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Canopy Temperature: A Potential Technique for Evaluating Genetic Response to Drought in Crop Plants

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Abstract

Remote sensing of crop water stress using infrared radiation thermometers is one of the several important remote sensing applications. Remotely-sensed infrared canopy temperatures provide an efficient method for rapid, nondestructive monitoring of whole plant response to water stress. A logical extension of this technology is the use of canopy temperatures in screening crop genotypes for drought resistance. The potential of using canopy temperatures in evaluating the genotypic response to drought is reviewed in this paper.

Key words: Remote sensing, infrared radiometry; Water stress, Canopy temperature, Drought, Genotypes.

Introduction

Plant temperature has been recognized as an indicator of plant-water availability (Gates, 1964; Wiegand and Namken, 1966; Ehrler *et al.*, 1978; Blum *et al.*, 1982). Tanner (1963) stated that plant temperature may be a valuable qualitative index to differences in plant water availability. Early work reported by Idso *et al.* (1977) and Jackson *et al.* (1977) established a method for quantification of stress based on canopy and air temperature measurements. Jackson (1982) also developed a crop water stress index (CWSI) based on the equations of Monteith and Szeicz (1962), which provides a rational basis for relating crop water stress and canopy temperature.

Use of canopy temperature to detect water stress in plants is based upon the close, inverse relationship between canopy temperature and transpiration cooling (Jackson, 1982). Transpired water evaporates and cools the leaves below the temperature of the surrounding air or at least below the temperature they would have without evaporation. Campbell and Norman (1990) stated that as water stress increases the iesistance for vapor transport incident energy will be partitioned increasingly toward sensible heat. Canopy temperature must then rise in order to dissipate the additional heat. Sensible heat transport between the canopy and the air above it is proportional to the difference between canopy and air temperatures. Therefore, the estimation of these temperature differences may provide a basis for detecting and quantifying crop water stress.

Canopy temperature and screening for drought tolerance: The concept of using canopy temperatures measured with an infrared thermometer to infer transpirational rates and moisture stress in plants was advanced by Tanner (1963) and has received some interest as a drought tolerance screening technique, particularly with the advent of portable infrared thermometers (IRT). The infrared technology has progressed to the point that light weight (about 1 kg), handheld Infrared thermometers, accurate to the ± 0.5 °C, are available for use (Jackson *et al.*, 1981). Moreover, IRTs can be equipped with dedicated microprocessors that translate canopy temperatures and ambient weather conditions directly into relative indices of plant water stress. A logical extension of this technology is the use of canopy temperatures for screening crop genotypes for drought resistance (Sojka, 1985).

Remotely-sensed infrared canopy temperatures provide an efficient method for rapid, non-destructive monitoring of whole plant response to water stress (Idso et al., 1981; Jackson et al., 1981). There are several schools of thought regarding how canopy temperature measurements might best be used in the selection process. The first suggests that temperatures should be measured under low soil moisture conditions, reasoning that plants with the cooler canopy temperatures are transpiring at higher rates and likewise are capable of relatively high photosynthetic rates, growth and yields. Passioura (1982) called this the "prodigal" (wasteful expenditure) strategy of plants. Mtui et al. (1981) found that certain maize (Zea mays L.) hybrids were cooler and used more water in transpiration, but had higher yield and water use efficiencies than their inbred parent lines. Gardner et al. (1986) reported that reduction of yield in maize under water-stressed conditions was less for hybrids which maintained slightly cooler temperature under stress. Plant water potential data published by Sojka et al. (1981) also imply a prodigal response for several of the wheat cultivars.

The second school of thought is that genotypes with warmer canopy temperatures under well-watered conditions would have greater drought resistance, reasoning that plants with higher canopy temperatures transpire less, thus saving soil water for growth and reproductive efforts later in the season. This is what Passioura (1982) called the "conservative" strategy of plants.

The use of canopy temperature responses of plants from

well-watered or water-stressed plots depends upon the predominant pattern of precipitation in an area, the crop species involved and its sensitivity to moisture stress at different stages of growth., There are, however, several limitations in using canopy temperatures from droughtstressed environments. As soil water deficits increase, variability in soil texture and water holding capacity become an increasingly important' source of variation that may mask genotypic differences. A second major limitation is that remote canopy temperature measurements require a dense canopy which covers the soil surface (Blum et al., 1982; Clarke and McCaig, 1982) to avoid errors resulting from viewing exposed soil surfaces. Indeed, under extreme drought conditions, complete canopy closure may never be achieved. Furthermore, establishment of a parallel set of non-irrigated plots or the use of rain shelters increase management costs for drought screening. On the other hand, canopy temperature measurements from well-watered plots should have significant variation among genotypes tested and also have relationship with yield under water stress conditions. A study by Blum et al. (1982) found canopy temperature differences of various wheat and triticales strains were minimal when plants had a favorable moisture status but showed significance differences as water stress increased.

