NCAAR

NATIONAL CENTER FOR ALLUVIAL AQUIFER RESEARCH

USDA United States Department of Agriculture

MISSISSIPPI STATE UNIVERSITY

2022 ANNUAL REPORT

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MISSISSIPPI STATE UNIVERSITY™
MS AGRICULTURAL AND FORESTRY EXPERIMENT STATION

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COORDINATORS' MESSAGE

Another Year of Progress

Dear Readers:

The mission of the National Center for Alluvial Aquifer Research is to conduct research and provide information for issues surrounding water use for agriculture and natural resources in the Lower Mississippi River Basin (LMRB). The work documented in our second annual report, we believe, reflects this important mission. With our partners, NCAAR's skillful scientists have continued to conduct significant research projects that ultimately identify practices that reduce water usage in the LMRB. Our faculty successfully completed several multi-year studies and continue to make progress in new projects covering irrigation water management, soil conservation, and evaluating new technologies and tools for solving water quantity and quality issues in the LMRB. Understanding practices that affect infiltration and soil water-holding capacity, recommendations for row rice irrigation and understanding the water budget of an on-farm storage and recovery system are just some highlights from this past year. NCAAR's research impact is demonstrated through the 53 high-quality research articles in 2022.

Drew Gholson
Coordinator / Extension Irrigation Specialist

Amanda Ashworth
Acting Research Leader

Chris Delhom
Acting Research Leader

The second facet of our mission is the crucial work of outreach. Our Extension research projects, education, and outreach efforts were effectively disseminated to our partner-growers. You'll find a snapshot of those efforts and gain an understanding of the impact NCAAR makes in the agricultural community on the infographic on page 77. We had 155 consultations and demonstrations, which allow us to showcase the tools and research to further help producers in the Mississippi Delta and throughout the LMRB. We also added a monthly seminar series in 2022 that allows us to exchange ideas with our partners in real-time. These meetings are hosted in Capps Classroom, but our partners attend via Zoom as well, and they're available anytime on our website.

We are in a year of growth at the West Farm as well. We said goodbye to several colleagues who retired or left for other positions, and we appreciate the commitment and invaluable insight they lent to our mission. We now are tasked with finding those who will help us fulfill the center's goals to reduce LMRB drawdowns by improving production efficiency and promoting alternate water sources through science-based, proven production methods. Lastly, we completed lab renovations that will help our efforts to solve regional water problems. Renovations included the formation of four laboratories with built-in gas, pressurized air, and vacuum lines, gas tank storage, isolated exhaust systems, and safety facilities such as emergency showers and eyewash stations. Our collection of analytical protocols keeps growing as we continue establishing procedures for various biochemical measurements. NCAAR will have the capabilities to analyze soil, water, and plants for numerous parameters in house. These new capabilities will allow researchers to evaluate conservation practices' ability to reduce sediment and nutrients in the LMRB.

We look forward to a successful year in field research and outreach efforts that will continue to improve the sustainability of the Mississippi River Alluvial Aquifer!

IRRIGATION & FERTILIZER MANAGEMENT

Evaluating the Uniformity of Sensor-Based Recommendations on Irrigation Timing

Himmy Lo, Jacob Rix, Drew Gholson, and Lyle Pringle

Introduction

The timing of irrigation is important for growing profitable crops while stewarding water resources. When timing is too early, irrigation is applied more frequently, and the soil stays too wet. Such conditions reduce the ability of the ground to soak up rain and the availability of oxygen and nutrients around plant roots. Not only are irrigation water and expenses wasted, but also crop yield is decreased especially if heavy rain occurs shortly after irrigation. On the other hand, when timing is too late, the soil becomes too dry to supply the water needs of the plants. While such delays can conserve irrigation water, drought stress can limit crop yield. Given all these tradeoffs, appropriate irrigation scheduling may be easier with tools that can suggest irrigation timings when the benefits would most exceed the risks.

One such tool is soil moisture sensors. These devices provide convenient, objective, and science-based assessment of water availability in the plant root zone. Typically, irrigation would be recommended whenever the sensor reading reaches a predetermined trigger value. However, sensors of the same make and model rarely report the same reading even when installed at the same depth within the same field. So how different are the sensor readings and their corresponding recommendations on irrigation timing? Although replicate installations of soil moisture sensors may be uncommon on commercial farms, the answer to this question describes the expected uncertainty in irrigation timing recommendations based on only one sensor installation.

Materials and Methods

Two soil moisture sensor models—Irrometer Watermark 200SS and Sentek Drill & Drop—were compared over two soybean growing seasons in a rectangular, precision-leveled field of the Sharkey soil series near Stoneville, MS. At twelve locations across this field, a Watermark installation and a Drill & Drop installation were placed side by side each season. Each of the

Table 1. *Standard deviation (days) in date of reaching the equivalent of 70 centibars among 12 replicate installations of Irrometer Watermark 2000SS and Sentek Drill & Drop; higher standard deviation indicates worse uniformity, whereas lower standard deviation indicates better uniformity.*

	Season 1 Cycle 1	Season 1 Cycle 2	Season 1 Cycle 3	Season 2 Cycle 1	Season 2 Cycle 2	Season 2 Cycle 3
Watermark	**2.3**	**1.6**	**2.1**	**2.5**	**2.5**	**2.0**
Drill & Drop	**2.4**	**2.0**	**1.8**	**3.6**	**4.3**	**1.8**

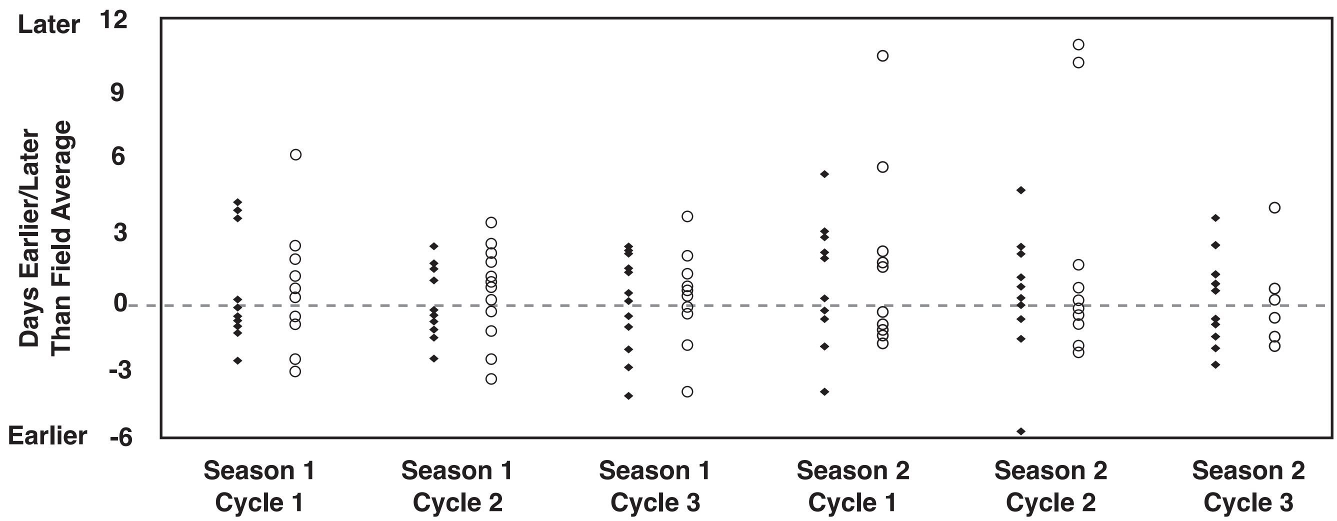

Figure 1. *Differences from the field average in date of reaching the equivalent of 70 centibars among 12 replicate installations of Irrometer Watermark 200SS (solid diamonds) and Sentek Drill & Drop (hollow circles).*

twelve locations was 360 feet downstream from the polypipe out of a total furrow length of 570 feet. All locations were within 1120 feet of each other and were managed identically. During three drying cycles per season, the date when the sensor reading reached the equivalent of 70 centibars was identified for each installation of each sensor model. The standard deviation in these dates was calculated to summarize the uniformity of sensor-based recommendations on irrigation timing.

