A VARIABLE-RATE IRRIGATION DECISION SUPPORT SYSTEM FOR CORN IN THE U.S. EASTERN COASTAL PLAIN

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HIGHLIGHTS

- A decision support system using the USDA-ARS Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) system was evaluated for spatially managing corn irrigation in the U.S. Eastern Coastal Plain.
- The ISSCADA system was compared to traditional scheduling methods based on measured soil water potentials.
- The ISSCADA system with feedback on allowable soil water depletion shows potential as a tool for growers for managing variable-rate irrigation systems.

ABSTRACT. *Variable-rate irrigation (VRI) systems are capable of applying different water depths both in the direction of travel and along the length of the irrigation system. VRI systems maybe useful for improving crop water management and efficiency. Although VRI technology is available and has high grower interest, it has had limited adoption. To address this, researchers have developed a decision support system that uses remote sensing of plant, soil, and microclimate to schedule VRI irrigations. In this research, we evaluated the use of the USDA-ARS Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) system for spatially managing corn irrigation in the U.S. Eastern Coastal Plain. The ISSCADA system consists of center pivot mounted infrared thermometers (IRT) to measure crop canopy temperatures and* in situ *soil water sensors. An integrated crop water stress index (iCWSI) was calculated from the canopy temperatures. The ISSCADA system analyzes the iCWSI and soil water measurements to provide an irrigation recommendation. The ISSCADA system was evaluated using (1) iCWSI values and (2) a hybrid ISSCADA system that incorporated both iCWSI values and soil water depletion criteria. These ISSCADA treatments were compared to traditional irrigation management using measured soil water potentials. The ISSCADA system was evaluated for four years. In 2016 and 2017, corn yields and water use efficiency were not significantly different between the irrigation treatments due to adequate rainfall during the growing season. In 2018 and 2019, mid-season drought conditions and sporadic rainfall patterns required frequent irrigations. In both years, the irrigation treatment corn yields were not significantly different from each other but were greater than the rainfed yields. In 2018, the irrigation treatments produced corn yields of 10.7, 10.4, and 10.1 Mg ha^{-1} for the hybrid, ISSCADA, and SWP treatments, respectively. Over the four-year study, the water use efficiencies of the irrigation treatments were not significantly different from each other or the rainfed treatment and ranged from 16.6 to 22.7 kg ha^{-1} mm^{-1}. In the two years that the hybrid ISSCADA system was used for managing irrigations, it produced higher corn yields and required less irrigation than the standard ISSCADA treatments. Results from this experiment will help to evaluate and refine the ISSCADA system to provide a tool for growers to use in managing spatial irrigation with VRI systems.*

Keywords. *Crop water stress, Decision support system, Variable rate irrigation.*

Variable-rate irrigation (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 limited water resources while potentially increasing profits (Evans and King, 2012). Spatially variable water applications with VRI systems attempt to overcome site-specific problems that include spatial variability in topography, soil type, soil water availability, and other landscape features but may also be used in response to site-specific crop water requirements. These VRI systems can 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

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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). Using VRI, spatial water application can be either static or dynamic during the growing season based on soil and crop monitoring. Static water application maps are usually based on soil survey maps, aerial photographs, producer knowledge of the fields, and on soil electrical conductivity (EC) field maps together with historic yield maps (Lund et al., 2001; Perry et al., 2007). Static water application maps are problematic in that spatial variability of crop water stress throughout the growing season is often overlooked. This spatio-temporal crop variability can be a consequence of spatially variable precipitation, topography, soil infiltration rates, soil fertility, and soil water storage capacity (Sadler et al., 2005), as well as other factors such as variable plant stand, or disease and pest infestation (Falkenberg et al., 2007). For dynamic spatial water applications, 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 crop canopy temperatures.

Canopy temperature measurements are widely used as indicators of crop water stress. An early study by Idso et al. (1981) used remotely sensed canopy temperature to calculate a foliage-air temperature differential that was related to crop water stress. Jackson et al. (1981) also reported the use of remotely sensed crop canopy temperatures and related them to a crop water stress index (CWSI). Canopy temperatures have also been used to measure spatial crop responses to irrigation. Sadler et al. (2002) mounted infrared thermometers (IRT) onto a center pivot irrigation system to measure spatial variation in water stress for a corn crop with four irrigation treatments and were able to determine significant differences among the irrigation treatments as well as within and among the soil mapping units. In the Texas High Plains, Peters and Evett (2004a) developed a similar system to measure spatial soybean canopy temperatures. They automated their center pivot irrigation system using the temperature-time-threshold (TTT) irrigation scheduling method based on a method of modeling diurnal canopy temperatures using one-time-of day measurements (Peters and Evett, 2004a, 2004b, 2008). Later, O'Shaughnessy and Evett (2010) developed a wireless sensor network for monitoring crop canopy temperatures using a moving irrigation system. O'Shaughnessy et al. (2013) combined the CWSI with the method of Peters and Evett (2004b) into an integrated CWSI (iCWSI) that better represented crop water stress than did a single time of day CWSI. This iCWSI approach was then used in automating irrigations and developing dynamic prescription maps for VRI management using the ARS Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) system (Andrade et al., 2015; O'Shaughnessy et al., 2013).

