Remote Sensing for Variable Rate Irrigation Management

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Abstract: *Irrigation using overhead sprinkler systems (primarily center pivots) is commonly used for corn and cotton production in the southeast USA. Technology for variable rate water application is available; however, it is not widely used due to increased management requirements. Methods to develop prescriptions in-season in response to changing crop conditions are needed to move this technology forward. The objective of this research was to evaluate the potential of using normalized difference vegetative index (NDVI) to estimate crop coefficients for development of spatial irrigation prescriptions. Field studies were conducted near Florence, SC, USA under center pivot irrigation systems equipped with variable rate technology. Studies in maize were conducted over several years comparing NDVI-based irrigation management to management with soil water sensors. The two methods did not significantly differ for yield or water volume applied. A cotton irrigation study was initiated in 2016 that compared the checkbook method (applying irrigation amount based on age of the crop and weekly precipitation totals) to NDVI-based irrigation prescriptions. Soil water sensors were used to initiate irrigation events. Irrigation amounts during the season for the NDVI-based method often differed from rates prescribed by the checkbook method up until about 70 days after planting when differences in NDVI among plant density treatments and field areas no longer existed. The results, along with the emerging use of air- and land-based remote sensing techniques, suggest continued research into the use of NDVI-based irrigation prescription technology is warranted.*

Introduction

Agricultural water management in the humid coastal plain region of the southeastern United States is problematic. Although this region generally receives adequate rainfall, the amount and distribution of rainfall is highly unpredictable. Additionally, croplands in the region have varying soil types with differing soil water holding capacities resulting in variable crop growth and yields (Sadler, et al., 2000). Variable rate irrigation systems (VRI) may be a tool to address these production problems. VRI systems are irrigation systems capable of applying different water depths both in the direction of travel and along the length of the irrigation system (Evans, et al., 2010). Thus, VRI systems can be tools for conserving water and spatially allocating water resources while potentially increasing profits (Evans and King, 2012). These VRI systems could also be used as a tool for improving crop water management and efficiency by delivering water to plants where needed, when the crop demands it, and in the appropriate amounts (O'Shaughnessy, et al., 2015). Although spatially variable water application technology is available and has high interest among growers, there has been limited adoption of VRI systems (Evans, et al., 2013). One potential reason for this limited adoption of VRI systems is the lack of science-based information on how to precision-apply water with these systems (Sadler, et al., 2005).

Both Sadler et al. (2005) and Evans, et al. (2013) identified critical research needs that included the development of decision support systems and integrated management systems to sense within-field variability in real time and dynamically define irrigation management zones. Dynamic management zones for VRI system management can be estimated using remote sensing methods including canopy reflectance and crop canopy temperatures. A popular method of estimating vegetation from growing plants is to use remotely sensed spectral vegetative indices. One of the most commonly used vegetative indexes is the normalized difference vegetation index (NDVI). It is defined as the difference between visible and near infra-red (NIR) measurements divided by their sum. The NDVI measurements can be used to assess the overall general health of the plants (Berger, et al., 2010).

NDVI can be used in irrigation management. For example Hunsaker et al. (2005a, 2005b) used NDVI measurements to calculate within-season real-time crop coefficients for irrigating wheat and cotton in Arizona. In Spain, Gonzalez-Piqueras et al. (2004) used NDVI measurements to calculate within-season crop coefficients for corn. Likewise, in South Carolina, Stone et al. (2016) investigated the use of NDVI to spatially irrigate corn and found that NDVI based irrigation has the potential to be effectively used in delineating dynamic management zones in fields irrigated with VRI systems. In this research, our objective was to evaluate the potential of using NDVI to estimate crop coefficients for developing spatial irrigation prescriptions for both corn and cotton crops.

Methods

Irrigation experiments were conducted at the USDA-ARS Coastal Plain Soil, Water, and Plant Research Center and at Clemson University's Pee Dee Research and Education Center using variable-rate irrigation (VRI) systems.

