MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECT NO. 54-2015 (YEAR 3)
2015 Final Report

TITLE: Developing Strategies for Improving Furrow Irrigation Efficiency

PI: L. Jason Krutz, Associate Extension/Research Professor
MAFES-Delta Research and Extension Center
662-588-8974,jkrutz@ext.msstate.edu

EXECUTIVE SUMMARY

This study measured the effect of surge irrigation (SURGE) vs. conventional continuous furrow irrigation (CONV) on water use, cost and returns, and seed yield of soybean grown on clay-textured soils in the Midsouth.

Compared to CONV, SURGE reduced the amount of water applied per irrigation event by 22%.

Compared to CONV, SURGE reduced the total amount of seasonal irrigation water application by 24%.

Soybean seed yield averaged 66.3 bu/acre and did not differ between SURGE and CONV treatments.

SURGE increased irrigation water use efficiency by 29% compared to CONV.

Net return above irrigation cost did not differ between SURGE and CONV regardless of diesel price or pumping depth.

These results indicate that Midsouth soybean producers can adopt SURGE on clay-textured soils without affecting seed yield and profitability, while concurrently decreasing the amount of irrigation water applied to irrigated sites.

SURGE IRRIGATION TO REDUCE IRRIGATION REQUIREMENTS FOR SOYBEAN (*GLYCINE MAX* L.) ON MID-SOUTH CLAY-TEXTURED SOILS

C. W. Wood[1*], L. J. Krutz[1], L. Falconer[1], H.C. Pringle[1], T. Irby[2], C. J. Bryant[1], R. L. Atwill[1], D. M. Pickelmann[1]

[1]Mississippi State University Delta Research Extension Center, Stoneville, Mississippi
[2]Mississipi State University Department of Plant and Soil Sciences, Starkville, Mississippi
*Corresponding author- wwood@drec.msstate.edu

ABSTRACT

In the Midsouthern United States, twenty-five percent of the soybean (*Glycine max* L.) acres are planted on clay-textured soils and irrigated using conventional continuous flow (CONV), the least efficient irrigation delivery system. The objective of this study was to determine the effect of surge irrigation (SURGE) on amount of water applied, soybean grain yield, irrigation water use efficiency, and net return above irrigation costs when implemented on clay-textured soils.

The experiment was conducted during the 2013 through 2015 growing seasons in Stoneville, Mississippi and consisted of paired fields, with the same cultivar, soil texture, planting date, and management practices used on both sites. Paired fields were randomly assigned as SURGE or CONV. Water applied to each field was monitored with flowmeters, and irrigations were initiated based on soil moisture sensor thresholds. Treatments were mechanically harvested, and soybean grain yield determined with a yield monitor. Relative to CONV, SURGE reduced the amount of water applied per irrigation event by 22%, and total water applied in-season by 24% ($P \leq 0.0349$). Soybean grain yield averaged 66.3 bu/acre and was not different between delivery systems ($P = 0.7711$), but SURGE increased irrigation water use efficiency by 29% compared to CONV ($P = 0.0076$). Net return above irrigation cost was not different between CONV and SURGE, regardless of diesel price or pumping depth ($P \geq 0.1149$). Results from this study indicate that Mid-South producers can adopt SURGE for soybean on clay-textured soils without adversely affecting yield or on-farm profitability, while concurrently decreasing the demand on depleted groundwater resources.

INTRODUCTION

The number of agricultural wells and subsequent water withdrawals from the Mississippi Alluvial River Valley Aquifer (MARVA) have increased exponentially over the past 50 yrs (Mississippi Department of Environmental Quality, Personal Communication). In Arkansas County, Arkansas, withdrawals increased from 133 million gallons per day in 1965 to 581 million gallons per day in 2000, a 396% expansion (Halberg and Stephens, 1966; T.W. Holland, U.S. Geological Survey, written communication 2002). Agricultural withdrawal from MARVA exceeds the aquifer's recharge rate, thereby causing a decline in groundwater levels (Guzman et al. 2014). The Mississippi Department of Environmental Quality (MDEQ) has responded to declining MARVA levels by requiring withdrawal permits, implementing maximum allowable permitted withdrawal values, and mandating that prescribed irrigation Best Management Practices (BMPs) be implemented on permitted wells.

