

Variable-rate irrigation management using an expert system in the eastern coastal plain

K. C. Stone · P. J. Bauer · W. J. Busscher · J. A. Millen ·
D. E. Evans · E. E. Strickland

Received: 14 September 2012 / Accepted: 21 December 2014 / Published online: 4 January 2015
© Springer-Verlag Berlin Heidelberg (outside the USA) 2015

Abstract Variable-rate irrigation (VRI) systems have the potential to conserve water by spatially allocating limited water resources. However, when compared to traditional irrigation systems, VRI systems require a higher level of management. In this 3-year study, we evaluated spatial irrigation management of a peanut crop grown under a VRI system using an expert system (Irrigator Pro). The irrigation management treatments evaluated were: (1) using Irrigator Pro (IP) to manage irrigation uniformly in plots with varying soils; (2) using Irrigator Pro to manage irrigation in plots based on the individual soils (IPS); (3) a treatment based on maintaining soil water potential (SWP) above -30 kPa (approximately 50 % depletion of available water) in the surface 30 cm of each soil within a plot; and (4) a non-irrigated treatment. Over the 3-year study, all irrigated treatments had significantly higher yields (4,230, 4,130, and 4,394 kg ha⁻¹ for the IP, IPS, and SWP treatments, respectively) than the non-irrigated treatment (3,285 kg ha⁻¹), yet the yields of the three irrigation treatments were not significantly different. Averaged over the 3-year experiment, the three treatments did not differ significantly in water usage. In the 2007 and 2009 growing seasons with below normal rainfall, the IP and IPS treatments required significantly greater total water than the SWP treatment. Overall, water use efficiency was significantly higher for the non-irrigated and SWP treatments (9.4 and 8.9 kg ha⁻¹ per mm, respectively). The lower water use efficiency for the IP and IPS

irrigation treatments (7.8 kg ha⁻¹ per mm) was attributed to greater water applications mainly due to earlier growing season initiation of irrigation applications. However, the IP and IPS treatments maintained soil water potentials at the 30- and 60-cm depths at higher levels throughout most of the season. The two Irrigator Pro expert system treatments functioned as well as the SWP-based treatment. The Irrigator Pro expert system can be effectively used for site-specific management where management zone soils do not greatly differ. Further refinement of the expert system may be needed to improve its application in spatial irrigation applications.

Introduction

Variable-rate irrigation systems are capable of spatially allocating 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. Spatial water application technology is available, and it has high grower interest. Farmers that have retrofitted their center pivot systems to make precision applications base their spatial applications on their past experience and 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 irrigation systems.

Decision support systems can assist in determining spatial water applications. Currently, there are no readily identified decision support systems for site-specific water

Communicated by P. Waller.

K. C. Stone (✉) · P. J. Bauer · W. J. Busscher · J. A. Millen ·
D. E. Evans · E. E. Strickland
Coastal Plains Soil, Water, and Plant Research Center,
USDA-ARS, Florence, SC, USA
e-mail: ken.stone@ars.usda.gov

management. However, the USDA-ARS-National Peanut Laboratory in Dawson, Georgia, has developed and distributed an expert system (Irrigator Pro) for peanut management (Davidson et al. 1998a, b). Irrigator Pro assists producers with irrigation management by integrating several factors including soil type, yield potential, previous crop, cultivar, and planting date. During the growing season, the expert system requires inputs of rainfall, soil temperature, percent chance of rain, canopy size, and date of fruit initiation, among others, to recommend a decision on when and how much to irrigate. Peanut is a major cash crop in the southeastern US, and irrigation is a major component in peanut production management (Smith et al. 2005). In the U.S. peanut producing regions during most growing seasons, irrigation is essential to maintain crop yield, quality, and income during most years (Lamb et al. 2004). Irrigation is critical because it allows the grower to take advantage of other inputs, improves the effectiveness of herbicides, lowers soil temperature to improve peg development, and greatly reduces aflatoxin risk (Chapin and Thomas 2005). Irrigator Pro integrates these factors together to assist growers in recommending irrigation management. Irrigator Pro has typically been used for uniform (whole field) applications. In this research, the potential of using

Irrigator Pro to spatially manage irrigation under a site-specific variable-rate irrigation system was evaluated. The specific objective was to compare spatial irrigation management using (1) Irrigator Pro for a whole plot containing multiple soil types, (2) Irrigator Pro for individual soil types within a plot, and (3) traditional soil water potential measurements for individual soils within a plot.

Materials and methods

Peanut (*Arachis hypogaea*) was grown under conservation tillage on a 6-ha site under a variable-rate center pivot irrigation (VRI) system near Florence, SC. Soils (Fig. 1) under the center pivot irrigation system are highly variable (Table 1). Three irrigation treatments were evaluated for their potential utilization for spatial irrigation management using the VRI system and compared to a non-irrigated treatment. The first two irrigation treatments were based on the Irrigator Pro expert system that was developed by the USDA-ARS-National Peanut Research Laboratory, Dawson, GA. This expert system has been tested extensively in uniformly irrigated fields (Davidson et al. 1998a, b; Lamb et al. 2004, 2007). In this research, the model will be

Fig. 1 Irrigated and non-irrigated plot layout for the 2007 peanut growing season. The plots were re-randomized for the 2009–2010 growing seasons. The numbers represent the locations for yield and soil water potential measurements