These studies have demonstrated the effectiveness of canopy temperature measurement in observing spatial crop response to water stress and in automating VRI systems. These VRI automation methods need to be evaluated in different environments, particularly more humid environments where interactions with rainfall make irrigation scheduling a more complex process. In this research, the ISSCADA system was evaluated for potential use in managing VRI of corn in the humid southeastern U.S. and was compared to a method used in the region based on soil water potential (SWP) measurements. Our specific objective was to compare irrigation management using (1) the ISSCADA system, (2) a hybrid ISSCADA system, and (3) SWP irrigation scheduling.

Materials and Methods

The experiment was conducted from 2016 to 2019 under a center-pivot VRI system located at the USDA-ARS Coastal Plains Soil, Water, and Plant Research Center in Florence, South Carolina (34° 14′ 43″ N, 79° 48′ 26″ W). The experiment consisted of three treatments: (1) irrigation management using the ISSCADA system, (2) irrigation management based on maintaining SWP in the rooting zone < -30 kPa (~50% depletion of plant available water), and (3) non-irrigated. In 2018 and 2019, the ISSCADA plots were divided into either into an ISSCADA-only treatment or a hybrid treatment based on a combination of ISSCADA plus soil water depletion.

Treatment plots were established under the VRI system in a randomized complete block plot design with eight replicates (fig. 1). The pivot area was divided into eight 45° segments with a complete block containing each of the three treatments in each segment. The plot width along the VRI lateral was approximately 15 m. To reduce impacts from overlap between management zones, two zones were combined into one management zone approximately 30 m wide. If multiple soil types occurred within a plot, irrigation management using SWP was based on the plots' dominant soil type, while irrigation management with the ISSCADA system used an average of the entire plots' canopy temperature.

Irrigation Management

The ISSCADA system integrates soil water, plant, and weather data together to produce prescription map recommendations for managing VRI systems (Andrade et al., 2015; O'Shaughnessy et al., 2013, 2016). The ISSCADA system calculated an integrated crop water stress index (iCWSI) to estimate when to initiate irrigation and the soil water depletion to determine the amount of irrigation. Prior to canopy closure, when the ISSCADA infrared thermometers (IRT) were reading both ground and vegetation temperatures, the ISSCADA treatments irrigations were based on measured soil water depletion. After canopy closure, when the IRTs were only reading vegetation, irrigations for the ISSCADA system were initiated based on IRT measurements and calculated iCWSI. A schematic of the ISSCADA process for determining a spatial irrigation application is

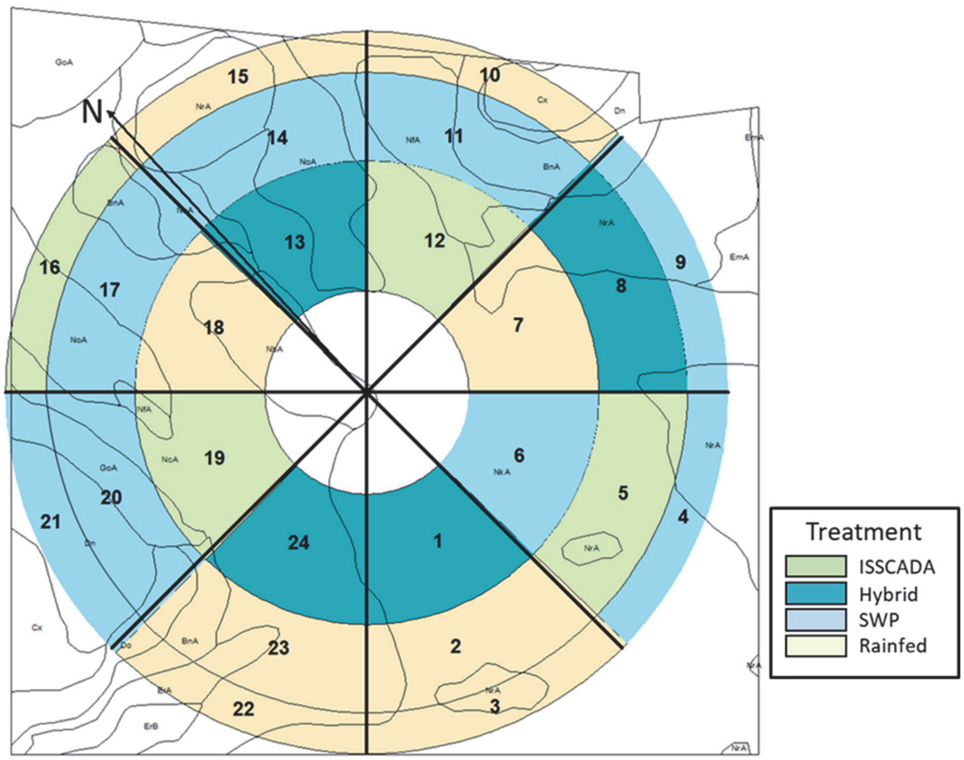

Figure 1. Plot layout for the irrigation experiment overlaid on a field soil map. In 2018 and 2019, the eight initial ISSCADA plots were divided into four ISSCADA plots and four hybrid plots. The treatment map is rotated approximately 44° from north to accommodate the underlying soil map. The numbers represent the plot numbers.

shown in figure 2. Irrigation application depth for the ISSCADA treatments based on iCWSI was as follows:

If iCWSI < 100 then no irrigation.
If 100 < iCWSI < 150 then minimum depth irrigation (6 mm).
If 150 > iCWSI < 250 then medium depth irrigation (10 mm).
If iCWSI > 250 then maximum depth irrigation (12.5 mm).