Conventional continuous flow furrow irrigation (CONV) is the predominant delivery system used by producers for soybean (*Glycine max* L.) grown on clay-textured soils across the Mid-South. Practitioners of CONV utilize lay-flat polyethylene tubing which is attached to the well or riser and then laid perpendicular to the furrows at the upper end of the field. Holes are punctured in the tubing to facilitate the continuous flow of water down each furrow. The method quickly moves water over large amounts of land, but application efficiency with CONV is only 55% (Israeli 1988). Poor irrigation application efficiencies with CONV on clay-textured soils is attributed to deep percolation losses (infiltration exceeds irrigation requirements), tail-water runoff, and slow wetting front advance time (Goldhamer et al. 1987; Varlev et al. 1995; Eid et al. 1999; Matter 2001). Currently, CONV irrigated soybean (*Glycine max* L.) planted on clay-textured soils (2:1 shrink-swell capacity) accounts for approximately 25% of the Mid-South's irrigated acres (Heatherly et al. 2002, USDA-NASS 2015). Improving irrigation application efficiencies on clay textured soils will reduce the amount of water withdrawn from MARVA, which is imperative if furrow irrigation in the Mid-South is to continue.

Surge irrigation (SURGE) is the intermittent application of water to surface irrigated furrows in a series of relatively short, on and off time periods. The intermittent application of water with SURGE on clay textured soils reduces infiltration and deep percolation losses, increases furrow advance time, decreases total irrigation water applied, and improves irrigation application efficiency (Goldhamer et al. 1986; Israeli 1988; Musick et al. 1987; Eid et al. 1999; Testezlaf et al. 1987; Bishop et al. 1981; Izuno et al. 1985). Surge flow irrigation has not been evaluated on clay textured soils in the Mid-South. The objective of this study was to determine the effect of SURGE on irrigation water applied, soybean grain yield, irrigation water use efficiency (IWUE), and net return above irrigation cost when implemented on clay textured soils.

MATERIALS AND METHODS

Site Description

The experiment was conducted at the Delta Research and Extension Center in Stoneville, Mississippi on Sharkey Clay (very-fine, smectitic, thermic Chromic Epiaquerts) during the 2013 through 2015 growing seasons. The Sharkey series consists of very deep, poorly and very poorly drained, very slowly permeable soils that formed in clayey alluvium with a maximum rooting depth of 4 ft (USDA NRCS OSD; USDA/SCS, 1974). The study consisted of paired fields, with the same cultivar, planting date, and management practices in each field. Paired fields were randomly assigned with one being CONV and the other as SURGE (Table 1). All fields were managed for weed and insect pests according to Mississippi State University Extension Service recommendations.

Computerized hole selection and Surge flow irrigation

Computerized hole selection was used on both CONV and SURGE fields. Input parameters for computerized hole selection include accurate elevation of the crown profile where lay-flat irrigation pipe will be installed, accurate water output (gpm), furrow spacing (ft), length of irrigated furrows (ft), diameter of lay-flat irrigation pipe, furrow flow rate (gpm) required for soil to be effectively irrigated, and wall thickness (mil) and allowable pressure (ft. of head) of selected lay flat irrigation pipe (Atwill et al., 2017). Flow rate at the field inlet was determined with a M^{c}Crometer flow tube with attached M^{c}Propeller bolt-on saddle flowmeter (M^{c}Crometer Inc., Hemet, California). Pad elevation was measured every 100 ft with a Topcon® self-leveling slope matching rotary laser level (Topcon Positioning Systems Inc., Livermore, CA), while furrow and pad length were determined from aerial imagery. Furrow spacing was determined as the width between planted rows. Computerized hole selection was calculated with the Pipe Hole And Universal Crown Evaluation Tool (PHAUCET) version 8.2.20 (USDA-NRCS, Washington, DC). Surge flow irrigation was applied with a P&R STAR surge valve (P&R Surge Systems, Inc., Lubbock, TX). Four advances phases were utilized and soak cycles were eliminated.

Irrigation Scheduling

Irrigation was applied when the average soil moisture content in the 0- to- 24-in rooting depth was between -75 and -100 cbar as measured by Watermark Model 200SS soil water potential sensors (Irrometer Co., Riverside, CA), installed at 6, 12, and 24-in depths. Irrigation was terminated at the R6.5 growth stage as recommended by the Mississippi State University Extension Service. Treatments were mechanically harvested at physiological maturity and yields determined with a calibrated yield monitor.