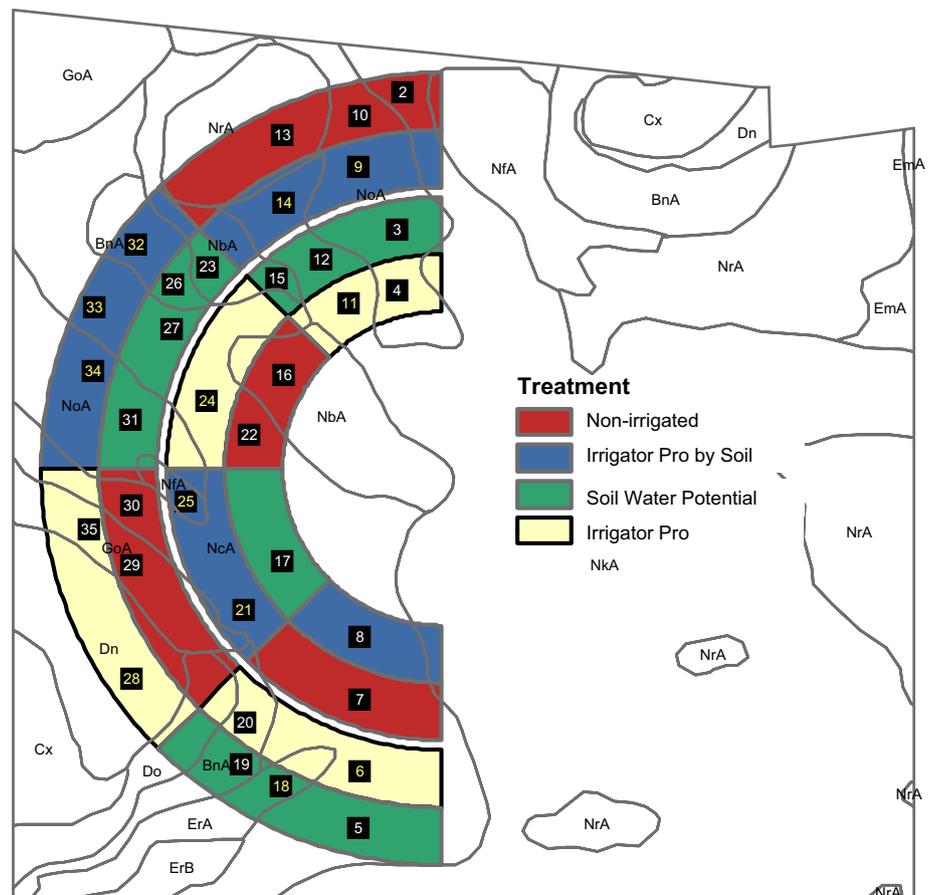


Table 1 Description of soils located under the variable-rate irrigation system at Florence, SC (after Sadler et al. 2002)

Symbol	Soil classification
BnA	Bonneau loamy fine sand (lfs), 0 to 2 % slopes
Cx	Coxville loam
Dn	Dunbar lfs
Do	Dunbar lfs, overwash
ErA	Emporia fine sandy loam (fsl), 1–2 % slopes
GoA	Goldsboro lfs, 0–2 % slopes
NbA	Noboco lfs, moderately thick surface, 0–2 % slopes
NcA	Noboco lfs, thick surface, 0–2 % slopes
NfA	Noboco fsl, 1–2 % slope
NkA	Norfolk lfs, moderately thick surface, 0–2 % slopes
NoA	Norfolk lfs, thick surface, 0–2 % slopes
NrA	Norfolk fsl, 1–2 % slopes

implemented using spatial management zones corresponding to variable soil types. Utilizing the expert system, the following treatments were used: (1) using Irrigator Pro (IP) to manage irrigation uniformly in plots with varying soils; and (2) using Irrigator Pro to manage irrigation in plots based on the individual soils (IPS). These two treatments were compared with an irrigation treatment based on maintaining soil water potential (SWP) above -30 kPa (approximately 50 % depletion of available water) in the surface 30 cm of each soil within a plot. The fourth treatment was not irrigated; it served as a measure of the effectiveness of irrigation.

The experiment was conducted in 2007, 2009, and 2010. The treatments were initially randomized in 2007 and were re-randomized in 2009 (Fig. 1) to ensure that each soil was included in the treatments. The 2010 treatments were the same as in 2009. In 2009, all irrigations were halted after August 20 due to equipment failure on the center pivot irrigation system (approximately the last 25 % of the growing season).

Irrigation was performed with a center pivot irrigation system modified to permit variable application depths to individual areas 9.1×9.1 m in size (Omary et al. 1997; Camp et al. 1998). The center pivot length (137 m) 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 had nozzles sized to deliver $1\times$, $2\times$, or $4\times$ of a base application depth at that location along the center pivot length. All combinations of the three manifolds provided application depths of 0 through $7\times$ of the base rate, and the $7\times$ depth was 12.7 mm when the outer tower was operated at 50 % duty cycle. The manifolds were operated by individual solenoid valves controlled with a computer and programmable logic controller (PLC) (model 90-30, GE Fanuc, Charlottesville, Va.) that

obtained positional (angular) data from the C:A:M:S management system (Valmont Industries, Inc., Valley, NE). A software control program written in Visual Basic (Microsoft, Redmond, WA) controlled the PLC using fixed positional data and user-supplied data stored in the computer and angular positional data from the center pivot management system. 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).