For the SWP treatment, irrigation was initiated when the SWP at the 0.3 m depth decreased below -30 kPa. When this condition was met, the SWP plots received an irrigation application of 12.5 mm. The non-irrigated plots did not receive irrigation applications.

In 2018 and 2019, the hybrid treatment was managed according to the measured soil water deficit (SWD, ranging from 0 to 1) as follows:

If SWD < 0.1 then no irrigation.
If 0.1 < SWD < 0.5 then use iCWSI method.
If SWD > 0.5 then maximum depth irrigation (12.5 mm).

Measurements

In the SWP treatment plots, SWP sensors (Watermark, Irrometer, Riverside, Cal.) were installed at 0.3 and 0.6 m depths and recorded at least three times per week. In the ISSCADA plots, soil water content was measured using TDR-315 sensors (Acclima, Meridian, Ida.) at four depths (0.15, 0.3, 0.45, and 0.6 m). The soil water contents were recorded on an hourly basis coupling the TDR-315 sensors with a data logger (CR206X, Campbell Scientific, Logan, Utah). Crop temperature was recorded using Dynamax wireless infrared thermometers (IRT) (Dynamax, Houston, Tex.) mounted on the VRI pivot at each management zone border with opposing, oblique views of the management zone (two IRTs for each management zone). IRT measurements were recorded at 1 min intervals and collected at the ISSCADA controller. At defined intervals, the VRI system was operated (i.e., one complete revolution of center pivot system) without irrigating over the treatment plots to record the crop temperatures. These crop temperatures were then used for calculating iCSWI and managing irrigation applications in the ISSCADA plots (fig. 2).

Crop Management

Each year, field preparation started with an application of glyphosate via a tractor-mounted sprayer to control winter weeds. Field tillage at corn planting consisted of in-row subsoiling. The corn (Dekalb 66-97) was planted in 76 cm rows in a circular pattern with a planting population of 79,000 seeds ha^{-1}. The planting dates for the four years were 16 April 2016, 10 April 2017, 12 April 2018, and 18 April 2019. All nitrogen fertilizer, except pre-plant granular applications (25 kg N ha^{-1}), was applied via fertigation. The corn nutrient and weed management was based on Clemson University Extension recommendations. The field was planted in circles using a GPS-guided tractor to facilitate delineation of the irrigation management zones and plots. Irrigation was halted when the crop reached black-layer (2 August 2016, 2 August

