Visual monitoring of water deficit stress using infrared thermography in wheat

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SUMMARY

Infrared thermography was used to monitor changes in the leaf temperature of wheat plants grown under increasing soil water deficit in controlled conditions, and to examine the effect of soil water stress on canopy temperature under changing solar radiation in field conditions. Canopy temperatures of 11 wheat genotypes were also compared under moderate water stress in the field. Leaf temperature of flag leaves responded rapidly to the daily change in soil water content. Water deficit stress in the field generated large differences in canopy temperature, sufficient to instantly indicate the stress. There was a slight difference in canopy temperature among the 11 wheat genotypes. The results suggested that leaf or canopy temperature was a reliable indicator of thermal changes in wheat foliage under water deficit. Thus, infrared thermography can be used as a visual tool to instantly monitor leaf or canopy temperature under increasing soil water deficit in the field. Screening for drought tolerance using canopy temperature is discussed in relation to changing soil water stress.

Key words: wheat, leaf temperature, canopy temperature, infrared, thermography, water stress, transpiration, soil moisture, drought tolerance.

INTRODUCTION

Low rainfall in the latter half of plant growth is a characteristic feature of sporadic drought in wheat-producing areas of Central/West Asia and North Africa. Genetic improvement of drought tolerance has been enhanced by using synthetic bread wheat resources with alien genes from wild relatives (Del Blanco *et al*. 2001, Dreccer *et al*. 2007, Inagaki *et al*. 2007). Drought stress is caused mainly by increased soil water deficit during plant growth, and breeding methodologies for improving drought tolerance require the means to instantly monitor increasing water stress.

Available soil water is taken up by roots and transported to the leaves for transpiration during photosynthesis. Under soil water deficit conditions, however, water uptake is depressed and results in less leaf transpiration due to stomatal closure. Leaf temperature is closely related to transpirational cooling of the leaves. Leaf transpiration is also a physiological function that fluctuates significantly during grain filling after heading. Some physiological parameters, such as stomatal conductance and chlorophyll content, require laborious procedures for measuring leaf transpiration. However, water stress on plant growth can be monitored by leaf or canopy temperature using infrared thermometry that detects thermal radiation emitted from individual leaves. A crop water stress index estimated from canopy temperature has been developed for irrigation practices (Jackson *et al*. 1981, O'Toole *et al*. 1984). The advanced technology of infrared thermography gives visual information on a huge number of individual temperatures obtained simultaneously in a one-shot image. The temperature frequencies in thermal images of plant foliage have recently been used for instant, accurate, non-destructive, and remote monitoring of stomatal conductance (Jones *et al*. 2002).

This study aims to visually monitor the change in leaf or canopy temperature of wheat plants grown under changing soil water deficits and solar radiation using infrared thermography.

EFFECT OF INCREASING WATER STRESS ON LEAF TEMPERATURE

Two synthetic hexaploid wheat genotypes, SYN-10 and SYN-15, derived from a cross of Cham 6 ///Haurani /*Aegilops tauschii* ig47259 //Cham 6, along with the parental variety Cham 6 were used as plant materials. Cham 6 is an improved variety of bread wheat (*Triticum aestivum* L.) and Haurani is a landrace of durum wheat (*T. turgidum* L. spp. durum). SYN-10 and SYN-15 are tolerant and susceptible to soil water deficit, respectively, compared to Cham 6 (Inagaki *et al*. 2007). Two replications of five plants of each genotype were grown in potted soil (1100 g dry weight per pot) in a growth chamber with 20/10°C day/night, 10-h day-length and 185 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light intensity. Potted soil consisted of field-soil:sand:peat-moss (8:4:3 in volume proportions), with a permanent wilting point of 14.6% by weight. Irrigation was performed every five days to hold soil water content at 34.0% by weight. When plants reached the booting stage of growth, thermal images of whole plants were taken using a camera (Nippon Avionics, TVS-200) with a non-cooling bolometer of 0.08°C sensitivity, 1.0 emissivity and 320 x 240 pixels per frame. Leaf temperatures were collected daily from ten individual pixels each in the flag, middle, and lower leaves of plants. At the same time, the soil water contents were obtained by weighing.