Preliminary Findings and Next Steps

The Sentek Drill & Drop was found to be less uniform than the Irrometer Watermark 200SS during four of the six drying cycles studied (**Table 1**). Nonetheless, the readings from replicate installations were quite variable for both sensor models (**Figure 1**). The largest differences from the field average were caused by rain occurring between the date when a particular installation reached the equivalent of 70 centibars and the date when the field average reached the equivalent of 70 centibars. Given these observations, NCAAR researchers have been developing and testing strategies to minimize the uncertainty of sensor-based recommendations on irrigation timing. Successful strategies, once proven, will be shared with stakeholders to improve irrigation scheduling across the Lower Mississippi River Basin.

Drought Response Based on Modeling of Leaf Photosynthetic Parameters in Two Gossypium Species

Daryl Chastain, Bhupinder Singh, and John L. Snider

Introduction

Cotton is well adapted to dry areas, but progressive water deficits can lead to decline in net photosynthesis (A_N), ultimately reducing yield and resulting in excessive aquifer depletion. However, the exact mechanism responsible for this decline in net photosynthesis (stomatal or non-stomatal) is not fully understood under field conditions, partially due to limitations in the ability to collect these critical field-scale data. To this end, a field study was conducted to quantify the impact of drought, as measured by midday stomatal conductance to water vapor (g_{sw}), on cotton leaf metabolism in pima (*Gossypium barbadense*) and upland (*Gossypium hirsutum*) cotton. Survey gas exchange and rapid photosynthetic CO_2 response (RACiR) were conducted during flowering. We hypothesized that light saturated midday stomatal conductance could define a pattern of photosynthetic response to moderate drought stress in cotton and could be used as basis for rapid comparisons in photosynthetic limitation under drought. Additionally, we hypothesize that chlorophyll fluorescence may be a target for indicating plant stress and may be used to fine-tune the need for irrigation using remote and proximal sensing techniques.

Materials and Methods

Two cotton species PHY490 WRF (*Gossypium hirsutum*) and PHY881 RF (*Gossypium barbadense*) were sewn in the 2017 and 2018 growing-seasons to evaluate the effects of mild and moderate drought on leaf-level metabolism and to determine if fluorescence signals are a potential indicator of stress. Plant water status was monitored using midday leaf water potential and gsw as a reference parameter. Survey gas exchange was conducted on uppermost fully

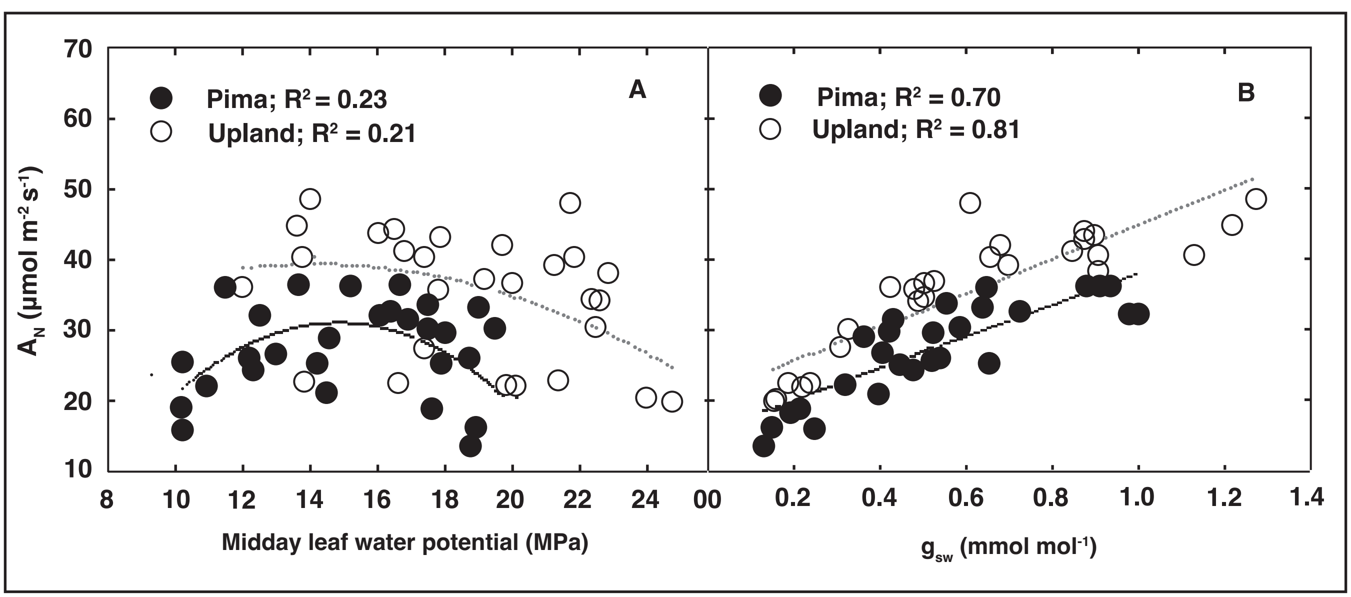

***Figure 1**. The relationship between net photosynthesis (A_N) and midday leaf water potential (ΨMD) (A) and midday stomatal conductance (g_{sw}) (B).*

expanded leaf after allowing for stability at 60% relative humidity and 400 ppm CO_2 using a Li-COR 6800F at flowering stage. Rapid Photosynthetic CO_2 response (RACiR) experiments were conducted on the same leaf following survey measurements. Briefly, leaves were acclimated at 400 ppm CO_2 before rapidly decreasing to approx. 10 ppm. CO_2 was then increased to 1,000 ppm over 10 minutes. Mesophyll conductance (g_m), CO_2 concentration at the carboxylation site (C_c), and ETR were also calculated by standard methods.

Results and Discussion

In this study, we observed no relationship between midday leaf water potential (ΨMD) and net photosynthesis (A_N), however we did observe a decline in A_N as g_{sw} declined for both Gossypium species (**Figure 1**).

Correlation analysis indicated typical relationships with A_N and parameters associated with stomatal limitations (Ci, C_c, g_{sw}, E); however, it was found that while pima exhibited a strong relationship between maximum electron transport rate and instantaneous electron transport rate (ETR), upland cotton did not. Furthermore, when ETR is broken down into proportions contributing to net photosynthesis and photorespiration (ETR_A, ETR_P, respectively), we found that a greater proportion of ETR is being shuttled to the photorespiratory pathway in upland, relative to pima, as g_{sw} decreases (**Figure 2**).

Interestingly, the increase in ETR_P observed in upland under drought (**Figure 2A**) suggests it acquires an alternative pathway to consumes excess energy for normal plant metabolism and to prevent oxidative damage of Photosystem I (PSI) by limiting free electrons beyond acceptor side of PSI. Similarly, **Figure 2B** indicates lowered steady state chlorophyll florescence (Fs), an indication of non-photochemical quenching, in upland cotton under mild drought stress than pima cotton. The relationship between ETRP and basal fluorescence (Fs) to g_{sw} give insights into biochemical limitations leading to interspecific differences in photosynthetic rates under drought stress. The information could be useful to fill gaps associated with stomatal and non-stomatal limitations under drought in cotton. In addition, Fs could be used as an indicator of drought stress in upland cotton and could potentially be measured using remote or proximal sensing to indicate the need for irrigation prior to a yield-limiting stress event.

