Peanut Canopy Temperature and NDVI Response to Varying Irrigation Rates

K. C. Stone[1], P. J. Bauer, W. J. Busscher, J. A. Millen, D. E. Evans, and E. E. Strickland

Abstract: *Variable rate irrigation (VRI) systems have the potential to conserve water by spatially allocating limited water resources. In this study, peanut was grown under a VRI system to evaluate the impact of differential irrigation rates on peanut yield. Additionally, we evaluated the impact of differential irrigation rates on crop canopy temperatures and vegetative indices. Canopy temperatures and vegetative indicies may be potential tools for VRI system management. The study consisted of four experiments with two planting dates (early and late plant). For each planting date there were two periods of imposed plant stress (early and late stress). Within of these four experiments there were four irrigation treatments (0, 33, 66, and 100% of the calculated crop evapotranspiration). The overall peanut yields for the study averaged approximately 4300 kg/ha with individual treatment means ranging from 3380 to 4958 kg/ha. Peanut yields across irrigation treatments were not significantly different. The peanut NDVI measurements were significant across irrigation treatments in only one experiment. In this experiment (#1) with significant differences across irrigation treatments, the non-irrigated treatment NDVI measurements began to indicate potential water stress. However, water stress based on NDVI measurements occurred several days after both canopy temperatures and soil water potentials began to indicate potential water stress. The crop canopy temperatures in experiments 1 and 3 were significantly different across irrigation treatments and did indicate potential water stress. In contrast to NDVI measurements, the crop temperature measurements were able to quickly differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems.*

Keywords: Variable-rate Irrigation, Canopy Temperature, NDVI, Peanut

INTRODUCTION

Variable rate irrigation systems provide a tool to spatially allocate limited water resources while potentially increasing profits. Spatial water applications attempt to overcome site-specific problems that include spatial variability in topography, soil type, soil water availability, and landscape features. Although technology for spatial water application is available and it has high grower interest, farmers that have retrofitted their center pivot systems to precision apply water are basing spatial applications on their past experience and historical knowledge of variability in their fields. Science-based information is needed on how to precision-apply water with these systems. Sadler et al. (2005) identified critical needs for site-specific irrigation research that included decision support systems for spatial water application and improved real time monitoring of field conditions with feedback to

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irrigation systems. To address the issues of real time monitoring of field conditions, variable rate irrigation experiments were conducted on peanuts to evaluate methods of obtaining spatial irrigation management data. In this research, peanut was grown under a variable-rate irrigation system with different irrigation treatments to impose water stress during two parts of the growing season.   The crop response to the irrigation treatments were monitored using both NDVI and infrared thermometers. These responses need to be quantified and assessed as potential measurements needed to spatially manage variable-rate irrigation systems. The objectives of this research were to: 1) Determine the yield response of peanut to varying irrigation water treatments; and 2) Determine the impact of varying irrigation water treatments on peanut canopy temperature and reflectance.

MATERIALS AND METHODS

Peanut (*Arachis hypogaea*) was grown under conservation tillage on a 6-ha site of uniform Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) near Florence, South Carolina.   Four individual experiments were conducted to evaluate peanut response to water stress at different stages of production and with different irrigation levels (Figure 1).

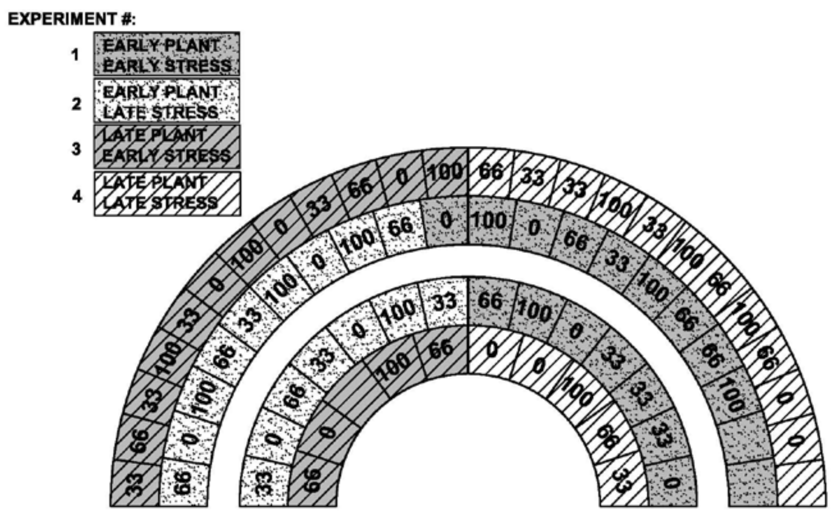

Figure 1. Diagram of the peanut experimental plot layout for the four irrigation treatments and four experiments.

