Diurnal Variations in Leaf – Air Temperature and Vapor Pressure Deficit of Sunlit and Shaded Kenaf Leaves

Ippolitos Gintsioudis[1], Elpiniki Skoufogianni[2], Dimitrios Bartzialis[2], Kyriakos Giannoulis[2], Nicholaos Danalatos[2]

[1]Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Greece; e-mail: igints@yahoo.com
[2]Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Greece

Abstract. The microclimatic conditions within a crop canopy are differentiated from those outside resulting to the exposure of plant organs in different environmental conditions. In the present study, the diurnal variation of leaf temperature, air temperature and vapor pressure deficit (VPDis presented, of leaves inside (shaded) and outside (sunlit) a kenaf canopy, for a period of two days is presented. During the solar day, the VPD inside and outside the canopy showed no differences and maximized at 2.7 kPa. Inside the canopy air temperature showed statistically significant differences from the outside temperature the period from 6 am to 10 am and the leaf - air temperature comparison of sunlit leaves showed significant differences during 6 pm - 11 pm, while the leaf - air temperature comparison of shaded leaves showed significant differences, almost constantly, throughout the day.

Keywords: kenaf; leaf temperature; vapor pressure deficit (VPD).

1 Introduction

Canopy temperature is primarily correlated with stomatal conductance, a physiological process which affects photosynthesis rate, transpiration rate, plant water use, leaf area index (LAI) and therefore crop yield (Lopes and Reynolds, 2010). Leaf temperature depends on air temperature, humidity, and wind speed (Jones et al. 2009) factors which affect leaf transpiration. Thermal imaging provides a good solution in screening leaf temperature, either in laboratory or field conditions, and differences between leaf and air temperature can be used as a measure of plant stress(Jackson et al. 1977). The canopy – air temperature differential has been used in many studies to quantify crop water stress index (CWSI) (Ahi et al. 2015; Erdem et al. 2006; Carroll et al. 2017). The infrared temperature measurements in most studies are captured from the top of the canopy, considering the top canopy leaves as representatives for the whole canopy. The microclimate inside and outside of a canopy is different with the plant organs being exposed to different factors affecting

Proceedings of the 9th International Conference on Information and Communication Technologies in Agriculture, Food & Environment (HAICTA 2020), Thessaloniki, Greece, September 24-27, 2020.

their physiological processes and growth. In crop modelling, data obtained from local weather stations or national networks are used (Jucker et al. 2018) and it is assumed that every plant part in a field is exposed in the same conditions. This bias can have implications when modelling plant responses to climate change. To reduce inaccuracies, research of crop microclimate inside and outside of the canopy is required.

Kenaf (*Hibiscus cannabinus* L.) is a crop mainly cultivated for fiber and biomass production. It is well adapted to Greek climatic conditions and it has a high potential biomass productivity, about 22 t ha^{-1} (Danalatos & Archontoulis 2010; Alexopoulou et al. 2000). Kenaf has the potential to be integrated as a new crop in Greece and further research of plant – environment interactions are required.

2 Materials and Methods

2.1 Experimental Area

The experiment took place in a kenaf experimental field, located in Thessaly plain of Greece (coordinates: 39°30'45" N, 22°28'03.1" E, altitude 170 m) during 14th (1st day) and 15th (2nd day) of October 2013. The soil was characterized as clay. The kenaf variety was Whitten and plant density 20 plants m^{-1}. Emergence of kenaf dated on 20/5/2013. Plot fertilization consisted on 200 kg N ha^{-1} (as ammonium nitrate) and 50 kg P ha^{-1} without any K fertilization applied, since soil analyses showed adequate K concentration. Irrigation was applied weekly with the amount of applied water being calculated as equal to maximum evapotranspiration.

2.2 Temperature Measurement System

A custom leaf temperature system was designed for automatic measurements and data storage of leaf and air temperature, and air humidity. The main system components were the microcontroller, the sensors, the power supply and a datalogging system.