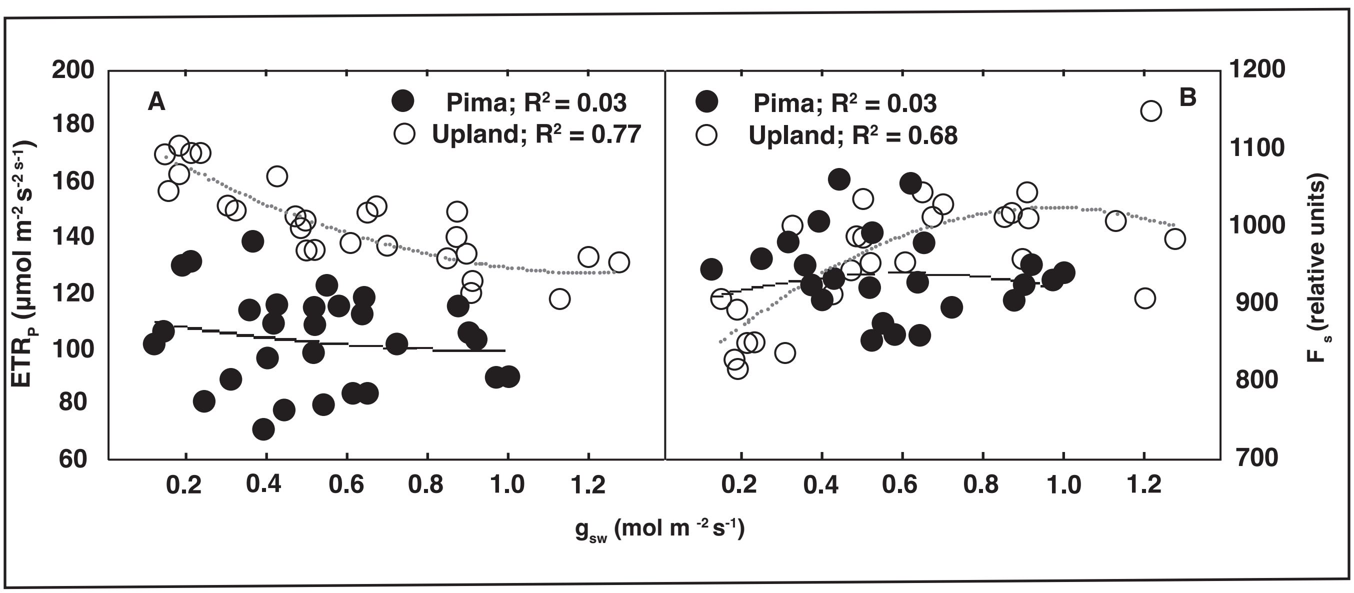

Figure 2. *The relationship between stomatal conductance (g_{sw}), photorespiratory electron transport (ETR_P; A), and basal fluorescence (Fs; B).*

Using Capacitance Probes to Schedule Furrow Irrigation on Cracking Clay Soils

Himmy Lo, Jacob Rix, Drew Gholson, and Lyle Pringle

Introduction

Using soil moisture sensors to schedule irrigation is a best practice promoted by the Row-Crop Irrigation Science Extension and Research (RISER) initiative at Mississippi State University. These sensors make it easier to give greater consideration to soil water reserves when making irrigation scheduling decisions. Over the past decade, Mississippi State University Extension Service has developed, validated, and disseminated guidelines on using the Irrometer Watermark 200SS sensor model (please see https://www.ncaar.msstate.edu/outreach/ for details). However, equivalent guidelines have not been established for other sensor models such as the Sentek Drill & Drop.

A major obstacle has been the difficulty of determining the threshold value for scheduling irrigation using the Drill & Drop. In other words, how dry can Drill & Drop readings become until drought stress starts to reduce crop yield? Existing data showed that this threshold value can differ widely across soil types and even among Drill & Drop installations within the same field. Thus, there is no universal threshold value, and there may not be a reliable way to predict the threshold value before installation.

As an alternative to focusing on the exact readings, both the manufacturer and other researchers have suggested scheduling irrigation by examining the daily drying rate of the Drill & Drop. However, past implementations of this method have depended heavily on the user's subjective interpretation. To tackle this limitation, NCAAR researchers have chosen to calculate a "relative drying rate" from the Drill & Drop and have been testing "relative drying rate" thresholds for scheduling furrow irrigation on cracking clay soils.

Materials and Methods

Four sensor-based irrigation scheduling treatments were each replicated on eight plots in a rectangular, precision-leveled field of the Sharkey soil series near Stoneville, MS. Pioneer P47A64X soybean was planted on April 29th at 140,000 seeds per acre in 40-inch twin rows and reached full maturity on September 22nd. Between the R2 and R6.5 growth stages, alternate-furrow irrigation was scheduled according to treatment-specific rules (**Table 1**). No irrigation was applied during other growth stages. Every irrigation application was cut off around the completion of furrow advance to minimize tailwater. From an area 20 feet wide by 500 feet long in the center of each plot, soybean yield was measured on September 27th using a Precision Planting YieldSense yield monitor with field-specific calibration by a weigh wagon.

Preliminary Findings and Next Steps

The Watermark 70-centibar treatment received the highest number of irrigation applica-

***Table 1**. Irrigation scheduling rules for each of the four sensor-based treatments.*

	Irrigate if…
Watermark 70-centibar	**Watermark soil water tension increased to 70 centibars**
Watermark 100-centibar	**Watermark soil water tension increased to 100 centibars**
Drill & Drop 70%	**Drill & Drop relative drying rate decreased to 70%**
Drill & Drop 50%	**Drill & Drop relative drying rate decreased to 50%**

Table 2. *Tentative results from the 2022 field experiment; treatments sharing a superscript letter are not statistically different in soybean yield.*

Treatment	Irrigation Applications	Total Irrigation Amount (inches)	Soybean Yield at 13% Moisture (bushels per acre)
Watermark 70-centibar	9	11.4	88.9^{A}
Watermark 100-centibar	5	11.3	85.8^{B}
Drill & Drop 70%	5	9.4	86.3^{B}
Drill & Drop 50%	3	7.5	83.6^{C}

tions, received the highest amount of irrigation water, and produced the highest soybean yield (**Table 2**). On the opposite extreme, the Drill & Drop 50% treatment received the lowest number of irrigation applications, received the lowest amount of irrigation water, and produced the lowest soybean yield. Such a pattern of more irrigation leading to more yield was partially broken by the Drill & Drop 70% treatment. This exceptional treatment received almost two inches less irrigation but achieved statistically indistinguishable and numerically higher soybean yield when compared against the Watermark 100-centibar treatment. Further research is planned in preparation for creating proven guidelines on using Drill & Drop probes to schedule irrigation across the Lower Mississippi River Basin.

Evaluation of Irrigation Practices and Nutrient Management to Close the Gap in Furrow Irrigated Rice

Anna Smyly and Drew Gholson

Sponsored by Mississippi Rice Research Promotion Board under project 10-2023.

Introduction

Rice (*Oryza sativa L.*), in Mississippi, is typically grown using a continuous flood production system that requires large inputs of water throughout the growing season. On average, rice uses approximately 3.0-acre feet per year of water, which based on average acreage of rice production equates to approximately 600,000-acre feet per year being pumped in Mississippi. Irrigation water in the Mississippi Delta is extensively drawn from the Mississippi River Valley alluvial aquifer (MRVAA). The MRVAA is beginning to deplete at a rate of 300,000-acre feet per year and irrigation water is becoming scarce. Determining a more efficient irrigation approach is vital to the sustainability of the aquifer for agricultural needs. Research in Mississippi has shown furrow-irrigated rice (FIR) to produce rice with less water, but there is limited information on how to efficiently irrigate and fertilize FIR. The objective of this study was to evaluate the effect of 4 different irrigation frequencies on soil moisture, water depth levels, water use efficiency (WUE), and rice grain yield of FIR.

