Effectiveness of Irrigation Water Management Practices for Mid-South Furrow Irrigation

C.G. Henry, Associate Professor and Water Management Engineer, University of Arkansas, Rice Research and Extension Center, Stuttgart, AR 72160, cghenry@uark.edu

J. P. Gaspar, Irrigation Program Associate, University of Arkansas, Rice Research and Extension Center, Stuttgart, AR 72160

A. P. Horton, Irrigation Program Technician, University of Arkansas, Rice Research and Extension Center, Stuttgart, AR 72160

Abstract

Arkansas is the third largest irrigated state and is only 46% sustainable in its groundwater withdraws for irrigation. The objective of this research was to evaluate the efficacy of Computerized Hole Selection (CHS), Surge Irrigation (SURGE), and Soil Moisture Monitoring (SMM). The research consisted of 12 paired furrow irrigated fields where water use was measured with portable propeller flow meters and yield was measured on cooperating farmer fields. Water use and relative yields were compared between the treated field (IWM) and control field (CONTROL). IWM fields that used SURGE, CHS and SMM were found to use 27% less water than the CONTROL field. Fields that used CHS and SMM used 19% less water than CONTROL fields (p=0.015). There were no significant difference in yields (p=0.86) between IWM and CONTROL fields or less than a 1% difference. On-farm pump testing identified a water savings of $511 per site. This study demonstrates that widespread adoption of these practices can significantly reduce the overdraft of the alluvial aquifer in the mid-south and can be done without any yield penalties.

Keywords: Irrigation Water Management, furrow irrigation, surge Irrigation, Soil Moisture Sensors, Computerized Hole Selection

Introduction

Arkansas is the third largest irrigated state (5.0 million acres) in the United States after Nebraska (8.3 million acres) and California (7.5 million acres) (USDA, 2012). The Arkansas Natural Resources Commission (2014) projects that about 70 percent of water demand in Arkansas is supplied using ground water with 80 percent of the water used to irrigate field crops. The largest category of irrigation expense for producers in these states is energy cost associated with pumping of water from surface and subsurface water resources. Approximately 4.3 million of the 4.9 million irrigated acres in Arkansas utilize flood or furrow irrigation (USDA, 2012).

Furrow and flood irrigation (surface irrigation) are the most common form of irrigation methods practiced in Arkansas (Maupin et al., 2014). These forms of surface irrigation are appealing to farmers because of the minimal capital investment and lower energy costs in comparison to pressurized irrigation systems. However, more labor is required than sprinkler irrigation. However, with the advent of lay-flat irrigation pipe, which became available and quickly adopted in Arkansas in the mid-1990's. The labor needs are greatly lessened compared to rigid gated pipe. The challenge with lay-flat pipe is that a hole is punched after the pipe is filled with water and there is no adjustment compared to gated pipe systems that can be adjusted by the irrigator to maintain even furrow advances.

Computerized Hole Selection (CHS) is a tool used for lay-flat polyethylene irrigation pipe products. In lay-flat irrigation pipe, the pipe comes in rolls, the irrigator lays the pipe out and fill it with water. Then when the pipe is full of water the irrigator punches holes in the pipe, typical hole sizes range from ¼ inch to 1 inch. Inefficiencies arise when the holes are too large or too small, resulting in over pressuring the pipe when holes are too small and bursting, or when holes are too large, inadequate volume is delivered to the holes farthest from the inlet. Additionally when fields are not square, longer furrows require higher flowrates than shorter ones. Finally, the pipe crown slope when not level must be accounted for in the hydraulic calculations for each hole to deliver the appropriate volume. Thus using a computer to iterate out the proper hole sizes and changes along the pipe often can result in pipe distribution uniformities of around 90% (low quarter distribution) or higher, even on very irregular and undulating slopes where the pipe is placed.

Surge irrigation (SURGE) is the practice of intermitting applying water to furrow irrigated fields for the purpose of improving down furrow uniformity. Water delivery is alternated between a “right” and “left” side of an irrigation set. Initially the cycles are longer in order to advance the water through the field, then are shortened in order to reduce deep percolation near the top end of the field and deliver more water to the lower end. Infiltration rates are high when soil is dry and reduce as the soil seals from being wetted. Surge irrigation has been shown to reduce deep percolation, increase advance time, decease total water applied and reduce tail water ratios. (Bishop et al., 1981; Izuno et al., 1985; Goldhamer et al., 1987b; Musick et al., 1987; Testezlaf et al., 1987; Israeli, 1988; Eid et al., 1999).

