temperature (Tc) was investigated in the three treatments (factor A), i.e. T1-fully irrigated, T2-sustained deficit irrigated (Goldhamer et al., 2006) and T3-control, non irrigated for three cardinal points (factor B): South, North and East-West aspects combined, and five up-down vertical position measurements (factor C: upper, middle upper, middle, middle lower and lower) across the tree canopy viewed by thermal images taken from a distance of 1.0-1.5 m and a height of 1.5 m perpendicular to the area being imaged towards the middle of the tree canopy. The three irrigation regime treatment plots were at least 50 m apart from one another. Canopy width and height were approximately 2.5 m each. There were also five positions horizontally, these being considered replicates. All these squared spatial positions had the dimensions of 6 cm. Thus, a 3-factor analysis of variance using the Duncan test for Tc due to the factors investigated (A, B, C) was carried out for each of the three sampling occasions further described using the SPSS 14 Program in order to separate the influence of the above studied factors. Coefficients of variation for

Tc were also calculated. Even if there were only three, these occasions covered a wide range of soil moisture content and leaf temperatures. Thermal images were taken by a termovision camera, Flir i3 thermal imaging camera (Portland, OR – FLIR Systems, Inc. NASDAQ: FLIR), version 2011, operating in the 7.5-13 μm wave bands, with an image resolution of 240 × 240 pixels and an accuracy of 2%, thermal sensitivity of 0.15 ºC detecting temperature differences of 0.1 ºC.

Tc was usually determined during clear sky days between 13:00 and 14:00, when SMC was near management allowed deficit (MAD) in T1 and below this value in the others (T2 and T3), for two trees (replicates) in each irrigation regime treatment, i.e. in the center of the middle row; in total, six trees were measured. According to Zia et al. (2012), this time of taking pictures is recommended because crop water stress and vapor pressure deficit are likely to be at maximum levels, and there is a minimum influence of solar angle on the canopy. Ben-Gal et al. (2009) also recommended the early afternoon as the best time for image acquisition. The importance of cardinal point, i.e. sunlit and shaded leaves, has previously been stressed (Leinonen and Jones, 2004; Paltineanu et al., 2013; Zia et al., 2012).

The images of canopies had capturing areas of about 30 cm × 30 cm (0.09 m^2). Determinations were taken twice for each aspect, separated by 30-second intervals, and were recorded three times during summer: on 27 July, 7 August, and 23 August when SMC and water stress for trees were usually different in the irrigation treatments. A set of measurements took about half an hour.

Thermal imaging has the potential to replace direct leaf measurements and to provide a more robust measure of the crop water status and its spatial pattern, through mapping of extended areas of the crop (Cohen et al., 2005). Spatial interpolation between leaf temperature values within each measured canopy area was achieved by the kriging method (Cressie, 1990; Deutsch and Journel, 1992), using the Surfer Program (*Surface Mapping System, Golden Software Inc 2002). Gridding from the Surfer Program was made by using an interpolation density of 200 gridding lines on both horizontal and vertical dimensions of the measured 0.09 m^2 leaf temperature tree canopy areas. To perform this, the point-kriging type with no-drift and ordinary kriging options was used in this study. With the help of the 25 data points located in the center of each elementary square of 6 cm in size, i.e. the 5 vertical and 5 horizontal positions in the canopy image, the Program drew the spatial distribution of leaf temperature for the imaged canopy areas. The vertical and horizontal scales of the graphs range from 3 cm (center of the first 6-cm elementary square) to 27 cm (center of the last elementary square) for each image.

The drip irrigation regime of T1 was set up according to the irrigation needs (100% of ETc = ETo x Kc, Penman-Monteith method, Allen et al., 1998) as previously described for the region by Paltineanu et al. (2007), while the sustained deficit irrigation treatment T2 was irrigated with half the amount of water in T1 (50% of ETc), and T3 was not irrigated. Irrigation application was usually carried out in T1 when SMC was about to reach the management allowed deficit (MAD), the mid-interval between field capacity (FC) and wilting point (WP). After mid August, the treatments were no longer irrigated. The dripper spacing was 0.6 m and the dripper discharge 2.0 L h^{-1}. The irrigation period lasted from June to August. In addition to ETc and SMC dynamics, the weather forecast was also considered in irrigation scheduling. We applied five irrigation applications in 2012, each with 300 m^3 ha^{-1}. As a consequence of irrigation, various SMC values occurred in the treatments, and T1 had a bigger canopy volume and leaf and shoot density than the other irrigation regime treatments.