Planting details

Field preparation started with an application of glyphosate to control winter weeds. Field tillage prior to peanut planting consisted of in-row sub-soiling. The NC-V 11 peanuts were planted in single rows 0.96 m apart, with a planting population of 19.7 seeds per meter. Temik and implant inoculants were added in-row using a split chemical drop applicator on the planter at a rate of 5.6 kg/ha each. The planting dates for the 3 years were 5/17/2007, 5/20/2009, and 5/13/2010. Herbicide and fungicide rates were applied according to Clemson's Peanut Money-Maker Production Guide (Chapin and Thomas 2005).

Soil water potential measurement

Soil water potentials (SWP) were measured at thirty-five individual locations (Fig. 1) within the experiment. In each treatment and replication, tensiometers were installed in the individual soil types within each plot. The gage type tensiometers (Soilmoisture Equipment Corp, Santa Barbara, CA) were installed at two depths (0.30 and 0.60 m). Measurements were recorded at least three times each week. The 0.30-m tensiometers in the SWP treatments were used to trigger irrigation applications. When the soil water potential in the predominate soil of a SWP plot decreased below -30 kPa, a 12.5-mm irrigation application was applied to that plot. Additionally, if soil water potentials decreased below -50 kPa, an additional 12.5 mm of irrigation was applied if the rainfall forecast was less than 50 %. In the IP and IPS treatment, the soil water potentials were monitored to compare to the other non-irrigated and SWP treatments.

Harvest details

Peanut digging was accomplished using a KMC 2-row peanut digger. 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 crop for the entire field. The peanut plots were harvested on 10/15/2007, 11/06/2009, and 10/13/2010. Small subplot areas were harvested separately to compare with the yield monitoring system. All samples were

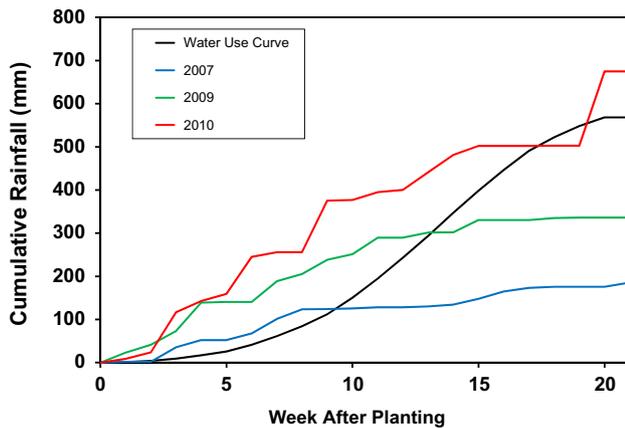


Fig. 2 Yearly rainfall distribution for the 2007, 2009, and 2010 peanut growing seasons along with the peanut crop water use curve (Beasley 2007)

oven dried, and plot yields were adjusted to 7 % moisture content. After yields and total water applied to each treatment were determined, the water use efficiency (WUE) was calculated by dividing the mean plot yield by the total water applied (irrigation + rainfall). The WUE values were reported in units of kg ha^{-1} of crop per mm of water applied.

Statistical analyses

All data were statistically analyzed in SAS (Statistical Analysis System, SAS Institute, Cary, NC) using Proc GLM. The experimental design was a randomized block design with four replicates. Replicates were considered random. An initial analysis combined over all years indicated that the years were significantly different, so analysis was conducted on each year individually for yield and total water usage. Treatment means were separated using the Waller-Duncan *k*-ratio and Fisher's least significant tests. Homogeneity of variance test was used to determine differences among the treatments using Bartlett's test in Proc GLM.

Results and discussion

Rainfall

Long-term, average seasonal (May–September) rainfall for the study area was 559 mm (SC State Climatologist 2010). For 2007 and 2009, seasonal rainfall totals were below the long-term average with 185 and 336 mm, respectively (Fig. 2). The 2010 seasonal rainfall total was 675 mm and was greater than the long-term average. Additionally for each study year, the rainfall distribution was different. In

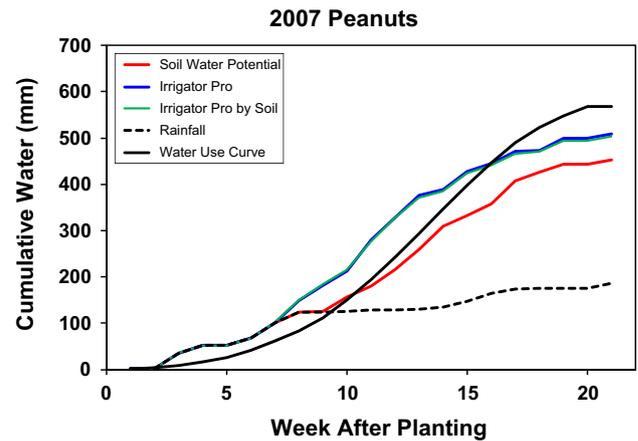


Fig. 3 Weekly cumulative water for the 2007 peanut growing season for the four irrigation treatments

