REGIONAL EVALUATION OF WIRELESS SOIL MOISTURE SENSOR SYSTEMS TO OPTIMIZE WATER USE EFFICIENCY

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Abstract

Although the large number of dryland cotton (*Gossypium hirsutum*, L.) variety trials conducted each year allow producers to examine the yield response of varieties in similar growing conditions to their own, local trials may not fully express all varietal characteristics, specifically those of drought stress. The ability to characterize the drought stress of these trials would allow for a larger extrapolation of varietal yield response. The main objective of this initiative was to develop a crop/soil sensor-based index to accurately characterize location drought-stress. Trials at each location tested the response of drought-stress monitoring sensors to differences in variety and replication. Monitored data included standard meteorological parameters at the location scale and canopy temperature, soil moisture, or both at the plot scale. Soil moisture data was collected by PureSense Inc. (Fresno, CA). Drought stress was characterized by an available soil moisture stress index, which was a function of total available water (TAW) adjusted for rooting depth. Canopy temperature data was collected and analyzed by Smartfield Inc. (Lubbock, TX). Strongest relationships between the accumulated available H_2O drought stress index units and seedcotton yield were found when the upper and lower limits of TAW were determined from in-season sensor readings. Preliminary results suggest a limited number of sensors under a standard variety could be used to characterize location drought stress, therefore increasing the utility of dryland variety trials. Still, further research is needed to more accurately define the response of the index to variety and spatial variability and to include and test a crop susceptibility factor.

Introduction

Row crop agriculture in areas considered in the past to have abundant water supply have recently seen an emphasis placed on water use efficiency. This is in part due to increased 'water wars', or conflicts in rural and urban demands caused by declining supply, specifically in the western United States. Also contributing is the depletion of several nonrenewable aquifers located across the cotton belt and severe drought in several areas of the country, which have resulted in complete crop loss for some producers. In response to these factors and many others, several companies have increased research on drought management and resistance. One successful example of this is a BASF Corporation (Florham Park, NJ) and Monsanto Company (St. Louis, MO) collaboration. These companies have isolated drought-tolerant genes and are beginning to test the inclusion of these genes in some varieties. This project is in the early stages of development, but results look promising.

Even though this technology is several years away from general production, producers currently lack the tools required to evaluate the benefit of these genes and more basically evaluate varietal drought tolerance. Although a large number of dryland cotton variety trials are located throughout the cotton belt, these are typically characterized by rainfall amounts alone. Due to runoff, leaching, and lack of information on soil moisture at planting and rainfall timings, accumulated seasonal rainfall fails to fully describe drought. Specific drought parameters necessary to accurately characterize seasonal growing conditions include timing, magnitude, and length of water deficit.

A drought stress index which utilizes in-field, sensor measurements has the potential to define these parameters, and therefore serve as the framework for compiling regional yield responses to drought stress. The main benefit of this compiled dataset would be the ability of the producer to examine the relative varietal yield response to a range of drought timings, magnitudes, and lengths. This type of dataset would be much more powerful than single point observations of individual variety trials.

The concept of a drought-stress quantifying index is not new. The Stress Day Index (SDI) was first introduced by Hiler and Clark (1971) as a method of increasing water use efficiency by optimizing irrigation scheduling. Proposed parameters to calculate this index were either coarse-resolution plant measurements or meteorological data. Jackson et al. (1981) advanced this concept by developing the Crop Water Stress Index (CWSI), which utilized the much higher-resolution plant measurement of canopy temperature as the main stress indicator. Still, this index was developed in climates which rarely experience cloud cover or afternoon thunderstorms. These conditions greatly contrast conditions of the humid Southeast and Mid-South regions where a large percentage of dryland cotton is produced. More recent research by Colaizzi et al. (2003) compared the CWSI to a Soil Water Stress Index (SWSI) based on available H_2O in the effective rooting zone. Results showed a strong linear correlation between the CWSI and SWSI (r^2=0.86), suggesting soil moisture monitoring may be a plausible method for determining crop water stress from soil moisture data that is comparable to stress estimates from canopy temperature.

The main objectives of this research were to:

(1) develop a soil moisture-based index to quantify drought stress in dryland cotton variety trials and
(2) determine the plausibility of extrapolating accumulated index readings to the field scale from a limited number of point measurements.