Results and Discussion

Influence of the investigated factors on Tc and its spatial distribution across canopy

The analysis of variance of the studied factors revealed that Tc was significantly influenced by the irrigation regime (factor A) in all the three sampling occasions, Table 1. The lowest Tc values were within the fully irrigated treatment. On average, Tc differences between T1 and T3 were 2 – 3 ºC, with T2 in between. Cardinal point (factor B) showed a significant difference between South on the one hand and North and East-West on the other hand. Tc taken from South had the highest values, by about 0.7 – 1.8 ºC warmer than North, Table 1. North and East-West were only once out of three times significantly different from one another.

Factor C (vertical position within canopy image) did not significantly influence Tc in any of the three occasions; however, a low increase in Tc ranging from about 0.1 to 0.3 ºC was noted towards the base of the canopy image, Table 1, probably due to the proximity of the warmer soil, but the small size of the square image, of only 0.3 m, did not reveal a significant difference between the top and base of the canopy; further investigations should be done to obtain thermal images for the entire canopy area.

Table 1. Duncan's tests following ANOVA for canopy temperature (Tc) within the three studied factors (A, B, C), made three times during the summer of 2012 for the significance of 95%, with 75 measurements for each analysis; A - Irrigation regime, B - Cardinal points, C - Vertical position in the tree canopy. Values from the same date and the same column followed by a common letter are not significantly different at the P<0.05 level according to Duncan's Multiple Range Test

Factor analyzed	Sub-factor / occasions	27-July	7-August	23-August
A. Irrigation regime	T1-Fully irrigated	30.50 a	33.11 a	29.48 a
	T2-Deficit irrigated	31.55 b	35.93 b	31.06 b
	T3-Non irrigated	33.95 c	36.74 c	31.18 b
B. Cardinal points	North	31.63 a	34.34 a	30.27 a
	East-West	32.04 ab	35.34 b	30.33 a
	South	32.34 b	36.10 c	31.11 b
C. Vertical Position in the canopy image	Upper	31.88 a	35.14 a	30.49 a
	Middle upper	31.92 a	35.17 a	30.56 a
	Middle	31.97 a	35.20 a	30.57 a
	Middle lower	32.02 a	35.30 a	30.59 a
	Lower	32.21 a	35.48 a	30.65 a

For the first measuring occasion, 27 July, air characteristics were: T1 temperature = 32.8 ºC, T2 temperature = 32.0 ºC, T3 temperature = 32.2 ºC, vapor pressure deficit (VPD) for T1 = 2.98 kPa, 2.83 kPa for T2 and 3.26 for T3; In T1, Tc means of each thermal image were 30.9, 29.9 and 30.7 ºC for the three cardinal points used: South, North and East-West, respectively, Fig. 1 (up). The average of these means is 30.5 ºC, which is also shown in Table 1. Spatial distribution of Tc within each image is shown by the kriging curves. Tc homogeneity is very high across all T1 canopies regardless the cardinal point, with the coefficient of variation (CV) ranging from 1.24 to 2.06 %, the highest CV for South, Fig. 1, as is Tc. In T2, the same date, the means of Tc range between 31.4 (North) and 31.7 ºC (South), Fig. 1, middle, with their average of 31.55 ºC, Table 1. CV showed a high spatial Tc homogeneity again and ranged between 1.15 and 1.84%, the higher value for South.

Tc spatial distribution revealed by contour lines for T3 treatment during 27 July is depicted in Fig. 1 (low position), where one can see, as expected, the highest values of all treatments, ranging from 33.5 ºC (North) to 34.45 ºC (South), with their average 33.95 ºC (Table 1). CV values are higher in T3 than in the case of the other two irrigation regime treatments, also shown by a bigger curve density; CV shows, however, a relatively good homogeneity.

