Seasonal near-continuous patterns of leaf-to-air vapor pressure deficits in differentially irrigated cotton: potential importance in assessing water demand.

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Abstract

The application of water to crops, in the needed amount, at the right moment in time, is important. The water status of the crop is often used to determine the need for irrigation. Since the water status of a crop can be difficult to measure directly it is often inferred from the environment. Measurement of the above ground environment can be automated and the data can used used in models to predict irrigation amount and timing. The vapor pressure deficit (VPD) of the air is a good indicator of the potential water need. VPD is calculated with the assumption that the temperature of the canopy is similar to air temperature. Canopy temperature of cotton was monitored across irrigation regimes and was used to calculate leaf-to-airVPD. Leaf-to-airVPD declined with increasing irrigation amounts. The value of leaf-to-airVPD in the prediction of potential ET for the crops was assessed.

Keywords

canopy temperature, water defcits, cotton, vapor pressure deficit VPD

Introduction.

The application of water to crops, in the appropriate amount, at the right moment in time, is the underlying principle of irrigation management. These decisions, correctly made, several times over a growing season, result in successful production of crop. Errors in irrigation can result in either unintended crop water stresses or inefficient use of water associated with under or over irrigation respectively. With agricultural water generally increasing in price and/or declining in availability, improvements in irrigation management are increasingly important.

The soil, as the source of water for transpiration, is generally viewed as a reservoir that serves to buffer the water use by the plant. Between a saturated condition and the point at which water can no longer be withdrawn by the plant, the uptake of water by roots is a continuously variable process that involves both physical and biological constraints.

Irrigation management is often achieved through an iterative process of adding water to the soil, assessing the amount water used by the plant between irrigation events, and applying an amount of water sufficient to meet the needs of the plant until the next irrigation event. The physics of soil water are well understood, though often difficult to characterize in practice. The use of water by the plant is less well defined and generally difficult to characterize.

The water status of the plant is often described in terms of a balance between soil water available to the plant and the amount needed by the plant. Evaporation of water from the interior of the leaf to the atmosphere (transpiration) accounts for the overwhelming fraction of the water required by the plant over its lifespan. This process of water movement from the soil to the atmosphere serves several purposes; uptake and transport of nutrients from the soil, hydration of cells and dissipation of potentially harmful radiant energy. The water status of the crop is often used to determine the need for irrigation. Since the water status of a crop can be difficult to measure directly it is often inferred from the environment. Since the measurement of the above ground environment can be automated, such data is used in models to predict irrigation amount and timing.

The driving force for movement of water through the plant from the roots to the atmosphere is the evaporation of water at the leaf-to-air interface that results in the net movement of water from the plant to the atmosphere i.e water use. In order for water to evaporate from the leaf-to-air interface there are 2 conditions that must be met; 1) there must energy sufficient to convert the water from liquid to vapor and 2) a gradient in water vapor across the leaf-to-air boundary. The sun provides radiant energy sufficient to accomplish the vaporization and the inherent dryness of the atmosphere results in the needed gradient.

Given that the air inside the leaf is normally saturated with water vapor and that the atmosphere is seldom, if ever, saturated there is generally a water vapor gradient sufficient for evaporation. The magnitude of the gradient for leaf-to-air movement of water vapor is generally expressed in terms of the vapor pressure deficit of the atmosphere that is commonly abbreviated as VPD. The VPD of atmospheric water vapor, at any moment of time, is calculated as the difference between the vapor pressure of the air at saturation and the measured vapor pressure of the air. The saturation vapor pressure is a chemical parameter that is primarily a function of temperature and atmospheric pressure, both relatively simple to measure. The actual vapor pressure is a function of temperature and measured humidity. It can be derived from measured dewpoint temperature, wet bulb temperature measured with a psychrometer, or most commonly from relative humidity and air temperature.