Corn Experiment: From 2012 to 2014, corn was grown on a 6 ha site under a VRI system at the USDA-ARS site Florence, South Carolina. The soils under the center-pivot irrigation system are highly variable. Two irrigation treatments were evaluated and compared for their potential for spatial irrigation management. A treatment based on measured soil water potentials (SWP) was compared to a treatment based on remotely sensing the crop normalized difference vegetative index (NDVI treatment). The SWP treatment used SWP sensors to maintain SWP values above -30 kPa (approx. 50% depletion of available water) in the top 30 cm of soils. The NDVI treatment used the measured NDVI values to calculate spatial crop coefficients to similar to methods used by Bausch (1993), Hunsaker et al. (2003), and Glenn et al. (2011). These estimated crop coefficients were used in the FAO 56 dual crop coefficient method for estimating crop evapotranspiration (ET_c) and irrigation requirements. The VRI system was divided into 4 quadrants with each treatment having three replicates per quadrant. Irrigation management for the SWP treatments was a 12.5 mm irrigation application when the SWP decreases below -30 kPa in the rooting zone. For the NDVI treatment, irrigation depths were applied to 4 sub-plots zones within each quadrant. Crop coefficients of plants in each sub-plot were calculated using the NDVI-Kc relationships (Kc = 1.5*NDVI -0.1) developed by Hunsaker et al. (2005b) and Gonzalez-Piqueras et al. (2004). Irrigation depths were determined by using these Kc values in a 7-day water balance using reference ET calculated from an on-site weather station.

NDVI was measured using a crop circle NDVI sensor (Crop Circle ACS-430 Active Canopy Sensor, Holland Scientific, Lincoln, Nebraska) mounted on the tractor spray boom and collected at 1-2 week intervals starting after planting through full canopy.

Cotton Experiment: At Clemson University's Pee Dee Research and Education Center, an experiment on irrigated cotton was conducted in a field that contains a commercial 305 m long site-specific center pivot irrigation system that has five 60 m long spans with each span configured to provide three 20-m irrigation zones. This center pivot is on a field that contains soils that differ in texture of the A horizon (ranging from sand to sandy loam). This experiment was conducted only under the outer span of the pivot. Three irrigation application amount treatments (spatially dependent application using NDVI, uniform, and rain-fed) were evaluated at low and normal plant densities. Two plant densities were utilized to allow for a greater range of NDVI within each replicate. Low plant density treatment had 5 seeds per m of row while normal plant density had 11.5 seeds per m of row (1.5 and 3.5 plants per foot of row). Plot size was 6° of arc long (ranging from 26 m to 32 m, depending on distance from pivot) and one irrigation management zone (20-m) wide. Seven treatment replicates were used in 84° of pivot travel.

In four of the replicates, SWP was measured (30 cm deep) in the uniform - normal plant density treatment combination. These tensiometers were used to trigger all irrigation events and irrigations were applied when they average -30 kPa. All irrigations were applied in amounts to provide the recommended three-day water amounts. Irrigation amounts for the uniform method were based on recommendations of the University of Georgia - Georgia Cotton Production Guide (http://www.ugacotton.com/vault/file/2017-Georgia-Cotton-Production-Guide.pdf)

Table 1. Cotton Irrigation Schedule (UGA - Georgia Cotton Production Guide).

Crop Stage	**Weekly**		**Daily**	
	Inches	**mm**	**inches**	**mm**
Week beginning at 1st bloom	1.0	25	0.15	4
2nd week after 1st bloom	1.5	38	0.22	6
3rd week after 1st bloom	2.0	51	0.30	8
4th week after 1st bloom	2.0	51	0.30	8
5th week after 1st bloom	1.5	38	0.22	6
6th week after 1st bloom	1.5	38	0.22	6
7th week and beyond	1.0	25	0.15	4

When SWP readings approached -30 kPa, NDVI in two interior rows of each NDVI irrigation method plot were measured using a handheld Greenseeker NDVI sensor (Trimble Agriculture, Westminster, CO USA**).** Crop coefficients of the plants in each plot were estimated using the NDVI-Kc relationship (Kc = 1.5*NDVI -0.1) developed by Hunsaker et al. (2005b) and Gonzalez-Piqueras et al. (2004).

Results

Annual rainfall for the three-year corn irrigation study varied widely from 620 mm in 2013 to 414 mm in 2014. The annual corn yields were significantly different with overall mean annual yields from 2012 to 2014 were 15.6, 10.5, and 13.5 Mg/ha, respectively. Since the annual yields were significantly different, we analyzed them individually and found that for the three-year study the treatment yields were not significantly different.

The NDVI measurements were then used to calculate crop coefficients. NDVI measurements were taken periodically throughout the growing season until tasseling. Figure 1 shows a progression of NDVI measurements as the crop grew from May 14, 2013 to June 21, 2013. The plots show the variability in NDVI throughout the field at various growth stages.

