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Effect of Wind and Radiation on the Crop Water Stress Index Derived by Infrared Thermography

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Introduction

The increasing demand for water all over the world calls for precision agriculture which accounts globally about 70 percent of all water withdrawal. Therefore, there is a need to optimize water use efficiency and making the best use of available water for irrigation. Maize (Zea mays L.) is one of the most widely grown crops in the world, predominantly grows in arid and semi-arid regions. Irrigation scheduling based on methods like soil water content or by more advanced measurements like leaf stomata conductance to water vapour and leaf water potential, is labor intensive, time consuming and leaf to leaf variations require much replication for reliable data. Canopy surface temperature measured with infrared thermography to determine the water stress is a non-contact method and thus very fast and practical. It is capable to estimate large leave populations simultaneously and provides an overview on stomata conductance variation and dynamics (Jones et al., 2002). Leaf temperature however, depends on other environmental factors like air temperature, radiation, humidity and wind speed, which may lead to inaccuracies in thermography-based water status detection (Spreer et al., 2009). Therefore, the objective of this study is to determine the effect of wind and radiation on crop water stress index (CWSI).

Material and Methods

The experiment was conducted in a green house of Universität Hohenheim, Stuttgart (Germany) for a period of eight days (day of experiment, DOE 1-8) on twelve potted maize (Zea mays L.). Before the experiment was started, all the pots were irrigated to achieve the same soil moisture content. Two seeds per pot were sowed and 3 pots were allowed to dry out without irrigation and the soil water content data were simultaneously measured in a two hour interval with one two-rod TDR-probe (Trime-IT, Imko Germany) each. The remaining 3 served as references and were placed in a catchment tray to assure availability of sufficient water. When the plants were identified to be under water stress a wind of 1.12m/s and radiation by 400W sodium was applied.

Thermal images at every 15 and 20seconds were taken for wind and radiation effect investigation.

Thermal Imaging

Infrared Vario CAM has been used to take the thermal and visible images simultaneously. All the pictures were taken in the afternoon. A wet and petroleum jelly covered leaves were taken as wet and dry reference surfaces. The crop water stress index (CWSI) was calculated from the measured mean canopy temperature and wet and dry reference temperatures (Jones 1999).

$$CWSI = \frac{\left(T_{canopy} - T_{wet}\right)}{\left(T_{dry} - T_{wet}\right)}$$

Where, Tcanopy is the actual canopy temperature obtained from the thermal image and Twet and Tdry are the lower and upper boundary temperatures representing minimum (maximum transpiration) and maximum leaf heating (no transpiration) respectively.

Results and Discussion

At the start of the experiment all the pots were irrigated such that the volumetric soil moisture content (θ) was almost similar (θ = 32%). During the experiment θ values of non-irrigated maize decreased to a value of about 12% (Figure 1).

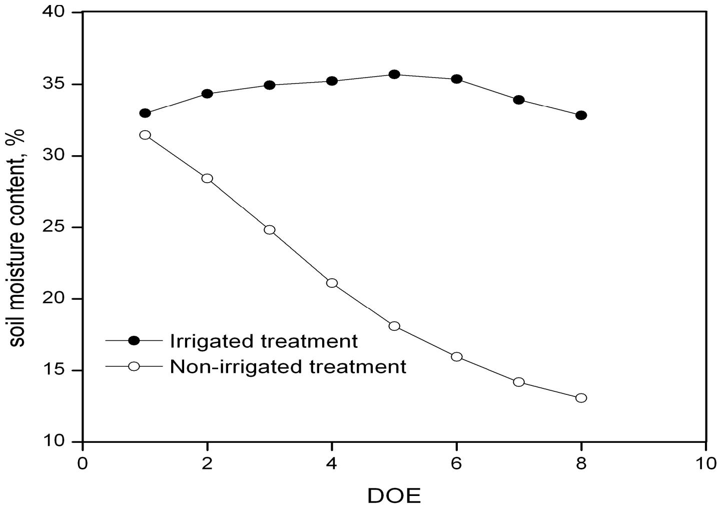

Figure 1 Volumetric soil moisture content (θ) trend during the experiment

The stomata conductance to water vapour of irrigated maize (Figure 2) remained around 80mmol/m^2/s whereas, it decreases gradually in the dry treatment and reaches to a value of 12 mmol/m^2/s. The decrease in stomata conductance is very well correlated with the increase in leaf temperature which results in water stress (Fuchs, 1990; Zia, et al., 2009). When a wind of speed (1.12m/s) was applied to the stressed maize canopy a cooling effect was observed (Figure 3). After 1 minute of wind application it was difficult to differentiate between irrigated and non-irrigated treatments. After 5min. the wind was stopped but the effect of wind was still visible. It was only after 2minutes that the plants regain their previous stress levels. The results are in accordance to the previous research (Spreer, et. al., 2009) where the effect of wind was investigated on longan and mongo trees.