Economic Analysis

The model used to estimate irrigation costs in this study incorporates irrigation enterprise budgets developed utilizing the Mississippi State University Budget Generator for conventional (CONV) and SURGE technologies at four different depths (RELIFT of 18 feet, Standard Depth of 140 feet, 200 Feet and 400 Feet). The model develops estimates of total receipts, total direct expenses, total fixed expenses, total specified expenses and net returns above total specified expenses on a per acre basis. The cost estimates are adjusted on an annual basis for the 2013, 2014 and 2015 crop years for changes in variable input costs other than diesel prices. Diesel costs are estimated for each observation based on the amount of water pumped at a baseline diesel cost of $2.83 per gallon, the average price used in developing MSU budgets for the 2013, 2014 and 2015 crop years. Soybean prices are held constant across all scenarios at $11.11 per bushel, the average price reported by USDA at Greenville, Mississippi for the August, September and October harvest time period for the 2013, 2014 and 2015 crop years. To test the sensitivity of both technologies to differences in the major variable costs associated with pumping, a high diesel price and a low diesel price were evaluated. Prices for the scenarios were taken from the USDA Prices Paid Survey for the 2006-2015 timeframe for the Delta States region. The maximum annual average reported diesel price for the 2006-2015 timeframe of $3.70 per gallon is used in the high diesel price scenario and the lowest price of $1.60 per gallon is used in the low diesel price scenario.

Assumptions related to equipment utilized in each enterprise budget are reported in Table 2. The values for purchase price and fuel consumption are based on personal communication with Mississippi Delta region irrigation equipment input and service providers. The RELIFT alternative utilizes a 75 hp tractor as a power unit, with all other alternatives using a 100 hp stationary diesel engine for power. Irrigation water is assumed to be supplied at 2600 gallons per minute (gpm) for the RELIFT alternatives, 2000 gpm for the 140 ft Standard Depth well alternative, 1800 gpm for the 200 ft well alternative and 1250 gpm for the 400 ft well alternative.

Statistical Analysis

Irrigation water applied per event, total irrigation water applied, soybean grain yield, IWUE, and net return above irrigation costs were analyzed using the MIXED procedure of SAS (Statistical Analytical System Release 9.4; SAS Institute Inc., Cary, North Carolina), with year and field (year) as random effects.

RESULTS AND DISCUSSION

Irrigation Water Applied

Surge flow had a significant effect on irrigation water applied per event and total irrigation applied in-season ($P \leq 0.0349$). Water applied per SURGE event and total water applied with SURGE in-season was reduced by 22% and 24%, respectively (Table 3). Others reported that SURGE on clay textured soils reduced total irrigation water use 31% to 80% (Izuno et al. 1985; Testezlaf et al. 1987; Musick et al. 1987; Rodriguez et al. 2004). Additionally, linear regression analysis indicated that 98% of the variability in the percent reduction in irrigation water applied by SURGE was a function of furrow length (Figure 1). Results indicate that SURGE reduces total irrigation water use on clay textured soils, and that reduction in water use with SURGE increases linearly from 10% on short furrow lengthss of 540 ft up to 35% at a furrow length of 1800 ft.

Advantages of SURGE expand beyond reduced irrigation water use in soybean on clay textured soils. At the farm scale, improved irrigation application efficiency provided by SURGE on clay textured soils reduces the time required for a well to be committed to an irrigation set. Surge irrigation, therefore, improves on-farm irrigation capacity, thereby allowing more acres to be irrigated in a timelier manner by a single well. Improved timeliness of irrigation reduces the potential for yield loss associated with drought stress. Additionally, water savings attributed to SURGE are scalable and have regional implications. The overdraft on the MARVA in the Delta region of Mississippi is 300,000 acre-ft/yr. These data denote that 25% of the agricultural overdraft in the Delta of Mississippi will be eliminated if SURGE is implemented on CONV soybean grown on clay textured soils.

Yield and Irrigation Water Use Efficiency

The principal hypothesis of this study was that SURGE will have no adverse effect on soybean grain yield, but that the technique will improve irrigation application efficiency, and subsequently, IWUE. Pooled over site years, soybean grain yield averaged 66.3 bu/acre and was not different between SURGE and CONV ($P=0.7711$, Table 3). As theorized, SURGE improved IWUE 29% relative to CONV ($P = 0.0076$; Table 3). Others noted that on clay textured soils, grain yields were either not affected by SURGE or were reduced up to 12% (Onder 1994; Kanber et al. 2001; Goldhamer et al. 1987; Musick et al. 1987). Many researchers, however, report that SURGE on clay textured soils increased IWUE up to 19% relative to the control (Izuno and Podmore 1986; Unlu et al. 2007; Okasha et al. 2013). These data indicate that SURGE will improve IWUE on clay textured soils throughout the Mid-South, while maintaining soybean grain yield equivalent to that of CONV.