Materials and Methods

Research was conducted at the Delta Research and Extension Center in Stoneville, MS on Sharkey clay soil in 2021, 2022, and will continue in 2023. The arrangement of the experiment design was randomized complete block, including 4 irrigation frequencies on a calendar-based schedule of irrigating every day, every 3, 5, and 7 days. Rice variety CLL16 was planted into freshly pulled beds spaced at 96 cm and a seeding rate of 73 lbs./ac. Treatment plots were 8 rows wide with a levee constructed on either side of the rice plot to keep irrigation frequency treatments separated. Soil moisture, water depth levels, and water usage were recorded before and after each irrigation occurrence from the top, middle, and bottom one-thirds of each treatment plot using WaterMark® Soil Moisture Sensors®, Pani-Pipes®, Precision King AgSense Sensors®, and flowmeters. Rice grain yield was taken from the middle 2 rows of each treatment plot and analyzed using statistical analysis software (SAS).

Results and Discussion

Average rice grain yield (bu ac-1) was measured for each treatment plot across the whole plot, as well as the three different zones within the plots. Table 1 shows average yields for 2021.The study observed in 2021 treatment plots irrigated every day, numerically, had the highest average yield (152 bu ac-1) compared to the other 3 irrigation timings. Average rice

Table 1. *Avg. Rice Grain Yield for each irrigation frequency treatment in 2021. Numbers followed by the same letter are not significantly different at α = 0.05.*

Treatment	Avg. Rice Grain Yield (bu ac^{-1})
Everyday	152 a
Every 3 Days	144 b
Every 5 Days	143 b
Every 7 Days	140 c

Table 2. *Avg. Rice Grain Yield for each irrigation frequency treatment in 2022. Numbers followed by the same letter are not significantly different at α = 0.05.*

Treatment	Avg. Rice Grain Yield (bu ac^{-1})
Everyday	162 a
Every 7 Days	160 a
Every 5 Days	153 a
Every 3 Days	152 a

Table 3. *2021 & 2022 combined average rice grain yield (bu ac-1) for the top, middle, & bottom zones of each irrigation frequency treatment; a) Every day, b) Every 3 days, c) Every 5 days, & d) Every 7 days. Numbers followed by the same letter are not significantly different at α = 0.05.*

a.

Everyday	
Zone	Avg. Rice Grain Yield (bu ac^{-1})
Bottom	165 a
Middle	158 b
Top	144 c

b.

Every 3 Days	
Zone	Avg. Rice Grain Yield (bu ac^{-1})
Bottom	151 a
Middle	146 b
Top	143 c

c.

Every 5 Days	
Zone	Avg. Rice Grain Yield (bu ac^{-1})
Bottom	150 a
Middle	147 a
Top	141 b

d.

Every 7 Days	
Zone	Avg. Rice Grain Yield (bu ac^{-1})
Bottom	152 a
Middle	147 b
Top	147 b

grain yields for irrigating every 3 days (144 bu ac^{-1}) and every 5 days (143 bu ac^{-1}) weren't significantly different from each other. Irrigating every 7 days produced the lowest yield (140 bu ac^{-1}) of the 3 irrigation treatments. Yield is numerically different, but not significantly different between the different zones in the treatment plots. Table 2 shows average yields for 2022. In 2022, there were no significant differences between average yields of each irrigation frequency treatment. Table 3 shows the 2021 and 2022 combined average yields for the top, middle, and bottom zones of each irrigation frequency treatment. The bottom zone resulted in a significantly greater average yield compared to the top zone for irrigation frequency treatment.

Conclusion

The 2021 study suggests irrigating FIR every day will produce a higher rice grain yield compared to irrigating every 3, 5, or 7 days. Treatment plots irrigated every day closely mimic a continuous flood production system, which could explain why watering FIR every day produced a higher rice grain yield. The study also suggests a farmer won't see a significant difference in yield when deciding whether to irrigate every 3 or 5 days. However, the 2022 study contradicts these findings in 2021 by finding no significant differences between the average yields of the 4 irrigation treatments. Lodging and consistent irrigation water delivery down the furrows in some irrigation treatment plots was an issue in 2022, which could have led to smaller yield differences and more similar yields. Constructing a well built-up seed bed with straight furrows is important for irrigation water delivery in FIR. Water usage, soil moisture, and water depth levels are still being analyzed. The study will be repeated again in 2023.

Furrow-Irrigated Rice Response to Different Pre-Flood Nitrogen Fertilizer Application Rates

Anna Smyly and Drew Gholson

Sponsored by Mississippi Rice Research Promotion Board under project 10-2023.

Introduction

Rice (*Oryza sativa L.*) prefers to be grown in a saturated, flooded environment requiring large amounts of water throughout the growing season. Rice farmers in the Mississippi Delta extensively draw water from the Mississippi River Valley Alluvial Aquifer (MRVAA) for irrigation purposes. Research shows the aquifer is depleting at fast rates. Furrow-irrigated rice (FIR) has become an increasingly popular method of growing rice with less water. However, FIR has its drawbacks with non-uniform yields and fertility unknowns. Nitrogen (N) is the most limiting nutrient to rice and has a strong impact on rice growth and development. Plant uptake of N fertilizer applications in FIR tend to be more unpredictable due to the aerobic environment under which rice is grown. The objective of this study is to evaluate the effect of different pre-flood N fertilizer applications on a FIR field.

Nitrogen has a strong impact on rice growth and development.

Materials and Methods

Research was conducted at the Delta Research and Extension Center in Stoneville, MS on Sharkey clay soil in 2021, 2022, and will continue in 2023. The arrangement of the experiment design was randomized complete block, including 5 pre-flood N treatments (0, 30, 60, 120, and 180 lbs. ac^{-1}). The study was repeated 3 times. Rice variety, CLL16, was planted into 2 row plots (each 7 ft. x 50 ft.) on 38" row spacing. Fertility treatments were broadcast applied at the 4- to 5-leaf growth stage using a manual variable rate fertilizer spreader. Irrigation water delivery was initiated across all treatment plots after fertilizer treatments were applied to incorporate fertilizer treatments into the soil. Between panicle initiation and panicle differentiation, a mid-season fertilizer application was uniformly applied aerially to all rice plots. All fertilizer plots were irrigated every 3 to 5 days throughout the growing season until

Table 1. *Average rice grain yield (bu ac-1) heat map of each nitrogen fertilizer rate for the three tests.*

	Test 1 Nitrogen Rate (lbs. ac $^{-1}$)					Test 2 Nitrogen Rate (lbs. ac $^{-1}$)					Test 3 Nitrogen Rate (lbs. ac $^{-1}$)				
	0	30	60	120	180	0	30	60	120	180	0	30	60	120	180
Top	63	67	83	92	91	69	73	69	80	88	68	70	59	68	66
	72	90	89	99	107	82	84	94	88	99	71	67	65	102	117
Middle	89	89	99	109	111	86	93	95	107	104	72	73	87	118	98
	75	88	96	116	102	90	103	104	124	119	84	111	83	98	83
Bottom	94	101	94	110	100	96	100	115	121	117	97	80	93	106	99
	91	88	93	105	107	94	108	100	115	119	89	86	80	82	137

plots were drained for harvest. Plant height, whole plant nutrient analysis, and lodging rates were collected at harvest from non-harvest rows. Rice grain yield and milling yield measurements were collected from 2 rows at harvest for each treatment plot and analyzed using statistical software SAS.