Experiments one and two were planted on May 25, 2006 and experiments three and four were planted two weeks later on June 8, 2006. The two planting dates were selected to provide potential differences in natural rainfall patterns during various parts of the peanut growing season. Experiments one and three had water stress imposed (using differential irrigation levels) on the peanut crop during the first half of the growing season (early stress) and extended throughout remainder of the growing season. Experiments two and four had full irrigation throughout the first half of the growing season and then had water stress imposed (using differential irrigation levels) on the peanut crop during the second half of the growing season (late stress).   The first growth stage was defined as 0 to 10 weeks after planting (doy 145 to 215 for experiments 1 and 2; doy 159 to 229 for experiments 3 and 4) and the second growth stage was defined as 11-20 weeks after planting (doy 216 to 285 for experiments 1 and 2; doy 230 to 299 for experiments 3 and 4). For each experiment, the irrigation treatments included 4 irrigation rates of 0, 33, 66, and 100% of calculated ET_{crop}.

The four experiments and irrigation treatments were arranged in randomized complete blocks with 4 reps of each treatment under the variable rate center pivot irrigation system.

The irrigation system utilized was a center pivot irrigation system modified to permit variable applications to individual areas 9.1 x 9.1 m in size. The center pivot length was divided into 13 segments, each 9.1 m in length. Variable-rate water applications were accomplished by using three manifolds in each segment, each with nozzles sized to deliver 1x, 2x, or 4x of a base application depth at that location along the center pivot length. A more detailed description of the water delivery system may be found in Omary et al. (1997) and for the control system in Camp et al. (1998).

ET and Irrigation Details

Reference evapotranspiration (ET_{os}) was calculated using the ASCE standard methods for grass or short surfaces (Walter et al. 2000). Weather data used in these calculations were obtained from an on-site weather station. ET_{crop} was calculated using the single crop coefficient method of Allen et al. (1998) and was obtained by multiplying the reference ET_{os} by the crop coefficient representing the peanut crop and growth stage. The crop coefficients used in the calculations were $K_{c\ ini} = 0.4$, $K_{c\ mid} = 1.15$, and $K_{c\ end} = 0.6$. A simple water balance for the preceding seven days was used to schedule irrigations. Irrigation and rainfall for the preceding seven days was subtracted from the accumulated ET_{crop}. Irrigation was initiated when the difference between accumulated ET_{crop} exceeded accumulated rainfall and irrigation by more than 12.5 mm. When the deficit exceeded 12.5 mm an irrigation of 12.5 mm was applied to the 100% irrigation treatments and the other treatments were irrigated with 8.25 for the 66% and 4.125 for the 33% irrigation rates. To evaluate how well the irrigation treatments were performing, soil water potentials (SWP) were measured using tensiometers at two depths (0.30 and 0.60 m) in each irrigation treatment. Measurements were recorded at least three times each week.

Canopy Temperature and NDVI

Within-season measures of canopy temperature and normalized difference vegetative index (NDVI) were made throughout the growing season and intensively during periods with little to no rainfall (days 199-200, and 212-216). The NDVI was measured using a Holland Scientific Crop Circle model ACS 210 canopy sensor (Holland Scientific, Lincoln, NE) mounted on a toolbar in front of a tractor at a height of approximately 1 m above the canopy.
The canopy temperature was measured using Infrared Thermometers (IRT) mounted on a toolbar in front of a tractor. The IRT's used were Exergen IRT/c .3X with a 3:1 field of view and type K thermocouple leads (Exergen Corp., Newton, Mass.) with a published accuracy of ±2%. These sensors were mounted on the front of a tractor at a height of approximately 0.4 m and adjusted to minimize the soil surface in the IRT's field of view. A global positioning system (GPS) unit mounted on the front of the tractor allowed for the data to be geo-referenced to the individual plots.