Economic Return

The estimated irrigation costs per acre calculated at the average acre inches of water pumped at the baseline diesel price of $2.83 per gallon for the CONV (6.25 acre inches) and SURGE (4.75 acre inches) technologies are reported in Table 4. The higher values for the "Other Direct" under SURGE are attributed to the extra cost associated with transfer pipe and surge valve batteries. The higher values for the "Total Fixed" values for SURGE are attributed to the capital recovery cost for the surge valves and elbows. As would be expected, the advantage of CONV in lower total specified cost declines as the depth that water is being lifted increases.

A premise of this study was that water savings afforded by SURGE would compensate for the additional costs required to implement the technology, regardless of fuel price or pumping depth. Estimated least square means for net returns above total specified irrigation costs for CONV and SURGE at the baseline soybean price of $11.11 per bushel and baseline diesel price of $2.83 per gallon, high diesel price of $3.70 per gallon, and low diesel price of $1.60 per gallon, are reported in Tables 5, 6, and 7, respectively. As theorized, regardless of diesel fuel cost or pumping depth, net returns above irrigation costs were not different between CONV and SURGE ($P \geq 0.1149$). These data confirm that the additional costs associated with the purchase of surge valves, elbows, transfer pipe, and batteries are offset by reduced water use, regardless of the pumping depth or diesel cost. Essentially, producers can adopt SURGE on clay textured soils across the Mid-South without adversely affecting on-farm profitability.

Conclusion

The objective of this study was to determine the effect of SURGE on irrigation water applied, soybean grain yield, irrigation water use efficiency, and net return above irrigation cost on clay textured soils. Surge flow irrigation on clay textured soils will have no adverse effect on soybean grain yield, but this technique will reduce irrigation water applied and the time required to irrigate a given site. Moreover, these data confirm that the water savings recouped by SURGE will compensate for the increased capital investment required for this irrigation strategy. In essence, SURGE on clay textured soils can be adopted by Mid-South producers without adversely affecting yield or on-farm profitability, while concurrently easing the region's groundwater shortage problems.

References

Bishop, A. A., W. R. Walker, N. L. Allen, and G. J. Poole. 1981. Furrow advance rates under surge flow systems. Am. Soc. Civil Engr., J. Irrig. and Drain. Div., v 107, n IR3, p 257-264.

Eid, S. M., M. M. Ibrahim, S. A. Gaheen, and S. A. Abd El-Hafez. 1999. Evaluation of surge flow irrigation system in clay soil under different land leveling practices. Soil Water and Environment Res. Inst. Agric. Res. Center. Third Conf. on Farm Irrigation and Agroclimatology, 25-27. Jan. 1990 Dokki, Egypt.

Goldhamer, D. A., A. H. Mohammad, and R. C. Phene. 1986. Comparison of surge and continuous flow irrigation in California. Am. Soc. Civil Engr. Proc. Irrig. and Drain. Div. Spec. Conf., Portland, Ore. pp 392-408.

Goldhamer, D. A., M. A. Alemi, and R. C. Phene. 1987. Surge vs. continuous flow irrigation. University of California Agricultural Experiment Station Sept-Oct Bulletin pp 29-32.

Halberg, H.N., and J.W. Stephens. 1966. Use of water in Arkansas, 1965. Arkansas Geological Commission Water Resources Summary 5, 12p.

Hardaker, J.B., J.W. Richardson, G. Lien, and K.D. Schumann. "Stochastic Efficiency Analysis With Risk Aversion Bounds: A Simplified Approach." The Australian Journal of Agricultural and Resource Economics, 48:2, 2004, pp. 253-270.

Heatherly, L. G. 2014. Irrigation water conservation for the Mississippi delta. www.mssoy.org. Accessed 1-April-2016.

Heatherly, L. G., S. R. Spurlock, J. G. Black, R. A. Wesley. 2002. Fall tillage for soybean grown on delta clay soils. Mississippi Agricultural and Forestry Experiment Station Bulletin 1117.