Results and Discussion

Rice grain yield data in 2022 shows a gradual increase in yield, numerically, from the lowest N fertilizer rate of 0 lbs. of N ac^{-1} to the highest N fertilizer rate of 180 lbs. of N ac^{-1} for all three-fertility tests (**Figure 1**). **Table 1** shows a heat map of average rice grain yields for each fertility rate within the top, middle, and bottom zones of each test. Across all 3 tests, average yield data indicated no N response in the upper zones of the treatment plots. The plots in the bottom zone of each treatment test tended to have greater yields than the other 2 zones of the treatment test.

Conclusion

Results from this study show regardless of the pre-flood N fertilizer rate, the top zone of

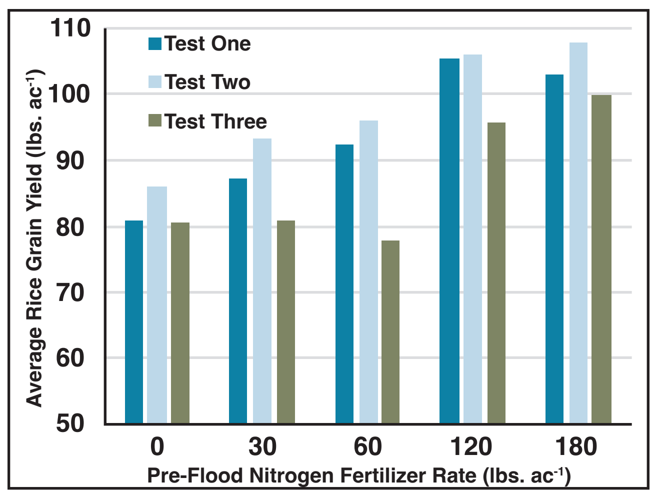

Figure 1. *Average rice grain yields for each N fertilizer rate and each test.*

the test plots had no N response. The upper zone of FIR tends to dry out most quickly when compared to the middle and bottom zones. This can lead to N losses and decrease plant uptake efficiency of N fertilizer applications. The study will be repeated in 2023 to further evaluate FIR response to different pre-flood N fertilizer rates and the causes of nonuniform yield throughout the 3 different zones of a FIR field.

Irrigation, row pattern and nitrogen placement effects on corn grain yield in the Mississippi Delta

Amilcar Vargas, Drew Gholson, Himmy Lo, Gurbir Singh, Dave Spencer, and Jason Krutz

Introduction

Early nitrogen applications in the spring are prone to nitrogen losses due to extended periods of rainfall events. Nitrogen losses such as runoff, volatilization, denitrification, and leaching can be mitigated by following the 4R nutrient stewardship system (right source, right rate, right timing, and right place). The objective was to evaluate different nitrogen placement methods, row patterns in irrigated and rainfed on corn.

The best method to apply UAN was with one knife-coulter and the least efficient was surface dribble in 2021.

Materials and Methods

This study was conducted in 2020 and 2021 at the National Center for Alluvial Aquifer Research (NCAAR) in Leland MS. The corn hybrid DKC70-27 was planted on raised beds on very fine sandy loam for both years of the study. Corn planting dates in 2020 and 2021 were April 05, and March 19, respectively. Field was disked and hipped in the fall; beds were spaced at 40 inches. Irrigation was performed with a furrow system. Row patterns evaluated were single- and twin-row. The nitrogen placement methods chosen were surface dribble, single knife and two knives application. The nitrogen rate was split into two equal applications of 128 kg ha^{-1} at V2 and V6 growth stages as urea-ammonium nitrate (UAN; 32-0-0). UAN applications were performed with a four-row nitrogen applicator knife-coulter, designed to perform as a single or two knives. The surface dribble application was performed by modifying the nitrogen applicator with drop tubes. Field management operations such as tillage, weed, and pest control were conducted following Mississippi State University Extension Service recommendations. Rainfall amounts were retrieved from a weather station located at NCAAR (**Figure 1**). Data collected included corn grain yield, dry weight biomass, and nitrogen agronomic efficiency (NAE). Corn was harvested from the two middle rows with a plot combine equipped with a weight measuring system. Statistical analysis was performed using the statistical analysis software, SAS v. 9.4. Analysis of variance was conducted using the GLIMMIX procedure. Mean separations were performed using Fisher's protected LSD at $\alpha = 0.05$.

Research & Discussion

Corn grain yield was higher in all nitrogen placement methods in both 2020 and 2021 compared to the control (**Table 1**). In 2021, irrigated corn had 10% more grain yield compared to rainfed conditions. Row pattern had no effect in corn grain yield in our study. However, placing nitrogen with one knife had 13 and 7% more grain yield compared to the surface dribble and two knifes, respectively (**Table 1**). Furthermore, side dressing nitrogen with one knife produced the highest dry biomass, resulting in at least 9% more compared to surface dribble or two knives methods.

The best method to apply UAN was with one knife-coulter (NAE = 45%), and the least efficient was surface dribble (NAE = 39%) in 2021 (**Table 1**). These results are consistent with other studies where surface dribble application is the least efficient method to delivered N into the soil due to N losses such as volatilization, runoff, and denitrification (Howard and Tyler, 1989; Malhi and Nyborg, 1985). Pronounced rainfall events during the spring 2021 caused nitrogen losses, which nitrogen availability in the root zone for surface dribble application (**Figure 1**). Our results indicate that one knife-coulter applicator is more efficient than surface dribble and two knives methods in either single or twin row pattern corn.

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Table 1. *Nitrogen placements methods, row pattern and its interaction effects on corn grain yield, dry weight biomass, and nitrogen agronomic efficiency. Same letters within a column are not significantly different at α = 0.05.*

Treatments	Corn grain yield* bu ac^{-1}		Dry weight biomass lb ac^{-1}		N agronomic efficiency	
	2020	2021	2020	2021	2020	2021
Nitrogen placement						
Surface dribble	182 a	192 c	12049 a	19815 b	22	39 c
Side dress w/ one knife	176 a	218 a	11068 a	21867 a	20	45 a
Side dress w/ two knives	172 a	204 b	10532 a	19636 b	19	42 b
Control (no N applied)	93 b	33 d	7497 b	6069 c		
Row pattern						
Single row	155	164	9907	16958	21	42
Twin row	156	159	10621	16691	21	41
Irrigation						
Irrigated	153	169 a	10711	17762	20	44
Rainfed	159	154 b	9907	15977	21	39
*Plant population in 2020 and 2021 were 35,000 and 36,000 seeds acre-1, respectively.						