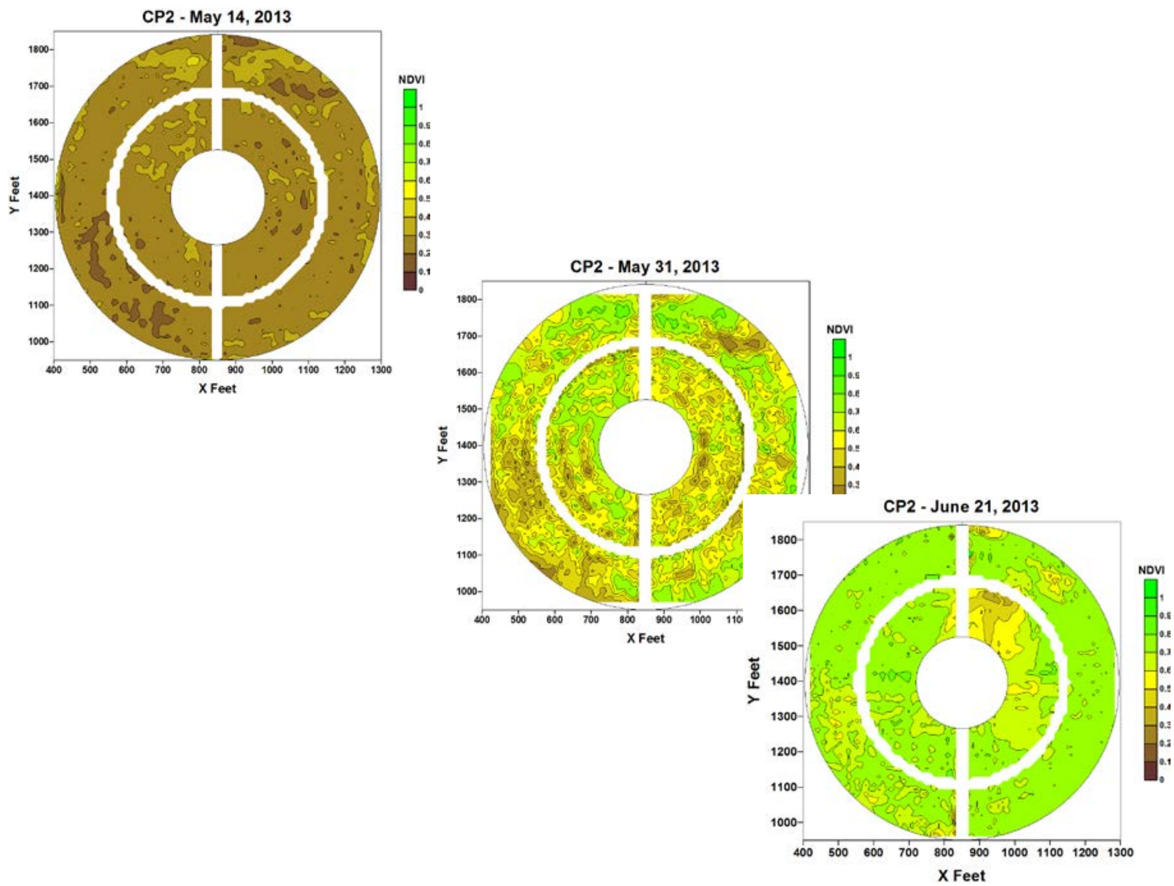

Figure 1. Example field maps of NDVI measurements over the growing season.

Since the treatment corn yields were not significantly different for any year of the study, we combined the NDVI reading across each treatment for analysis. Figure 2 shows a comparison of the yearly NDVI based calculated crop coefficients compared to the typical irrigation requirements based on the FAO-56 recommendations (Allen, et al. 1998). The 2012 growing season had near normal rainfall and the calculated crop coefficients were very similar to the FAO-56 coefficients. However, 2013 and 2014 had early season low temperatures that delayed crop growth and impacted the calculated crop coefficients. The 2013 and 2014 crop coefficients were approximately 1-2 weeks delayed from the recommended FAO-56 coefficients. During these years, if irrigation was based on the standard FAO-56 schedule, it would have applied irrigation in excess of crop demands during the early growing.