The microcontroller was an ATmega2560 (Arduino Mega board) with 54 digital input/output pins, 16 analog inputs, 256 KB of Flash Memory for storing code and with 16MHz operating frequency. The microcontroller connects via a USB type port to a computer for code upload and stored data download. Microcontroller's code was written in Arduino programming language with the Arduino IDE being used for the communication between computer and microcontroller.

For leaf temperature measurements, the infrared non-contact MLX90614 sensor (Melexis, Concord, NH) was used. This type of sensors are appropriate for field use and have been used in many plant leaf experiments (Fisher & Kebede 2010; Martinez et al. 2017). The sensor consists of an infrared-sensitive thermopile detector and a signal conditioning chip integrated into a single unit. The on-board 17-bit analog-to-digital converter DAC transforms the analog temperature signal of the thermopile detector into a digital signal, accessible to the microcontroller via the SMBus communication protocol. The version of the sensor used had a10^o Field of View (FOV) and was factory calibrated for temperature measurements in the range of -40 – 85^{o}C with 0.01^{o}C resolution and ±0.5^{o}C accuracy (Melexis 2019). A total of 7 infrared sensors were used.

For air temperature and relevant humidity (%RH) measurements, the SHT15 sensors (SENSIRION AG) were used. The SHT15 contain a capacitive sensor element for measuring relative humidity while temperature is measured by a band-gap sensor. The integrated CMOSens® technology of the sensor further increase its reliability and long-term stability. Both sensors are seamlessly coupled to a 14bit analog to digital converter (ADC) and a serial interface circuit. The sensor communicates with the microcontroller via the serial interface. The %RH accuracy of the sensor is ±2% and the temperature accuracy ±0.3-0.4^{o}C in the range of 5 - 40^{o}C (Sensirion 2015). 6 SHT15 sensors were used.

The power supply system was consisting of a 9-volt battery pack, capable to operate the device for at least 48 hours, and for datalogging, the OpenLog module (SparkFun Electronics) was used. The OpenLog module is an open source data logger for microSD cards that works over serial connection.

The leaf and air temperature sensors were coupled to form, a total of 6, sensor heads. Each sensor head was attached to the end of a pole and positioned underneath a healthy leaf, with the infrared sensor looking the underside of the leaf. The poles were stabilized to the ground and attached to the plant stems to reduce changes in plant leaf position due to wind streams. The fourth infrared sensor was placed looking at the sky to be used as a correction factor in case an infrared sensor would lose visual contact with the leaf. The system was often visually monitored to ensure proper operation.

2.3 Measurements

Three sensor heads were placed underneath sunlit leaves on top of the kenaf canopy (sunlit leaves) and another 3 underneath leaves inside the kenaf canopy (shaded leaves), not visible by sun rays. In this stage of development, the canopy Leaf Area Index (LAI) was ~ 3 ensuring good shading conditions inside canopy, although proper attention was paid to the position selection.

The measurements consisted of sunlit and shaded: a) leaf temperatures ($T_{leaf\text{-}sun}$, $T_{leaf\text{-}shade}$), b) air temperatures ($T_{air\text{-}sun}$, $T_{air\text{-}shade}$) c) relevant humidity (RH_{sun}, RH_{shade}). The sky temperature was not used because no errors in infrared measurements were detected. Measurements were logged every 5 mins and averaged in hourly means. From air temperature and %RH of each SHT15 sensor, the VPD was calculated based on the equations given in FAO 56 (Allen et al. 1998).

3 Results

In Fig.1 the diurnal patterns of leaf and air temperatures, along with VPD, are presented. During the 1st day, $T_{air\text{-}sun}$ had a minimum value of 13.7^{o}C, which maximized at 27.9°C at 15th hour of the day, while the 2nd day the minimum and maximum values were 16.1°C and 30.7°C. The respective values for $T_{air\text{-}shade}$ were 15.1-26.2°C for the 1st day, and 17.3-29.0°C for the 2nd day. Maximum value of $T_{air\text{-}shade}$ occurred one hour after $T_{air\text{-}sun}$.