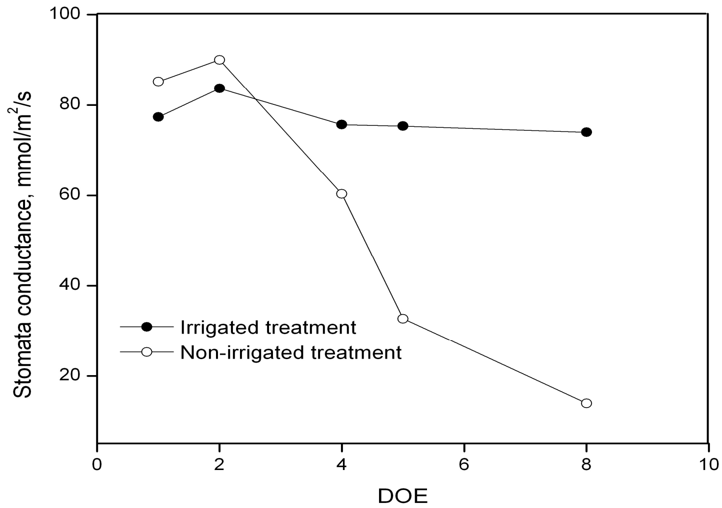

Figure 2: Stomata conductance to water vapour (gL) trend during the experiment

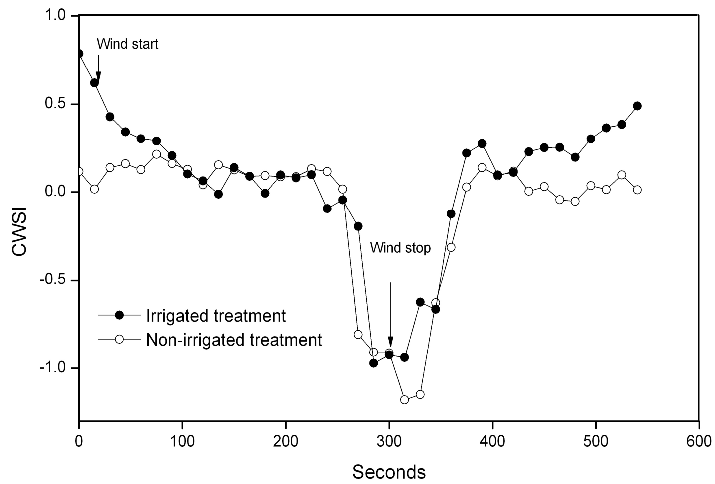

Figure 3: Crop water stress index of irrigated and non-irrigated treatments under the influence of wind.

The application of radiation to irrigated and non-irrigated maize plants (Figure 4) showed the similar results as that of wind. The cooling effect was more pronounced for the stressed (dry) treatment. However, in contract to the effect of windspeed marginal differences in CWSI between stressed and unstressed treatment still persisted. The temperature of the stressed treatment decreased to 3.5°C when the lamps were switched off. There is a high correlation between canopy temperature and the incoming solar radiation (Fuchs et al., 1990). In the present study a decrease and then the gradual increase of the canopy temperature when the lamps were switched on and off gave the sign of how important the timing of the picture acquisition is and the direction of the camera with respect to the sun.

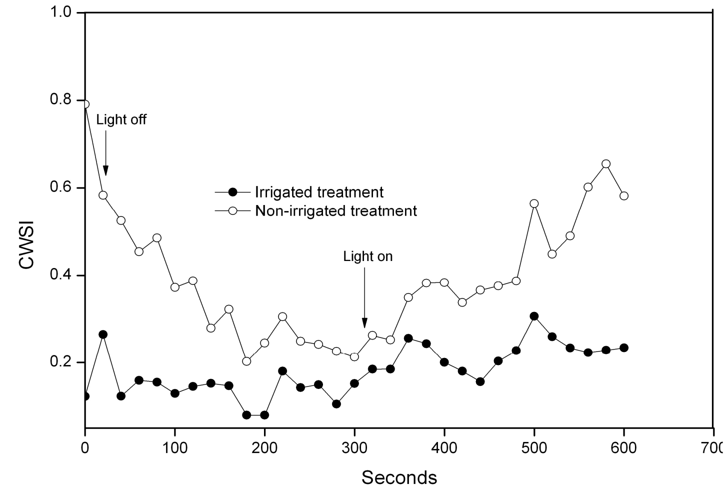

Figure 5 Crop water stress index (CWSI) of irrigated and non-irrigated treatment under the influence of radiation.

Conclusions

At low wind speed the CWSI is lower than the actual and results in the underestimation of water stress level which results in delay in irrigation, even while the crop experiences yield reducing levels of water stress. And the variation in the canopy temperature due to the changing solar radiation leads to the variations in the leaf temperature and results in over estimation of CWSI. Therefore, using CWSI for irrigation scheduling, the effect of windspeed and radiation must be taken into consideration for accurate estimation of the CWSI. In order to minimize the effect of radiation, all the measurements should be taken on a clear sunny day and from all the directions

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