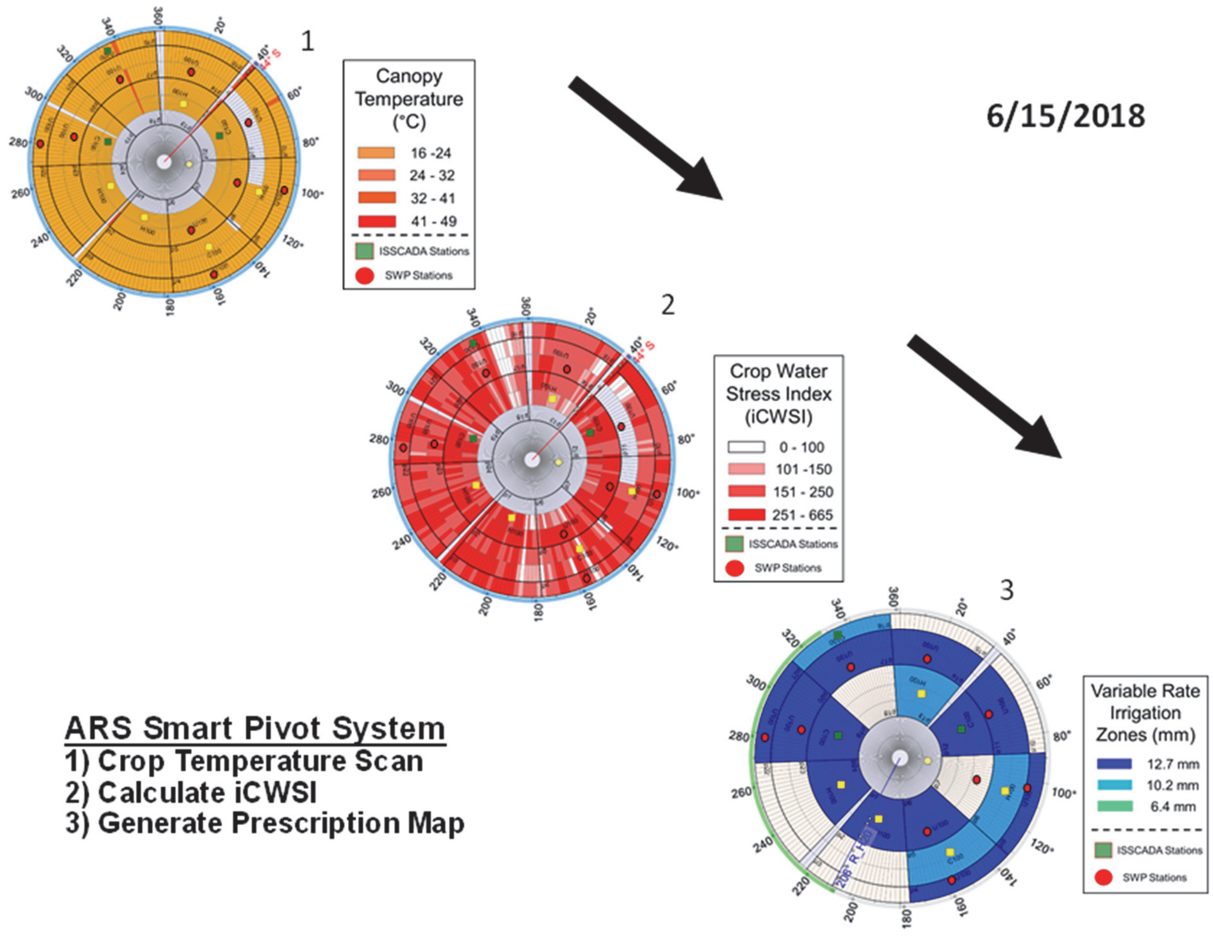

Figure 2. Example schematic of the ISSCADA process for determining a spatial irrigation prescription.

2017, 2 August 2018, and 8 August 2019). The corn was harvested on 1 September 2016, 8 September 2017, 29 August 2018, and 5 September 2019.

At harvest, grain yield in each plot was measured in 6 m of two corn rows near the center of each plot. In 2017 and 2018, the plots were hand-harvested. In 2019, a plot combine was used to harvest the plots. In 2016, due to an impending tropical storm and harvest urgency, plot yields were estimated from yield maps. Plot grain samples were weighed and dried, and all grain yields were adjusted to 15.5% moisture content (wet basis). An on-site weather station recorded rainfall and provided the environmental parameters used to calculate daily reference evapotranspiration (ET_o) using the ASCE standardized equation (Allen et al., 2005). Crop evapotranspiration (ET_c) was calculated using the dual-crop-coefficient method of Allen et al. (1998).

Data Analysis

The corn yield, water use efficiency (WUE), and irrigated water use efficiency (IWUE) were analyzed as a randomized complete block design using analysis of variance. The WUE was calculate by dividing the yields by the total water applied (rain + irrigation) to the plot. The IWUE was calculated as the yield increase over the rainfed yields divided by the plot irrigation. Treatment means were separated with the Waller-Duncan k-ratio and Fisher's least significant test using SAS (SAS Institute, Cary, N.C.). All significant differences between treatment mean are reported at the 95% confidence level.

Results and Discussion

Rainfall and Irrigation

Rainfall was generally equal to or higher than the estimated crop evapotranspiration in three of the four years of the study (table 1). In 2016 and 2017, rainfall was higher (512 and 494 mm, respectively) than normal during the growing seasons (424 mm, April to July long-term precipitation, South Carolina Climatology Office 2020, http://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php) and was well distributed through the tasseling and grain filling stages (table 1, figs. 3 and 4). In both 2016 and 2017, the SWP was generally below the threshold of -30 kPa (data not shown). On three days in both 2016 and 2017, irrigations were required (figs. 3 and 4). The SWP treatments required 38 mm of irrigation in 2016 and 47 mm of irrigation in 2017. The ISSCADA treatments in 2016 and 2017 required 25 and 43 mm of irrigation, respectively. In 2018, the seasonal rainfall was 487 mm and was not as well distributed throughout the growing season (fig. 5). The rainfall was generally adequate and greater than the crop evapotranspiration early in the growing season until approximately mid-June

Table 1. Growing season mean daily maximum and minimum temperatures and cumulative rain, crop (ET_c) and reference (ET_o) evapotranspiration.

	Daily Temperature				
Year	Max. (°C)	Min. (°C)	Rain (mm)	ET_c (mm)	ET_o (mm)
2016	29	17	512	491	583
2017	30	19	494	493	587
2018	30	19	487	419	510
2019	31	19	409	462	552

when tasseling occurred, resulting in the need for irrigation applications.

Greater irrigation depths were applied in 2018 than in the previous two years. The SWP treatments received an average irrigation depth of 117 mm. Average irrigation depths were 126 mm for the ISSCADA treatments and 113 mm for the hybrid treatments. The irrigation depth distribution between the treatments are shown in figure 6 and show the variability in irrigation requirement for individual plots. The ISSCADA treatment irrigation depths were fairly uniform, while the hybrid and SWP treatments were more varied depending on the individual plots.