Materials and Methods

Sensor deployment

Wirelessly monitored soil moisture sensors were deployed in Maricopa, AZ, Lubbock, TX, Marianna, AR, and Florence, SC during the 2012 growing season. Trials were designed as randomized, complete blocks with variety as treatment. Two of the three planted varieties varied by region, however, Phytogen 499 was planted as a standard at each location. The AR, AZ, and TX locations also maintained a well-watered Phytogen 499 plot as a reference to the adjacent drought stressed plots. Meteorological data, including rainfall, humidity, temperature, and estimated daily potential evapotranspiration was recorded by an in-field weather station. Soil moisture equipment was installed and data collected by PureSense Inc. (Fresno, CA). Decagon 5TE sensors (Decagon Devices Inc., Pullman, WA) were deployed at four depths in each plot relative to the effective rooting depth of each location (Figure 1). Sensor output was converted from dielectric permittivity to volumetric water content (VWC) using the Topp equation (Topp et al., 1980). Data from each plot was collected at 15-minute intervals by a central node and wirelessly transmitted to an edge-of-field base station. From the base station, data was cellularly transmitted to PureSense servers at which point it was accessible by the end user through a smart-phone application or a computer program, already converted to the %VWC form. Canopy temperature was also monitored at the Marianna, AR location. This equipment was installed and data was collected and analyzed by SmartField Inc. (Lubbock, TX).

Stress Index

After data was collected, a weighted, node-hourly average %VWC was calculated by establishing the number of sensors in the effective rooting zone and then weighting specific sensor depth to the volume of soil the sensor was assumed to represent (Figure 1). In this calculation, yield response to water at varying depths was assumed to be equal.

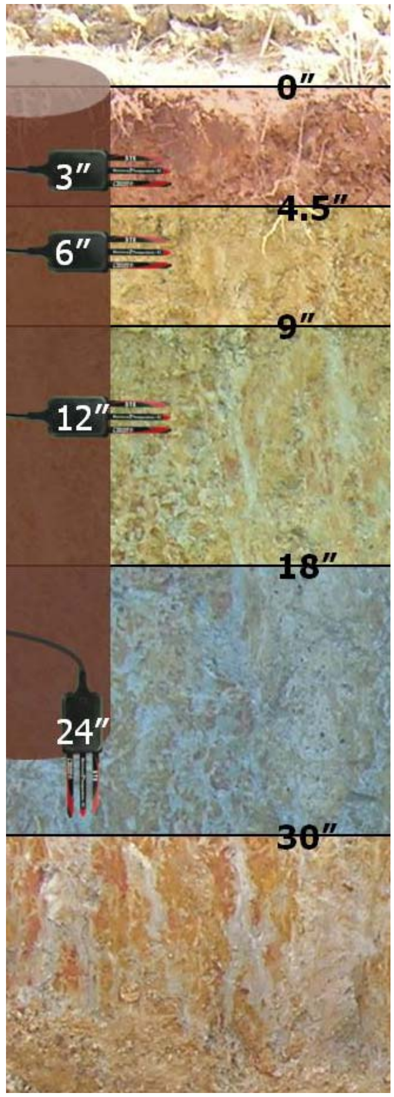


Figure 1: Deployment of soil moisture sensors and the relative volumes of soil which the sensor readings described.

Plant stress was assumed to begin when the soil fell below a threshold of 50% plant available water. Plant available water was determined by two separate methods. First, soil samples were taken at the time of sensor installation and laboratory analysis were conducted to determine field capacity and wilting point. The second method used to determine field capacity and sensor lower limit were based on in-season sensor readings, similar to methods of Colaizzi et al. (2003) (Figure 2). Field capacities were defined to be sensor reported readings 2-3 days after a saturating rainfall or irrigation event. Lower limits were defined to be sensor readings during periods of extended drought or at the end of the growing season after defoliation. Since a plant growing at 50% available water was assumed to experience less stress than a plant growing at 10% available water, stress units were weighted as available water declined below the threshold. Stress unit weights increased linearly as total available water decreased from 50% to 0% available water (Figure 3).