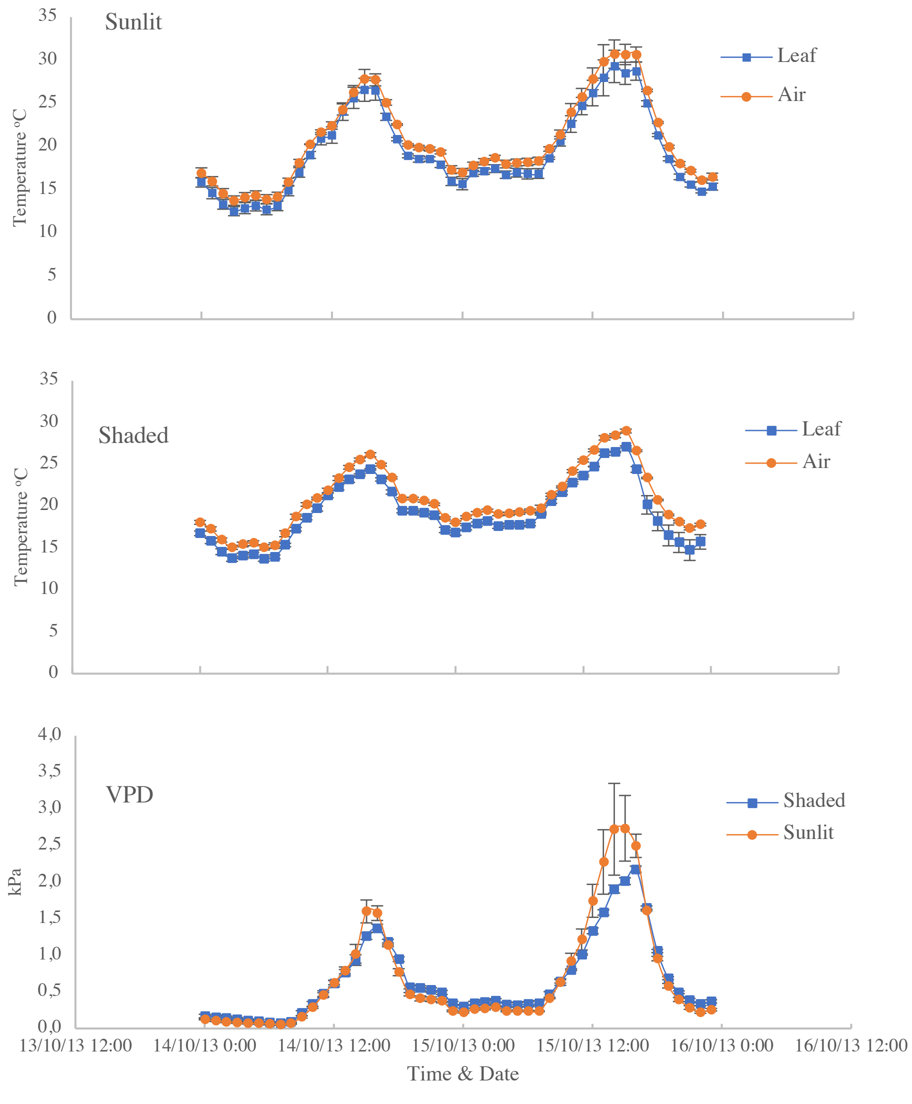

Fig. 1. Diurnal changes of leaf and air temperature, and vapor pressure deficit, of kenaf shaded and sunlit leaves. Error bars indicate mean ± SE.

The mean hourly air and leaf temperature was compared for differences during the 2-day period. During the 1st day hourly $T_{air\text{-}shade}$ to $T_{leaf\text{-}shade}$ pair comparison showed statistically significant differences ($p \leq 0.05$) only during the 10th and between the 17th and the 22nd hour of the day. During the 2nd day the statistically significant differences ($p \leq 0.05$) showed at the 8th hour and during the 17th and the 22nd hour, as on the 1st day. The pair comparison of hourly $T_{air\text{-}sun}$ to $T_{leaf\text{-}sun}$ showed constant statistically significant differences ($p \leq 0.05$) during both days, except hours 8, 9 and 19 to 23, of the 2nd day where no differences were found. During the experimental period, the mean hourly air temperature was constantly higher than leaf temperature. The range of $T_{air\text{-}shade}$ - $T_{leaf\text{-}shade}$ difference was 0.6-1.8°C during the 1st day and 0.7-3.2°C during the 2nd day. For $T_{air\text{-}sun}$ and $T_{leaf\text{-}sun}$ the range of their difference was 0.3-1.2°C and 0.8-2.1 for the 1st and 2nd day, respectively. $T_{leaf\text{-}shade}$ range between 13.7-24.4°C and 14.8-27.1°C for the 1st and 2nd day, respectively, while $T_{leaf\text{-}sun}$ range between 12.5-26.6°C and 14.8-29.3°C.