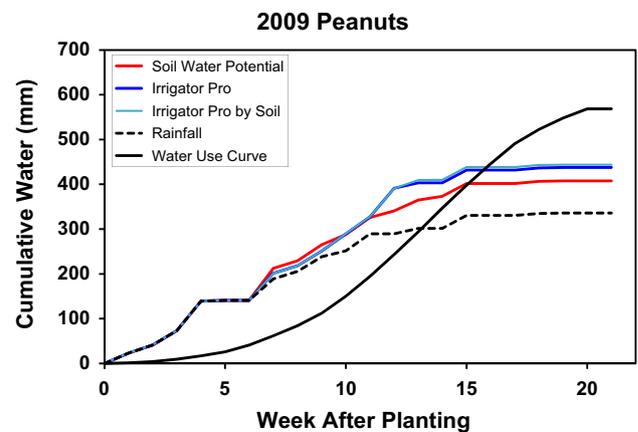


Fig. 4 Weekly cumulative water for the 2009 peanut growing season for the four irrigation treatments

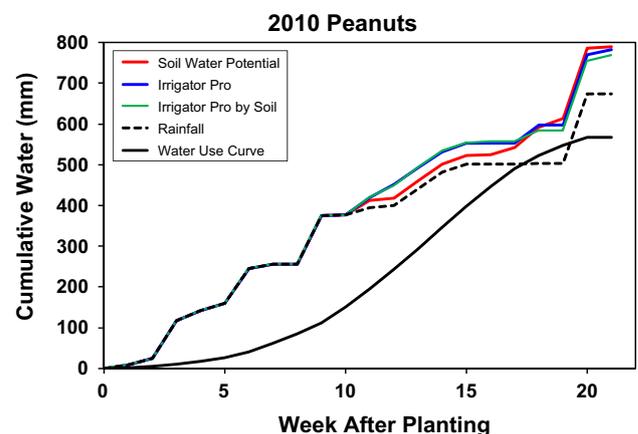


Fig. 5 Weekly cumulative water for the 2010 peanut growing season for the four irrigation treatments

Table 2 Mean peanut yields (kg ha⁻¹) for the irrigated and non-irrigated treatments

	Year			Total	
	2007 Yield (kg ha ⁻¹)	2009 Yield (kg ha ⁻¹)	2010 Yield (kg ha ⁻¹)		
<i>Treatment</i>					
* Column means with different capital letters represent significant differences at the $p = 0.05$ level. Row means with lower case letters represent significant differences at the $p = 0.05$ level	Non-irrigated	2,389 ± 274 B*	3,210 ± 502 B	4,078 ± 477 A	3,258 ± 812 A
	Irrigator Pro by soil	4,640 ± 650 A	4,082 ± 628 A	3,667 ± 727 A	4,130 ± 758 B
	Irrigator Pro	4,962 ± 539 A	3,931 ± 774 A	3,958 ± 815 A	4,230 ± 843 B
	Soil water potential	5,172 ± 944 A	3,714 ± 508 AB	4,004 ± 943 A	4,394 ± 1,048 B
	Yearly mean	4,349 ± 1298 a	3,725 ± 678 b	3,932 ± 736 a	

all years, the rainfall distribution was generally greater than the peanut crop water use curve (Beasley 2007) during the early season (Fig. 2). In 2007, the cumulative rainfall distribution dropped below the water use curve in the 8th to 9th week of the season (Fig. 3). Little significant rainfall occurred throughout the remainder of the 2007 growing season. In 2009, the cumulative rainfall distribution was greater than the water use curve until approximately the 13th week of the growing season and little rainfall occurred afterward (Fig. 4). For 2010, the rainfall distribution was greater than the water use curve throughout the growing season except for a 2-week period at the end of the season when the crop had reached maturity and water demand was low (Fig. 5).

Peanut yields

During the 3-year study, the average peanut yields across all treatments ranged from 2,389 to 5,172 kg ha⁻¹. An initial analysis of variance indicated that yields for the years were significantly different. The 2007 and 2010 average yields across all treatments were significantly higher than in 2009 (Table 2). For the entire study period, the non-irrigated treatment yields were significantly lower than the three irrigated treatments. Yields for the three irrigated treatments were not significantly different for the combined 3-year analysis.

In 2007, the average yields for the individual treatments were significantly different. The non-irrigated treatment had significantly lower yields (approximately 50 % lower) than the irrigated treatments (Table 2). The yield differences between the non-irrigated and irrigated treatments were mainly attributed to the weather conditions and the extended drought conditions for the latter part of the growing season. As previously discussed, little significant rainfall occurred during the latter part of the growing season. The average irrigated yields ranged from 4,640 to 5,172 kg ha⁻¹ and were not significantly different. The SWP treatment had the highest average yield

(5,172 kg ha⁻¹), while the IP and IPS treatments averaged 4,962 and 4,640 kg ha⁻¹, respectively.

