Thermographic Evaluation Of Water Stress In An Apple Orchard

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***Abstract*— All the objects warmer than absolute zero degrees (>0 K) emits radiation to different extent in infrared wavelength range. The water supply of plants can be defined based on the temperature level of the canopy and based on canopy temperature changes drought stress and the need for irrigation can be determined.**

During my research the thermal properties of irrigated and non-irrigated apple trees were studied during the summer heat days when the average temperature exceeded 25 °C degrees. Based on temperature properties the applicability of thermography was evaluated in apple orchard for the detection of stress symptoms of drought on canopy. The thermographic measurements were performed in apple orchard.

Beside the effect of irrigation on canopy, the impact of spatial structure and factors arising from the technology (hail net) on stress (caused by heat and lack of water) can be evaluated by thermographic survey. In addition, in irrigated orchards "underperforming" stressed trees can be identified even before the visible symptoms and yield loss occur, which can be useful to select trees affected by other biotic or abiotic stress factors.

Keywords—apple orchard, thermographic survey. water stress, CWSI

I. INTRODUCTION

Thermography is based on the fact, that all the objects in our environment zero, emit radiations in the infrared wavelength range.

From the temperature of the plant can be deduced its level of water availability and for changes in temperature, it can be determined the drought stress and the irrigation requirement as well [1]; [2]. It can be carried out making different indices. Based on the plant parameters - temperature of the amount of analogue - stress day index (Stress Day Index, hereinafter referred to as SDI) was developed [3]. The SDI is changed depending on the sensitivity of the plants and the degree of existing water stress, that the plant was an objective indicator of a lack of water. It was a big step forward to be developed stress degree day method (SDD) for determining the plant water stress on the basis of energy relations between leaf- and air temperature [4]; [5]. It is acknowledge that if the water supply of plant is uninterrupted, the temperature of the plant is near to the air temperature or directly under it. The different values suggest disruption in water supply of the plant. Relying upon mentioned, from the plant temperature and the derived water stress index (CWSI = Crop Water Stress Index) should be appropriate for quantifying the effects of drought stress as well [6]. The indices can be divided into two categories: theoretically to the heat budget of the leaf [7], and to the empirical indices [8]. The index, found by temperature differences, is to be set the connected limit to define the water shortage condition of the plant. The water supply problem limit in CWSI range from 0.2 to 0.3, as if the CWSI is greater than 0.3, the growth rate decreases. However, the too high humidity content can modify the development of the plant and air temperature difference by influencing the transpiration intensity, particularly in relation to the originally formulated amount of soil moisture content concerning information [9]. High humidity reduces the transpiration, making the plant temperature - regardless of soil moisture-increase. Beside foliage apple fruits can also be affected by heat stress. The sunburn is physiological damage of the fruit-bearing plants. Symptoms usually appear in the form of gold-bronze spot to the sunny side of the fruits [10]. Over the essential role of the solar radiation, principally the apple variety, physiological condition and the structure of the orchard can be a key factor in developing the damage [11]. Beside the sun radiation components, another essential change is that the surface of the sunlit side may as well be higher with 18 °C than the air temperature, and 8-9 °C from the shaded part [12], if the air temperature exceeds 28-32°C in July, August and September, then the development of the sunburn is more often [13]. The transpiration heat loss decreases the fruit overheating whose efficiency deteriorates in the dry periods (drought) or on little available water supply (e.g. sandy soils). At this time, the risk of the sunburn development is increasing. If the surface of the apple, exposed to the solar radiation, is warmer with 14°C than the air temperature, so the deterioration have already developed [14]. It is heat and not under the influence of solar radiation. Therefore it is crucial that the risk of sunburn due to the heat to be detected even before the onset of symptoms