The vapor pressure deficit (VPD) of the air (airVPD) is a measured environmental parameter that is generally used as an indicator of the evaporative "demand" of the atmosphere for water. Given sufficient available soil moisture, it is expected that the evaporative demand is an indicator of water use and, as such, provides information on transpirational water use by the plant. The temperature of the air at the time of measurement is used to calculate both the saturation vapor pressure of the air and the actual vapor pressure of the air. The saturation vapor pressure, when based on air temperature, does not explicitly define the gradient between the interior of the leaf and the air when the temperature of the air is not equal to the temperature of the leaf. In an effort to quantify the extent of this possible difference, a measure of the plant temperature is needed. Canopy temperature measurements provide a means to accomplish this.

In this study we have used a dataset consisting of near-continuous canopy temperature in cotton over a 65-day period to investigate the potential value of leaf-to-air canopy temperatures in the quantification of water use by cotton. Recent advances have made the continuous measurement of canopy temperature in the field somewhat simpler we believe there may be some value in the use of leaf-to-air VPD in the assessment of plant/environment interactions.

Materials and Methods

Cotton (Fibermax 9180) was planted on May 14th, 2009 and was grown under 4 irrigation regimes which applied 0mm, 1.5mm, 3.0mm or 6mm of irrigation on a daily basis using a sub-surface drip irrigation system. Cultural practices were typical for the region.

Canopy temperature measurement

Canopy temperature of cotton was monitored across irrigation regimes using a Smartcrop IRT system. Canopy temperature was measured on 1-minute intervals and reported as 15-minute averages over a 65-day period in 2009 in Lubbock TX. Temperature was collected from a single IIRT sensor in each plot.

VPD calculations

Relative humidity and air temperature were monitored on a 1-minute interval with 15-minute averages reported at 2 meters above ground level at the edge of the field. Air VPD was calculated on a 15-minute interval based on measured air temperature and relative humidity over the 65-day interval by equation 1.

1) Air VPD= VP air saturation - VP air actual saturation

Leaf-to-air VPD

The leaf-to-air VPD was calculated in a manner similar to the airVPD calculation, with the substitution of canopy temperature for air temperature in the calculation of the saturating vapor pressure by equation 2.

2) Leaf-to-air VPD= VP canopy saturation - VP air actual saturation

Results

Air and canopy temperatures

The seasonal air and canopy temperature for the 4 cotton irrigation regimes in 2009 are shown in Figure1. The effect of variable plant water status, generated by the irrigation regimes, is present though not readily apparent.

In figure 2 air and canopy temperature data are shown in the context of time surfaces that present the temperatures over time with DOY as the X axis, time of day (midnight to midnight) on the Z axis and the temperature as the Y axis. A side view and a nadir view are shown. These figures indicate that the irrigation regimes resulted in differences in air and canopy temperature in terms of their magnitude and temporal distribution over the season.

Figure 3 shows the values of air VPD and leaf-to-air VPD in a time surface format. The upper panel indicates the seasonal pattern and magnitude of the air VPD which is the same for all irrigation regimes. The lower panels indicate the effect of irrigation-related differences in canopy temperature on the leaf-to-air VPD. Irrigation-related differences are evident in terms of both magnitude and seasonal distribution of leaf-to-air VPD. At higher irrigation levels (6mm and 3mm), the canopy temperatures are generally lower than air temperatures resulting in leaf-to-air VPD values that are lower that the air VPD while in the lower irrigation levels (1.5mm and 0mm), the canopy temperatures are higher than air temperatures resulting in leaf-to-air VPD values that are higher than air VPD.

Figure 4 shows the distribution of leaf-to-air VPD as functions of the air temperature. The overall pattern indicates that in the 6mm irrigation treatment the maximum leaf-to-air VPD values are constrained to less than 2kPA with the lowest irrigation regime experiencing leaf-to-air VPD values up to 7kPa. Leaf-to-air VPD values for the middle irrigation amounts produce leaf-to-air VPD vales that are intermediate between the extremes.