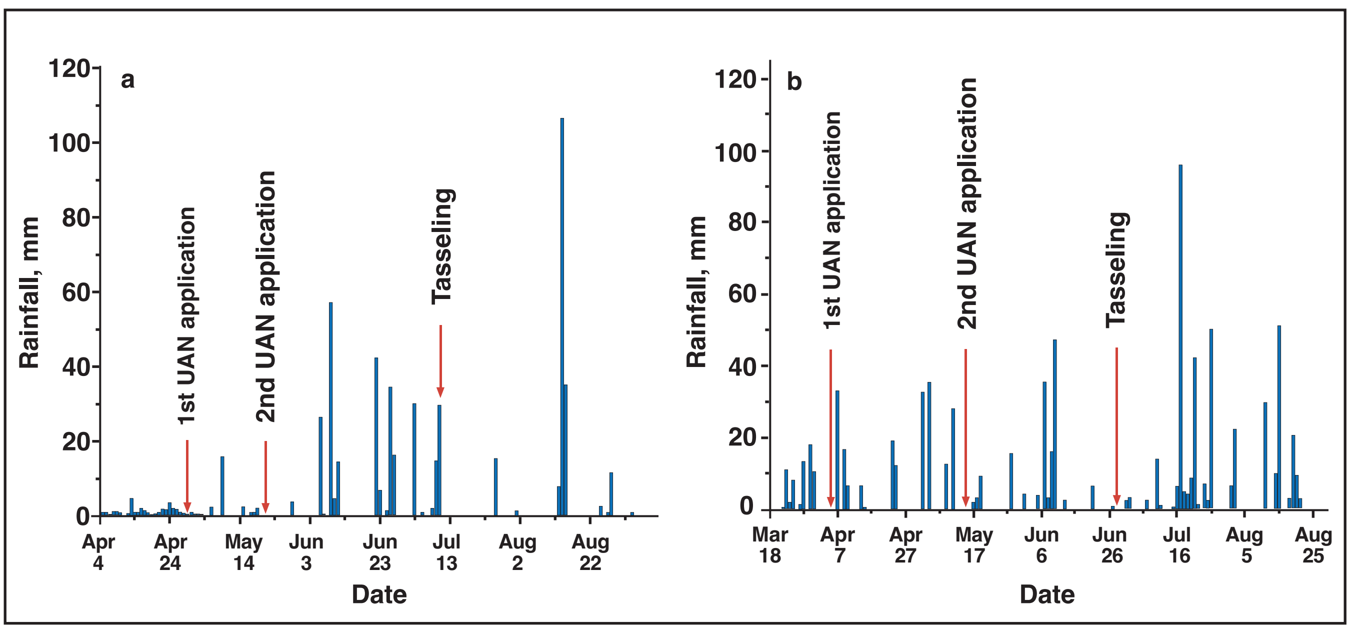

Figure 1. *Daily rainfall during the growing seasons of 2020 (a) and 2021 (b).*

Irrigation method and row pattern effects on soybean grain yield and water use efficiency

Amilcar Vargas, Drew Gholson, Himmy Lo, Gurbir Singh, Dave Spencer, and Jason Krutz

Introduction

The majority of soybean in the Mississippi Delta are grown on heavy clay soils and irrigated with furrow irrigation systems. Water management practices are needed in Mississippi to increase irrigation water use efficiency (IWUE). Increasing IWUE will help to reduce the groundwater withdrawals from the Mississippi River Valley Alluvial Aquifer. The objective was to determine the effects of two irrigation methods and row patterns on soybean grain yield, grain quality, and IWUE in the Mississippi Delta.

Materials and Methods

This study was conducted at the Delta Research and Extension Center on a Sharkey clay soil. The soybean variety AG 43x0 was planted on May 12, at the seeding rate of 135,000 seeds acre^{-1}. Soybean was planted in two-row patterns twin- and single-row spaced at 40 inches. Soybean in twin row treatments were plan ted with a Monosem NG Plus-4 8-row planter and single rows were planted with a John Deere 7300 6-row planter. Irrigation methods were overhead sprinkler and furrow irrigation (**Figure 1**). A rainfed control was also included. Field management operations such as tillage, weed, and pest control were conducted following Mississippi State University Extension Service recommendations. Irrigation decisions were based on soil moisture sensors readings. Three soil moisture sensors were installed at 6, 12, and 24 inches depth. Irrigation was triggered when the weighted average of the three soil moisture sensor readings reached -80 kPa. Sensors at 6 and 12 inches were assigned 0.25 weight value each and 0.50 for the 24 inches depth sensor. Data collected included soybean grain yield, grain quality analysis, and water amount used by each irrigation system. Soybean was harvested on September 26 with a plot combine. The plot combine was equipped with an H2 grain gauge and paired with a computer for data recording, such as test weight, harvest moisture, and weight. Soybean yield was adjusted to 13% moisture. Grain quality analysis was

Table 1. *Irrigation method and row pattern effects on soybean grain yield, irrigation water use efficiency and grain quality. Same letters within a column are not significantly different at α = 0.05.*

Treatment	Grain yield bu acre^{-1}	IWUE* bu acre^{-1} inch^{-1}	Test weight lb bu^{-1}	Protein %	Oil %	Moisture %
IRRIGATION METHODS						
Sprinkler	58.1 a	8.3 a	53.5 a	40.5	21.7	7.1
Furrow	58.7 a	4.9 b	51.2 b	39.8	21.5	6.8
Rainfed	55.1 b	NA	51.8 b	40.4	21.5	6.8
ROW PATTERN						
Twin	58.2	6.8 a	52.0	40.2	21.5	6.7
Single	56.4	6.4 b	52.1	40.3	21.6	7.0
*IWUE = Irrigation Water Use Efficiency (grain yield ÷ total amount of irrigation water).						

***Figure 1** Sprinkler and furrow irrigation systems at the Delta Research and Extension Center in Stoneville, MS.*

conducted to determine protein, and oil content. Statistical analysis was performed using the statistical analysis software, SAS v. 9.4. Analysis of variance was conducted using the GLIMMIX procedure. Mean separations were performed using Fisher's protected LSD at α = 0.05.

Results and Discussion

The total amount of water used to irrigate soybean from R1 to R6.5 growth stages for each method was 7 and 12 inches for sprinkler and furrow, respectively. Irrigation intervals for both sprinkler and furrow were 6.5 and 13 days, respectively. Soybean under sprinkler irrigation produced 3.4 buc acre-1 more soybeans per inch of irrigation water compared to furrow irrigation (**Table 1**). Soybean planted in a twin-row pattern produced 0.4 bu acre-1 more per inch of irrigation water than single-row soybean. The highest test weight was achieved by soybean under sprinkler irrigation 53.5 lb bu-1. Protein and moisture content was not affected by irrigation or row pattern. Sprinkler irrigation could be an alternative to furrow irrigation in the Mississippi Delta to ensure the Mississippi River Valley Alluvial Aquifer sustainability. Irrigating soybean with a sprinkler irrigation system and trigger irrigation at -80 kPa will help to reduced the groundwater withdrawals from the Mississippi River Valley Aquifer.

Alternate and Every Row Irrigation Management Effects on Soybean Yield and Economics on Very Fine Sandy Loam Soil

Gurbir Singh, Nicolas E. Quintana Ashwell, Gurpreet Kaur, and Himmy Lo

Introduction

Early Soybean Production System (ESPS) was developed to improve seed yield and water use efficiency (WUE) allowing farmers to plant early maturing varieties (Maturity Group III and IV) to capture spring season rainfall, achieve faster canopy closure, avoid reproductive growth under hot summer temperatures, prevent late-season insect feeding, and harvest early for higher profit (Hoeft et al. 2000; Alsajri et al., 2021, 2019). Traditionally, soybeans were planted in a single-row geometry on raised beds spaced 36 or 38 inches like other cash crops (cotton and corn) in the delta states. However, soybean planting in the last two decades shifted to a narrow or twin-row arrangement to take full advantage of ESPS (Smith et al., 2019b). Soybean planted in twin-row typically consists of two rows 10 inches apart on the same raised bed, with the beds 36 or 38 inches apart (Bruns, 2011). Twin-row planting of soybean results in several benefits including enhanced cold tolerance, high sunlight interception, rapid canopy closure, weed suppression and reduced evaporation under non-irrigated conditions (Smith et al., 2019 a,b; Pinnamaneni et al., 2020). The objective of this study was to evaluate individual and combined effects of irrigation management and planting patterns single row and twin row on soybean yield, quality, water productivity, irrigation water use efficiency, and net returns. The hypothesis is that alternate irrigation and twin-row will increase yield and irrigation water use efficiency (IWUE) resulting in enhanced soybean productivity.

