DROUGHT AND NITROGEN STRESS EFFECTS ON MAIZE CANOPY TEMPERATURE

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ABSTRACT

Water scarcity is a major threat to the sustainability of irrigated agriculture. Management practices, such as limited irrigation, that seek to maximize the productivity of a limited water supply are critical. Remote sensing of crop canopy temperature is a useful tool for assessing crop water status and for more precise irrigation management. However, there is potential that nutrient deficiencies could compound the interpretation of water status from leaf temperature by altering leaf color and radiation balance. This paper evaluates whether nitrogen (N) fertility status of maize interacts with remotely sensed leaf temperature under full and limited irrigation. A replicated study was conducted using maize grown in a glasshouse with combinations of full and limited irrigation and sufficient and deficient N levels. Leaf chlorophyll concentration and leaf area were reduced moderately by limited irrigation and more so by N deficiency. For most observations, the remotely sensed leaf temperatures were affected by irrigation, but not by N level. With limited irrigation, leaf temperature averaged 31.9 C, compared to 30.3 C for full irrigation, illustrating the utility of canopy temperature in detecting water stress and that the measurement was not confounded by N status. As further evidence, leaf temperature measurements taken at multiple times during a day were similar among treatments when taken early and late in the day, but were greater for N sufficient treatments for midday measurements. On three days, leaf temperature was observed to be greater for plants with sufficient N than for plants that were N deficient. These temperature differences were related to water stress but not to leaf color. Since these results suggest that plants with sufficient or excess N may experience more drought stress in water limited scenarios, N fertilizer management may be a critical factor in improving water productivity under drought conditions.

INTRODUCTION

Water scarcity is one of the most pressing contemporary challenges for agricultural and food sustainability. In many arid and semi-arid regions of the world, irrigation has been developed to enable stable, high yield agricultural production and to avoid the effects of drought. Despite advances in irrigation technology, water scarcity in many of these regions is now a pressing issue due to declining groundwater levels, increasing competition for water by municipal and industrial users, increasing frequency and severity of drought, and declining water quality due to pollution and salinity (Gleeson et al., 2012; Vorosmarty et al., 2000). Innovative strategies for assessing plant water status and scheduling delivery of irrigation water are a key component to the efficient use of limited irrigation water resources.

Remote sensing of canopy temperature and various stress indices based on canopy temperature have been widely used to assess crop water status (Idso et al., 1981; Jackson et al., 1981; Taghvaeian et al., 2012). The temperature of a plant leaf is a function of both environmental conditions (solar radiation, air temperature, humidity, wind, etc.), leaf properties (leaf color, leaf area, leaf angle, etc.), and transpiration rates. Transpiration is the primary plant mechanism for leaf cooling. If a plant closes stomata during the day in response to water stress, then the transpiration rate will decline, resulting in an increase in leaf temperature. If temperature changes in a crop canopy can be effectively measured and interpreted, the information can then be used to regulate the use and application of limited irrigation water supplies (Bausch et al., 2011). Recent advances in remote sensing technology and the development of precision irrigation techniques have created a renewed interest in the application of this technology.

If remotely sensed canopy temperature is to be widely applied for irrigation management, then researchers must develop an understanding of factors that may confound the interpretation of measured data. For example, plant nutrient status could interfere with canopy temperature due to effects on leaf color. Nitrogen deficiency is a common occurrence in many crops that results in changes in chlorophyll concentration and leaf color. Thus, there is a need to understand the effect of N deficiency on remotely sensed leaf temperature. The goal of this study was to evaluate the effects of limited irrigation and N deficiency on maize. It was hypothesized that N deficiency would result in a measureable decrease in leaf temperature due to lighter green leaf color and lower absorption of solar radiation.

