A STEP TOWARDS PRECISION IRRIGATION: PLANT WATER STATUS DETECTION WITH INFRARED THERMOGRAPHY

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ABSTRACT

The increasing demand for water all over the world calls for precision irrigation in agriculture, because irrigation accounts globally about 70 percent of all water withdrawal. Plant water status detection for advanced irrigation scheduling is frequently done by predawn leaf water potential (Ψ_{PD}) or leaf stomata conductance (gL) measurements. However, these measurements are time and labour consuming. A non-invasive approach for water status detection is the use of infrared thermography (IRT). The experiment was conducted in a greenhouse on two potted maize genotypes having different drought susceptibilities. In order to define the suitability of IRT measurements in terms of water status detection at maize, the IRT-based crop water stress index (CWSI) was calculated and compared with simultaneously measured Ψ_{PD} and gL data. Good correlations between CWSI data and gL (r^2 =0.699 to 0.86) as well as CWSI and Ψ_{PD} (r^2 = 0.82 to 0.85) showed the potential of IRT for water status detection and improved irrigation scheduling.

Keywords: infrared thermography, leaf temperature, stomatal conductance, leaf water potential, plant water stress, maize.

INTRODUCTION

The increasing demand for water all over the world calls for precision irrigation in agriculture which accounts globally about 70 percent of all water withdrawal. Therefore, there is a need for optimizing water use efficiency. Maize, one of the most widely grown crops in the world, predominantly grows in arid and semi-arid regions. However, in semi-arid areas, maize is often subject to short term or/and long term water stress. Water stress at different stages of crop development has been reported to reduce the yield significantly (Farre and Faci, 2009). For example, a short extent of water stress at silking may reduce yield to more than 50% and in some cases even a total crop failure is possible (Cakir 2004; Birch et al., 2008).Hence, the overall challenge is to accurately detect plant water status and beginning plant water stress with a minimal workload both fast and with a high accuracy.

Irrigation scheduling based on methods like soil water content and evapotranspiration or by more advanced measurements like leaf stomata conductance to water vapour (gL) and leaf water potential (Ψ_{PD}), all these methods are labor intensive and time consuming. This holds especially true for gL, as leaf to leaf variations require much replications if reliable data is needed. In addition, none of the methods mentioned above are possible to be automated.

Canopy surface temperature measured with infrared thermography to determine the water stress detection 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 gL variation and dynamics and therefore can provide physiological status information for all crops within the field (or entire crop population). Primarily, leaf temperature is a function of transpiration and stomata opening (Fuchs 1990) but depends also on other environmental factors like air temperature, radiation, humidity and wind speed, which may lead to inaccuracies in thermography-based water status detection. Attempts were made to normalize the data by incorporating temperature differences between air and canopy (Jackson et al., 1977), or using both, natural and artificial wet and dry reference surfaces (Jones, 1999a, 1999b; Jones et al., 2002; Cohen et al., 2005, Grant et al., 2006, Möller et al., 2006).

The calculation of crop water stress index (CWSI) can be based on two baselines (Idso, 1982; Jackson et al., 1981). The lower limit (maximum leaf cooling through maximum transpiration) represents the non-water stressed baseline and the upper limit (maximum leaf temperature due to fully closed stomata) corresponds to the stressed baseline. The CWSI has been correlated with yield (Walker and Hatfield, 1983), leaf water potential (Howell et al., 1986, Jackson 1991), stomata conductance (Zia et. al 2008, Leinonen, et. al., 2006) and soil water availability (Hatfield, 1983).