For the second measuring occasion, 7 August, air characteristics were: temperature for T1-T3 was 37.0ºC, vapor pressure deficit (VPD), 4.39 kPa;

In T1, Tc means of each thermal image were 33.81, 32.38 and 33.15 ºC for the three cardinal points, respectively, Fig. 2 up. The average of these means is 33.11 ºC, Table 1. Spatial distribution of Tc within each image shown by kriging curves reveals again a high homogeneity regardless of the cardinal point, with CV ranging from 1.39 (North) to 1.62 % (South), Fig. 2 up.

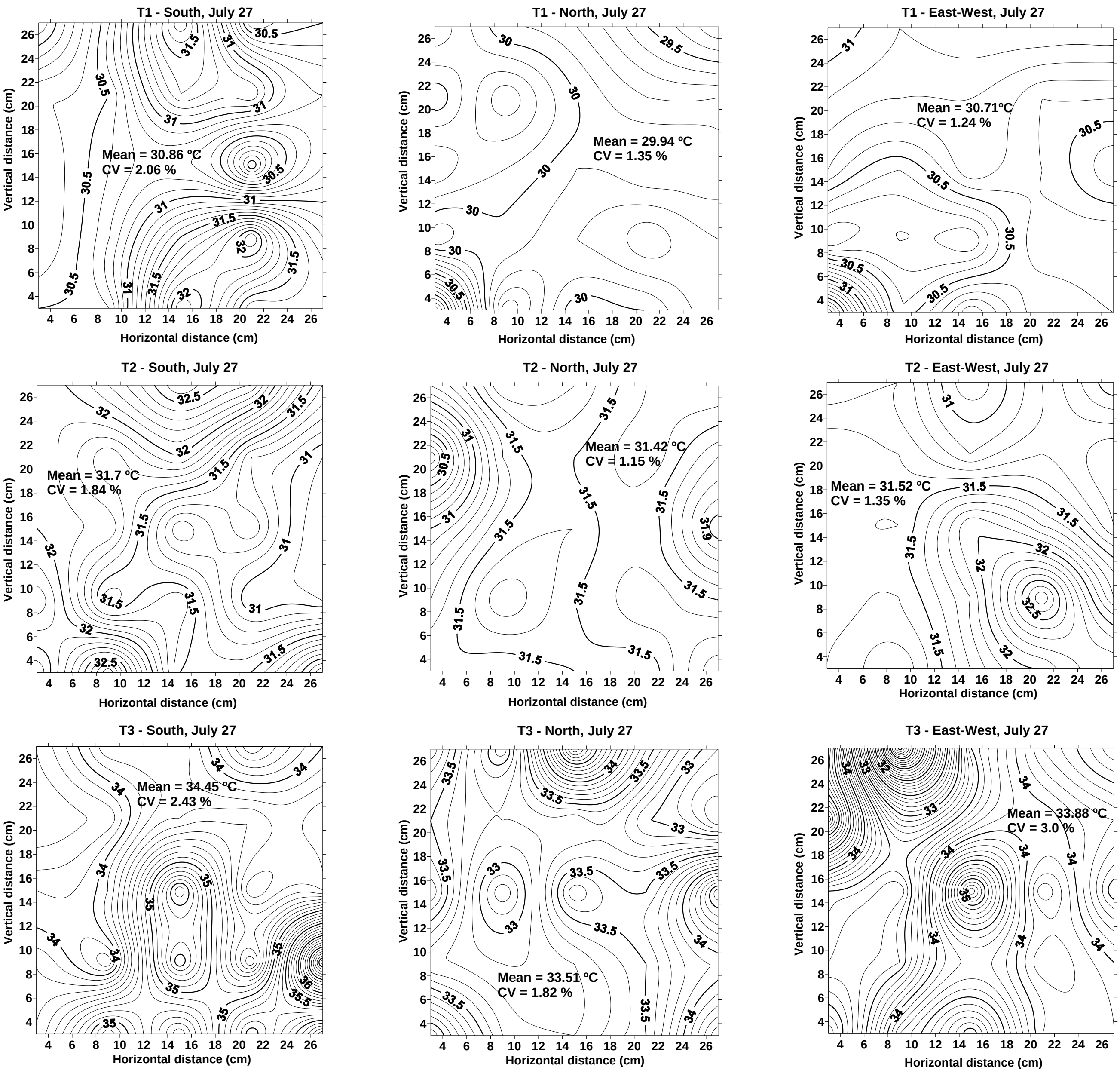

Fig. 1. Kriging curves showing the spatial distribution of canopy temperature (Tc, ºC) taken from all cardinal points (North, South and East-West combined) to a 0.3 m x 0.3 m square canopy area by thermal images taken from 1.0-1.5 m distance in all peach irrigated treatments (T1 – T3), the 27th of July 2012; note here and in the following graphs that the scales represent the dimensions of the square image