The 409 mm rainfall in 2019 was lower than the long-term seasonal average (table 1). The rainfall deficit started earlier in 2019 (mid-May) and continued sporadically throughout the growing season, with large rainfalls followed by periods with little or no rain (fig. 7). Irrigations for the hybrid and ISSCADA treatments were 115 and 126 mm, respectively, and were much higher than the SWP application depth (68 mm). The irrigation depth distribution in 2019 was similar to that in 2018, with the ISSCADA plots relatively uniform and the hybrid and SWP plots more variable (fig. 8). The 2019 irrigations for the hybrid and ISSCADA treatments were similar to those in 2018.

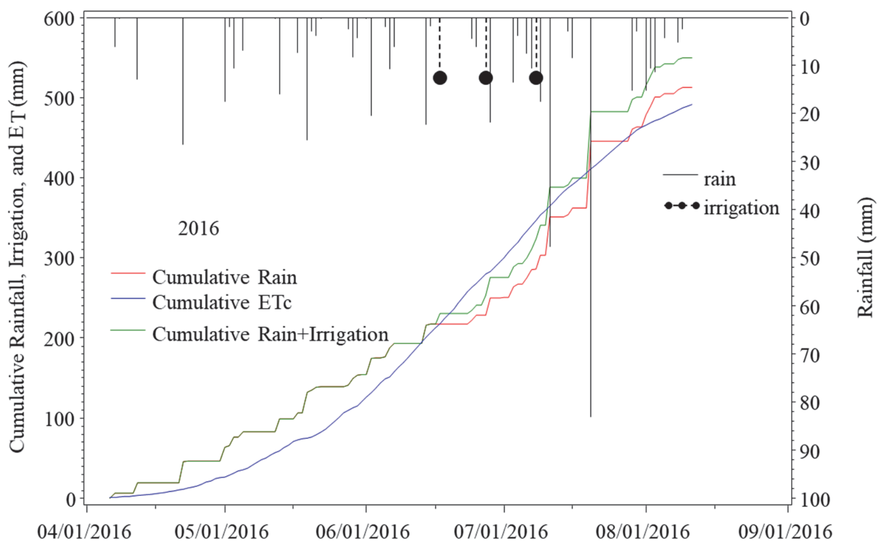

Figure 3. Cumulative rainfall, crop evapotranspiration (ET_c), rain and irrigation for the 2016 growing season. The irrigation symbols indicate days on which irrigation events occurred.

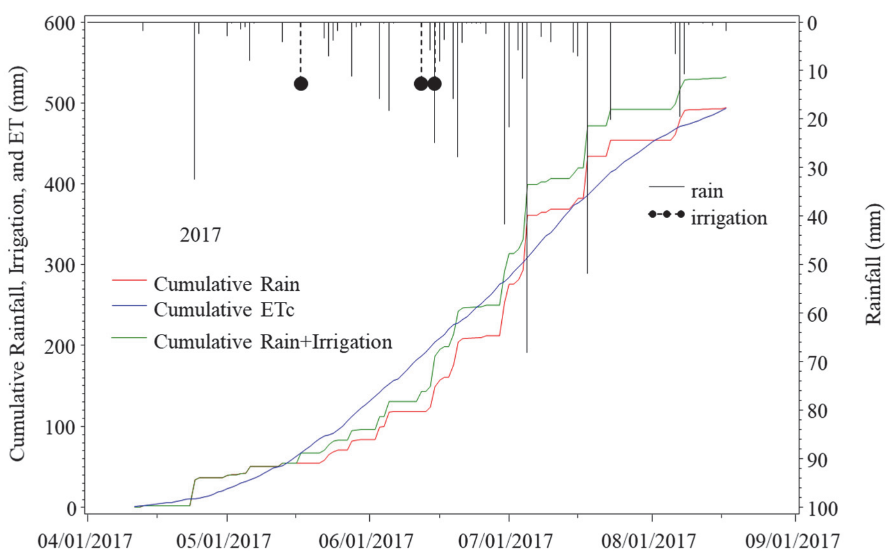

Figure 4. Cumulative rainfall, crop evapotranspiration (ET_c), rain and irrigation for the 2017 growing season. The irrigation symbols indicate days on which irrigation events occurred.

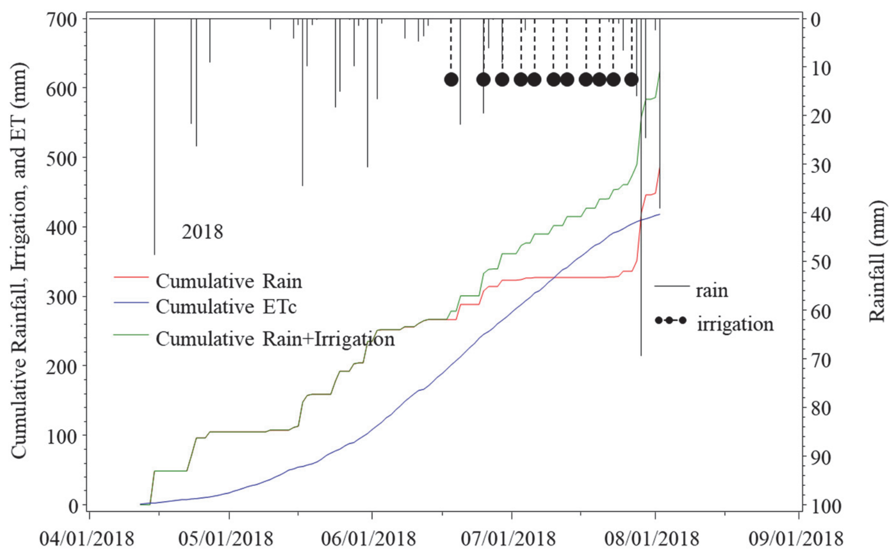

Figure 5. Cumulative rainfall, crop evapotranspiration (ET_c), rain and irrigation for the 2018 growing season. The irrigation symbols indicate days on which irrigation events occurred.