Although, a greater emphasis is being made for the use of CWSI for irrigation scheduling of grapevine (Jones, 2002; Möller et al., 2006) and olives tree (Bengal, et. al., 2009), but not yet used for assessing crop water status of maize. The main objective of this study is to determine the IRT-based crop water stress index (CWSI) for two maize genotypes and to evaluate the relationships between CWSI, soil water content, leaf water potential and stomata conductance.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse of the University of Hohenheim (Germany) from December 16th until 31st, 2009 within a time period of 16 days (day of experiment, DOE 1-16). Two maize genotypes, Amadeo and Sileno, which differ in terms of drought susceptibility, were used for the experiment. Altogether 48 potted maize plants were investigated. Before the experiment was started, the soils of all pots were saturated. 24 Amadeo maize plants, potted in 12 pots (each pot two plants) and 24 Sileno maize plants potted in 12 pots (each pot two plants) were subsequently divided in four groups. Twelve pots (6 Amadeo and 6 Sileno) were allowed to dry out without irrigation in which soil water content data in three dry Amadeo and Sileno pots were measured simultaneously in a two hour interval with one two-rod TDR-probe (Trime-IT, Imko Germany) each. The remaining twelve pots (6 Amadeo and 6 Sileno) served as references and were placed in a steadily irrigated catchment tray to assure availability of sufficient water. And one two rod TDR-probe in one pot of the treatment (Amadeo wet and Sileno wet) measured the soil water content in a two hour interval. Finally, all twenty four maize pots were covered with a tinfoil to prevent soil evaporation and soil heating.

Thermal Imaging

Thermal images were taken from each of the four separated groups at the same time. The pictures were taken at between 10 a.m and 3:00 p.m. Infrared VarioCAM has been used to take the thermal and visible images simultaneously. The IR-lens of the camera displays the object scenery on a micro-bolometer array with a resolution of 384 × 288 pixels. Irbis-professional-3 software allowed correction for object emissivity, object distance, temperature and relative humidity. The distance between the camera and the plants was 3.7 m; the selected emissivity value was 0.95. A leaf sprayed with water was used as the wet reference (approximating maximum adiabatic cooling of the leaves) and another leaf coated with petroleum jelly was used as the dry reference (approximating maximum heating of the leaves due to completely closed stomata).

Crop water stress index (CWSI) was calculated with (Jones, 1999a):

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

Where T_{canopy} denotes the mean canopy temperature and T_{wet} and T_{dry} represent the temperatures of the water sprayed and petroleum jelly coated leaves, respectively.

Other measurements

Temperature and relative humidity data were logged in a five-minute interval (Hobo U12-011, Hobo USA). Predawn leaf water potential (Ψ_{PD}) was measured at one leaf per pot with a Scholander pressure chamber. Leaf stomata conductance (gL) measurements were conducted with a porometer (SC-1, Decagon devices USA). gL measurements were made simultaneously with the IRT shots at every pot on two preselected leaves. In addition, daily pan evaporation (E_{pd}) from an open water surface (pan diameter = 21 cm) was determined gravimetrically.

RESULTS AND DISCUSSION

During the experiment, the day temperature was around 25°C and the night temperature was around 17°C. According to the temperature and humidity trends, calculated averaged vapour pressure deficit (VPD) values were highest at the beginning and distinctly lower during the last three day of the experiment (Figure 1). Daily pan evaporation (E_{pd}) values are shown in Figure 2. At the start of the experiment the volumetric soil water content (θ) of the two maize genotypes i.e., Amadeo and Sileno ranged from 33 to 35%. At the end of the experiment, θ values of the non-irrigated (dry) treatments were between 15.4% (Amadeo) and 10.6% (Sileno). The averaged θ values are shown in Figure 3. It is to be noted that the Amadeo showed earlier sign of stress for example leaf rolling and therefore the measurements were stopped after 12days of experiment while Sileno measurements were continued six days more until water stress signs were visible.

Application of derived CWSI by thermography

The effective use of thermal sensing is to estimate plant temperature and to study plant water relations. The leaf temperature affected by other physiological processes is very rare (Jones and Schonfield, 2008) for example it can be due to increase in respiration rate but the heat generated is too small to have an effect on leaf temperature (Seymour, 1999).

Temperature fluctuations are reflected in the CWSI (Figure 4). Both, for Amadeo and Sileno maize genotypes distinct differences between irrigated and not irrigated plants could be observed. While CWSI of the irrigated plants were more or less constant and fluctuated around 0.6 (Amadeo) and 0.5 (Sileno) CWSI of the not irrigated plants increased. These increase were related to the decreasing soil water content (Figure 3) and reached values of 1.21 (Amadeo) and 1.15 (Sileno). Here it is striking that the smaller soil water content decreases at Sileno plants were reflected in smaller CWSI increases when compared with Amadeo plants.