Leaf temperature and soil water content were taken of genotype SYN-10 grown in potted soil (Fig. 1). Soil water content decreased from 20.2% to 12.9% by evapotranspiration and then increased to 31.4% with irrigation. There were distinct differences in leaf temperature depending on leaf position. Leaf temperature of flag leaves varied the most at 21.0–24.7°C, responding rapidly to decreased soil water content. SYN-10 had slightly higher leaf temperature than SYN-15, suggesting less transpiration (Fig. 2).

These relationships indicate that leaf temperature is a reliable indicator of increasing water stress in wheat foliage.

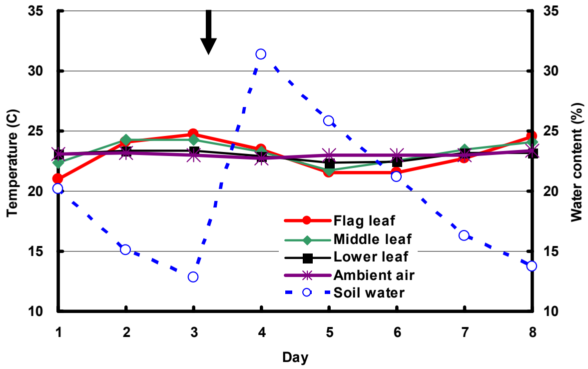

Figure 1. Changes of leaf temperature and soil water content in synthetic bread wheat genotype SYN-10 grown in potted soil. The arrow indicates irrigation time. LSD ($P < 0.05$) = 0.35°C for leaf temperature.

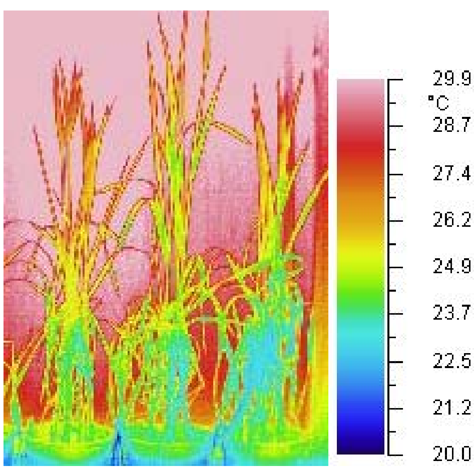

Figure 2. Infrared thermograph of two synthetic bread wheat genotypes, SYN-10 and SYN-15, and parental variety Cham 6 (from left to right) grown under water stressed conditions. Photo was taken at day 3.

EFFECT OF WATER STRESS ON CANOPY TEMPERATURE IN THE FIELD

A durum wheat variety Cham 1 was grown in field plots of 4 m^2 each, replicated four times, under two treatments of rain-fed and irrigated conditions, using standard crop management for yield trials at Tel Hadya station of the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, during the 2006/07 cropping season. Total water supply from planting to heading stage was 207 mm for rain-fed and 407 mm for irrigated plots. The permanent wilting point of soil was 24.8% by weight (Ryan *et al*. 1997). The thermal camera was held at a height of 4 m to view the entire wheat canopy of all field plots at once, and the thermal images taken every hour from 7:00 to 17:00 h at heading stage. Canopy temperature was expressed as a mean of approximately 2,000 pixels covering each wheat plot. After taking thermal images, ambient air temperature was recorded, and soil water contents by weight were obtained from auger samples of 105 cm depth. Photosynthetically active radiation (PAR) in the field was recorded at the ICARDA meteorological station.

Canopy temperatures of durum wheat variety Cham 1 in the rain-fed and irrigated plots are shown in Figures 3 and 4, along with ambient air temperature and PAR, at heading stage. At heading under completely sunny conditions, as PAR increased the difference in canopy temperature between rain-fed and irrigated plots increased to a maximum of 7.2°C at 12:00 h. Soil water contents of rain-fed and irrigated plots were 17.6% and 30.3%, respectively. Mean final grain yields in rain-fed and irrigated plots were 229 and 547 $g{\cdot}m^{-2}$, respectively. The results of the two experiments confirmed that leaf or canopy temperature increased correspondingly with soil water deficit in both the growth chamber and field plots. Leaf or canopy temperature increase was a physiological indicator detecting plant response to water stress.