Discussion

It is evident that irrigation-related differences in the magnitude and seasonal distribution of canopy temperatures result in large variation in leaf-to-air VPD across irrigation levels in cotton. It is perhaps worth noting that seasonal analyses of leaf-to-air VPD have been made simpler through recent advances in the technology available for canopy temperature monitoring. There is a great deal of literature that describes plant water use in terms of air VPD alone. Such approaches have proven valuable in understanding plant/environment interactions and have been widely applied in irrigation management. While the value of air VPD in such analyses is unmistakable, it is possible that the inclusion of leaf-to-air VPD measurements may serve to refine our understandings.

Given the proven utility of air VPD measurements in understanding plant/environment interactions, it is reasonable question the wisdom of adding another variable to consider. What is clear is that the leaf-to-air VPD as measured is an improved estimate of the gradient for water movement from the leaf to the atmosphere, when the temperature of the leaf is not equal to that of the surrounding air. In light of the probability that reduced irrigation and increased water deficits will become more commonplace in agriculture, the inclusion of leaf-to-air VPD in physiological and irrigation studies may prove to be useful.

While these leaf-to-air VPD values differ from the air VPD values measured purely in terms of the environment, the utility, if any, of leaf-to-air VPD is open to debate. The extent to which leaf-to-air VPD might provide additional insight into the interactions between plants and their environments and the effect of irrigation management on these interactions will be the object of additional studies.

Figure 1. Air and canopy temperature collected in cotton over 4 irrigation regimes for 65 days in 2009.

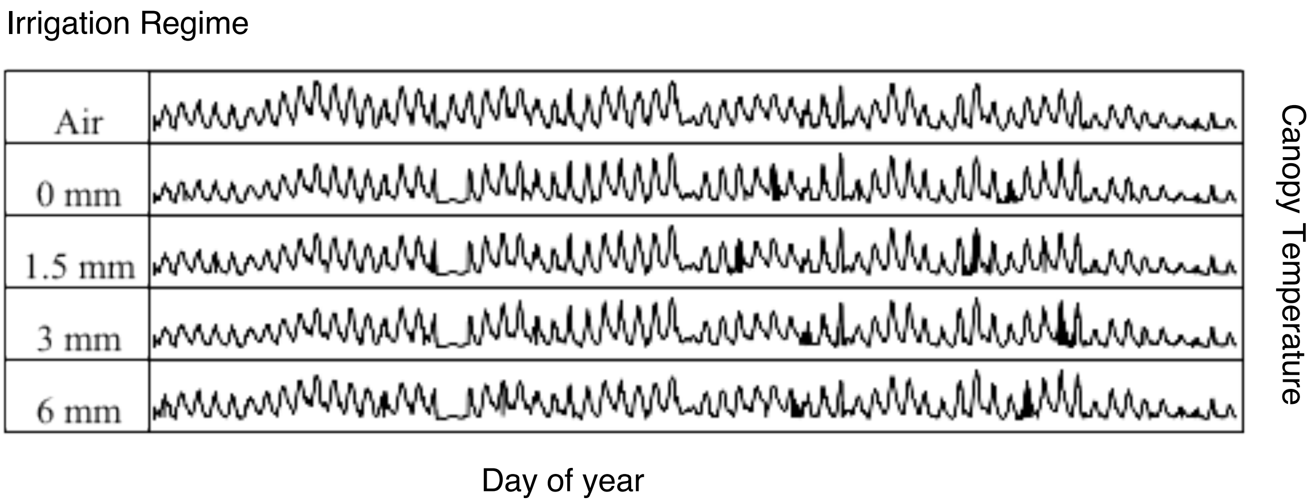

Figure 2. Time surfaces of air and canopy temperature collected in cotton over 4 irrigation regimes for 65 days in 2009. The time surfaces show the day of year, time of day, and temperature as the elevation. Green color indicates temperature of 28°C, blue indicates temperatures <28°C and yellow and red indicate temperatures >28°C.