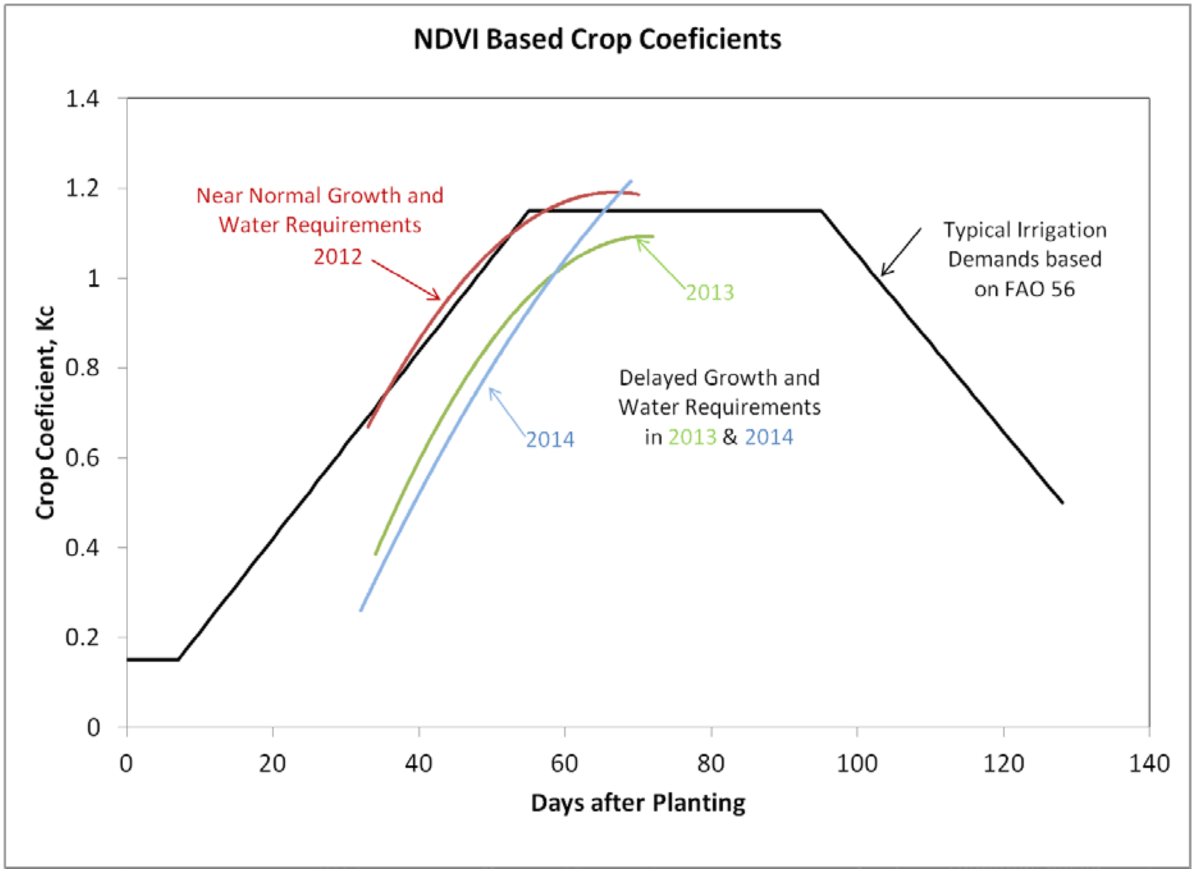

Figure 2. NDVI based crop coefficients for the 2012-2014 corn crops.

In 2016, we initiated an experiment to evaluate spatial irrigation of cotton based on NDVI readings. The calculated NDVI based crop coefficients are show in figure 3 and were compared to the FAO-56 recommended values. The NDVI based crop coefficients were similar to those of the FAO-56 recommendations. The different seeding rates show different NDVI measurements and associated crop coefficients indicating less total crop biomass and potentially reduced water requirements until they both reached full canopy closure.

An example irrigation event on June 21, 2016 for the cotton experiment is as follows. The checkbook treatment had an irrigation of 0.5 inches (13 mm). The VRI high plant population treatment had irrigation depths ranging from 0.2 to 0.6 inches (5-15 mm) with an average application of 0.39 inches (10 mm). The VRI low population treatment had irrigation depths ranging from 0.15 to 0.3 inches (4-8mm) with an average application of 0.24 inches (6 mm). Unfortunately, due to extreme weather at harvest, we were unable to obtain yield data. We plan on repeating the study in subsequent years.