Harvest Details

Peanut digging was accomplished using a KMC 2-row peanut digger. The peanuts were dug October 10-11, 2006 for experiments one and two and October 20, 2006 for experiments three and four. A two row KMC peanut combine retrofitted with a peanut yield monitor system developed by the University of Georgia (Vellidis, et al., 2001) was used to harvest the peanut crops for the entire field. Small sub-plot areas were harvested separately to compare with the yield monitoring system and were used for all analyses.

Statistical Analyses

The four experiments and irrigation treatments were arranged in randomized complete blocks with 4 reps each treatment under the variable rate center pivot irrigation system (Figure 1). The data were analyzed using the Statistical Analysis Software (SAS) version 9.2, (SAS Institute, Cary, NC). Regressions analyses were performed using Proc REG. Comparison of slopes for the different irrigation treatment was performed using Proc GLM.

RESULTS and DISCUSSION

Rainfall and Soil Water Potentials

Rainfall for the growing season was generally adequate. However, there was an extended period from days 180 to 220 (~40 days) that no significant daily rainfall (< 5 mm and cumulative rainfall of 19 mm) occurred. Rainfall totals for the experiments were 391 mm (experiments 1 and 2) and 378 mm (experiments 3 and 4). The rainfall totals accounted for 68 and 71% of the seasonal ET_{crop} respectively. The long term historical rainfall from May-September was 559 mm (SC State Climatologist, 2010). For experiments 1 and 2, rainfall was sufficient until the sixth week (~doy 184) after planting, at that time, irrigation was required to meet ET_{crop} through the thirteenth week (~doy 220) after planting. The majority (65%) of the irrigation applied for experiments 1 and 2 occurred during the first 10 weeks (until ~ doy216) of the growing season. Likewise, for experiments 3 and 4 the majority of the irrigation applied occurred during the first 8 weeks of the growing season. The simple weekly water balance irrigation scheduling method kept the soil water potentials generally below -40 kPa for the 100% and 66% irrigated treatments throughout most of the growing season for each experiment except for the extended drought period from days 180 and 220. In experiments 1 and 3 with early stress, soil water potentials for the non-irrigated and 33% irrigation treatments often exceeded -40 kPa, particularly during the extended drought period between days 180 to 220 and several times during the remainder of the season. During this drought period, even the 66 and 100% irrigation treatments had soil water potentials exceeding -40 kPa for a few days across all experiments. During this time, all treatments reached their highest soil water potentials levels for the entire season.

Peanut Yields

The peanut yields ranged from 3,380 to 4,958 kg/ha across the four individual experiments and exceeded the 2006 South Carolina state wide average yield of 3360 kg/ha (USDA-NASS, 2010). The irrigation treatment mean yields over all four experiments ranged from 4,130 to 4,464 kg/ha and were not significantly different (Table 1). The mean yield for each of the individual experiments ranged from 3,875 to 4,643 kg/ha over all irrigation treatments and were significantly different. The mean yields for the individual experiments were not significantly different for experiments 2, 3 and 4. For experiments 1 and 3 (early stress), the yields were not significantly different from each other, but experiment 1 was significantly different than experiments 2 and 4. These differences were most likely due to the water stress imposed during the early part of the growing season and the lower total water received particularly for the treatments irrigated at less than 100% of ET_{crop}. Overall, there did not appear to be a significant statistical relationship between peanut yield and irrigation treatment for this year, probably due the generally adequate rainfall during the latter part of the growing season. With the adequate rainfall during the latter part of the season, the lack of significant differences across irrigation treatments and experiments was somewhat

Table 1. Mean peanut yields and standard deviations for the four irrigated treatments and four experiments