METHODS

The study was conducted during a period from February to April, 2014 in a research glasshouse. The study consisted of a random complete block design with three replications of two water levels (100% and 60% ET) and two N levels (Sufficient = 1,048 mg N pot and Deficient = 131 mg N per pot). Four corn seeds of hybrid Fontenelle 4T105 were planted in each of 12 three-gallon pots on February 20, 2014. The growing media was a mixture of equal proportions of two porous ceramic soil conditioners, Turface Athletics MVP and PioneerOne Field Conditioner (Profile Products LLC, Buffalo Grove, IL). The bulk density of the planting medium was 0.587 g/cm^3, with a field capacity volumetric water content of 35%. After planting, the potting media was covered with a 3.0 cm deep layer of perlite to prevent evaporation from the soil surface. All pots were irrigated with a pre-treatment solution containing all essential plant macro and micronutrients until March 27, when corn was at the 5-leaf growth stage. Irrigation and N treatments were initiated February 27, 2014 for a 21 day treatment period. Daily evapotranspiration was determined by weighing individual pots every 24 hours and averaging the weight loss across all three replications in a given treatment. For full irrigation treatments, 100% of measured ET was replaced by irrigation. For the limited irrigation treatment, 60% of the measured ET was replaced by irrigation. Irrigation solution during the three-week experimental portion of the study was applied as a nutrient solution that assured adequate supply of all essential plant nutrients with the exception of N. Nitrogen was added to the nutrient solution by adding a volume of 1.0 molar ammonium nitrate solution to create an irrigation solution with a final concentration of either 240 or 30 mg N/L.

Leaf temperature was measured daily during the treatment period using an Ex-Series E6 infrared camera (FLIR Systems, Inc., Wilsonville, OR). Each pot was placed individually in front of a black surface and the temperature measurement taken on the newest, fully expanded leaf. Leaf temperature measurements were taken between 1:00 p.m. and 3:00 p.m. just prior to the daily irrigation. Leaf chlorophyll concentration was measured daily using a SPAD 502 Plus Chlorophyll Meter from Spectrum Technologies by averaging three measurements per pot on the youngest fully expanded leaf. Leaf area (L.A.) was determined biweekly by measuring the length and width of all leaves on the plant and then calculating L.A. using the following equation (Kang et al., 2003),

$$\text{L.A.} = \sum_{i=1}^{n} L_i W_i$$

where is the number of individual leafs, L is leaf length, and W is leaf width measured at the widest point.

Analysis of Variance was performed for all crop measurements using the PROC GLM procedure in SAS 9.1 (SAS Institute, 2009). Treatment means were compared using least significant difference (LSD) with 90% confidence limits in accordance with a randomized complete block experimental design to ascertain the effects of combined irrigation and N treatments. Contrast statements using the ESTIMATE statement in SAS were used to separately evaluate the effects of irrigation and N management.

RESULTS AND DISCUSSION

Leaf Chlorophyll Concentration

Leaf chlorophyll concentration varied with both irrigation and N level (Figure 1). There were no significant irrigation x N treatment interactions. When averaged over the treatment period, the SPAD reading was 36.2 for full irrigation and 34 for limited irrigation. Limited irrigation plants had lower SPAD readings than plants with full irrigation, and these differences were small and consistent throughout the treatment period. SPAD readings were not different between N treatments for the first 5 days of the treatment period, but then were significantly less for the N deficient treatment than for the N sufficient treatment (Figure 1). By the end of the treatment period, the average SPAD reading for the N deficient plants was 25, compared to 37 for the N sufficient plants. This shows that the experiment successfully created differences in plant N status for evaluation of remotely sensed canopy temperature.

Leaf Area

Both irrigation and N treatments affected the rate of above ground plant growth, as measured by leaf area development over time (Figure 1). Plants with full irrigation reached an average final leaf area of 124 cm^2, while limited irrigation plants reached a final average leaf area of 107 cm^2. Average final leaf area was 118 cm^2 for N-sufficient plants and 110 cm^2 for N-deficient plants. There was not a significant interaction between irrigation and N treatments on leaf area.

Leaf Temperature

For the first six days of the treatment period, there were no differences observed among leaf temperature measurements. Beginning seven days after initiation of treatments and for most days thereafter, leaf temperature was significantly greater for the limited irrigation treatment compared to full irrigation. During that time period, leaf temperature averaged 30.3 C for full irrigation plants and 31.9 C for limited irrigation plants. By 19 days after treatment, the limited irrigation treatments had leaf temperatures as much as 3.3 C greater than the full irrigation treatments. These observations confirmed that remotely sensed canopy temperature can be an effective tool for assessing plant water status. Despite the large differences observed in leaf chlorophyll concentration, there was no significant N treatment effect on leaf temperature for 11 of the 14 days of comparison, demonstrating that remotely sensed temperature is not consistently affected by plant N status and associated differences in leaf color. To further illustrate this point, leaf temperatures were also observed at seven specific times within a single day on April 10th (Figure 2). Leaf temperatures were similar among irrigation and N treatments when taken in the morning or late afternoon, but were greater for limited irrigation and for N sufficient treatments for a measurement taken at 2:00 in the afternoon. Similar to the effect of irrigation, the observed differences in leaf temperature between N treatments were due to plant water status and not to leaf color. Leaf rolling, a response of maize to drought stress, was also more apparent in sufficient N treatments than in deficient N treatments. Although the effects of N treatment on plant water status is an artifact of the experiment, it does suggest that N management may be important in managing water in drought affected crops and regulated deficit irrigation systems.