Materials and Methods

The experiment was conducted for three years (2019, 2020, 2021) at the National Center for Alluvial Aquifer Research (NCAAR) near Leland, Mississippi (33°25'45.5"N; -90°57'21.1"W). The soil series of the research site was Bosket very fine sandy loam (Fine-loamy, mixed, active, thermic Mollic Hapludalfs) (USDA-NRCS). The experimental layout was a randomized complete block design with four replications consisting of a factorial arrangement of row spacing single row planted at 40-inch spacing (SR) and twin-rows with 10 inches between planted rows on 40-inch beds (TR) and three irrigation treatments [(every row irrigated (ERI), alternate row irrigated (ARI), and non-irrigated (NI)]. The plot dimensions for every treatment were 26.67 x 200 ft. Tillage, fertilization, and weeds were managed according to Mississippi State University Extension Service recommendations. Soil water potential sensors (Watermark Model 200SS, Irrometer Company, Inc., Riverside, CA) were installed at 6-, 12-, and 24-inch depths in one replication of every treatment (Wood et al., 2020). An irrigation threshold of -40 kPa was used to trigger irrigation initiation. Irrigation was applied based on the weighted average of the soil water potential sensors in a 0- to 24-inch rooting depth (the weighted sum was calculated as 0 to 6-inch sensor x 0.25 + -12-inch sensor x 0.25 + -24 inch sensor x 0.5).

Plant population data from 3 feet of the row was determined from four random locations in each plot to calculate plants/ac. After physiological maturity, the two middle rows of the plot were harvested with a Kincaid 8XP plot combine (Haven, KS) equipped with Harvest Master H2 Grain Gauge (Juniper systems, Logan, UT). The seed yield (bu/ac) was adjusted to 13% moisture prior to analysis. Water productivity was calculated by dividing the soybean yield by the total water use (total rainfall + irrigation water applied). The irrigation water use efficiency was calculated by dividing the soybean yield by the amount of irrigation applied in a plot. The collected data was analyzed using the GLIMMIX procedure in

Table 1. Soybean plant population and seed yield, for different row spacing, and irrigation management from 2019 to 2021.

Year	Row spacing	Irrigation management	Soybean	
			Plant population	Yield
			---plants ac^{-1}---	bu ac^{-1}
2019			-	60 ± 8a†
2020			115002 ± 14962	54 ± 8b
2021			110355 ± 7379	51 ± 13c
	Single row		109194 ± 9678	54 ± 10
	Twin row		116164 ± 13060	56 ± 11
		Every row irrigated	111019 ± 11440	63 ± 5a
		Alternate row irrigated	114503 ± 12636	57 ± 6c
		Non irrigated	112512 ± 12124	45 ± 9b
2019		Every row irrigated	-	65 ± 6a
2019		Alternate row irrigated	-	62 ± 6a
2019		Non irrigated	-	52 ± 4c
2020		Every row irrigated	115002 ± 14816	61 ± 4ab
2020		Alternate row irrigated	116496 ± 17262	56 ± 5bc
2020		Non irrigated	113508 ± 14595	47 ± 7d
2021		Every row irrigated	110356 ± 4964	64 ± 6a
2021		Alternate row irrigated	45551 ± 5927	53 ± 5c
2021		Non irrigated	111517 ± 9985	35 ± 4d

†The same letter within a column indicates no significant difference for a given factor or combination of factors (α = 0.05).
± The observations were not recorded.

SAS 9.4 (SAS Institute, Cary, NC). The partial budget analyses was performed to compare the expected levels and variability of returns under each of the three irrigation treatments across the two planting geometries using the crop planning budgets (Mississippi State University's Department of Agricultural Economics, 2020, 2021, 2022).

Results and Discussion

Soybean seed yield was significantly affected by year, irrigation management, and their interaction (**Table 1**). Soybean yield was not affected by the planting patterns. The available soil water among irrigation treatments was ranked ERI > ARI > NI considering uniform rainfall and furrow-irrigated water across the field site. Every row irrigation showed no statistically significant (P >0.05) increase in the yield with twice the amount of water applied by ERI compared to ARI in 2019 and 2020 (**Table 1**). The ERI had 20% increase in yield over ARI in 2021. In all three years, the soybean yields were increased with application of irrigation either as ERI or ARI as compared to NI. The ERI had greater soybean yield than the NI by 26, 30, and 79% in 2019, 2020, and 2021, respectively. The ARI had 20% greater yield than NI in 2019 and 2020, whereas it had 50% greater yield than the NI in 2021 (**Table 1**). Further, yields with ERI were similar in all three years, while soybean yields significantly differed under the ARI and NI over years.

Significant irrigation-by-year interaction was observed for water productivity and IWUE (**Table 1**). The

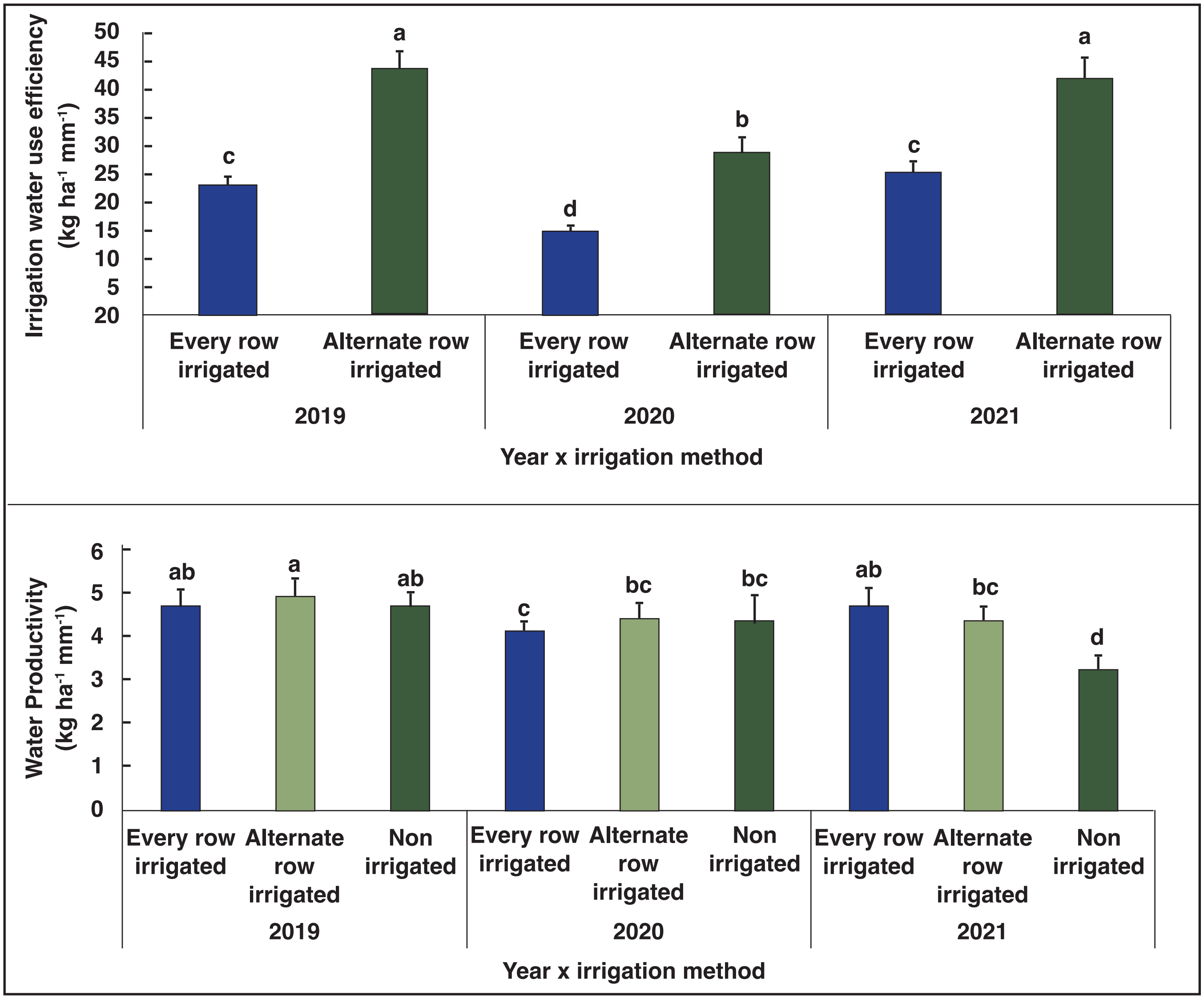

Figure 1. *Soybean irrigation water use efficiency and water productivity as affected by irrigation methods from 2019 to 2021. Similar letters above bars indicate no significant difference between means at P ≤0.05.*