In 2009, the average yields across the individual treatments were significantly different, ranging from 3,210 to 4,082 kg ha⁻¹. The average yields for the three irrigated treatments were not significantly different. However, the SWP average yields were not significantly different from the non-irrigated yields. During the 2009 growing season, little significant rainfall occurred during the latter portion of the growing season (approximately the last 33 % of the growing season). Additionally, due to equipment failure on the center pivot irrigation system, all irrigations were halted after August 20, 2009 (approximately the last 25 % of the growing season). The lack of irrigation during the late season likely impacted our irrigated treatment yields. In previous studies, Pallas et al. (1979) found that late season drought, imposed with rainfall shelters, impacted yields greater than early and mid-season drought. Also, Chapin et al. (2010) reported that peanut could recover from early drought stress if it received adequate late season rainfall.

In 2010, there were no significant differences across the treatments. The 2010 growing season total rainfall and its distribution were generally adequate for optimal peanut growth with only a few irrigations required for each of the three irrigation treatments. The non-irrigated treatment had the highest average yield (4,078 kg ha⁻¹), but it was not significantly different than the irrigation treatments.

Additionally, we evaluated each year's peanut yields for homogeneity of variance to determine whether there were significantly greater variances in yields between soils within individual plots as compared to variances between the whole plots (whole plot variability versus within plot variability). We observed no significant variance in homogeneity between the whole plots or within plot yield variability. Sadler et al. (1998) and Karlen et al. (1990) found similar variability results in corn, wheat, and sorghum. They observed that variability within a soil mapping unit was as great as variability among soil mapping units.

Table 3 Mean total water (mm) applied to peanut crop for the irrigated and non-irrigated treatments

	Year			Total	
	2007 Total water (mm)	2009 Total water (mm)	2010 Total water (mm)		
<i>Treatment</i>					
* Column means with different capital letters represent significant differences at the $p = 0.05$ level. Row means with lower case letters represent significant differences at the $p = 0.05$ level	Non-irrigated	185.7 ± 0.0 C*	336.0 ± 0.0 C	674.6 ± 0.0 C	407.0 ± 208.0 B
	Irrigator Pro by soil	503.2 ± 53.0 A	444.0 ± 18.0 A	755.6 ± 13.5 B	567.6 ± 141.6 A
	Irrigator Pro	508.6 ± 47.4 A	437.6 ± 0.0 A	770.6 ± 11.2 AB	577.3 ± 152.7 A
	Soil water potential	452.4 ± 35.5 B	407.4 ± 25.3 B	785.7 ± 48.8 A	537.8 ± 168.9 A
	Yearly mean	413.2 ± 135.4 b	405.1 ± 46.5 b	745.2 ± 50.3 a	

Table 4 Mean water use efficiency (kg ha^{-1} per mm) for the 2007, 2009, and 2010 peanut crop for the irrigated and non-irrigated treatments

	Year			Total
	2007 Water use efficiency (kg ha^{-1} per mm)	2009 Water use efficiency (kg ha^{-1} per mm)	2010 Water use efficiency (kg ha^{-1} per mm)	
<i>Treatment</i>				
Non-irrigated	12.9 ± 1.5 A*	9.6 ± 1.5 A	6.0 ± 0.7 A	9.4 ± 3.1 A
Irrigator Pro by soil	9.3 ± 1.8 B	9.2 ± 1.6 A	4.9 ± 1.0 A	7.8 ± 2.6 B
Irrigator Pro	9.8 ± 1.1 B	9.0 ± 1.8 A	5.1 ± 1.1 A	7.8 ± 2.5 B
Soil water potential	11.6 ± 2.6 AB	9.2 ± 1.5 A	5.1 ± 1.2 A	8.9 ± 3.3 A
Yearly mean	11.0 ± 2.3 a	9.2 ± 1.5 b	5.3 ± 1.1 c	

* Column means with different capital letters represent significant differences at the $p = 0.05$ level. Row means with lower case letters represent significant differences at the $p = 0.05$ level

Irrigation and water use efficiency

Total water received by the crops varied over the 3 years and by treatment (Table 3). As with the yields analysis, the total water received was significantly different across years. The mean yearly total water applied averaged across treatments ranged from 405 mm in 2009 to 745 mm in 2010. The 3-year average total water applied for the three irrigation treatments were significantly higher than the non-irrigated treatment. Although not significantly different, the IP and IPS treatments received higher total water than the SWP treatment.

In 2007 and 2009, the IP and IPS irrigation treatments received significantly greater total water than the SWP treatment (Table 3). In 2007, the IP and IPS treatments received 323 and 318 mm of irrigation, respectively. These irrigation depths were significantly greater than the 267 mm the SWP irrigation treatment received. However, the yields for the three irrigation treatments were not significantly different. The water use efficiency (WUE) was calculated using the yields and total water received by each treatment. The 2007 WUE calculations ranged from 12.9 kg ha^{-1} per mm for the non-irrigated treatment to 9.3 kg ha^{-1} per mm for the IPS treatment

(Table 4). The SWP and non-irrigated treatment WUE's were not significantly different, and the SWP treatment WUE was not significantly greater than the IP and IPS treatments.

In 2009, the non-irrigated treatment received 336 mm of rainfall. The irrigated treatments received average irrigation depths of 108, 102, and 71 mm for the IPS, IP, and SWP treatments, respectively. The IP and IPS treatments had significantly greater total water applied than the SWP treatment. The irrigation treatments would have had additional irrigation applications had the center pivot irrigation system not been damaged for the last 25 % of the growing season. Nonetheless, the yields associated with the three irrigation treatments were significantly higher than the non-irrigated treatment as previously discussed. The 2009 WUE values were not significantly different and averaged 9.2 kg ha^{-1} per mm.