	Peanut Yield (kg/ha)				
	Experiment				Irrigation Mean
	1	2	3	4	
Irrigation					
0%	3515 ±1443a*	4186 ±950 a	4046 ±733 a	4771 ±394ab	4130 ±974 a
33%	4721 ±909 a	4173 ±1911 a	3844 ±982 a	4167 ±920 b	4226 ±1168a
66%	3380 ±1788a	5422 ±915 a	4360 ±1372a	4678 ±328ab	4460 ±1333a
100%	3883 ±1804a	4601 ±151 a	4416 ±512 a	4958 ±135 a	4464 ±934 a
Experiment Mean	3875 ±1470b**	4596 ±1165a	4167 ±887 ab	4643 ±563 a	

* Column means followed by the same letter are not significantly different at the 5% level.
** Row means followed by the same letter are not significantly different at the 5% level.

expected. In previous studies, Chapin et al. (2010) reported that peanut was capable of recovering from early drought stress with adequate late season rainfall. Also, Pallas ea al. (1979) found midseason droughts, imposed with rainfall shelters, did not impact yields as great as drought stress during the latter part of the growing season.

Canopy NDVI Measurements

Characteristics of the peanut vegetation (NDVI and canopy temperatures) were analyzed for eight days during the growing season (Figure 2). The NDVI measurements for each irrigation level were compared across irrigation levels in each experiment. Initially on doy 199, there were no significant differences for the irrigation treatments or for any of the experiments. On doy 200, the non-irrigated treatment in experiment 3 had a significantly lower NDVI measurement than any of the irrigated treatments. Experiments 1, 2, and 4 had no significant difference in NDVI measurements. Throughout the other NDVI sampling days, only experiment 1 had significant NDVI differences across the irrigation treatments. These differences were typically between the non-irrigated treatment and the irrigated treatments. However, on the last observation day (doy 216), the 33% irrigation rate was significantly different from the non-irrigated and from the 66% and 100% irrigation treatments as well. For experiment 1 and the 0% irrigation treatment, decreasing NDVI measurements were observed for both measurement periods (doys 199-202, and 212-216; Figure 2). During the second sampling period (doy 212-216), the NDVI measurements for the 33% irrigation treatment also begin to separate from the other irrigation treatments. For experiment 3, the NDVI measurements were not as well separated over time as in experiment 1, particularly during the second half of the sampling period. However, the NDVI measurements were more scattered than those from experiments 2 and 4 (Figure 2). NDVI measurements for experiments 2 and 4 were not significantly different and the NDVI readings were