Summary

Water scarcity is one of the most pressing issues facing agriculture. Remote sensing of the crop canopy is a powerful tool for identifyingand managing crop stresses. Remote sensing of canopy temperature can provide valuable information about plant water status. This study evaluated whether plant N status affects the interpretation of canopy temperature due to water stress in maize. Leaf chlorophyll concentrations did vary with both irrigation and N levels, providing a contrasting fertility status over which leaf temperature could be compared. Leaf temperature did vary between irrigation treatments, but there was no significant N effect on leaf temperature for most of the experiment, demonstrating that leaf temperature is not affected by plant N status and associated differences in leaf color. Thus, canopy temperature appears to be a robust measurement over nutrient status.

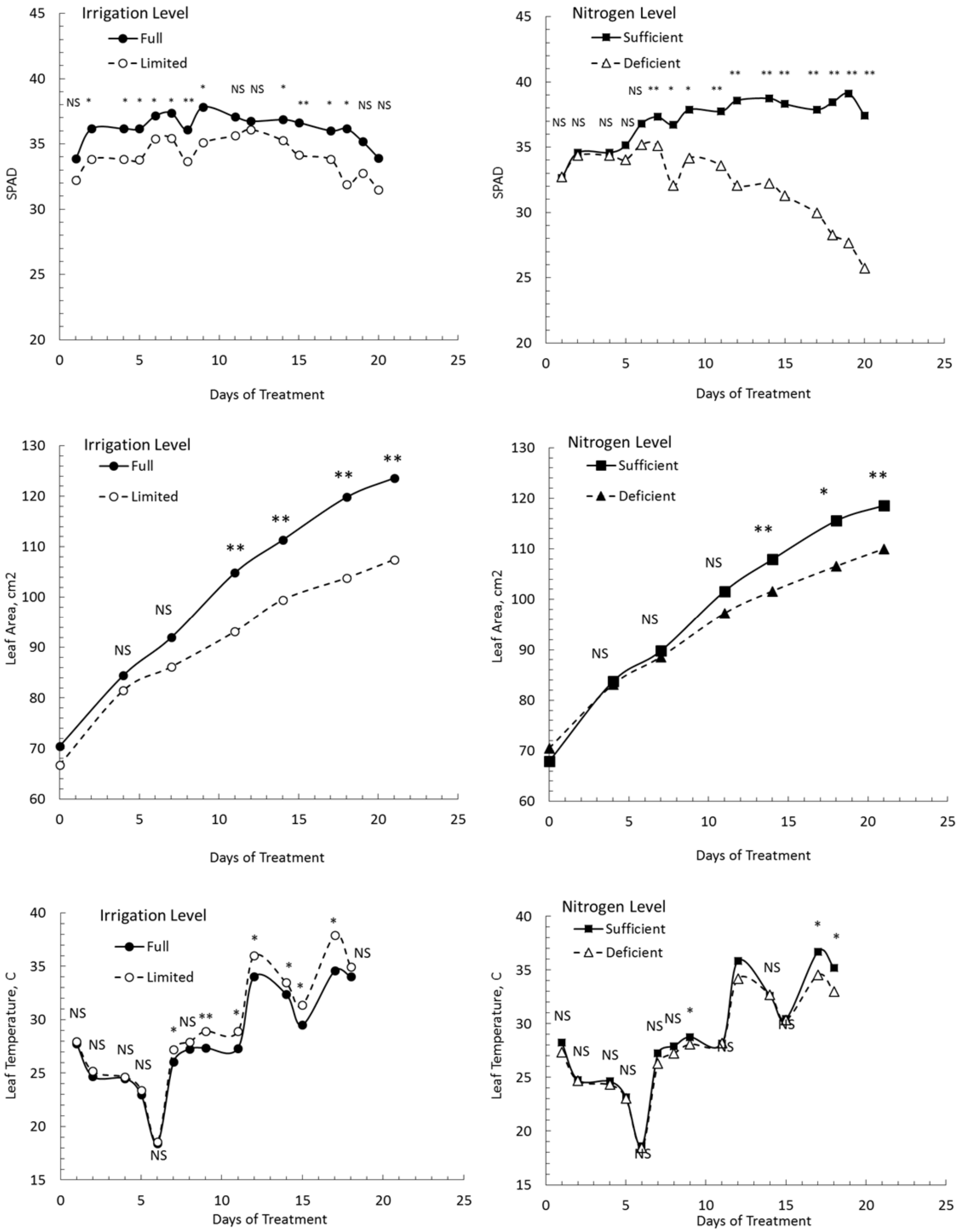

Figure 1. The effects of full and limited irrigation and sufficient and deficient nitrogen levels on maize leaf chlorophyll concentration measured by SPAD meter (upper figures), leaf area development (middle figures), and on remotely sensed leaf temperature (lower figures). NS = no significant difference (P>0,05), * = P < 0.05, ** = P < 0.01.