Israeli, I. 1988. Comparison of surge and cablegation to continuous furrow irrigation. Am. Soc. Agric. Engrs. St. Joseph, Mich. ASAE paper no. 88-2014, pp 14.

Izuno, F. T., and T. H. Podmore. 1986. Surge irrigation management. Agric Water Manage 11:279-291.

Izuno, F. T., T. H. Podmore, and H. R. Duke. 1985. Infiltration under surge irrigation. Trans. ASAE, v 28, n 3, pp 517-521.

Kanber, R., H. Koksal, S. Onder, S. Kapur, and S. Sahan. 2001. Comparison of surge and continuous furrow irrigation methods for cotton. Agric. Water Manage 47:119-135.

Matter, M. A. 2001. Relationship between ploughing methods and surge irrigation and its effect on water rationalization. M. S. Thesis. Fac. Of Agric. Kafr El-Sheikh. Tanta Univ. Egypt.

Musick, J. T., J. D. Walker, A. D. Schneider, and F. B. Pringle. 1987. Seasonal evaluation of surge flow irrigation for corn. Am. Soc. Agric. Engrs. Applied Engineering in Agriculture, v 3, n 2. Pp 247-251.

Okasha, E. M., R. E. Abdelraouf, and M. A. A. Abdou. 2013. Effect of land leveling and water applied methods on yield and irrigation water use efficiency of Maize (Zea mays L.) grown under clay soil conditions. Wrld App. Sci. J. 27(2):83-190.

Onder, S. 1994. The comparison of surge steady furrows under Cukurova conditions. Nata and App Sci, Inst, Irr and Drain. Eng Dept, Ph. D. thesis, University of Cukurova, Adana, p 273.

Pouliquen, L.Y. Risk Analysis in Project Analysis. Baltimore: The Johns Hopkins Press, 1970.
Reutlinger, S. Techniques for Project Appraisal Under Uncertainty. Baltimore: The Johns Hopkins Press, 1970.

Richardson, J.W., K. Schumann, and P. Feldman. "Simetar: Simulation for Excel to Analyze Risk." Simetar, Inc, College Station, Texas, January 2008.

Richardson, J.W. and H.P. Mapp, Jr. "Use of Probabilistic Cash Flows in Analyzing Investments Under Conditions of Risk and Uncertainty." Southern Journal of Agricultural Economics, 8(December 1976): 19 24.

Rodriguez, J. A., and A. Diaz, J. A. Reyes, and R. Pujols. 2004. Comparison between surge irrigation and conventional furrow irrigation for covered black tobacco cultivation. Spanish J. Agri. Res. 2:445-458.

Testezlaf, R. R., L. Elliot, and J. E. Garton. 1987. Furrow infiltration under surge flow irrigation. Trans. ASAE, v 30. N 1 pp 193-197.

Unlu, M., R. Kanber, S. Onder, M. Sezen, K. Diker, B. Ozekici, and M. Oylu. 2007. Cotton yields under different furrow irrigation management techniques in the Southeastern Anatolia Project (GAP) area, Turkey. Irrig Sci. 26:35-48.

Varlev, I., Z. Popova, I. Gospoodinov, and N. X. Tsiourtis. 1995. Furrow irrigation by surges as water saving technology. Proceedings of the EWRA 95 Symposium Nicosia. Cyprus. 14-18 March. 277-280.

Vories, E.D., P.L. Tacker and R. Hogan. "Multiple inlet approach to reduce water requirements for Rice production." Applied Engineering in Agriculture, 21 (4): 611-616.

Table 1. Fields used in the study located at the Delta Research and Extension Center in Stoneville, Mississippi, comparing surge flow irrigation (SURGE) with conventional flow irrigation (CONV) of soybean grown on clay textured soils during the 2013 through 2015 growing seasons.

			Field Size (acre)	
			Irrigation Method	
Year	Field	Max Furrow Length (ft)	CONV	SURGE
2013	1	540	18.0	18.0
2013	2	900	15.0	15.0
2014	1	540	14.2	14.2
2014	2	1,600	7.8	6.7
2015	1	1,600	6.3	7.6
2015	2	1,800	4.5	9.0

Table 2. Estimated purchase price, annual use, useful life, fuel consumption rate, fuel cost, repair and maintenance (R&M), total direct, fixed and total cost per year based on pumping nine acre-inches per year and 2015 input prices.