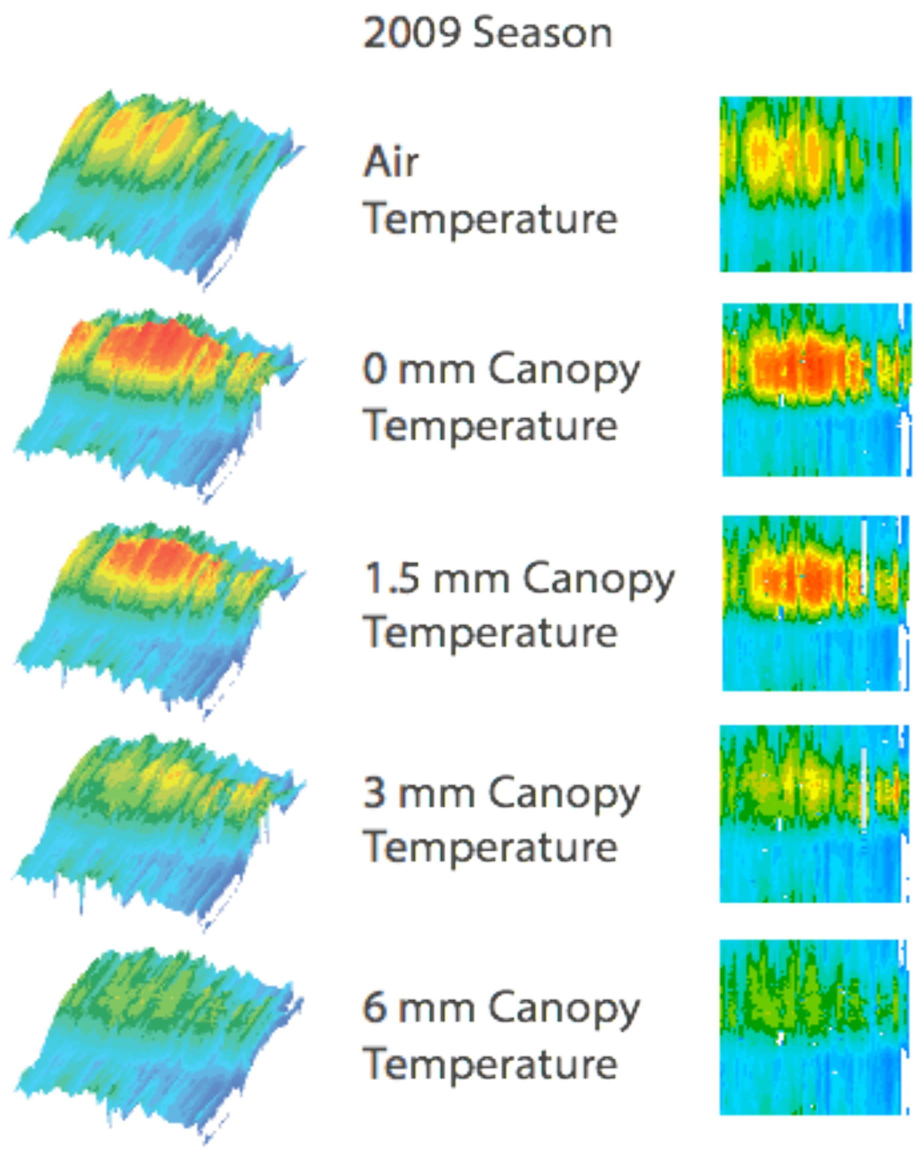

Figure 3. Time surfaces of air VPD and leaf-to-air VPD measured in cotton over 4 irrigation regimes for 65 days in 2009. The time surfaces show the day of year, time of day, and air VPD (AT-VPD) and leaf-to-air VPD (CTVPD) as the elevation. Dark green color indicates VPD values of 0, yellow indicates values ~3, and red indicates values >4.