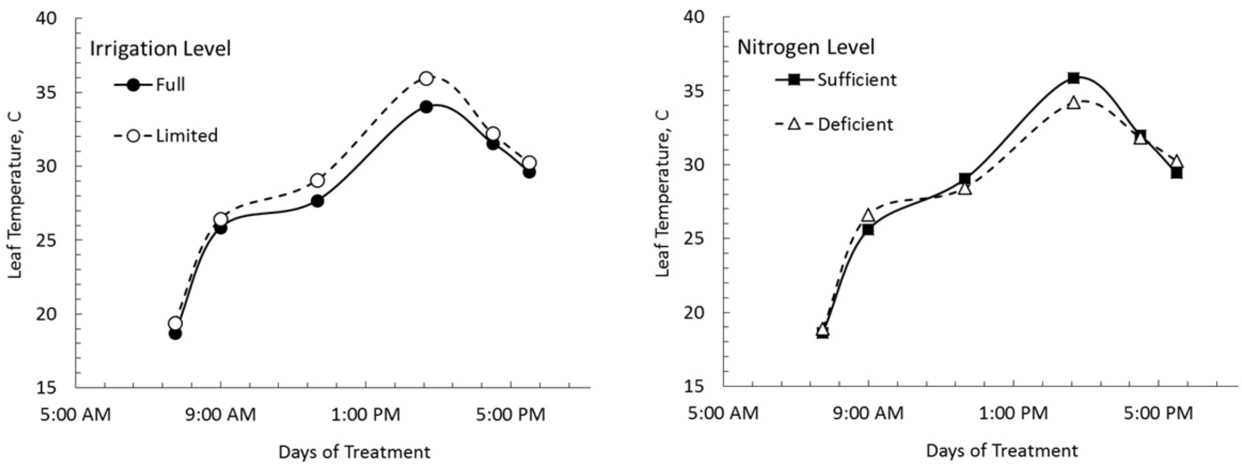

Figure 2. The effects of full and limited irrigation and sufficient and deficient nitrogen levels on remotely sensed maize leaf temperatures measured at six times of day on April 10, 2014 (14 days since treatments began).

REFERENCES

Bausch, W.C., T. Trout, and G. Buchleiter. 2011. Evapotranspiration adjustments for deficit-irrigated corn using canopy temperature: a concept. Irrig. Drain 60:682–693.

Idso, S.B., R.D. Jackson, P.J. Pinter Jr., R.J. Reginato, and J.L. Hatfield. 1981. Normalizing the stress-degree-day parameter for environmental variability. Agric. Meteorol. 24:45–55.

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

Taghvaeian, S., J.L. Chávez, and N.C. Hansen. 2012. Infrared thermometry to estimate crop water stress index and water use of irrigated maize in Northeastern Colorado. Remote Sens. 4:3619–3637.

Vorosmarty, C. J., P. Green, J. Salisbury, and R.B. Lammers. 2000. Global water resources: vulnerability from climate change and population growth. Science 289:284–288.

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