	Unit of	Purchase	Useful	Fuel	----------------------Costs--------------------				
Item Name	Measure	Price	Life	Use	Fuel	R&M	Direct	Fixed	Total
		dollars	*years*	*gal/hr*	-----------------------*$/yr*---------------------				
Land Forming ($390)	acre	450	25	0	0.00	0.00	0.00	31.92	31.92
Surge Valve - 10"	each	3,483	10	0	0.00	0.00	0.00	348.30	348.30
Pipe Elbows	each	127	20	0	0.00	0.00	0.00	6.35	6.35
RELIFT Tractor-75hp	ac-in	21,113	10	3.86	1924.09	1055.56	2979.74	1894.94	4874.68
Engine-100 Hp 140 ft	ac-in	20,000	20	3.6	2346.13	750.00	3096.13	1604.85	4700.98
Engine-100 Hp 200 ft	ac-in	20,000	20	3.6	2592.00	750.00	3342.00	1604.85	4946.85
Engine-100 Hp 400 ft	ac-in	20,000	20	3.6	3732.48	750.00	4482.48	1604.85	6087.33
RELIFT Pump	each	6,670	25	0	0.00	160.08	160.08	473.25	633.33
Well & Pump - 140 ft	each	20,250	25	0	0.00	486.00	486.00	1436.78	1922.78
Well & Pump- 200 ft	each	25,150	25	0	0.00	603.60	603.60	1784.45	2388.05
Well&Pump- 400 ft	each	43,150	25	0	0.00	1035.60	1035.60	3061.59	4097.19

Table 3. Findings from the study comparing surge flow irrigation (SURGE) with conventional flow irrigation (CONV) of soybean on clay textured soils at Stoneville, Mississippi during the 2013 through 2015 growing seasons.

	Least Square Mean Value		
	Irrigation Method		
Parameter	CONV	SURGE	P value
Irrigation Water Applied per event (acre in^{-1})	3.98 (0.21)[a]	3.11 (0.16)	0.0285
Irrigation Water Applied in Season (acre in^{-1})	6.25 (1.36)	4.75 (1.14)	0.0349
Soybean Grain Yield (bu $acre^{-1}$)	66.3 (1.02)	66.2 (1.16)	0.7711
Irrigation Water Use Efficiency (bu $acre^{-1}$)	14.0 (3.31)	18.0 (3.85)	0.0076

[a]Standard Deviation

Table 4. Estimated irrigation costs per acre by system for conventional continuous flow irrigation (CONV) and surge flow irrigation (SURGE) at average quantities of water pumped and baseline diesel prices.

Estimated Costs per Acre for CONV Technology for 6.25 acre-inches water and $2.83/gal. diesel price.

Water lift depth	Diesel	Other Direct	Total Direct	Total Fixed	Total Specified
Relift at 18 ft	13.65	21.55	35.20	54.98	90.18
Standard well at 140 ft	16.24	21.76	38.00	59.22	97.22
200 ft	17.75	22.52	40.27	61.41	101.68
400 ft	24.76	25.39	50.15	69.46	119.61

Estimated Costs per Acre for SURGE Technology for 4.75 acre-inches water and $2.83/gal. diesel price.

Water lift depth	Diesel	Other Direct	Total Direct	Total Fixed	Total Specified
Relift at 18 ft	10.81	24.30	35.11	59.86	94.97
Standard well at 140 ft	12.78	24.51	37.29	64.10	101.39
200 ft	13.92	25.27	39.19	66.29	105.48
400 ft	19.25	28.14	47.39	74.34	121.73

Table 5. Estimated Least Square Means for net returns above irrigation costs at baseline soybean price of $11.11 per bushel and baseline diesel price of $2.83 per gallon for continuous flow irrigation (CONV) and surge flow irrigation (SURGE) when water is lifted from four depths: relift at 18 ft, standard well at 140 ft, deep depth at 200 ft, and sparta depth at 400 ft.

Water lift depth	CONV	SURGE	P value
Feet	--------------$/acre--------------		
Relift—18 ft	649.34	644.89	0.2063
140	642.33	638.54	0.2810
200	638.13	634.82	0.3481
400	621.15	619.98	0.7544

Table 6. Estimated least square means for net returns above irrigation costs at baseline soybean price of $11.11 per bushel and high diesel price of $3.70 per gallon for continuous flow irrigation (CONV) and surge flow irrigation (SURGE) when water is lifted from four depths: relift at 18 ft, standard well at 140 ft, deep depth at 200 ft, and sparta depth at 400 ft.