In T2, the same date, the means of Tc range between 35.03 (North) and 37.08 ºC (South), Fig. 2 middle, with their average of 35.93 ºC, Table 1. CV ranged from 1.83 % (North) to 3.12% (South). Tc spatial distribution for T3 treatment during 7 August is depicted in Fig. 2 down, with the highest values of all T1-T3 treatments, ranging from 35.60 ºC (North) to 37.41 ºC (South), with their average 36.74 ºC (Table 1). CV values in T3 varied from 1.66 % for North to 2.26 % for South, and an intermediate value for East-West, 2.03 %. For the third measuring time, 23 August, air characteristics were: T1-T3 temperature = 31.0ºC, vapor pressure deficit (VPD) = 2.07 kPa;

In T1, Tc means of each thermal image varied between 29.10 ºC (North) and 30.1 ºC (South), with CV ranging from 1.37 to 1.64 %, Fig. 3 up. The average of these means is 29.48 ºC, Table 1. Spatial distribution of Tc within images shown by kriging curves reveals the same high homogeneity as above.

Fig. 3 middle depicts Tc distribution in T2 for the same date, i.e. the means varying from 30.40 to 31.80 ºC, with the average of these means of 31.06 ºC, Table 1. CV range is from 1.44 to 2.05 %.

Tc spatial distribution for T3 treatment during 23 August is depicted in Fig. 3 down, with values close to those of T2 due to their close SMC values, ranging from 31.0 ºC (North) to 31.45 ºC (South), with their average 31.18 ºC (Table 1). CV values in T3 varied from 1.07 % for South to 1.88 % for East-West, and an intermediate value for North, 1.43 %.

For each measuring times and cardinal points the average values are shown in Table 1.