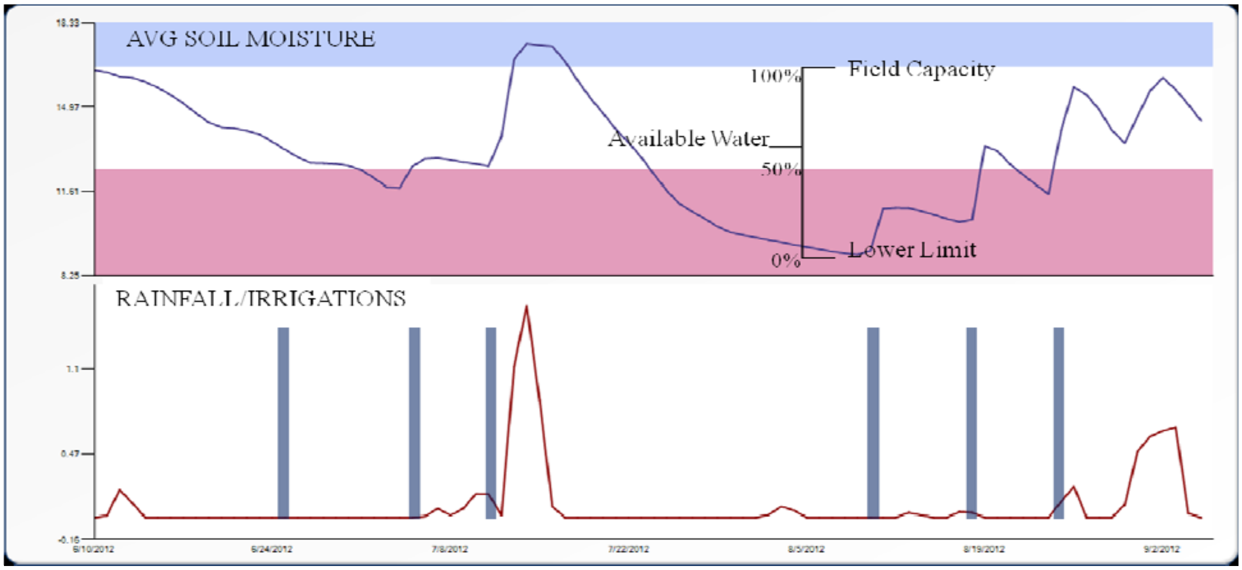


Figure 2: Average soil moisture and rainfall/irrigation graphs during the Marianna, AR 2012 growing season. Visual representations of the lower limit and field capacity are shown in the average soil moisture graph.

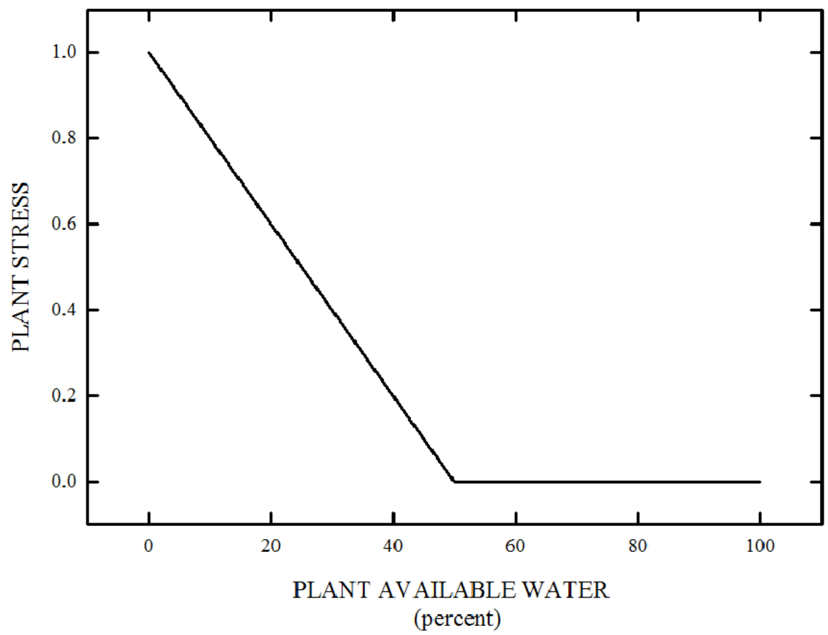


Figure 3: Stress unit weight as a function of plant available water. No stress was assumed to occur between 100% and the established threshold of 50% available water. Stress was assumed to increase linearly as plant available water decreased from 50% to 0%.