II. MATERIALS AND METHODS

During the thermography research, the heat budget characteristic of the irrigated and non-irrigated apple trees were studied on the hot days in the summer period when the average temperature has reached the 25 °C in 2013. Based on the temperature conditions, applicability of the thermography was evaluated for detecting the stress symptoms of the apple fruit caused water stress. The thermographic measurements were performed on solitary apple trees and trees in orchards. The irrigated and non-irrigated solitary apple trees were 4-years-old "Easter Rosemary" variety. The thermographic measurements among irrigated and non-irrigated conditions were measured hourly from 8 AM to 3 PM under sunny and shaded conditions, for 3 days from 8 to 10 July 2013. Daily development of the heat budget of full foliage, a defined shoot and a selected fruit were measured. During the test, it was placed behind the apple trees a white projection screen which helps being separated the thermographically disturbing effect of the background for the later data processing. The white background also were used for shading. The foliage of regularly microirrigated Golden Reinders, Early Gold, Gala Galaxy and Gala Must varieties were examined at the Pallag apple orchard. Since it has already been a several years orchard therefore the background adoption cannot have been implemented. In accordance with structure of the orchard, the thermographic measurements were performed from northeast and southwest sides of the rows from both hail protected and without hail protection. The thermographic measurements were performed on varieties from 5 trees, on 33 °C air temperature for 3 days from 15 to 17 July 2013.

The thermographic images were made HEXIUM PYROLATER 12 thermocamera. Its technical details are as follows:

- Sensor: pixel number: 76800 elements (320x240), uncooled microbolometer
- Sensitivity: on average 0.05ºC @ 30ºC; F0.68
- Spectral sensitivity: 8µm…14µm
- Optical data: f=40mm; F0.68
- Optic angle: 21º(H) x 16º(V) Viewing angle: 21º (H) x 16º (V)
- Measurement range: -20ºC +120ºC (without filter)
- Output: Composite (CVBS) video signal (50 fields)
- Control: ViCam protocols (RS232 / RS485)
- Operating temperature: -25ºC to 60ºC.

The recorded images were analyzed with self-software of the thermocamera. With the use of the software, we can record and save the temperature scale as well. The temperature range can be set in the software which best characterizes the temperature of the surface (Fig. 1). However, the software is not suitable for being undertaken further studies. The data can only be exported in image form with the loss of temperature data. The software made it possible to export the temperature values of the pixels on an external .csv file, but the matrix is numerically not included the original coordinates.

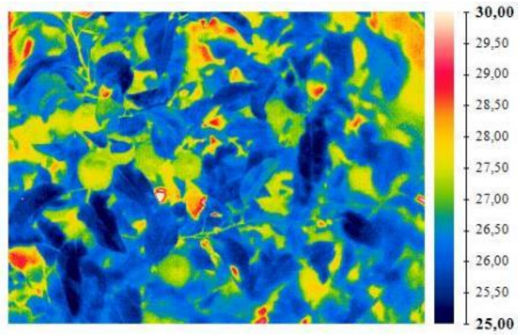

Fig. 1. Thermographic images of apple tree canopies

The original raster locations of the temperature values can be read from the number of row and column. MS. Excel macro was written to arrange the CSV matrix to XYZ data matrix. Thereafter, spatial grid networks grids were created and then conversed into raster images. After the raster conversion, the vegetation characteristic temperature means and standard deviation were calculated based on the temperature histograms of the individual raster images Subsequently, the background were masked from the "heat maps", resulting raster images which only represented the foliage and the fruit.

CWSI images were then calculated on these raster images based on JONES et al., (2002) [15]:

$$CWSI = \frac{T_c - T_w}{T_d - T_w} \quad (1)$$

where:

Td: Foliage maximum reference temperature (minimum transpiration)

Tw: Foliage minimum reference temperature (maximum transpiration)

Tc: actual temperature values for each pixel.

Based on the temperature distribution of foliage the difference in the air temperature and the CWSI index, the thermographic effects of the irrigated and non-irrigated conditions, the variety characteristics were studied with the use of correlation analysis and Tukey type multivariate analysis of variance.

III. Results and Discussion

According to the thermographic images, the average temperature of foliage, trunk and fruit increase parallel with the air temperature. The water shortage appears in the warming up of the plant leaves at first. The values of the leaf temperatures exceeded many times the atmospheric values which relates clearly to the strong decrease of transpiration and water shortage (Fig. 2.). As a consequence, increased water stress was observed in the orchard, whereas the intensity of photosynthesis depends on the water supply of the plant.