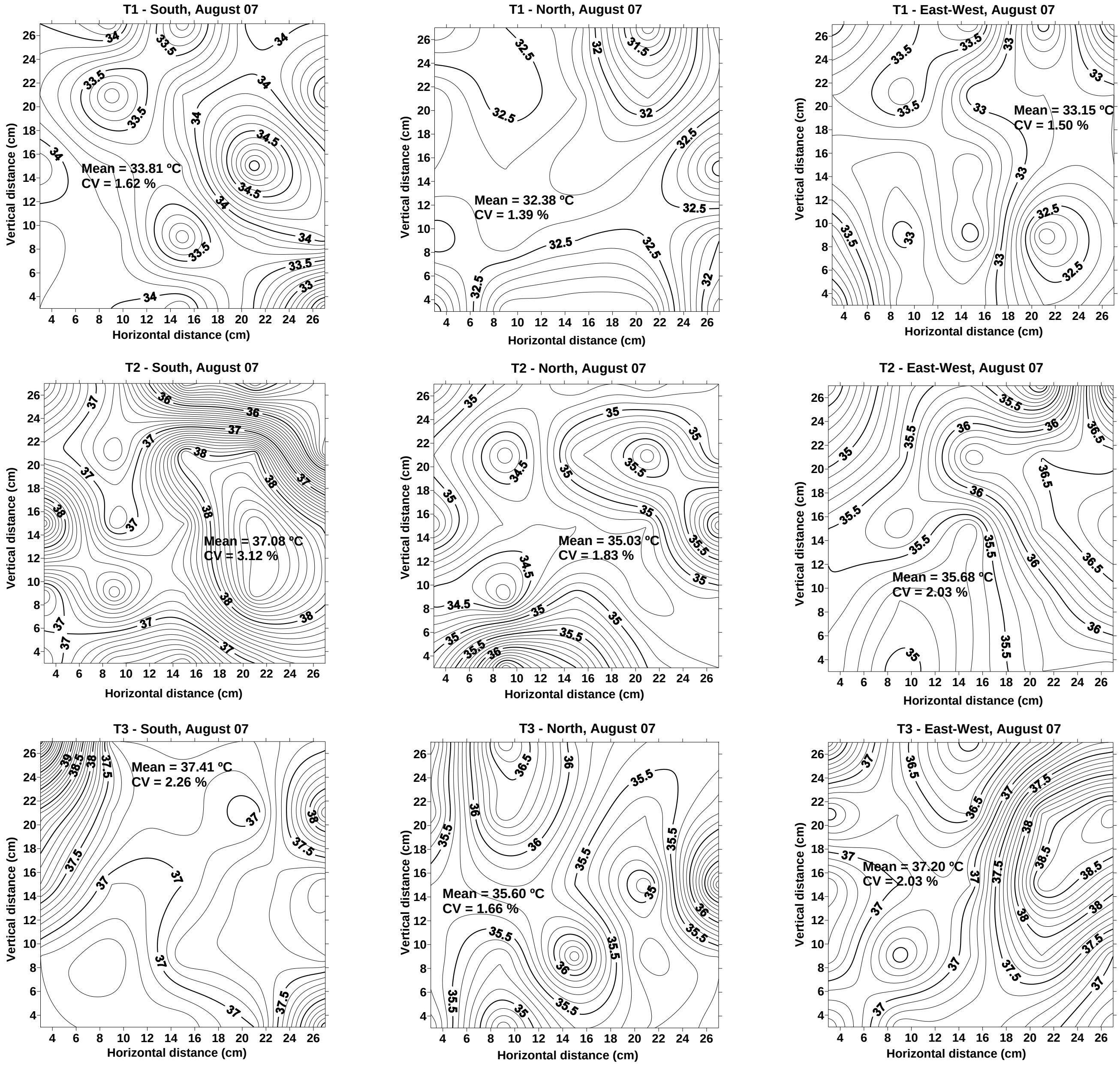

Fig. 2. Kriging curves showing the spatial distribution of leaf temperature (ºC) taken from all cardinal points (North, South and East-West) to canopy area by thermography in all peach irrigated treatments (T1 – T3), the 7th of August 2012

Tc differences between irrigation treatments, i.e. fully irrigated versus stressed plants, for various fruit tree species or vine depending on SMC were previously reported by many authors (Grant et al., 2007; Ben-Gal et al., 2009). Working with mature peach trees under similar soil and climate conditions, Paltineanu et al. (2013) found similar values for Tc as in the present paper, even if this time we used a termovision camera, instead of an infrared thermometer as we did before. Similar Tc differences were also obtained for sunlit and shaded leaves.

One of the causes could be the different tools used to measure Tc in these two experiments, and another one could be the age of orchards. Thus, there was an infrared thermometer used in mature peach orchards (Paltineanu et al., 2013), and a thermovision camera and a young peach orchard in this present paper. The infrared thermometer focuses measurements on a few leaves from a short distance (10-15 cm) and uses various angles, whereas the thermovision camera takes images horizontally from a larger distance and with a larger area, where there are not only sunlit or shady leaves but also mixed leaves; that is why Tc taken with these two tools could generate such differences.