Accumulated Available H_2O Stress Units were defined as the summation of hourly plant stress values during the active growing season, from squaring to defoliation. Although data analysis is currently underway, included are preliminary results from the AR, AZ, and SC soil moisture datasets. Not included are the results from the FL, GA, and TX soil moisture trials and the AR canopy temperature trials.

Results

Stress Index

Soil samples taken at the time of sensor installation were combined, resulting in two reported field capacity and wilting point values. Resulting relationships of seedcotton yields and accumulated stress index values were very poor, most likely due to the substantial changes in soil properties between each soil moisture sensor. In comparison to laboratory determined field capacity and wilting point values, using in-field observed values as boundaries to calculate TAW resulted in stronger relationships between accumulated available H_2O stress units and yield (

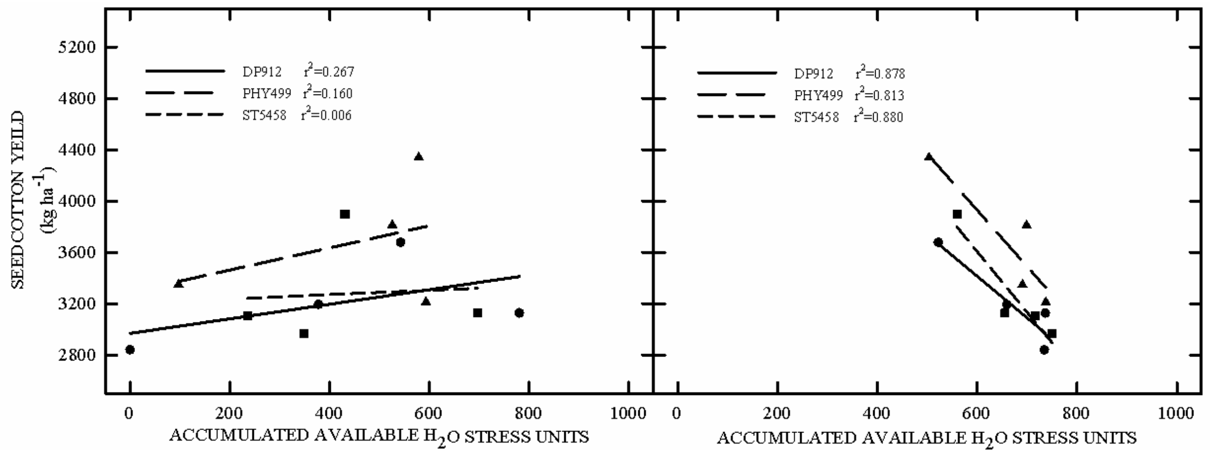
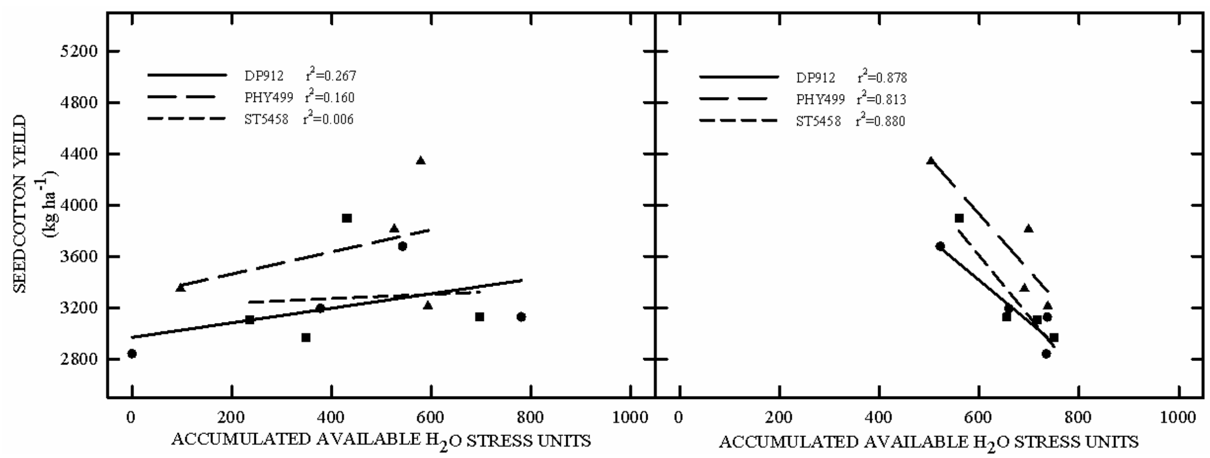


Figure 4 and Figure 5).