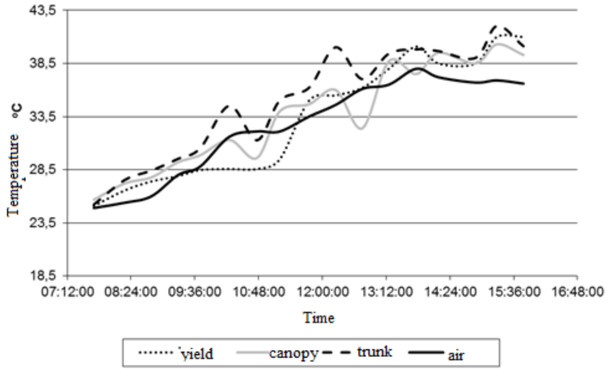

Fig. 2. Temperature changes of apple leaves, yield and trunk

Because the plant uses more water than it can take up in non-irrigated orchard, due to the water shortage in the noonday hours, the stomata close thus occurs minimum in photosynthesis intensity. It does not occur in irrigated, adequate water-supply orchard. It is not only prevented the transpiration through the closed stomata, but also is the uptake of CO_2 and under these conditions, the terminal electron donor of the electron transport is not disposable. Thus electron flow comes to the photosynthetic O_2 so superoxide, H_2O_2, finally, reactive hydroxyl radical and singlet oxygen is generated, which can also damage the chloroplast membrane system [16]. The temperature rise of the foliage, the trunk, the fruit, and the observed temporary valleys and temperature decreases were as a consequences of the shielding effects of the periodic cumulus clouds.

Thermographic evaluation of the foliage water balance and water shortage, which were caused by stress symptoms, were performed on irrigated and non-irrigated, different water supply "Rosemary Easter" apple trees. The daily changes of the foliage were studied with Thermographic camera and intra thermometer. The foliage drought stress were analyzed compared with the foliage air temperature. Based on the thermal images, the lack of watering can be clearly detected, because of the irrigated tree has lower temperature values (Fig. 3).

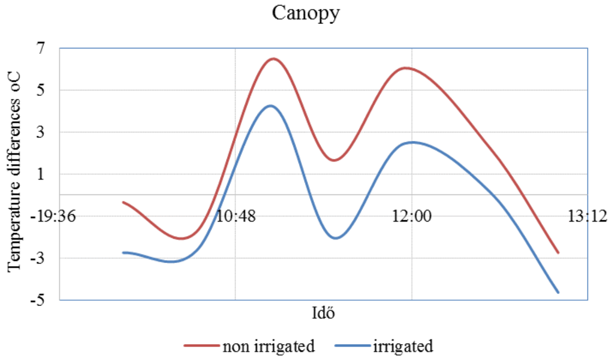

Fig.3. Daily canopy temperature differences between canopy and air in the case of irrigation and not irrigated circumstances

In the case of non-irrigated apple tree, the difference is +1.66 °C between the average foliage temperature and the air temperature but in case of irrigated apple tree, the same values is -0.19 ^{o}C. The results suggest the water shortage of non-irrigated apple tree, while periodical stress conditions also can be observed for irrigated orchard which was primarily due to the low humidity (25-30%) and the temperature of more than 30 °C. However, the extent of the stress is lower with 30-50 % than is in case of non-irrigated tree.

The sunburn is the physiological damages of the fruit-bearing plants. It is crucial that the risk of sunburn caused by the heat even be detected before the appearance of the symptoms. It can be one way to overcoming this obstacle that the temperature of the fruit are being monitored. Although, during the measurements, signs of the sunburn cannot have been observed on the fruit, but the temperature changes of the fruits were measured both thermography and infra thermometer. The difference between the average temperature of the fruit and the air temperature was +1.41 ^{o}C for non-irrigated apple tree but it was +0.46 ^{o}C for irrigated apple tree (Fig. 4). Thus, the effect of the irrigation could also be detected on the fruit in addition to the foliage with the use of thermography. Based on the measurements, the risk of sunburn did not exist.