Water lift depth	CONV	SURGE	P value
Feet	--------------$/acre--------------		
Relift—18 ft	645.15	641.57	0.3091
140	637.39	634.66	0.4421
200	632.69	630.56	0.5549
400	613.52	614.05	0.8985

Table 7. Estimated least square means for net returns above irrigation costs at baseline soybean price of $11.11 per bushel and low diesel price of $1.60 per gallon for continuous flow irrigation (CONV) and surge flow irrigation (SURGE) when water is lifted from four depths: relift at 18 ft, standard well at 140 ft, deep depth at 200 ft, and sparta depth at 400 ft.

Water lift depth	CONV	SURGE	P value
Feet	--------------$/acre--------------		
Relift—18 ft	655.26	649.58	0.1149
140	649.44	644.13	0.1370
200	645.87	640.89	0.1605
400	631.88	628.32	0.3117

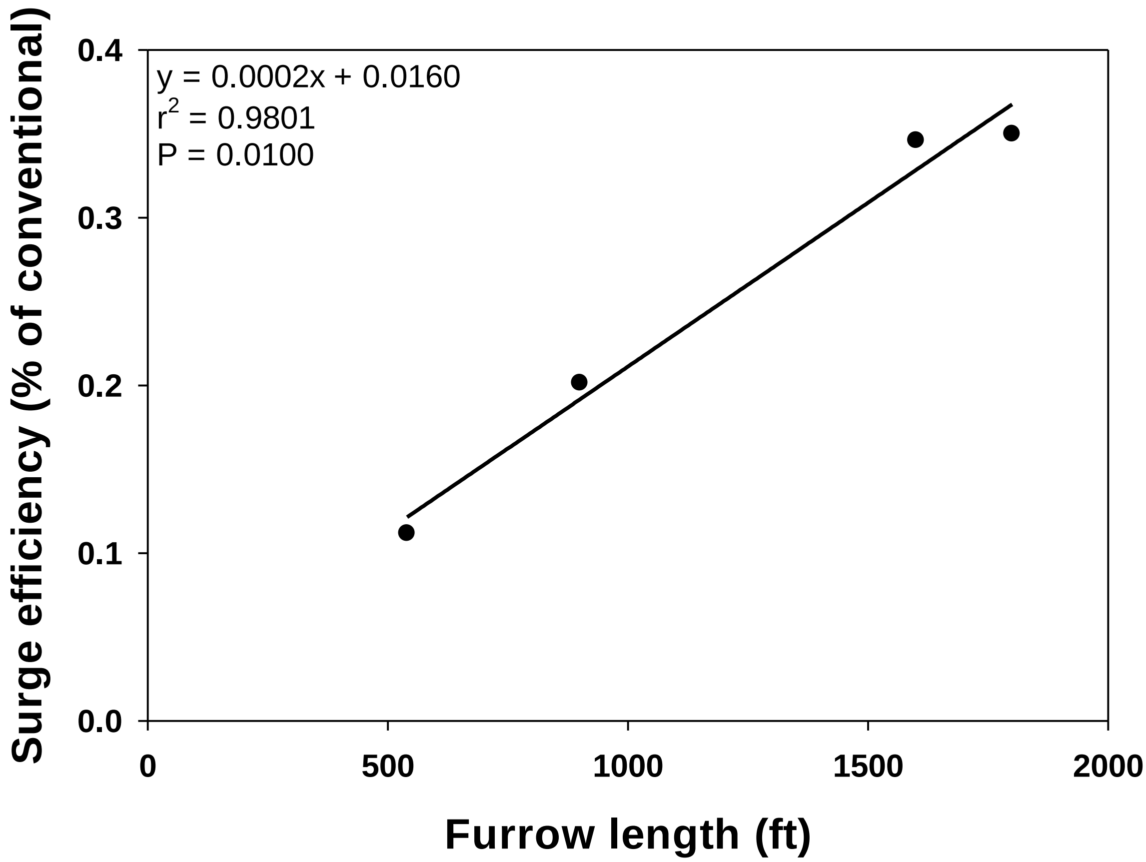

Figure 1. Surge flow irrigation efficiency on clay textured soils as a function of furrow length.