In 2010, the non-irrigated treatments received 675 mm of rainfall. This was greater than the long-term seasonal average rainfall of 559 mm. However, its distribution throughout the growing season required additional irrigation applications of 81, 96, and 111 mm for the IPS, IP, and SWP treatments, respectively. The total water received by the three irrigation treatments was

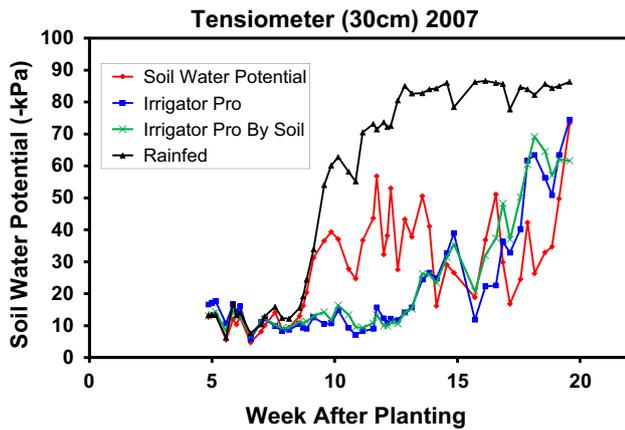


Fig. 6 Soil water potential measurements at 30-cm depth for the 2007 peanut growing season for the four irrigation treatments

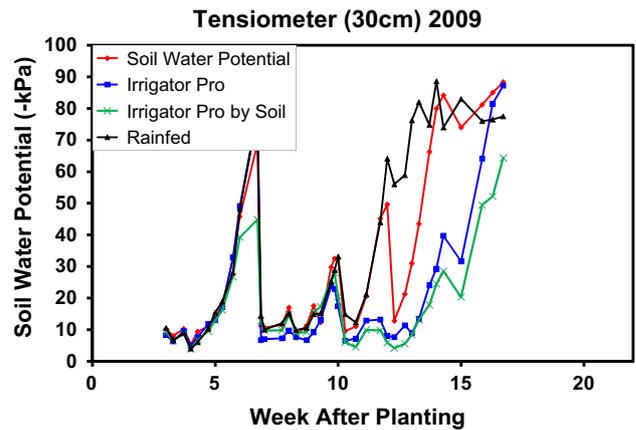


Fig. 8 Soil water potential measurements at 30-cm depth for the 2009 peanut growing season for the four irrigation treatments

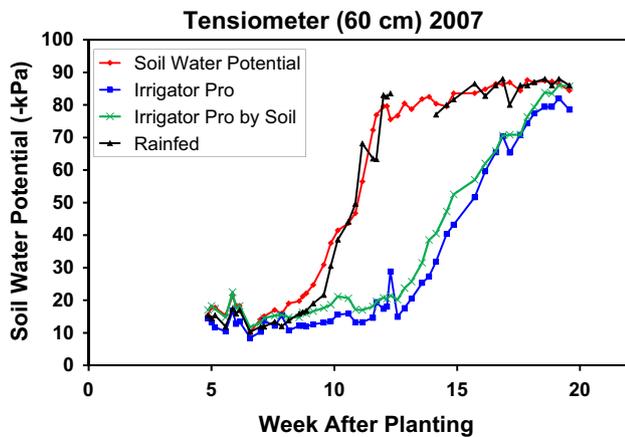


Fig. 7 Soil water potential measurements at 60-cm depth for the 2007 peanut growing season for the four irrigation treatments

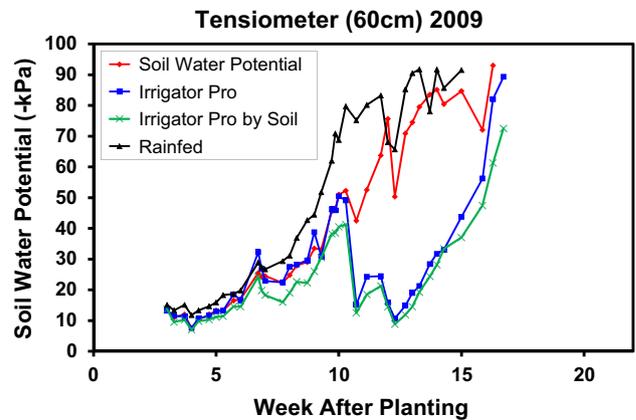


Fig. 9 Soil water potential measurements at 60-cm depth for the 2009 peanut growing season for the four irrigation treatments

significantly greater than the non-irrigated treatment. The SWP treatment had significantly greater total water than the IPS treatment but not significantly greater than the IP treatment. The WUE values for the treatments were not significantly different and averaged 5.3 kg ha⁻¹ per mm.

Over all 3 years, the calculated WUE values ranged from 12.9 to 4.9 kg ha⁻¹ per mm. Our WUE values were similar to those observed by Chauhan (2010), whose dry season WUE for peanut ranged from 6.2 to 7.3 kg ha⁻¹ per mm, and those from Collino et al. (2000) for argentine peanut varieties with WUE values ranging from 7.5 to 12.4 kg ha⁻¹ per mm. In an arid climate, Abou Kheira (2009) reported WUE values of 6.1 kg ha⁻¹ per mm for peanut.