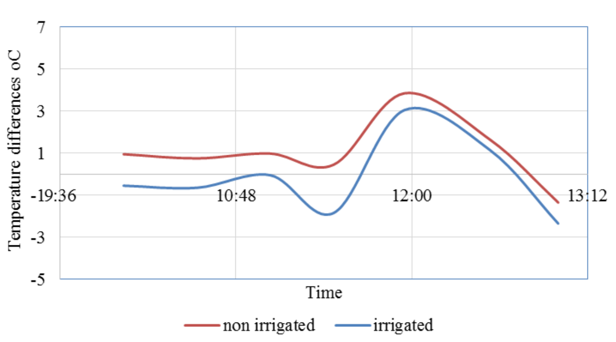

Fig. 4. Daily yield temperature differences between canopy and air in the case of irrigation and not irrigated circumstances

Besides the irrigation survey of the orchard, an analysis were carried out the effects of spatial structure on the stress condition of the fruit trees by using CWSI-index calculated from thermographic images. Rows of the studied orchard are in the direction of NW-SE so the two sides of the rows are exposed different amounts of sunlight and consequently thermal energy. Most of the energy is, of course, given SW side. Its effect can be seen at the temperature of the foliage and directly to the CWSI index as well (Fig. 5). Based on the results, the sun-exposed foliage shows stronger stress than NW shaded side, but as we reach around noon, the degree of the difference is shrinking. It is due to a greater angle of the Sun incidence and the lower shading which results uniform heat distribution of the foliage. It can also be demonstrated with the usage of the index that the temperature changes of the two sides follow each other and the stressed (CWSI<0.3) period is shorter nearly with an hour on the NE sides.

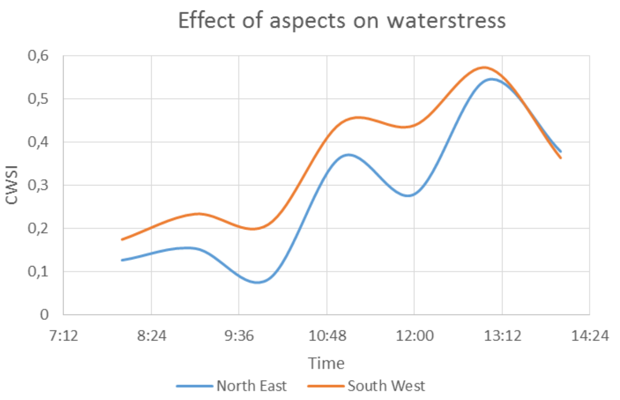

Fig. 5. Effect of aspect on canopy water stress conditions

The thermographic measurements were performed in the hail protection net and non-hail protected conditions for each of the four varieties, the effect of hail net influences the stress conditions of the foliage which the temperature of the hail protected orchard is lower with 0.74±0.42 than without hail protection net (Fig. 6).

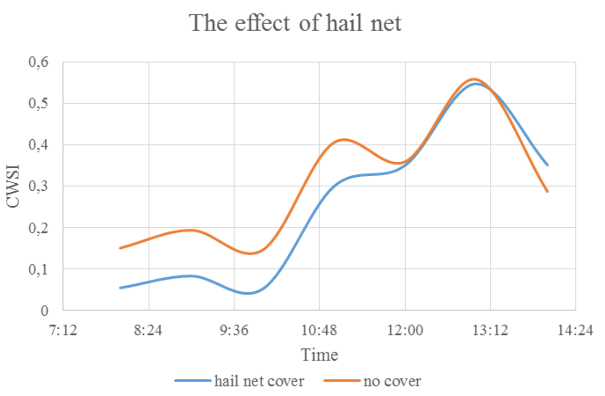

Fig. 6. Effect of hail nets on canopy water stress conditions

The temperature difference is likely to be explained by the effect of the hail protection net to the microclimate. Based on the measurements of [17], the hail protection net has a detectable effect to the microclimate of the orchard. Lower temperature, higher relative humidity and lower global radiation were observed under the hail protection net. Due to the lower transpiration, temperature of the leaves are lower. The measured data have not yet produced conclusive results among the water shortage of the four varieties during the stress tolerance difference of the analysis in the same orchard, rootstock and growing condition. The Gala Galaxy variety was to be proved tolerant to water shortage but this difference cannot be proved statistically just above at 30 ^{o}C air temperature (Fig. 7). For the other varieties and when the outside temperature was below 30 ^{o}C, there was no statistically significant difference regarding the varieties tolerance. It should also be noted that, the stress tolerance of the Gala Galaxy were the most characteristics under the hail protected orchards but without hail protection, due to the significant difference of the other varieties, only a few times were statistically different. To the given results need further studying and measuring for drawing a definite conclusions. However, the results may confirm that NEMESKÉRI (2011) [18] also identified the group of Gala varieties, like drought tolerant apple variety, it is being drawn attention to the major role of the rootstock in absorption of water.