Some investigators have used canopy temperatures from drought-stressed plots to assess genotypic. response to drought. Blum et al. (1989) used canopy temperatures of drought-stressed wheat genotypes to characterize yield stability under various moisture conditions. A positive correlation (r = 0.72; $p \le 0.01$) was found across wheat genotypes between drought susceptibility index and canopy temperatures, indicating that drought susceptible genotypes which suffered greater yield loss under stress also tended to be under greater water-stress and had warmer canopies at midday. Chaudhuri and Kanemasu (1982) found that canopy temperature of the water-stressed sorghum was generally 3.2-3.7°C warmer than canopy temperatures of wellwatered plants. The yields of sorghum (Sorghum bicolor L.) hybrids were negatively correlated with the seasonal average canopy temperature (r = 0.92; p<0.05) and canopy-air temperature differences (r = 0.94; p<0.05). Genotypic variation in leaf temperature has also been observed in soybean (Glycine max L. Merr.) grown in stressed environments (Harris et al., 1964). Similar results have also been reported for potatoes (Stark and Pavek, 1987).

Results from several recent studies show that canopy temperatures under well-watered conditions do provide an indication of potential yield performance during drought and could effectively be used as a technique to assess genotypic response to drought. Singh and Kanemasu (1983) found negative and significant correlation (r = -0.81; $p \le 0.05$) between grain yield and average afternoon canopy temperatures measured in pearl millet genotypes under irrigated conditions. The correlation between yield and average afternoon canopy temperatures measured under non-irrigated conditions was also negative but weak (r -0.27; $p \le 0.05$). They classified pearl millet

(*Pennisetum americanum* L.) genotypes with relatively warmer and cooler canopy temperatures measured under irrigated conditions. Genotypes with warmer canopy temperatures under irrigated conditions, when grown under non-irrigated conditions, had significantly higher yield than genotypes with cooler temperature under non-irrigated conditions.

Hatfield et al. (1987) demonstrated that cotton (Gossypium hirsutum L.) strains that were relatively warm under irrigated conditions also produced more biomass under dryland conditions. Chaudhuri et al. (1986) found that warmer sorghum and pearl millet genotypes were generally more productive than cooler genotypes, under drought stressed conditions. In another study Stark et al. (1991) reported that warmer potato (Solarium tuberosum L.) genotypes under well-watered conditions were also generally less susceptible to drought than cooler genotypes. Pinter et al. (1990) compared midday canopy temperatures of well-watered wheat genotypes with relative grain Yields under drought stress. Cultivars that were warmest when well-watered conditions maintained the highest relative yield when exposed to deficit irrigation regimes (r = 0.78; p<0.05). Zipoli et al. (1987) reported that wheat cultivars which had the warmest midday canopy temperatures under well-watered conditions used the least amount of water (r = 0.95; p < 0.01 for water use and average canopy minus air temperature under well-watered conditions) during the season and had the highest relative yields when water was limited. A positive and significant correlation (r = 0.80; p<0.01) was also observed between relative yields under water stress and average canopy minus air temperature under well watered conditions.

In addition to comparing drought susceptibility directly with canopy temperatures, others have used the relationship between canopy-air temperature differences (ΔT) and air vapor pressure deficit (VPD) to evaluate drought response. Chaudhuri et al. (1986) for 219 sorghum genotypes developed relationships between VPD and ΔT measured from well-watered plots and then used these relationships to assess genotypic response to drought. They found that genotypes that were less sensitive to changes in VPD produced more grain under drought stress conditions. Stark et al. (1991) reported that the relationships between VPD sensitivity for 14 potato genotypes and DSI were not as high (r = 0.42; p<0.01) as those between mean ΔT and DSI (r = -0.78; p \leq 0.01). Therefore, more straightforward approach of measuring ΔT in well-watered plots appears to be a more effective means of assessing potato drought susceptibility than comparing ΔT vs. VPD relationships. They also found a positive correlation (r = 0.77; p<0.01) between 051 and mean ΔT measured in well-watered plots. Gardner et al. (1986) used the relationships between a temperature stress index (TSI) and relative grain yield for evaluating drought tolerance of corn hybrids. They defined TSI as the difference in midday canopy temperature between a specific location and the area producing maximum yields for each hybrid. They found positive correlations (r = 0.70; p<0.01) between non-stress canopy temperatures and grain yields of corn hybrids. They

also reported that cumulative TSI values could be used to estimate grain yield within ± 4 percent for specific hybrids. They considered this approach to be a potentially important tool for screening for drought response among corn hybrids. In summary, thermal infrared measurements of canopy temperature have been used to screen for drought tolerance in many crops. Two basic approaches for using canopy temperatures to select for drought resistance are: (1) To identify genotypes with relatively cooler temperatures under low soil moisture conditions or (2) To identify relatively warmer genotypes under well-watered conditions. Using canopy temperature measurements from well-watered conditions. Using canopy temperature measurements from well-watered environments to characterize genotypic response to drought, however, offers several logistic advantages over selection under low moisture conditions (Stark et al., 1991).

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