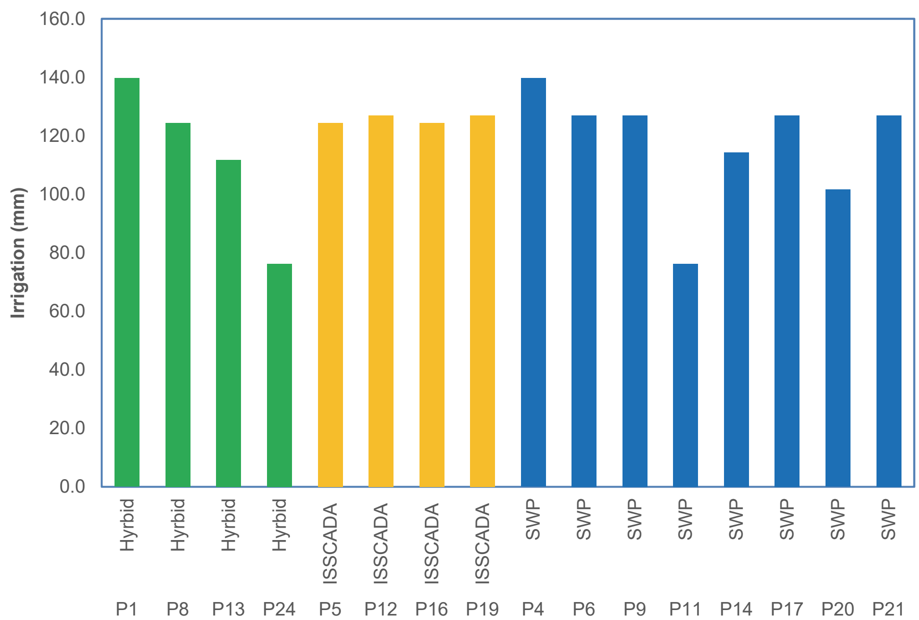

Figure 6. Irrigation depth distribution for the treatments in 2018.

Grain Yields

Overall for the four-year study, the corn grain yields were significantly greater for the irrigation treatments than for the rainfed treatments (table 2). However, the irrigated treatment grain yields were not significantly different from each other. Due to annual differences in rainfall and climatic conditions, the corn grain yields were analyzed individually for each year.

The 2016 corn grain yields for the irrigation treatments were significantly greater than the rainfed yields (table 3). The ISSCADA and SWP treatments averaged 11.3 and 11.7 Mg ha^{-1}, respectively, while the rainfed treatment averaged 10.5 Mg ha^{-1}. Due to the above-average and well-distributed seasonal rainfall, the SWP treatment required only three irrigations, and the ISSCADA treatment required only two irrigations. Even though there were only a few irrigations, their timing was sufficient to provide significantly greater grain yields than the rainfed grain yields.

In 2017, the grain yields for all treatments were not significantly different (table 3). The growing season rainfall was generally adequate, and there were only three days in which irrigation was required for the SWP and ISSCADA treatments. The average ISSCADA, SWP, and rainfed treatment grain yields were 10.2, 10.8, and 10.6 Mg ha^{-1}, respectively.

In 2018, all irrigation treatments grain yields were significantly greater than the rainfed treatment (table 3). The corn grain yields were 10.7, 10.4, and 10.1 Mg ha^{-1}, for the hybrid, ISSCADA, and SWP treatments, respectively, and the rainfed treatment yield was 7.8 Mg ha^{-1}. Due to the lower