The hourly VPD means of shaded and sunlit leaves, throughout the day, were compared for statistically significant differences. During solar day there were no significant differences contrary to the period between 18th to 24th hour, of each of the days. For both days, VPD_{sun} was maximum at 15th hour of the day, while the VPD_{shaded} maximized one hour later. VPD_{sun} maximum daily value was 1.6 and 2.7 kPa and VPD_{shaded} maximum value was 1.4 and 2.4 kPa, for 1st and 2nd day, respectively.

4 Discussion

Temperature and vapor pressure deficit (VPD) are important environmental factors affecting crop growth and productivity by regulating leaf stomatal conductance. In the present study VPD inside and on top of the canopy, showed no significant differences throughout the solar day, apart from after 6 pm when the sun is low on the horizon and the photosynthetic rate is low. The same pattern was observed both in the inside and outside air temperature, and in both sunlit leaves temperature and their air temperature. In both cases there was differentiation after 6 pm. On the contrary the shaded leaves had almost constantly statistically significant different temperature from the temperature of their microclimate. These findings suggest that leaf temperature varies within the day and depending on the canopy height, and thus they should not be considered stable.

Acknowledgments. This paper is part of PhD thesis of Ippolitos Gintsioudis and the first author would like to thank the Laboratory of Agronomy and Applied Crop Physiology of University of Thessaly for helping in the completion of this project.

References

1. Ahi, Y. et al., 2015. The canopy temperature response to vapor pressure deficit of grapevine cv. Semillon and Razaki. *Agriculture and agricultural science procedia*, 4, pp.399–407.
2. Alexopoulou, E. et al., 2000. Growth and yields of kenaf varieties in central Greece. *Industrial Crops and products*, 11(2-3), pp.163–172.
3. Allen, R.G. et al., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, 300(9), p.D05109.
4. Carroll, D.A. et al., 2017. Leaf temperature of maize and Crop Water Stress Index with variable irrigation and nitrogen supply. *Irrigation Science*, 35(6), pp.549–560.
5. Danalatos, N. & Archontoulis, S., 2010. Growth and biomass productivity of kenaf (Hibiscus cannabinus, L.) under different agricultural inputs and management practices in central Greece. *Industrial Crops and Products*, 32(3), pp.231–240.
6. Erdem, T. et al., 2006. Use of a crop water stress index for scheduling the irrigation of sunflower (Helianthus annuus L.). *Turkish Journal of Agriculture and Forestry*, 30(1), pp.11–20.
7. Fisher, D.K. & Kebede, H., 2010. A low-cost microcontroller-based system to monitor crop temperature and water status. *Computers and electronics in agriculture*, 74(1), pp.168–173.
8. Jackson, R., Reginato, R. & Idso, S., 1977. Wheat canopy temperature: a practical tool for evaluating water requirements. *Water resources research*, 13(3), pp.651–656.
9. Jones, H.G. et al., 2009. Thermal infrared imaging of crop canopies for the remote diagnosis and quantification of plant responses to water stress in the field. *Functional Plant Biology*, 36(11), pp.978–989.
10. Jucker, T. et al., 2018. Canopy structure and topography jointly constrain the microclimate of human-modified tropical landscapes. *Global change biology*, 24(11), pp.5243–5258.
11. Martinez, J. et al., 2017. A cost-effective canopy temperature measurement system for precision agriculture: a case study on sugar beet. *Precision Agriculture*, 18(1).
12. Melexis, 2019. *MLX90614 Datasheet*.
13. Sensirion, 2015. *SHT15 Datasheet*.