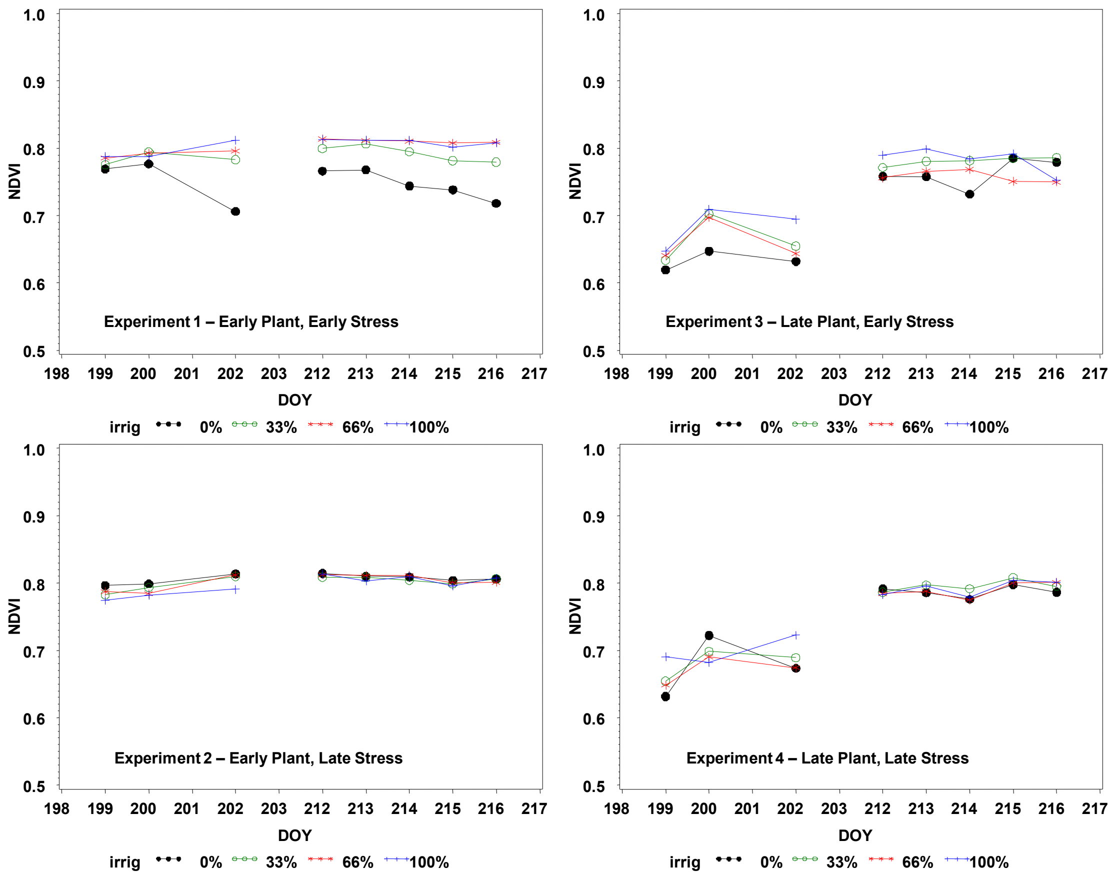

Figure 2. Peanut NDVI measurements for the DOY 199-201 and 212-216 sampling periods for the four irrigation treatments and four experiments.

almost identical for each irrigation treatment (Figure 2). It appears that from these results that the early water stress (experiments 1) did have some impact on the NDVI readings. These initial results indicated that NDVI measurements may be able to detect water stress, particularly in experiment 1.

Canopy Temperature Measurements

Crop canopy temperatures were collected simultaneously with the NDVI measurements (Figure 3). Rainfall during the sampling period was minimal. For the 10 days prior to day 199, rainfall occurred on day 196 (1.1 mm). During the sampling period, rainfall occurred on day 201 (2.9 mm), 203 (2.6mm), 204 (1.0 mm), 205 (4.8 mm), 206 (1.2 mm), 207 (2.8 mm), and 210 (0.7mm) for a total of 16 mm over 18 days which was much lower that the calculated ET_{crop} requirement of 105 mm.

The canopy temperatures above air temperature were compared across irrigation treatments for each experiment. Experiments 1 and 3 had the most differences in canopy temperatures across the irrigation treatments. In experiment 1 with the early imposed stress, the canopy temperature for the 0% irrigation treatments was significantly higher than the other irrigated treatments throughout the sampling period. As time passed without rainfall (days 212-216), the canopy temperatures for the other irrigation treatments also began to separate themselves. The 33% irrigation treatment became significantly different from the 66% and 100% treatments. The canopy temperatures for the 66% and