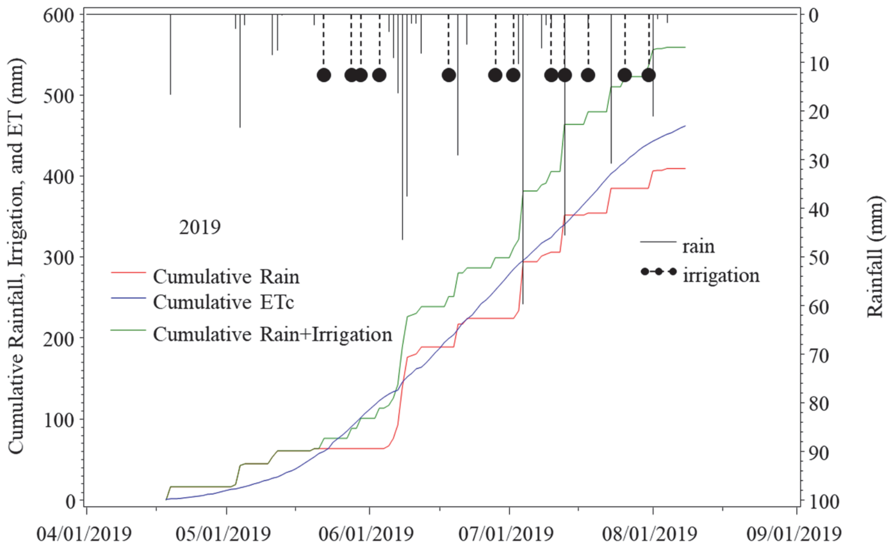

Figure 7. Cumulative rainfall, crop evapotranspiration (ET_c), rain and irrigation for the 2019 growing season. The irrigation symbols indicate days on which irrigation events occurred.

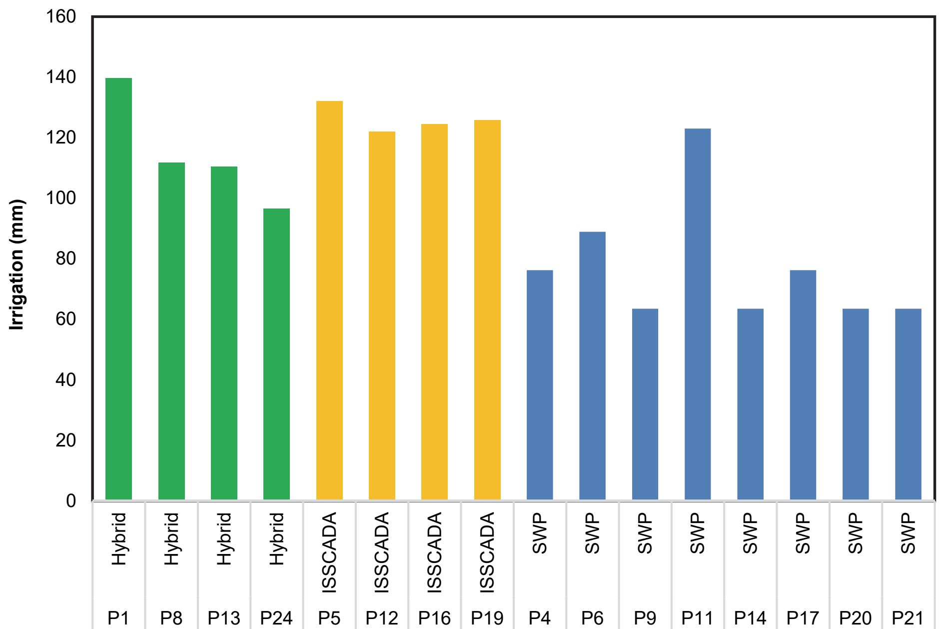

Figure 8. Irrigation depth distribution for the treatments in 2019.

Table 2. Overall results from the 2016-2019 irrigation studies.

	Yield[a] (Mg ha^{-1})		Irrigation (mm)	
Treatment	Mean	SD	Mean	SD
Hybrid	11.0 a	1.5	114	21
ISSCADA	10.6 a	1.0	58	49
SWP	10.6 a	1.5	62	38
Rain	9.6 b	1.6	0	0

[a] Column means with the same letter are not significantly different at the 5% level.

rainfall during the tasseling through grain filling stages, the rainfed yield in 2018 was considerably lower than the rainfed yields in either 2016 or 2017. The hybrid treatment had a greater average yield than the ISSCADA-only treatment while requiring less average irrigation. The use of canopy temperature along with soil water feedback improved the irrigation management.

In 2019, the corn grain yields were mixed. As previously discussed, rainfall was sporadic during the growing season, and the irrigation treatments benefitted from irrigation, resulting in greater yields than the rainfed treatment (table 3). The hybrid treatment yield was significantly greater than the rainfed treatment yield but was not significantly greater than the ISSCADA or SWP treatment yields (table 3). The hybrid treatment yield (11.3 Mg ha^{-1} was slightly higher than the ISSCADA and SWP treatment yields (10.1 and 9.8 Mg ha^{-1}, respectively).

The South Carolina statewide average corn grain yields for 2016 to 2019 ranged from 6.7 to 8.5 Mg ha^{-1}, and the 2017 average irrigated grain yield was 11 Mg ha^{-1} (USDA-

Table 3. Yearly results for the irrigation studies for yield, irrigation, water use efficiency, and irrigation water use efficiency.