Soil Moisture Monitoring (SMM) is the use of soil moisture sensors and telemetry to monitor the soil water balance. SMM is used for scheduling irrigation events, but also verify the efficacy of the irrigation event in refilling available water capacity. SMM are comprised of soil moisture sensors that may include tensiometers, gypsum blocks, granular matrix potential sensors, heat dissipation sensors, and soil psychrometers (Munoz-Carpena, 2004). One of the most commonly used sensors is the Watermark Model 200SS (Irrometer Company Inc, Riverside, CA) and is a matric potential sensor comprised of two electrodes in a granular matrix. The sensors are attached to schedule 20 polyvinyl chloride pipe and placed in the soil at depths appropriate for representing the managed depth selected by the irrigators. In addition to sensors, SMM are comprised of electronics that measure soil moisture sensor output, provide power to sensors, record, and relay data wirelessly to a server. A cellular modem or other radio communication is used to relay data wirelessly from the SMM to the internet. Sensor data is then displayed to irrigators through web browsers or smartphone devices.

Materials and Methods

Cooperating farmers volunteered with this research by contacting their local Extension Agent during the 2015 crop year. The Agents and farmers located comparable fields that were the same soil texture, slope and productivity. Field were planted to the same variety and had planting dates that were within a few days. Computerized Hole Selection (CHS, SURGE irrigation, and Soil Moisture Monitoring (SMM) was implemented on each Irrigation Water Management Field (IWM). In some fields, sets were divided so that there were two sets utilizing SURGE and one without but did have CHS implemented, so the effect of SURGE relative to CHS and a CONTROL could be assessed. Each CONTROL and IWM field was instrumented with portable propeller mechanical flow meter (McCrometer Corporation, Hemet, CA) to totalize the water use of the field during the season. Farmers managed CONTROL fields according to their conventional practices, punching hole sizes and irrigation timing according to their experience. Generally farmers irrigated their control fields every 7-10 days on a calendar method. County Extension agents communicated with farmers to help time irrigation using the SM. SMM was accomplished using AgSense Aquatrac data collection and telemetry units and Watermark™ soil matric potential sensors.

Sensors were installed at 6, 12, 18 and 30 inch depths. The SMM units provided data to smartphones and through a website, so farmers, agents and the authors could monitor soil moisture trends and status. For each site, an allowable depletion was developed from soil samples taken at the top foot and second foot depths. Soil texture, bulk density, organic matter, field capacity and wilting point were determined through laboratory analysis. This data was used to develop an allowable depletion using the pedotransfer functions published by Saxton and Rawls (2006). This information was used to set a range of irrigation thresholds in the interface for the telemetry unit for each IWM field. The vast majority of sites were a silt loam texture with a few loam or sandy loam soil textures.

P and R Surge valves (P&R Surge, Lubbock, Texas) were used and coupled to the portable propeller flow meters (McCrometer, Hemet, CA). Totalizers were read before the first irrigation, between and after the last irrigation. Each field had a CHS plan developed using either a computer program called PHAUCET (Pipe Hole And Universal Crown Evaluation Tool) or an online web tool provided by Delta Plastics Pipe Planner (Delta Plastics, Little Rock, AR). Agents were trained through in-service trainings on how to implement CHS, read and install meters, surge valve programming (Henry and Krutz, 2017) and soil moisture sensors. Advance time adjustments were only made during the first irrigation. Often the first irrigation takes longer than subsequent irrigations, so additional improvement would be possible if irrigators adjusted advance times after the first irrigation. Irrigation decisions were made by the county Agent and farmer with consultations with the authors when needed. Terminations were done according to UA Extension recommendations for R6.5 and good soil moisture and 50% of the starch line for corn and good soil moisture. For cotton termination was determined by DD60 and 5 Nodes Above White Flower. Good soil moisture was defined as an average reading in the profile were less than a 30% MAD was available or about -60 cb for silt loams and less than -30 cb for sandy loams.

After termination, valves, meters, sensors and telemetry units were removed from the fields. Yields were calculated for each CONTROL, CHS and IWM field in entirety by either certified scale tickets or calibrated yield monitors. In some cases herbicide or other crop damage occurred in part of the field, and yield monitor data was used to adjust yields for direct comparison between the paired fields.

Irrigation Water Use Efficiency (IWUE) was calculated according to Vories et al (2005) as the yield in bushels per acre-inch divided by the irrigation water applied in acre-inches per acre. Data was analyzed with SYSTAT version 13.2 (Systat, San Jose, CA).

For each site, the cost of water was determined to calculate potential energy savings by optimizing the irrigation pumping plant with the CHS Plan. Testing and analysis was conducted using the methodology described by McDougall (2012) for pumps that did not have pump monitors and electric meters energy consumption was conducted as described by Henry and Bingham (2013). For the electric pump sites, the cost of water was determined by measuring the flow from the on-site flowmeter and by measuring the energy consumption by reading the electric meter during the test. The data was done once mid-season. For diesel power units, the fuel use was measured by isolating the engine from the fuel tank and suppling fuel from a 2.5 liter graduated cylinder plumbed to the supply and return lines of the engine. The consumption of fuel or electricity over a several minute time period was measured with a stopwatch. For diesels the tests were conducted over the operating range of the engine as reported by the irrigator. Also the cost of energy in kWh and $/gallon as reported by the irrigator were used to determine the cost of water for each site.