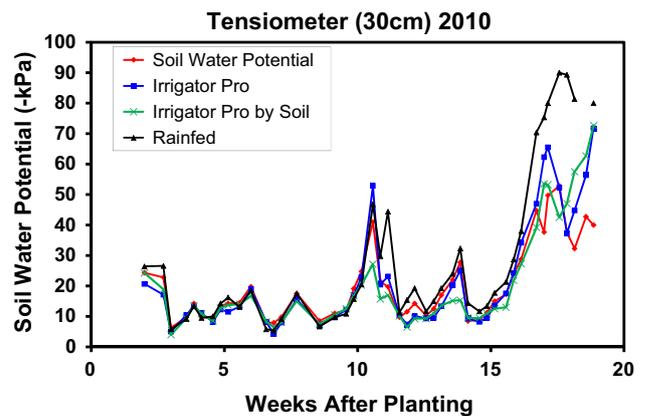


Fig. 10 Soil water potential measurements at 30-cm depth for the 2010 peanut growing season for the four irrigation treatments

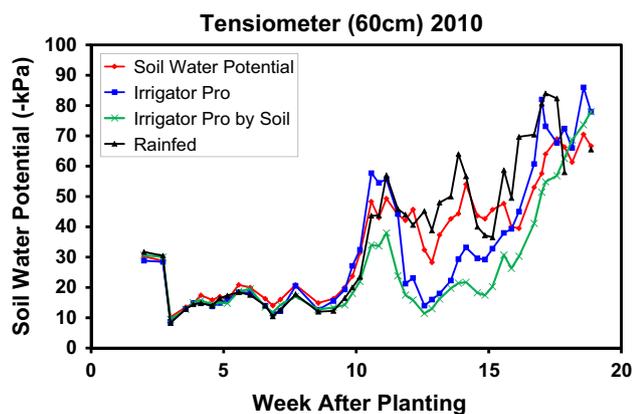


Fig. 11 Soil water potential measurements at 60-cm depth for the 2010 peanut growing season for the four irrigation treatments

Soil water potentials

The soil water potential data for the 30- and 60-cm depths are shown in Figs. 6, 7, 8, 9, 10 and 11. In 2007, the IP and IPS treatments called for irrigation applications earlier in the season than the SWP-based treatment. The early initialization of irrigation for the IP and IPS treatments maintained the 30-cm soil water potential above -30 kPa throughout most of the growing season (Fig. 6). It also maintained 60-cm soil water potentials above -30 kPa for 5 weeks longer than the SWP-based treatment (Fig. 7). Near the end of the growing season, the IP and IPS treatments began to reduce irrigation application before the SWP-based treatment. The average soil water potential throughout the growing season for the IP, IPS, and SWP treatments were -21 , -23 , and -28 kPa, respectively. In 2009, the soil water potentials were similar to the pattern seen in 2007. The 2009, 30-cm soil water potentials for the IP and IPS treatments were higher than the SWP treatment throughout the growing season (Fig. 8). The 60-cm soil water potentials also remained higher in the IP and IPS treatments for approximately 5 additional weeks longer than the SWP treatment (Fig. 9). The average 2009 seasonal 30-cm soil water potentials for the IP, IPS, and SWP treatments were -19 , -18 , and -30 kPa, respectively. In 2010, fewer irrigation events were required, and the soil water potentials of all treatments were similar throughout the growing season for both measurement depths. The average 2010 growing seasonal 30-cm soil water potentials were -20 , -17 and -20 kPa for the IP, IPS, and SWP treatments, respectively (Figs. 10, 11). Additionally, the 2010 non-irrigated 30-cm soil water potential averaged -21 kPa. Over all 3 years of the study, the IP and IPS treatments maintained soil water potential higher than the SWP and non-irrigated treatments. This was particularly observed in 2007 and 2009 when there was less rainfall

and the treatments required more frequent irrigation applications. In both years, the IP and IPS peanut yields were not significantly greater than the SWP treatment, yet they had significantly greater water application depths. A recent modification of Irrigator Pro has incorporated the use of soil water potential measurements for feedback into the expert system. This should allow improvements in future water use estimates.

Summary

Peanut was grown under a variable-rate center pivot irrigation system for 3 years to evaluate the potential of using an expert system for spatial irrigation management. The expert system was compared to irrigation management, utilizing measured soil water potentials to initiate irrigations. Growing season rainfall for the 3-year study varied widely. The 2007 growing season rainfall was approximately 33 % of the long-term seasonal average, required the greatest irrigation application depths, yet had the highest overall yield for the 3-year study, especially for the irrigated treatments. The 2010 growing season rainfall was approximately 20 % greater than the long-term seasonal average, required the least irrigation, and had insignificant yield differences. The 2009 results were intermediate between 2007 and 2010 results for rainfall, water applied, and yield.

Over the 3-year study, all irrigated treatments had significantly higher yields than the non-irrigated treatments. In 2007, all irrigated treatment peanut yields were significantly higher than non-irrigated yields. In 2007 and 2009, the IP and IPS treatments had significantly higher yields than the non-irrigated yields, but they were not significantly different from the SWP treatment yields.