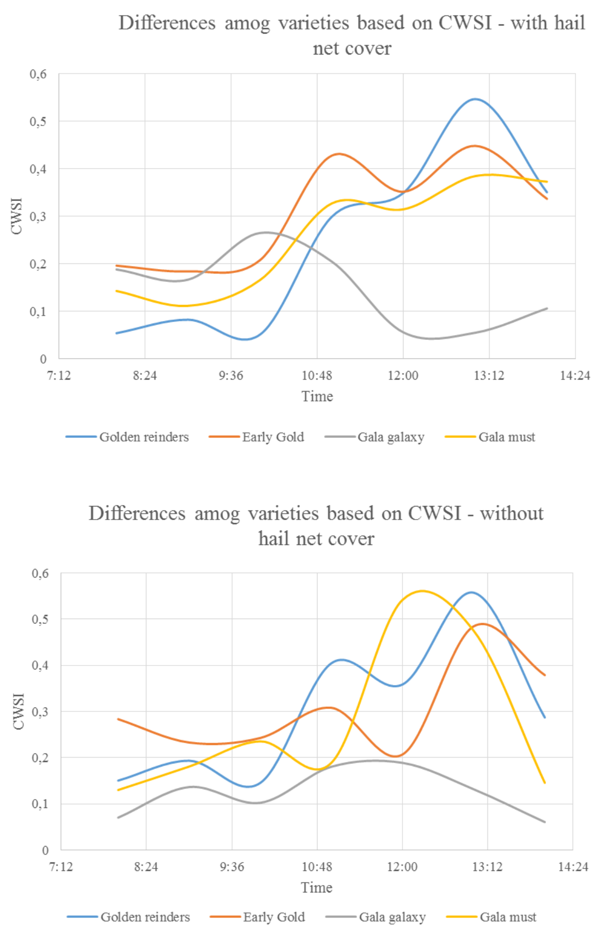

Fig. 7 Drought sensitivity of apple species

In the orchard, trees suffering from water shortage, indicated strong water scarcity condition for the high outdoor temperature and the low –despite the micro irrigation is only 15%- soil moisture content on the basis of CWSI values (Fig. 8).

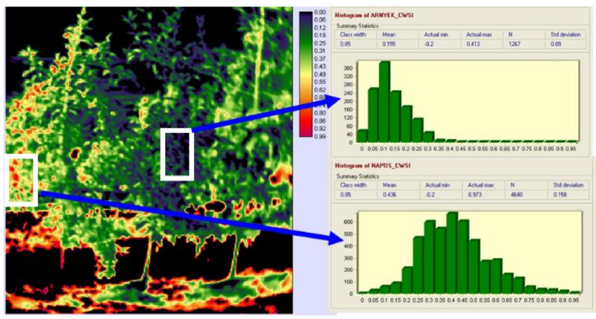

Fig. 8. CWSI image of a not irrigated and irrigated apple tree and their histograms

The average index values of the stressed foliage were 0.436±0.158 which means that the values were above the 0.3 threshold value. In contrast, the stress cannot been measured from the CWSI index image and CWSI histogram of the next apple trees in the orchard. Besides the shading, the reason is the higher moisture content of the soil (20-22%). Based on the spot investigation, the difference is the deficiency of the irrigation system because the microirrigation pipe got clogged in places so it caused irregular distribution of the irrigation water. The measurements were also proved that under the stressed trees the soil surface had higher temperatures. The results suggest that the thermography can be used effectively to check fast the technical condition of the drip pipes, but a number of other reasons can be traced back (e.g. the differences in soil texture, specific pathological problems). Thus, stressed trees can be identified before the visible symptoms and fruit loss and it can be treated after the identification.

IV. Conclusions

With thermal imaging and the use of calculated from CWSI index stress can be indicated before the visible appearance of symptoms, facilitating the proper continuous drip irrigation application in the orchards. Beside the effect of irrigation on canopy, the impact of spatial structure and factors arising from the technology (hail net) on stress (caused by heat and lack of water) can be evaluated by thermographic survey. In addition, in irrigated orchards "underperforming" stressed trees can be identified even before the visible symptoms and yield loss occur, which can be useful to select trees affected by other biotic or abiotic stress factors. Furthermore, the effects of heat stress on fruit can also be evaluated with the use of imaging thermography.

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