Results

Yield data was converted to relative yield between the treatment (IWM or CHS) to the control yield for comparison between the three crop types, of corn, soybean, and cotton. There were 11 fields (n=11) comprised of 11 soybean, 1 corn and 1 cotton field. These fields had 26 treatments of CHS (4), CONTROL (12) and IWM (10 SURGE AND CHS). All CONTROL fields (100%) applied more water than IWM treatments. The non-parametric Kruskal-Wallis one way Analysis of Variance (ANOVA) on Ranks was used to analyze the data. The Dunns's Method was used for a multiple pairwise comparison to test for differences between water use and yield between the three treatments. A 0.6-1% increase in relative yield was observed. There was no significant difference in relative yields found between the treatments (p=0.864). However, there was a difference in relative water use between CHS and CONTROL (p=0.015) and IWM and CONTROL (p<0.001). No difference between CHS and IWM was found (p=1). Although the water use was 8% less with IWM than CHS. These results show a reduction in water use using IWM of 27% equating to a 2.6 ac-in/ac savings. The analysis was repeated using the parametric ANOVA test and yielded the same results.

The data strongly supports the conclusion that the use of surge, CHS, and SMM can reduce water use with no yield penalty. There was no significant difference between CHS and IWM, suggesting that surge may not have a treatment effect. However, there are only a four data points, and generally the surge sets were twice the size of the CHS sets. In fields that compared CHS and IWM, there were usually three sets, two were put together to make one surge set, while the third was a left over set and only used CHS. In retrospect, the experimental design should had CHS and IWM sets of equal size for a fair comparison. So the insignificance between CHS and IWM, representing the treatment effect of surge irrigation likely does not represent the true treatment effect of surge irrigation.

Table 1. Relative Yield and Relative Water Use of IWM, CHS and CONTROL Paired Fields

	Relative Yield		**Relative Water Use**		**Dunn's Method**
	ratio	% Difference from Control	ratio	% Difference from Control	Relative Water Use Difference from Control
IWM	1.006	**+ 0.6 %**	0.738	**- 27 %**	YES
CHS	1.01	**+ 1 %**	0.811	**- 19 %**	YES
Control	1.00	**0**	1	**0**	
P-value	p=0.864		IWM, p<0.001; CHS, p=0.015		

The Hawthorne effect is described in Roethlisberger (1941) as "human subjects of an experiment change their behavior, simply because they are being studied." As these studies were being implemented the authors and County Extension Agents noted that farmers changed their irrigation scheduling based on the information or request of the Agent to irrigate the IWM field. The field were always nearby, sometimes serviced by the same pump, so it was often convenient to irrigate the two fields at the same time or one right before or after the other. Additionally, as the cooperators were looking at sensor data and learning how to use the information from the Agents managing the IWM fields, the irrigators may have subconsciously used this information to manage the CONTROL field. The larger differences were often found when a different person, such as a father or other hired person managed the CONTROL field and the main decision maker and the agent managed the IWM field. However it is not always possible to facilitate such management, and even if agreed to, the close working relationship often cannot maintain separation of management of the paired fields. Thus, these results may underestimate the potential savings because of the Hawthorne effect.

Cost of Water for Irrigation Pumping Plants Studied

The cost of water for several of the sites was collected. Cost of water in US dollars per acre-inch of water are reported in Tables 2 and 3. Data for sites was collected on motor size, make, speed, and flowrate. The area the pumps serviced was checked and the capacity and cost of water was determined for each pump. Pumping plants for rice-soybean rotations should have at least 10 gpm/ac capacity, only one site did not have adequate capacity. The cost of water for electric pumps varied greatly, from $0.10/ac-in/ac to $1.86/ac-in/ac. Generally the cost of water for electric powered pumps was about half or a third of the diesel powered pumps, but some of the electric pumps cost as much as diesel.