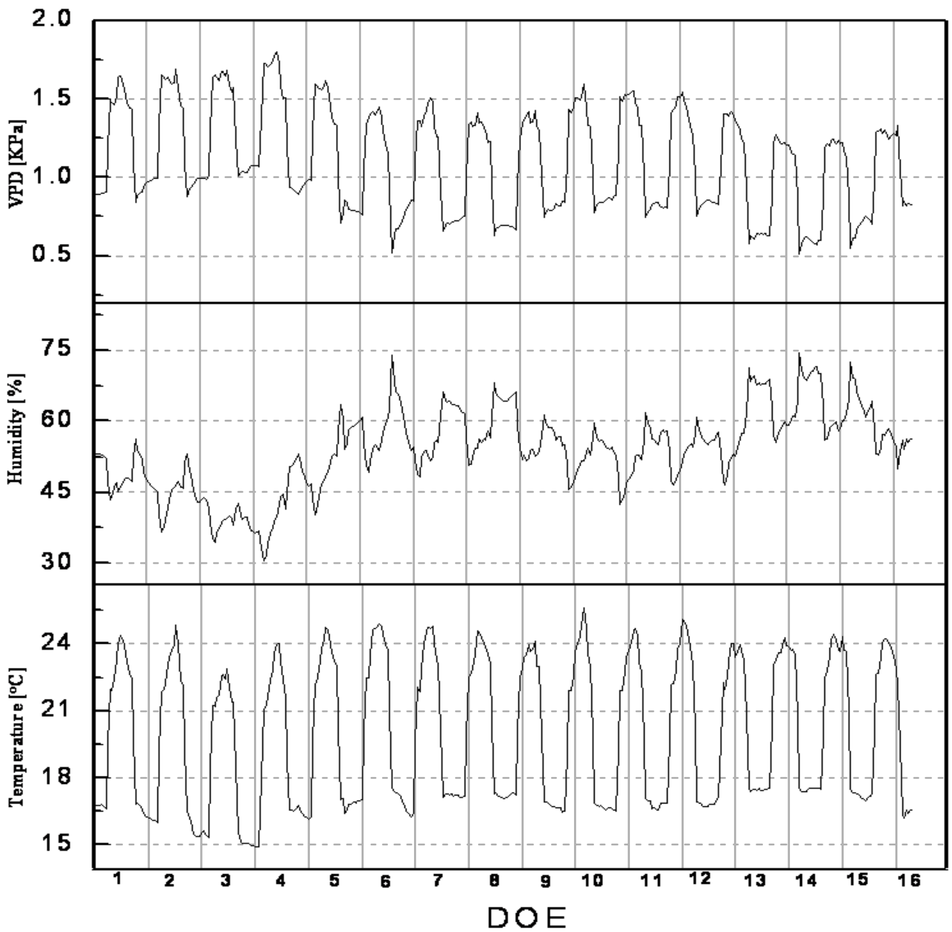

Figure 1. Daily course of temperature, humidity and vapour pressure deficit (VPD) during the days of experiment (DOE).