DP912 r^2=0.267
PHY499 r^2=0.160
ST5458 r^2=0.006
DP912 r^2=0.878
PHY499 r^2=0.813
ST5458 r^2=0.880
SEEDCOTTON YEILD (kg ha^{-1})
5200
4800
4400
4000
3600
3200
2800
0
200
400
600
800
1000
ACCUMULATED AVAILABLE H_2O STRESS UNITS
ACCUMULATED AVAILABLE H_2O STRESS UNITS

Figure 4: Florence, SC 2012 relationships between seedcotton yield and accumulated available H_2O stress index units. LEFT: Wilting point and field capacity as determined by laboratory analysis. RIGHT: Wilting point and field capacity as determined by in-season observations.

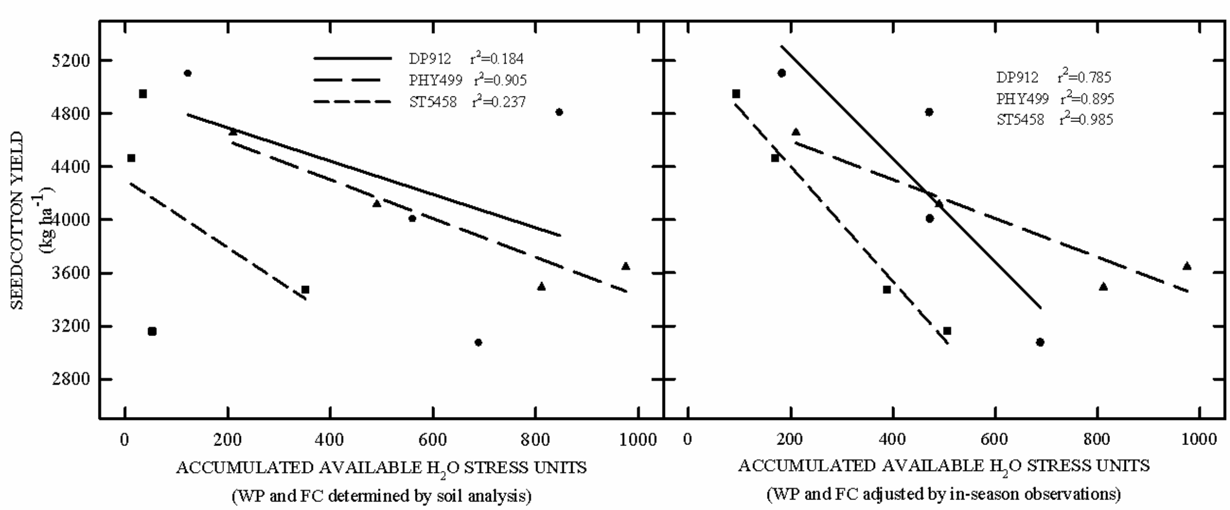


Figure 5: Marianna, AR 2012 relationships between seedcotton yield and accumulated available H_2O stress index units. LEFT: Wilting point and field capacity as determined by laboratory analysis. RIGHT: Wilting point and field capacity as determined by in-season observations.

Spatial Response

Very significant responses of the drought stressed plots to replication were noted at the Marianna, AR location, as seen in Figure 6. These yield responses were due to differing water statuses with varying replication, as yields in the adjacent well-watered strip did not follow similar trends. As a result, a wide range of accumulated available H_2O stress units were noted, with AR plot values ranging from roughly 100 to 1000 stress units (Figure 5). In contrast, a wide range of accumulated available H_2O stress units were not noted at the Florence, SC location (Figure 4).