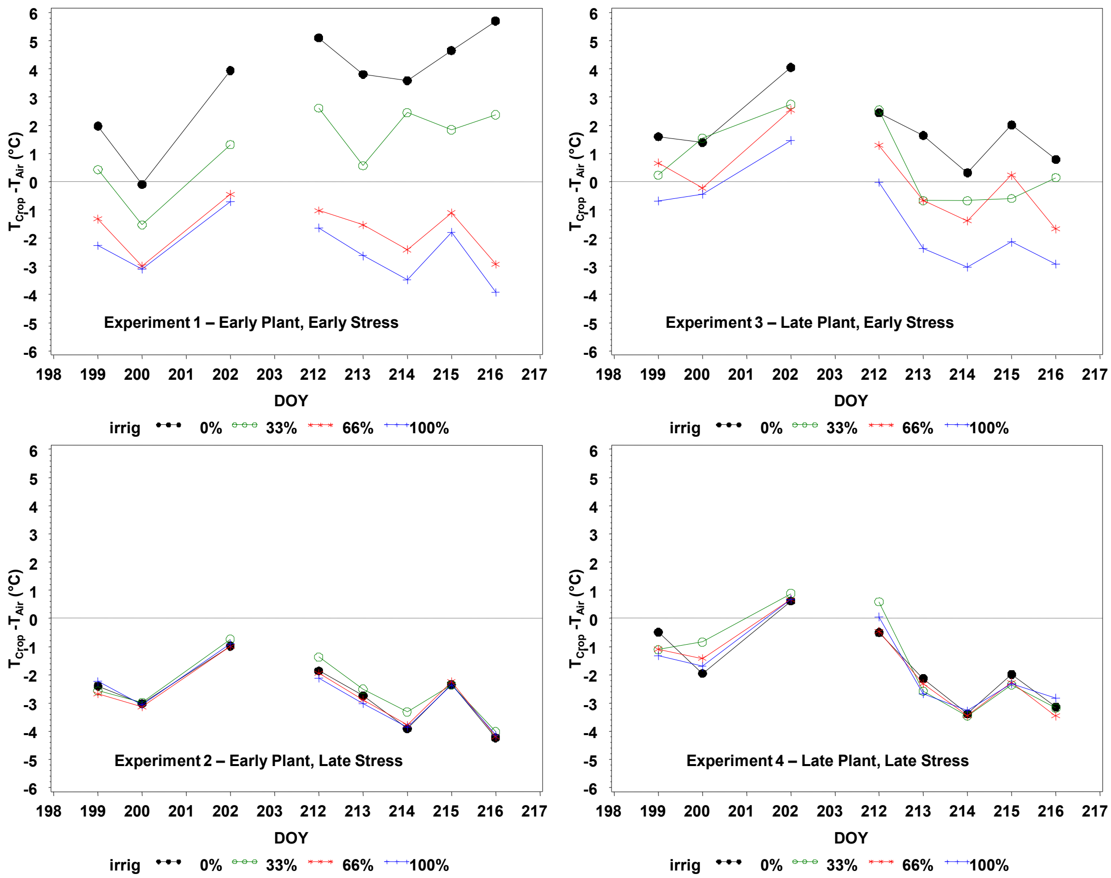

Figure 3. Peanut Crop canopy temperature above air temperature measurements for the DOY 199-201 and 212-216 sampling periods for the four irrigation treatments and four experiments.

100% treatments remained below the air temperature throughout the sampling period, whereas the temperatures for the 0% irrigation treatment were much higher than the air temperature which generally indicates water stress (Aston and Van Bavel, 1972; Sadler et al. 2002). In experiment 3, also with the early imposed stress, the canopy temperature for the 0% irrigation was above air temperature for all sampling dates. Experiment 3 also had several days where there were significant canopy temperature differences among the irrigation treatments. The 0% irrigation treatment was generally had a higher temperature and was significantly difference from the 100% treatment throughout the sampling period.

The canopy temperature results along with the NDVI measurements indicated that the irrigation treatments that had differential irrigation rates applied during the first 10 weeks experienced water stress. However, the water stress was not enough to significantly impact yields during this growing season. The irrigation treatments that had differential irrigation rates applied during the last 10 weeks of the growing season did not experience any observed water stress. Overall, it appears that NDVI measurements responded to water stress; however, it may not be able to be used as an indicator to initiate irrigations. The canopy temperature measurements were able to differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems.

CONCLUSIONS

Experiments were conducted under a variable rate center pivot irrigation system to determine the impact that varying irrigation rates would have on crop canopy temperatures and vegetative indices for potential use in site-specific irrigation management. Rainfall for the growing seasons accounted for approximately 70% of the seasonal ET_{crop}. However, there were periods during the growing season with little to no rainfall when irrigation was required. The overall peanut yields across irrigation treatments were not significantly different. However, the experiments that had differential irrigation rates applied throughout the season (early water stress) had lower yields than treatments only differentially irrigated during the last half of the growing season (late stress). The peanut NDVI measurements were significant across irrigation treatments in experiment 1 only, and did show an indication of potential water stress for the non-irrigated treatment. However, it may not be able to be used as an indicator for irrigation management. The crop temperatures were significant in experiments 1 and 3 (early water stress) across the irrigation treatments. Overall, the crop temperature measurements were able to differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems. Additional research is needed to investigate the use of canopy reflectance and temperature measurements for irrigation scheduling in humid regions.

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