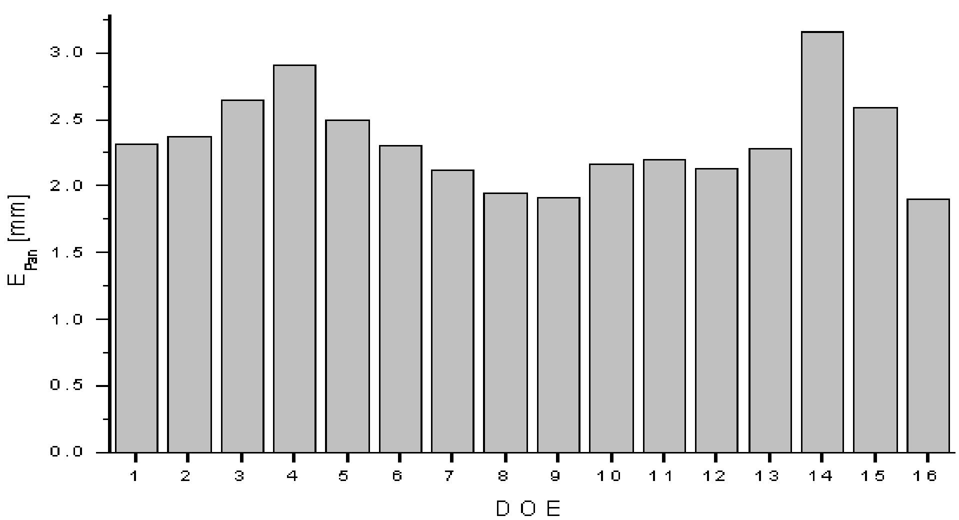

Figure 2. Daily pan evaporation (E_{pd}) during the days of experiment (DOE).

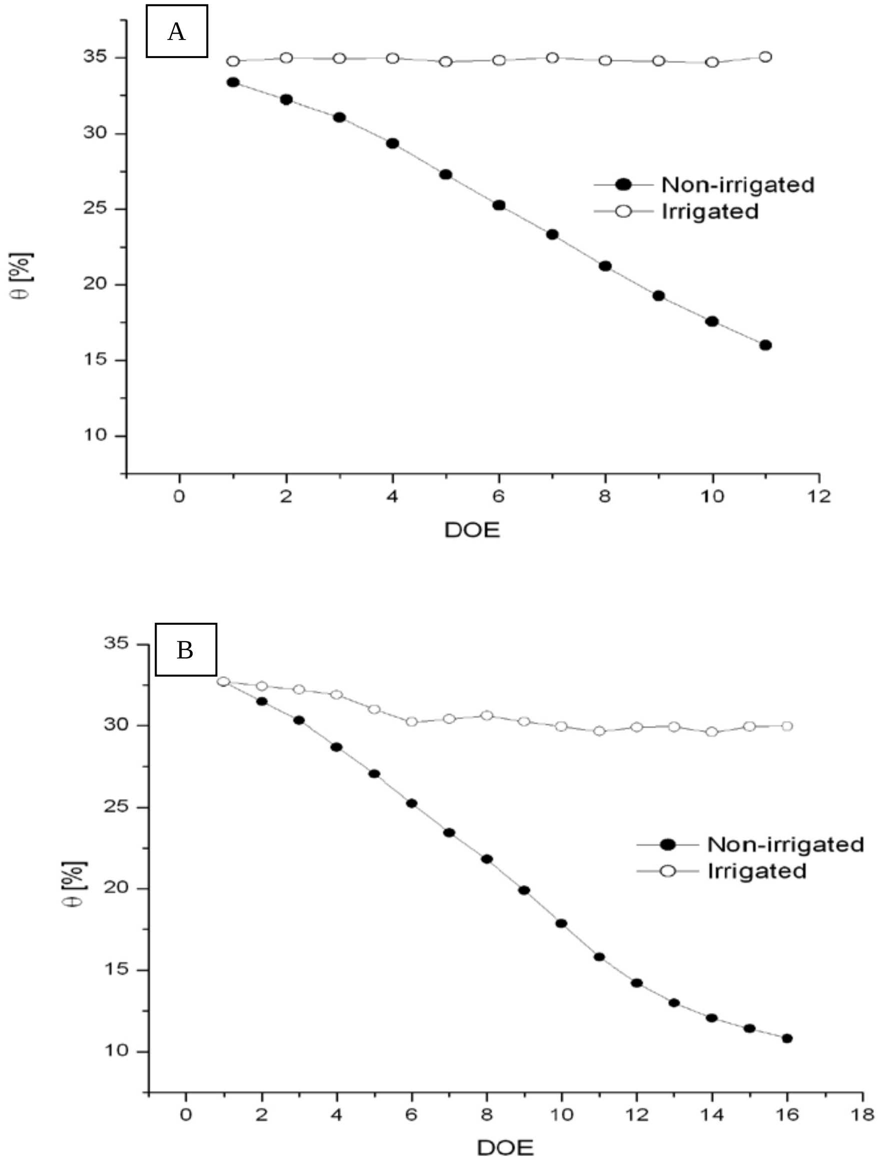

Figure 3. Average volumetric soil moisture content (θ) during the days of experiment (DOE). Figure A- Amadeo maize irrigated and non-irrigated and Figure B-Sileno maize irrigated and non-irrigated.