Table 2. Electric Pump Size, Make, RPM, Flowrate, Acres, Capacity and Cost of Water

County	Motor Power (HP)	Motor Make	RPM	Flow Rate	Acres	GPM/Ac	Cost of Water $/Ac-in
Ashley	60	Emerson	1775	1300	101	12.9	0.10
Cross	*	Submersible	1700	600	36.3	16.5	1.38
Cross	75	North American Electric	1780	870	36.3	24.0	1.58
Cross	*	Submersible	1770	850	*	*	0.50
Greene	60	WorldWide Electric	1750	1467	79.8	18.4	0.53
Lee	*	Submersible	1770	667	37.5	17.8	0.53
Lonoke	75	WEG	1770	833	45.9	18.1	1.86
Mississippi	60	Emerson	1775	2708	80	33.9	0.58
St. Francis	50	North American Electric	1770	1083	65	16.7	0.20
White	20	Submersible	1770	300	32.6	9.2	1.49
White	15	Submersible	1770	400	32.6	12.3	1.11
White	15	Submersible	1770	400	32.6	12.3	1.09

For diesel powered pumps, an additional analysis was conducted. For each field, the CHS plan was obtained. The CHS plan was adjusted from the plan as designed by the irrigator to a plan that used the lowest cost of water engine speed but accomplished the irrigation in less than 40 hours. Typical water use for crops in rotation or other fields serviced by the pump were used to estimate potential savings. For example, for one site the CHS plan was designed for 24 hours at 1650 RPM that delivered 2000 gpm.

However after testing it was found that this engine speed resulted in a cost of water of $2.11/ac-in. Reducing the engine speed to 1500 RPM provided 1700 gpm at a cost of $1.68/ac-in. The pump serviced two fields of equal size that were rotated between soybeans and rice. Water use estimates of 13 ac-in/ac for soybeans and 32 ac-in/ac for rice were used to estimate total volume pumped per year. Making the engine speed change increased the irrigation time from 24 hours to 28 hours but resulted in a difference of $0.43/ac-in/ac which worked out to an annual savings of $1,518 in fuel savings for the fields the pump supplied. Similar analysis was performed for each site (Table 3) where a savings could be identified. For one electric site that was traditionally serviced by three submersible wells, a savings of $1,008 was found, by only using two pumps instead of all three.

Table 3. Diesel Powered Irrigation Pumping Planted Tested and Cost of Water and Potential Savings

County	Motor Size (HP)	Motor Make	Motor Model	RPM	Flow Rate	Acres	GPM/Ac	Cost of Water $/Ac-in	Potential Savings ($/ac-in)
Clay	99	John Deere	4045TF285B	1750	2250	157.9	14.2	2.05	0.43
Craighead	105	Case IH	4390T	1250	950	37.7	25.2	1.35	0.00
Crittenden	152	Cummins	6BT5.9-C	1692	1550	65.8	23.6	2.05	0.04
Lawrence/Randolph	66	Deutz	F4L912	*	1200	37.9	31.7	1.76	0.20
Phillips	60	John Deere	4039D-001	900	800	19	42.1	1.45	0.21
Poinsett	127	Isuzu	AI-4JJ1X	1800	1600	93.6	17.1	2.14	0.25

Diesel powered pumping plants had a cost of water between $1.35/ac-in/ac and $2.14/ac-in/ac. All pumps tested, albeit one, found a savings that could be generated by optimizing the cost of water and irrigation set time to engine speed. The Craighead site was experiencing cavitation, and thus as engine speed increased the flow decreased. The average savings from the eight locations was $511.66 with a range of $0 for the pump that was experiencing cavitation to $1,518 for a fairly new installation in Clay County. There did not appear to be any obvious trends, between age of pumps or power units. There seems to be an opportunity to reduce irrigation costs by testing the cost of water of when multiple electric pumps are used and diesel pumps. Given that some of the electric pumps cost almost as much as diesel to operate, measuring the cost of water for electric pumps could identify pumps and motors that have reached the end of their service life.

Table 4. Annual Site Savings

Site	Site Annual Savings
White	$1,008
Clay	$1,518
Phillips	$304
Lonoke	$104
Poinsette	$104
Craighead	$0
Crittenden	$35.36
Arkansas	$1,020
Average	$511.66

Conclusions

Water use and relative yields were compared between the fields that utilized Computerized Hole Selection, SURGE irrigation, and Soil Moisture Monitoring relative to a CONTROL field. Water use from both fields were measured with portable propeller flowmeters and yield were measured with combine yield monitors or scale tickets. IWM fields that used SURGE, CHS and SMM were found to use 27% less water than CONTROL ($p<0.001$). Fields that used CHS and SMM used 19% less water, but there were only a few observations of CHS and set sizes were not equal, so the real treatment effect of surge irrigation likely was not captured in this study. There were no significant difference in yields ($p=0.86$) between IWM and CONTROL fields or less than a 1% difference. On-farm pump testing identified a water savings of $511 per site and showed that measuring the cost of water for a surface irrigation pump and operating at is lowest cost can produce substantial annual energy savings. This study demonstrates that widespread adoption of these practices can significantly reduce the overdraft of the alluvial aquifer in the mid-south with no yield penalty.

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