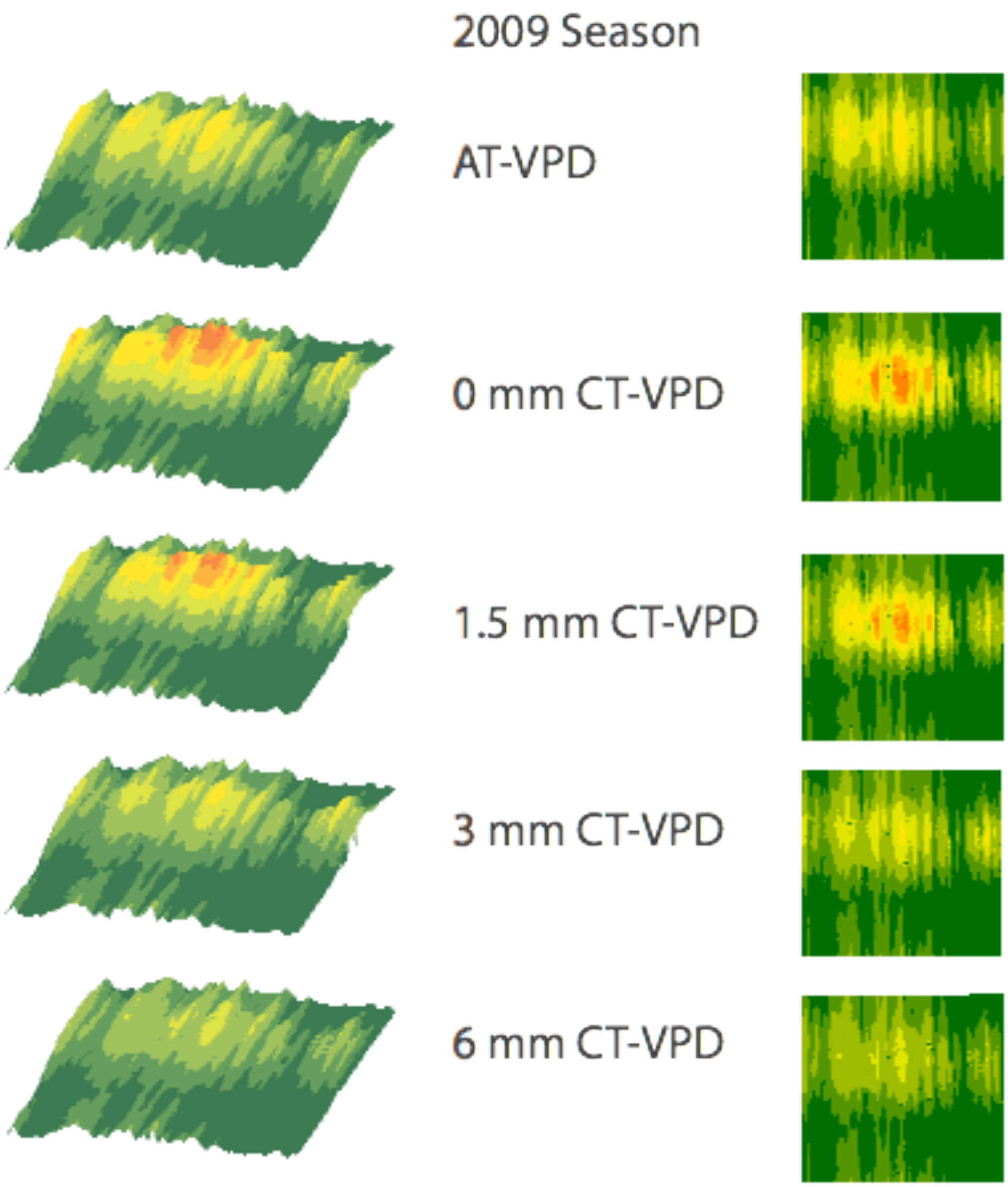

Figure 4. Leaf-to-air VPD. Leaf-to-air VPD as a function of canopy temperature in cotton under 4 irrigation regimes.