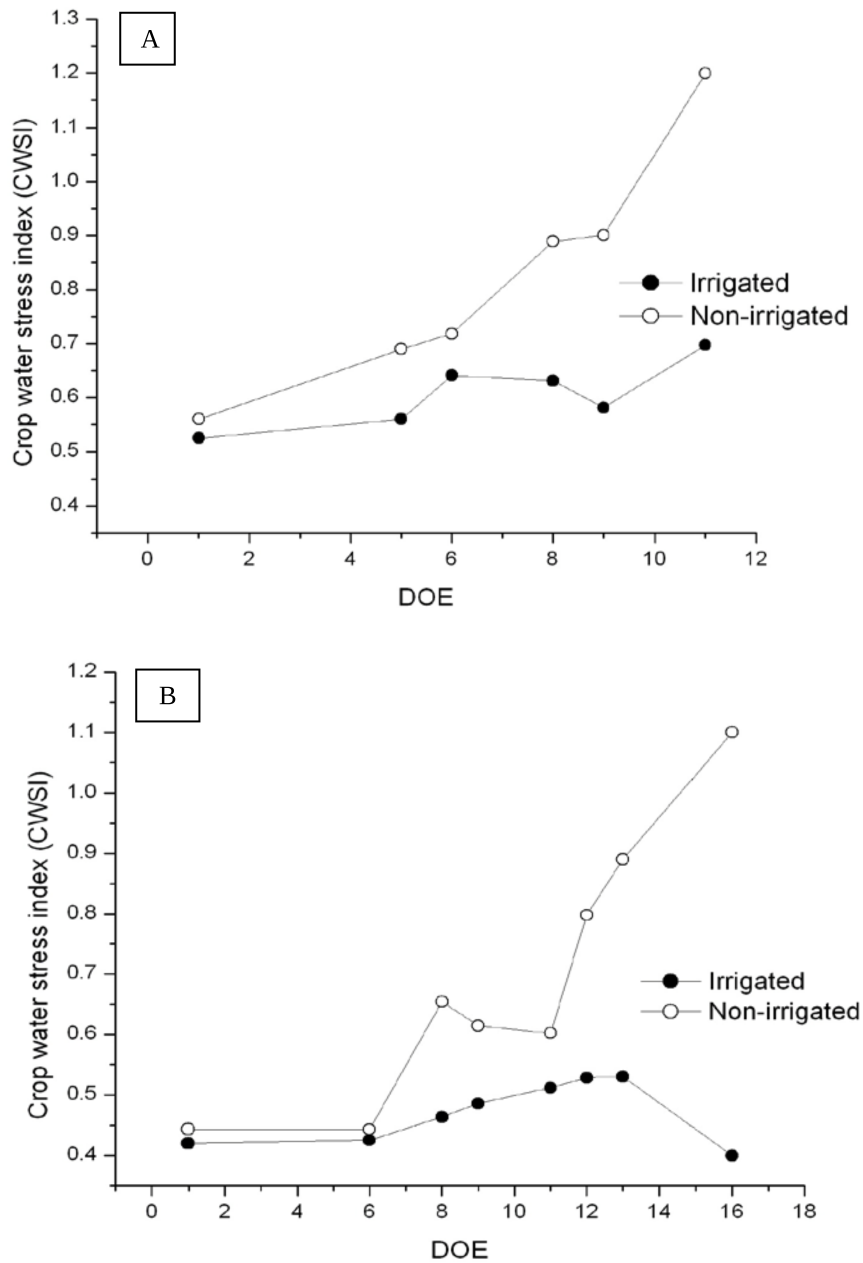

Figure 4. Crop water stress index (CWSI) during the days of experiment (DOE). Figure A- Amadeo maize irrigated and non-irrigated. Figure B- Sileno maize irrigated and non-irrigated.