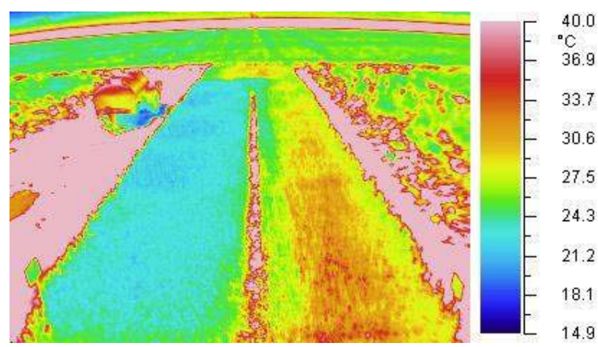

Figure 3. Infrared thermograph of durum wheat Cham 1 plots under irrigated (left) and rain-fed (right) conditions. Photo was taken at 12:00 h.

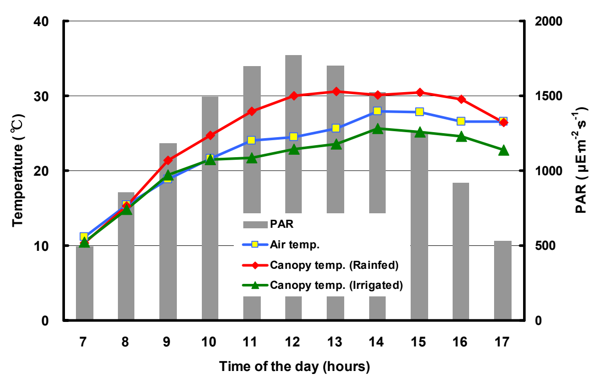

Figure 4. Canopy temperatures of durum wheat Cham 1 at the heading stage grown under rain-fed and irrigated conditions along with PAR. LSD ($P < 0.05$) = 0.49°C.

VARIATION IN CANOPY TEMPERATURE AMONG 11 WHEAT VARIETIES UNDER WATER DEFICIT STRESS

Eleven wheat genotypes (five durum wheat and six bread wheat varieties) from West Asia and North Africa were grown in 10 m^2 field plots, three replications each, at Tel Hadya during the 2006/07 cropping season. Durum wheat genotypes: Cham 1, Cham 3, Cham 5, Gidara 2, and Ammar 3. Bread wheat genotypes: Cham 4, Cham 6, Cham 8, Cham 10, Hamam 4, and Babaga 3. Irrigation was planned to supply an evapotranspiration estimate of 420 mm in this region (Zhang *et al*. 1998) during the period from germination to heading. Canopy temperature was obtained from thermal images containing ten plots each taken at 12:00 h at heading stage.

The total water supply with supplemental irrigation for the whole growing season was 456 mm, including unexpected rainfall of 52 mm at the grain filling stage. Mean soil water content over all soil layers decreased gradually from 31% at tillering to 22% at heading and 18% at the maturity stage. The reduction of available soil water during these critical growth stages suggested that wheat plants grew under moderate soil water deficit before and after heading. There was a slight difference of 1.2°C with a range of 23.6–24.8°C, LSD ($P < 0.05$) = 0.55°C, in canopy temperature among the 11 wheat genotypes.

USE OF INFRARED THERMOGRAPHY UNDER INCREASING WATER STRESS CONDITIONS

Infrared thermography can give frequency distributions of leaf temperature over the target area. A one-shot thermograph has more than 70,000 pixels, each pixel with visual temperature information of sensitivity < 0.1°C. The canopy temperature difference of approximately 7°C in this study is large enough to visually detect transpiration changes in foliage and instantly monitor the soil water stress during plant growth. Thus, infrared thermography has great potential as a tool to instantly monitor water stress in fields.