The overall total water usage was not significantly different for the IP, IPS, and SWP irrigation treatments. In the 2007 and 2009 growing seasons with below normal rainfall, the IP and IPS treatments required significantly greater total water than the SWP treatment. A later version of IP has incorporated field measurements of soil water potential for feedback to the expert system and may improve irrigation recommendations. Overall, water use efficiency was significantly higher for the non-irrigated and SWP treatments. The IP and IPS irrigation treatments initiated irrigation applications earlier in the growing season and maintained soil water potentials at the 30- and 60-cm depths at higher levels throughout most of the season.

The two Irrigator Pro expert system treatments functioned as well as the SWP-based treatment. The IP and IPS treatments generally were not significantly different from each other for yield, total water use, or water use efficiency. The Irrigator Pro expert system can be effectively used for site-specific management where management zone soils do

not greatly differ. Further refinement of the expert system may be needed to improve its application in spatial irrigation applications, particularly in the definition and number of soil types available.

References

- Abou Kheira AA (2009) Macromanagement of deficit-irrigated peanut with sprinkler irrigation. *Agric Water Manag* 96(10):1409–1420
- Beasley JP Jr (2007) Irrigation strategies. In: 2007 Peanut update. Bulletin Number: CSS-03-0105. The University of Georgia, College of Agricultural and Environmental Science, Cooperative Extension Service. (<http://www.caes.uga.edu/commodities/field-crops/peanuts/2007peanutupdate/irrig.html>)
- Camp CR, Sadler EJ, Evans DE, Usrey LJ, Omary M (1998) Modified center pivot irrigation system for precision management of water and nutrients. *Appl Eng Agric* 14(1):23–31
- Chapin JW, Thomas JS (2005) Peanut money-maker production guide—2005. Clemson Extension, Clemson University, Revised January 2005
- Chapin JW, Marshall M, Prostko EP, Thomas JS (2010) peanut money-maker production guide—2010. Circular 588, Revised January 2010. Clemson Extension, Clemson University (http://www.clemson.edu/extension/rowcrops/peanuts/peanut_guide/complete_guide10.pdf)
- Chauhan YS (2010) Potential productivity and water requirements of maize-peanut rotations in Australian semi-arid tropical environments—a crop simulation study. *Agric Water Manag* 97(3):457–464
- Collino DJ, Dardanelli JL, Sereno R, Racca RW (2000) Physiological responses of argentine peanut varieties to water stress: water uptake and water use efficiency. *Field Crops Res* 68(2):133–142
- Davidson JI Jr, Griffin WJ, Lamb MC, Williams RG, Sullivan G (1998a) Validation of EXNUT for scheduling peanut irrigation in North Carolina. *Peanut Sci* 25:50–58
- Davidson JI Jr, Bennett CT, Tyson TW, Baldwin JA, Beasley JP, Bader MJ, Tyson AW (1998b) Peanut irrigation management using EXNUT and MOISNUT computer programs. *Peanut Sci* 25(2):103–110
- Karlen DL, Sadler EJ, Busscher WJ (1990) Crop yield variation associated with coastal plain soil map units. *SSSAJ* 54:859–865
- Lamb MC, Masters MH, Rowland D, Sorensen RB, Zhu H, Blankenship RD, Butts CL (2004) Impact of sprinkler irrigation amount and rotation on peanut yield. *Peanut Sci* 31(2):108–113
- Lamb MC, Rowland DL, Sorensen RB, Butts CL, Faircloth WH, Nuti RC (2007) Economic returns of irrigated and non-irrigated peanut based cropping systems. *Peanut Sci* 34:10–16
- Omary M, Camp CR, Sadler EJ (1997) Center pivot irrigation system modification to provide variable water application depths. *Appl Eng Agric* 13(2):235–239
- Pallas JE Jr, Stansell JR, Koske TJ (1979) Effect of drought on florunner peanuts. *Agron J* 71(5):853–858
- Sadler EJ, Busscher WJ, Bauer PJ, Karlen DL (1998) Spatial scale requirements for precision farming: a case study in the southeastern USA. *Agron J* 90(2):191–197
- Sadler EJ, Camp CR, Evans DE, Millen JA (2002) Corn canopy temperatures measured with a moving infrared thermometer array. *Trans ASAE* 45(3):581–591
- Sadler EJ, Evans RG, Stone KC, Camp CR (2005) Opportunities for conservation with precision irrigation. *J Soil Water Conserv* 60(6):371–379
- SC State Climatologist (2010) FLORENCE FAA AP, SOUTH CAROLINA (383106) Monthly Climate Summary. <http://www.dnr.sc.gov/cgi-bin/sco/hsums/cliMAINnew.pl?sc3106>
- Smith NB, Beasley JP, Hook JE, Baldwin JA (2005) An economic evaluation of irrigation strategies for peanut. In: Proceedings American Peanut Research and Education Society, Inc., vol 37, Portsmouth, VA, July 12–15
- Vellidis G, Perry CD, Durrence JS, Thomas DL, Hill RW, Kvien CK, Hamrita TK, Rains G (2001) The peanut yield monitoring system. *Trans ASAE* 44(4):775–785