Before using remotely sensed CWSI as a field management tool, it is important to verify its correlation with accepted and commonly used methods for estimating crop water stress. Data reported here show significant correlations of leaf water potential Ψ_{PD} and stomatal conductance versus CWSI indices (Fig. 5 and Fig. 6). The remote sensing-based technique i.e., thermography agreed well with the soil- and plant-based measures of water status, showing a clear response to varying irrigation levels. A high correlation (R^2 = 0.82 to 0.85) between Ψ_{PD} and CWSI (Fig. 7) and between gL and CWSI (R^2= 0.69 to 0.89) of both Amadeo and

Sileno (Fig.8) shows that CWSI is a promising technique in replacing the traditional and laborious methods for estimating water status and stress level in maize crop. The Ψ_{PD} of the wet treatments remain below 2 bar whereas for the dry treatments as the soil moisture decreases (Fig.5) its value increases and reached a value of 9 bar for Amadeo in 12 days while Sileno reached its highest value in 18 days.

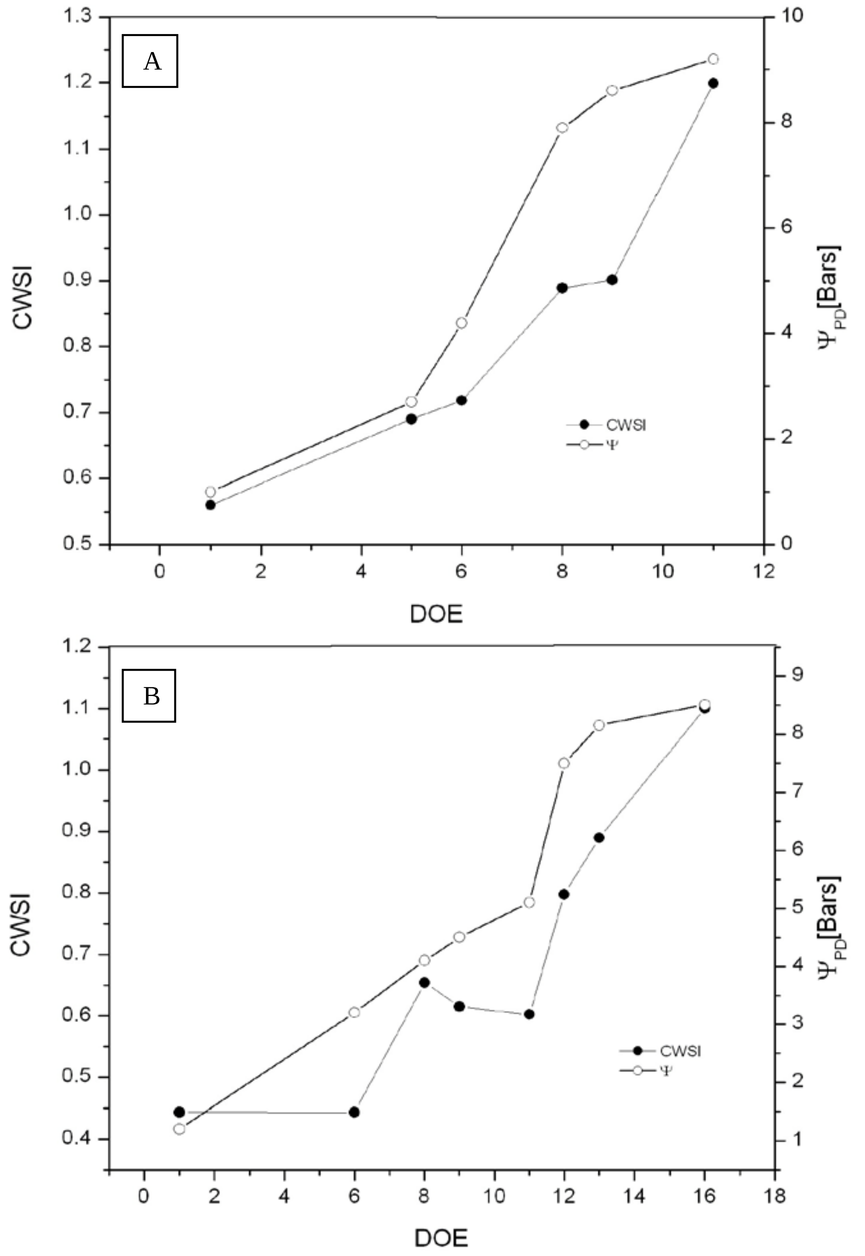

Figure 5. Leaf water potential (Ψ_{PD}) and crop water stress index (CWSI) during the days of experiment (DOE). Figure A- Amadeo maize irrigated and non-irrigated. Figure B- Sileno maize irrigated and non-irrigated.