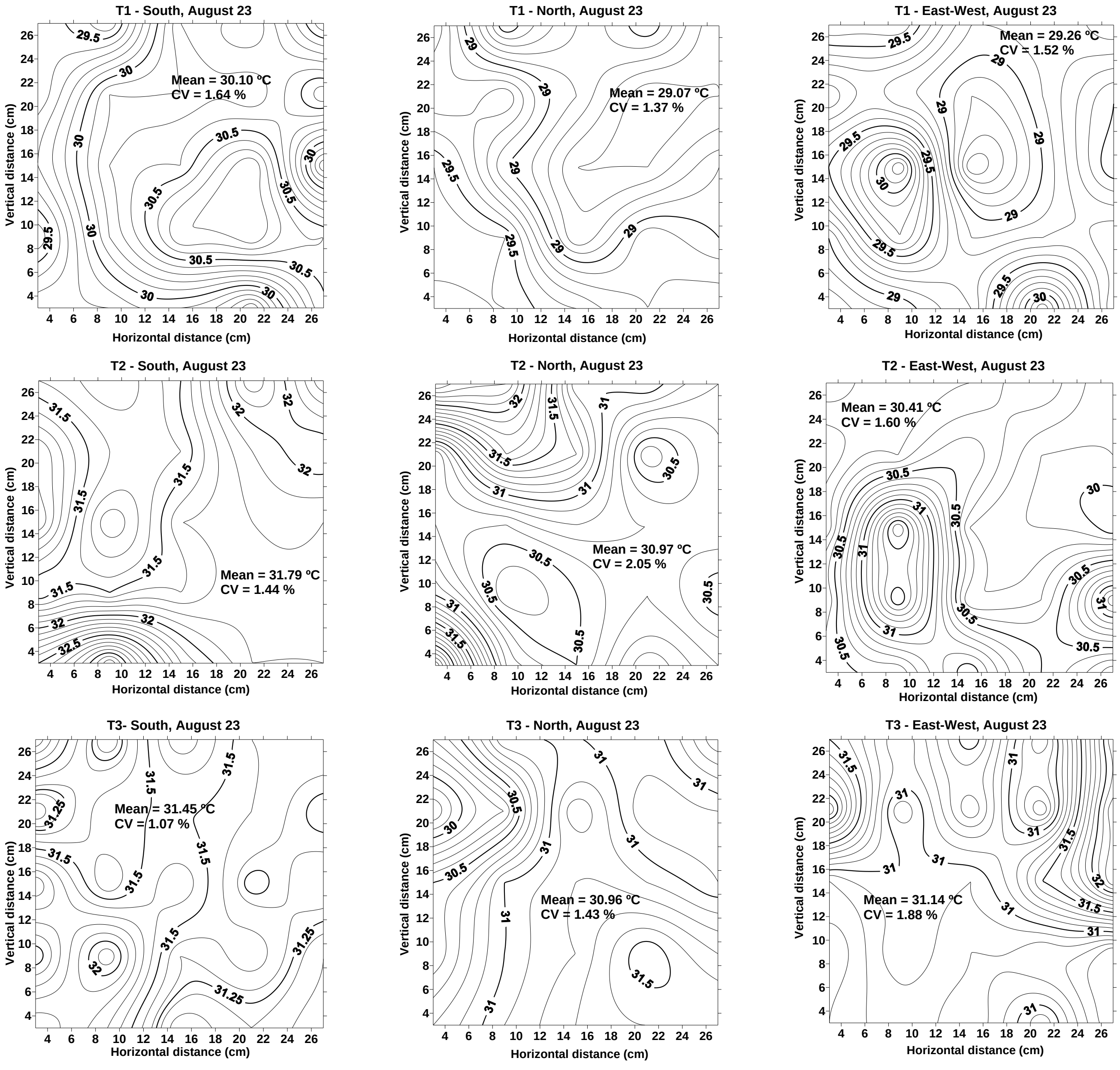

Fig. 3. Kriging curves showing the spatial distribution of leaf temperature (ºC) taken from all cardinal points (North, South and East-West) to canopy area by thermography in all peach irrigated treatments (T1 – T3), the 23rd of August 2012

Conclusion

Canopy temperature (Tc) measured by help of a thermovision camera was significantly influenced by the irrigation regime in all the three sampling occasions in a young peach orchard, with the lowest values in the fully irrigated treatment. On average, Tc differences between fully irrigated and non-irrigated treatment were 2 – 3 ºC, while the sustained deficit irrigation was in between.

Cardinal point showed a significant Tc difference between South on the one hand and North and East-West on the other hand, with South showing the highest values, by about 0.7 – 1.8 ºC higher than North. North and East-West were only once in three times significantly different from one another. The vertical position within the small canopy image taken by the termovision camera did not significantly influence Tc in any of the three occasions; however, a low increase in Tc ranging from about 0.1 to 0.3 ºC was noted towards the base of the canopy image versus its top, probably due to the proximity of the warmer soil. Spatial distribution of Tc within each image shown by the kriging curves revealed a high Tc homogeneity across canopies in all irrigation regime treatments regardless of the cardinal point, with coefficients of variation usually not exceeding 3 %. The results recommend the spatial characteristics used in this experiment: 1.5 m for height and 1.0-1.5 m for distance from the peach for taking thermal images that could be used in irrigation scheduling.

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