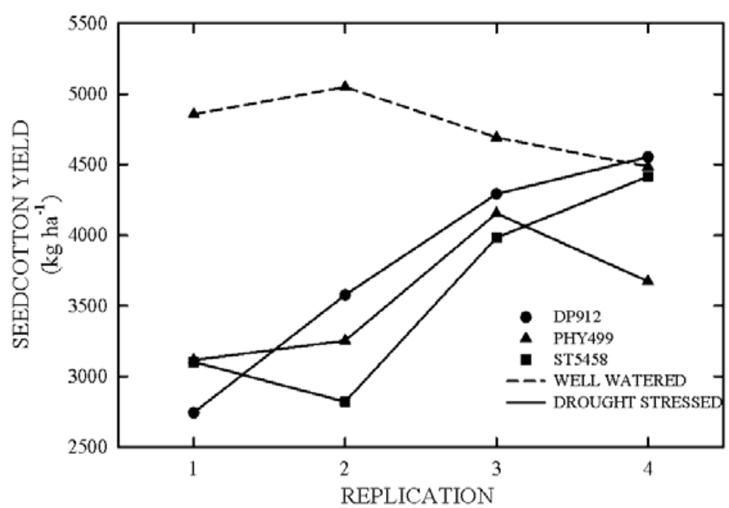


Figure 6: Marianna, AR 2012 response of seedcotton yield to replication for both drought stressed plots of each variety and the well-watered strip of Phytogen 499.

The wide range of accumulated available H_2O stress units noted at the AR location suggest one trial can experience significant variability in drought stress under the same limited irrigation treatment. To accurately characterize the AR location, a large number of soil moisture monitoring nodes would be required. These results are contrasted by the narrow range of accumulated available H_2O stress units noted at the SC location. Placement of a limited number of soil moisture monitoring nodes at this location could most likely characterize seasonal drought stress. Results from the AZ location were similar to the SC location.

Combined Response

After calculating accumulated available H_2O stress index units for the AR, AZ, and SC locations, the paired yield and accumulated stress values were combined to test response of the index to location. The first combined relationship considered absolute yields. The relationship was characterized by a coefficient of determination of 0.461. Although moderate, this relationship fails to take into account the maximum yield potential of each individual location. As a result, yields from each location were noticeably grouped (Figure 7). Therefore, a combined relationship considering relative yield by location was examined. This relationship was characterized by a coefficient of determination of 0.593 (Figure 8).

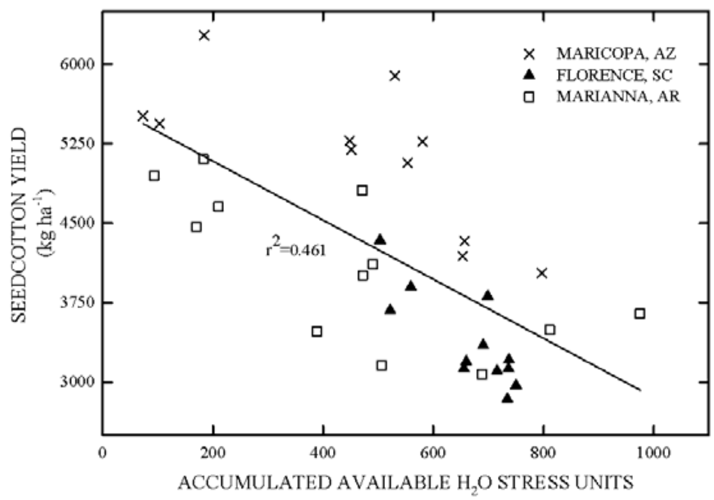


Figure 7: Relationship between accumulated available H_2O stress units and absolute seedcotton yield.

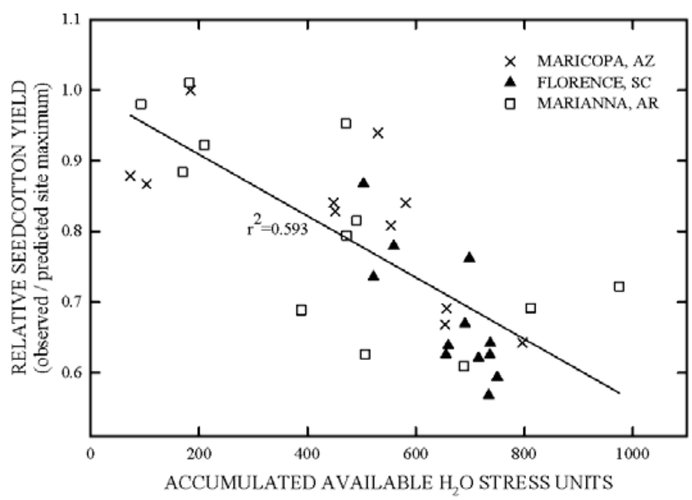


Figure 8: Relationship between accumulated available H_2O stress units and relative seedcotton yield, where relative seedcotton yields represent the observed plot yield divided by the measured (if available) or estimated maximum yield of the location.