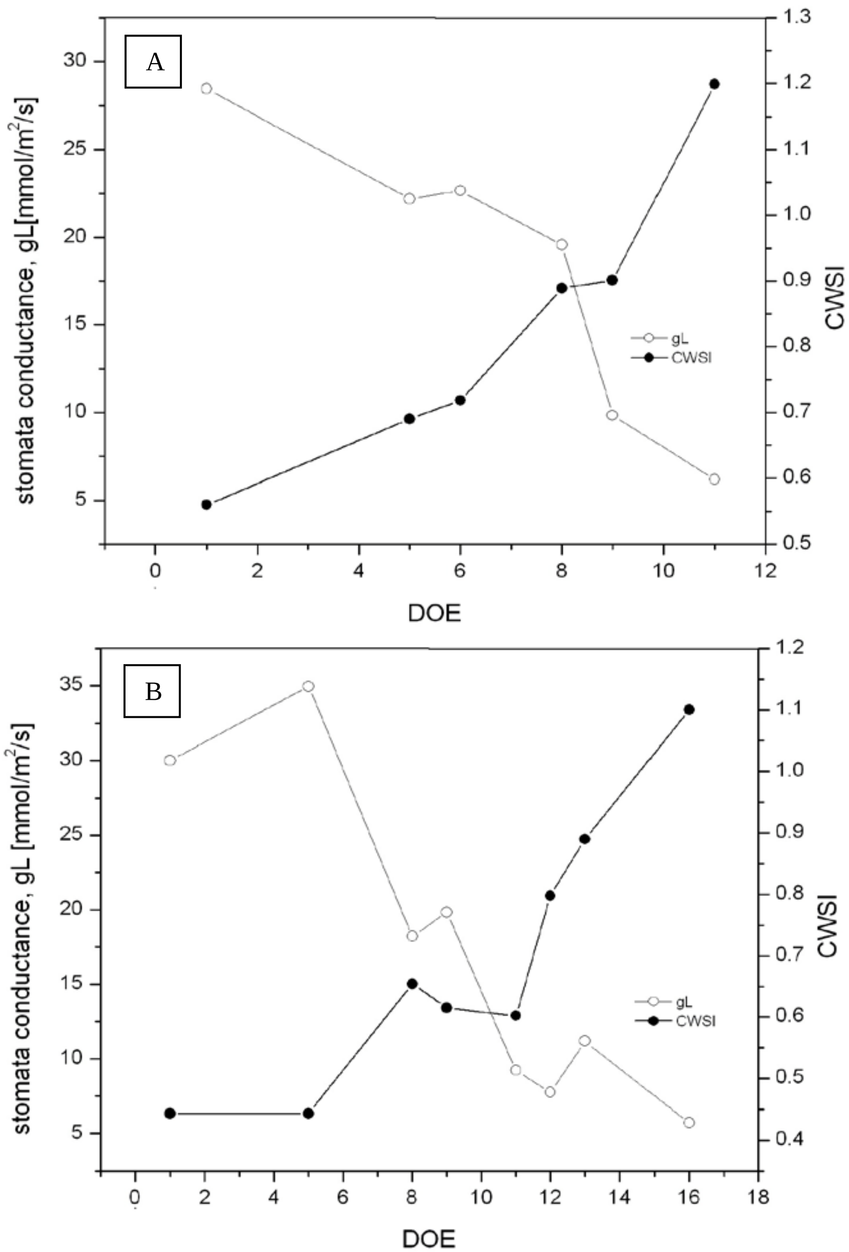

Figure 6. Stomata conductance to water vapour (g_L) and crop water stress index (CWSI) during the days of experiment. Figure A- Amadeo maize irrigated and non-irrigated. Figure B- Sileno maize irrigated and non-irrigated.