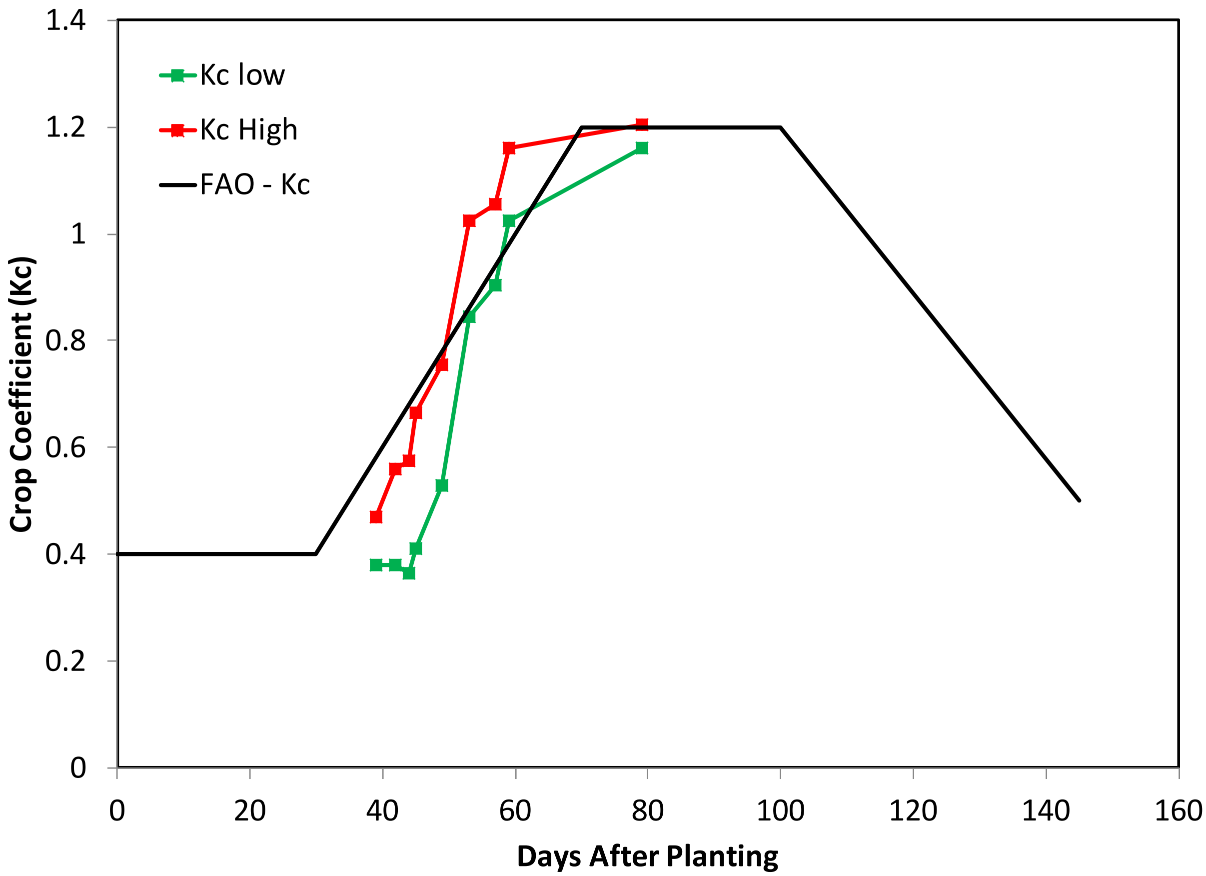

Figure 3. NDVI based crop coefficients for cotton.

Conclusions

Two experiments were carried out to evaluate the potential of using normalized difference vegetative index (NDVI) to estimate crop coefficients for development of spatial irrigation prescriptions. Field studies were conducted near Florence, SC under variable-rate irrigation systems. Studies in corn were conducted over several years comparing NDVI-based irrigation management to management with soil water sensors did not significantly differ for yield or water volume applied. However, there were annual differences indicating delayed crop water demand in two of three years due to delayed growth. A cotton irrigation study NDVI-based irrigation prescriptions had differing irrigation amounts during the season as compared to rates prescribed by the checkbook method up until about 70 days after planting when NDVI differences among the treatments no longer existed. The results of these two studies along with the emerging use of air- and land-based remote sensing techniques, suggest continued research into the use of NDVI-based irrigation prescription technology is warranted.

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