For genetic improvement of drought tolerance in wheat, canopy temperature has been expected to be a useful physiological parameter to screen genotypes for tolerance to water stress and for yield potential, but it is strongly influenced by environmental conditions (Blum *et al*. 1989, Rashid *et al*. 1999, Richards *et al*. 2002). Canopy temperature is also phenotypically and genetically associated with grain yield under drought stress (Olivares-Villegas *et al*. 2007, Reynolds *et al*. 2007), with lower canopy temperature expected to indicate higher grain yield under a given water stress. However, water stress frequently fluctuates with genotypic variation of root water uptake. The ability to take up water from the soil under increasing water deficit may also be a critical factor for remobilizing assimilates to the grain in the latter half of plant growth. The use of canopy temperature for screening requires uniform water stress conditions because canopy temperature responds directly to fluctuating water stress. In addition, the genotypic differences in canopy temperature under moderate water deficits in this study were not large enough to distinguish responses to water stress. A significant correlation of canopy temperature with grain yield may appear under severe water stress and requires further experiments on root water uptake. Successful application of infrared thermography for screening requires a technical arrangement for measuring canopy temperature that excludes the background effect of the soil surface from thermal images of sparse plants growing under severe water stress.

REFERENCES

Blum, A., Shpiler, L., Golan, G., Mayer, J. 1989. Yield stability and canopy temperature of wheat genotypes under drought-stress. Field Crops Res. 22: 289–296.

Del Blanco, I. A., Rajaram, S., Kronstad, W. E. 2001. Agronomic potentials of synthetic hexaploid wheat-derived populations. Crop Sci. 41: 670–676.

Dreccer, M. F., Borgognone, M. G., Ogbonnaya, F. C., Trethowan, R. M., Winter, B. 2007. CIMMYT-selected derived synthetic bread wheat for rainfed environments: yield evaluation in Mexico. Field Crops Res. 100: 218–228.

Inagaki, M. N., Valkoun, J., Nachit, M. M. 2007. Effect of soil water deficit on grain yield in synthetic bread wheat derivatives. Cereal Res. Commun. 35: 1603–1608.

Jackson, R. D., Idso, S. B., Reginato, R. J., Pinter, Jr, P. J. 1981. Canopy temperature as a crop water stress indicator. Water Resour. Res. 17: 1133–1138.

Jones, H. G., Stoll, M., Santos, T., De Sausa, C., Chaves, M. M., Grant, O. M. 2002. Use of infrared thermography for monitoring stomatal closure in the field: application to grapevine. J. Exp. Bot. 53: 2249–2260.

Olivares-Villegas, J. J., Reynolds, M. P., McDonald, G. K. 2007. Drought-adaptive attributes in the Seri/Babax hexaploid wheat population. Funct. Plant Biol. 34: 189–203.

O'Toole, J. C., Turner, N. C., Namuco, O. P., Dingkuhn, M., Gomez, K. A. 1984. Comparison of some crop water stress measurement methods. Crop Sci. 24: 1121–1128.

Rashid, A., Stark, J. C., Tanveer, A., Mustafa, T. 1999. Use of canopy temperature measurements as a screening tool for drought tolerance in spring wheat. J. Agron. Crop Sci. 182: 231–237.

Reynolds, M., Dreccer, F., Trethowan, R. 2007. Drought-adaptive traits derived from wheat wild relatives and landraces. J. Exp. Bot. 58: 177–186.

Richards, R. A., Rebetzke, G. J., Condon, A. G., van Herwaadenet, A. F. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci. 42: 111–121.

Ryan, J., Masri, S., Garabet, S., Diekmann, J., Habib, H. 1997. Soils of ICARDA's agricultural experimental stations and sites: Climate, classification, physiological and chemical properties, and land use. ICARDA, Aleppo, p107.

Zhang, H., Oweis, T., Garabet, S., Pala, M. 1998. Water-use efficiency and transpiration efficiency of wheat under rain-fed conditions and supplemental irrigation in a Mediterranean-type environment. Plant Soil 201: 295–305.