It is worth mentioning that decreased stomatal conductance (Fig. 6) in maize crop as a response to decreasing available water has previously been reported (Kunzhi Li, 2002) and the results presented here agree well with those studies. The use of thermal camera as an indicator of plant water status, which has not previously been tested for maize, showed a similar response to the irrigation treatments. The sharp decline in leaf water status and stomata conductance to water vapour indicates the necessity for water status monitoring for precise irrigation scheduling to prevent damage.

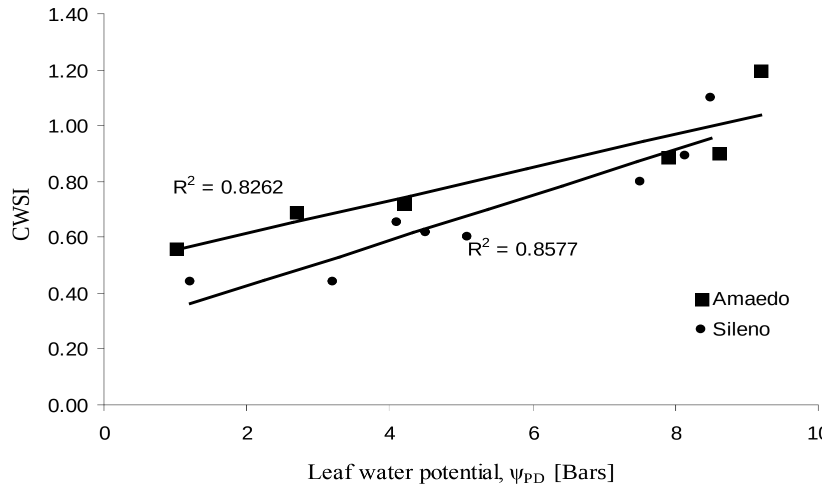

Figure 7. Regression analysis between stomata conductance to water vapour (g_L) and crop water stress index (CWSI) of Amadeo and Sileno maize genotypes.

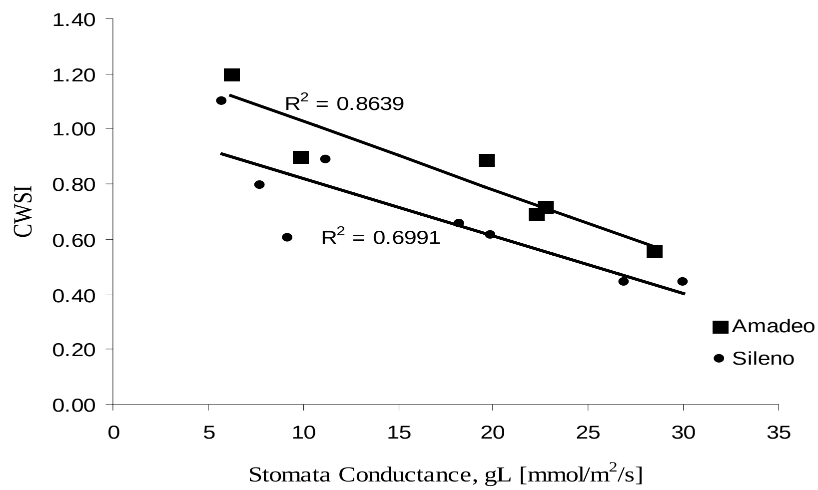

Figure 8. Regression analysis of stomata conductance to water vapour (g_L) and crop water stress index (CWSI) of Amadeo and Sileno maize genotypes.

It has been suggested to use the variation in temperatures within the canopy (Fuchs, 1990; Jones 2005) to determine water stress but no evidence was found in our result to support this hypothesis as there was no large variation within the canopy to distinguish between stressed and non-stressed plants, which is in accordance with findings of (Grant *et al.*, 2006).

CONCLUSIONS

In conclusion, it is evident from the data presented that infrared thermography can be a useful method in irrigation scheduling for maize. One of its major advantages when compared with predawn leaf water potential is the possibility to study large areas of canopy. Thermal imaging has the potential to substitute direct leaf measurements and to provide a more robust signal of the crop water status. It has been demonstrated that thermal images can be used as an alternative to direct gL and Ψ_{PD} measurements. In addition, it can also be used to distinguish between genotypes with different drought susceptibility. Further research should include field experiments under different climatic conditions as well as other genotypes.

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