Currently, the index assumes one stress unit at flowering results in the same yield reduction as one stress unit prior to squaring. As indicated by previous research, the impacts of stress units at the aforementioned times on seedcotton yield are not equal. Inclusion of a crop susceptibility factor should remove much of the location-related variability in the combined datasets and further solidify varietal response (Figure 9).

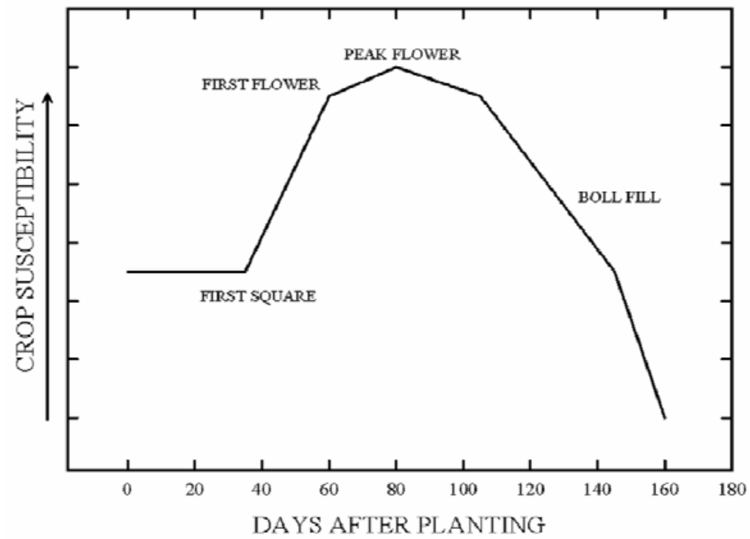


Figure 9: Proposed weighting of a crop susceptibility factor as a function of days after planting.

Varietal Response

Preliminary analysis of relationships between relative seedcotton yield and accumulated available H_2O stress index units suggests most varieties significantly affect regression intercept but not slope. Evidence for this can be seen in Figure 10. Each line in the aforementioned figure represents a single location-variety response. Although only two location-variety responses display noticeable differences in slope, a large number display differences in intercept. These responses suggest sensor deployment for the purpose of characterizing drought stress in dryland variety trials should be less than one standard variety. This will remove varietal response until the response is more fully understood.

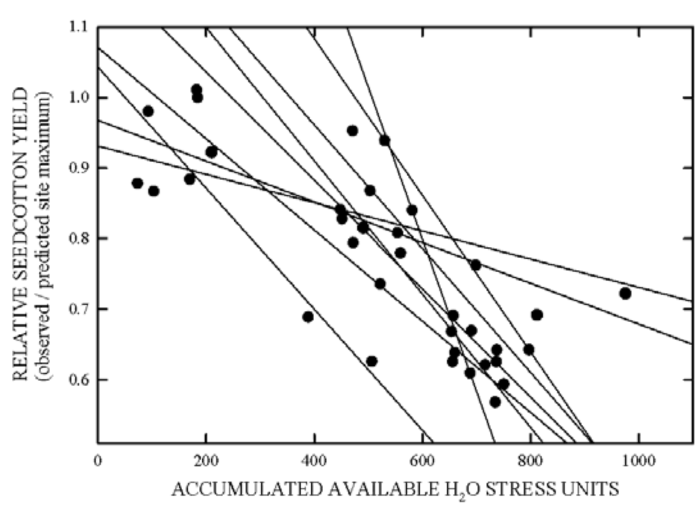


Figure 10: Response of accumulated available H_2O stress index units to relative seedcotton yield graphed by variety.

Conclusions

The determination of upper and lower boundaries of TAW by in-season readings resulted in the greatest correlations between accumulated available H_2O stress units yield. Spatial response within the same irrigation treatment suggests the number of sensors will be a response of field variability, as seen by the contrasting AR and SC locations. Initial analysis suggests varietal response is significant, and therefore if sensors are to be deployed into regional dryland variety trials, all soil moisture observations should be made under a standard variety. The utilized accumulated available H_2O index does seem to be a practical method of monitoring drought stress experienced during the growing season. However, more observations are needed to more accurately define the response of the index to variety and spatial variability and to include and test a crop susceptibility factor.

Acknowledgements

Funded by Cotton Incorporated project number 12-338.

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