Year	Treatment	Yield[a] (Mg ha^{-1})		Rain (mm)	Irrigation (mm)		Water Use Efficiency[a] (kg ha^{-1} mm^{-1})		Irrigation Water Use Efficiency[a] (kg ha^{-1} mm^{-1})	
		Mean	SD	Mean	Mean	SD	Mean	SD	Mean	SD
2016	ISSCADA	11.3 a	1.0	512	25	0	21.0 a	1.8	32.0 a	38.5
	SWP	11.7 a	0.6	512	38	0	21.3 a	1.1	31.4 a	16.3
	Rain	10.5 b	1.0	512	0	0	20.5 a	2.0	-	-
2017	ISSCADA	10.2 a	0.5	494	23	4	19.8 b	1.0	-18.0 a	22.5
	SWP	10.8 a	1.1	494	27	10	20.8 ab	2.0	-5.5 a	63.5
	Rain	10.6 a	0.7	494	0	0	21.5 a	1.5	-	-
2018	Hybrid	10.7 a	0.7	487	113	27	17.8 a	1.1	26.4 a	7.4
	ISSCADA	10.4 a	0.7	487	126	1	17.0 a	1.2	20.9 a	5.8
	SWP	10.1 a	2.1	487	117	20	16.6 a	3.1	17.3 a	17.1
	Rain	7.8 b	1.3	487	0	0	16.0 a	2.6	-	-
2019	Hybrid	11.3 a	2.1	409	115	18	21.5 a	3.3	15.8 a	15.4
	ISSCADA	10.1 ab	1.4	409	126	4	18.9 a	2.6	6.3 a	11.3
	SWP	9.8 ab	1.1	409	68	12	20.54 a	2.1	6.4 a	15.1
	Rain	9.3 b	1.6	409	0	0	22.7 a	4.0	-	-

[a] Column means with the same letter are not significantly different at the 5% level.

NASS QuickStats 2020, https://quickstats.nass.usda.gov/). The grain yields in this study exceeded the statewide averages and were approximately the same as the state average irrigated grain yield. Overall, the corn grain yields were greater for the irrigation treatments than for the rainfed treatment in three of the four years. In 2017 and 2018, when rainfall was more sporadic, the irrigation treatments were not significantly different from each other. In 2018 and 2019, the hybrid treatment had greater yields than the ISSCADA and SWP treatments.

Water Use Efficiency (WUE) and Irrigation WUE

The corn grain yield was divided by the combined irrigation and rainfall to calculate the water use efficiency (WUE) for each treatment. The WUE values for the four-year study varied from 16 to 22 kg ha^{-1} mm^{-1} across all treatments (tables 2 and 3). In only one year of the four-year study was there a significant difference between WUE for the treatments, with the 2017 rainfed WUE significantly greater than the ISSCADA WUE. In that year, the ISSCADA and SWP treatments were not significantly different. In 2017 and 2019, the rainfed treatment had greater WUE values, although not significantly greater. In 2017, there was little irrigation, and in 2019 considerable irrigation was required. In three of the four years, the WUE values were greater for SWP than for ISSCADA. In 2018 and 2019, the hybrid treatment had the highest WUE of the irrigation treatments. In a previous study at this site, Stone et al. (2016) reported WUE values ranging from 17 to 30 kg ha^{-1} mm^{-1}. The WUE values in our study were within that previous study's values. Previously reported WUE values for corn in Colorado ranged from 10 to 22 kg ha^{-1} mm^{-1} (Benjamin et al., 2015), and WUE values in Texas ranged from 14 to 25 kg ha^{-1} mm^{-1} (Kiniry et al., 2008). O'Shaughnessy et al. (2019) reported WUE values ranging from 16 to 22 kg ha^{-1} mm^{-1} in north Texas.

The irrigated water use efficiency (IWUE) values in our study ranged from 32 to -18 kg ha^{-1} mm^{-1}. The negative IWUE values occurred in 2017 when little irrigation was required and the rainfed yields were greater than the irrigated treatment yields. This indicates that there is little or no benefit from irrigation in certain years at this location. For each year of the study, the IWUE values for each treatment were not significantly different.

The IWUE values for the SWP and ISSCADA treatments during the study period were generally very close in magnitude each year. In 2018 and 2019, the hybrid treatment had greater IWUE values than the other irrigation treatments. Similar IWUE values were reported by Gonçalves et al. (2020), ranging from 12 to 35 kg ha^{-1} mm^{-1} under center pivots in Nebraska.

Conclusions

From 2016 to 2019, we evaluated the USDA-ARS Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) system for irrigation management of a corn crop in the humid U.S. Eastern Coastal Plain. The ISSCADA system was evaluated against a scheduling method using SWP measurements to manage irrigation. Over the entire study period, the ISSCADA and SWP treatment yields were not significantly different, although the individual years had considerable variation in rainfall and different numbers of irrigation applications.

In both the 2016 and 2017 irrigation seasons, only two or three irrigations were required, and there were no statistical differences in corn yields across the two irrigation treatments due to the well-distributed seasonal rainfall. In 2018 and 2019, rainfall was not well distributed during the growing season, and considerably more irrigation was required than in the previous two years. In 2018 and 2019, a hybrid irrigation treatment using both the ISSCADA system and soil water deficits was added to the experiment. The hybrid treatment produced higher but not significantly greater yields than the other two irrigation treatments. The water use efficiencies were not significantly different between the irrigation treatments and the rainfed treatment, and the irrigation water use efficiencies were not significantly different between the irrigation treatments. Overall, the hybrid treatment showed promising improvements over the ISSCADA-only treatment. Results from this study indicated that the ISSCADA and hybrid treatment were effective in managing irrigation in the humid U.S. Eastern Coastal Plain. This study and ongoing research into the use of decision support systems that incorporate crop stress and available soil water will improve the utilization of water for crop production.

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