IWUE in 2020 was ~35% lower than 2019 or 2021, when data were averaged over-irrigation methods and row spacings. Averaged over row spacing, IWUE was 66 to 91% greater with ARI compared to ERI (**Figure 1**). Water productivity was 4.7 kg ha^{-1} mm^{-1} in 2019 and 4.24 kg ha^{-1} mm^{-1} in 2020 (**Figure 1**). The water productivity showed no significant differences among irrigation methods in 2019 and 2020. Water supplied with a low rainfall scenario in 2021 was not enough to reach maximum water productivity compared to the previous two years, and therefore, water productivity increased with ARI and ERI than the NI (**Figure 1**). Irrigation water from ARI showed a 34% increase in water productivity over NI. Additional water supplied by ERI showed no significant increase in water productivity compared to ARI in all three years.

The relationship between expected returns and variability (**Table 2 and Figure 2**), a measure of risk, is an important consideration for farmers making decisions on these practices and conservation agencies providing incentives and policies related to irrigation water conservation. Considering ERI as the benchmark to evaluate ARI and NI cropping systems, TR soybean produced the greatest average risk-return than other treatments. The ARI with TR had the second highest overall risk-return trade-off. For SR soybean, ARI resulted in an equivalent risk-return production system as ERI which is evident from the ray origin including both points (**Figure 2**).

__Table 2.__ Expected returns and variability by row spacing and irrigation management. †Indicates standard deviation.

Row spacing	Non irrigated	Alternate row irrigated	Every-row irrigated	Overall Average
		$ ac^{-1}		
Single-row planting	**102 ± 99†**	**96 ± 59**	**185 ± 114**	**128 ± 100**
Twin-row planting	**108 ± 82**	**146 ± 73**	**188 ± 63**	**147 ± 78**
Overall Average	**103 ± 89**	**100 ± 70**	**162 ± 90**	**125 ± 90**

Conclusion

This study revealed a positive soybean yield, quality, and water productivity response to a conservation furrow irrigation practice. However, the amount of water required through furrow irrigation could be modified by rainfall amounts. In terms of risk-return, planting soybean in twin-row and irrigating every row presents the best risk-return proposition. For SR planting, both irrigated systems offered an equivalent risk-return proposition as the reduction in expected returns is associated with a reduction in the variability of those expected returns.

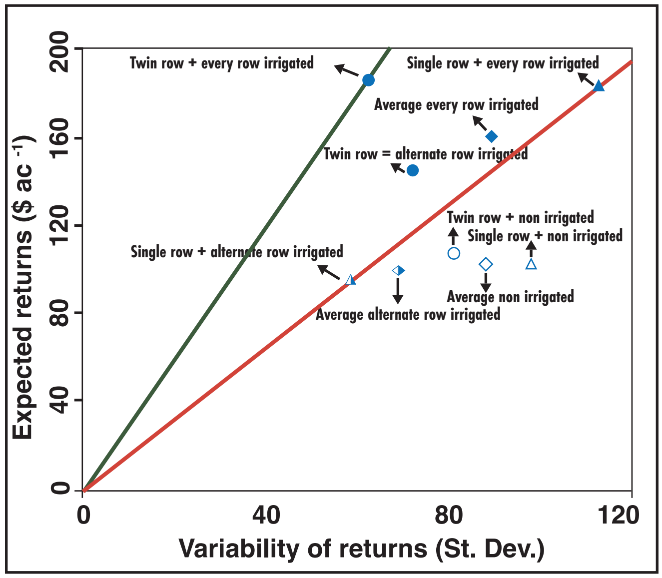

__Figure 2.__ Expected returns and variability based on row spacing and irrigation methods. Data were also averaged over row spacings for irrigation treatments ($ ac^{-1}). The green line indicates the baseline for every row irrigation for twin row spacing, whereas the red line indicates the baseline for every row irrigation for the single row soybean. Values above these lines represent better risk return then the values below these lines. (The arrow in the figure only indicates the labels for each point).

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Irrigation thresholds and nitrogen rates effects on irrigated corn grain yield and water use efficiency under a sprinkler irrigation system

Amilcar Vargas, Drew Gholson, Himmy Lo, Gurbir Singh, Dave Spencer, and Jason Krutz

Introduction

Groundwater resource is the most exploited resource to irrigate row crops in the Mississippi Delta. The overuse and excessive pumping from agriculture and fisheries has exceeded the natural water recharge of the Mississippi River Valley Alluvial Aquifer (MRVAA). Limited research has been conducted on the use of overhead irrigation in corn production systems in the Mississippi Delta. Water and nitrogen are considered the major driving factors for corn production. Therefore, understanding the relationship between sensor-based irrigation and nitrogen rates on corn grown in sandy loam and clay under a sprinkler irrigation would help to reduce the groundwater withdrawals from MRVAA.

Materials and Methods

This study was conducted at Delta Research and Extension Center, Mississippi State University, Stoneville, MS in 2022. Corn hybrid DKC 65-93 was planted on May 05 at 35,000 seeds acre^{-1} in a twin row pattern. Treatments were three irrigation scheduling thresholds, based on soil water tension (-40, -70, -100 cb, and rainfed control), four nitrogen rate (0, 100, 200, and 300 lbs N ac^{-1}), and two distinct soil textural classes (Sandy Loam and Clay). The nitrogen source was urea ammonium nitrate (UAN, 32%) applied in a single application at V6 growth stage. Field management operations such as tillage, weed, and pest control were conducted following Mississippi State University Extension Service recommendations. All treatments were replicated five times. The plot size for individual nitrogen rate treatment was 26.6 x 50 feet. In total there were 160 plots (**Picture 1**). Soil moisture sensors were installed at 6, 12, and 24 inches to determine soil moisture tension. Irrigation was triggered when the weighted average of the three sensors

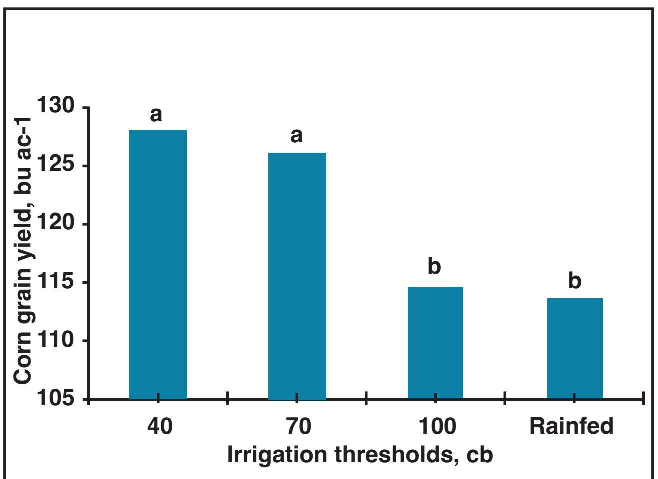

Figure 1*. Irrigation threshold effects on corn grain yield. Data averaged over nitrogen rates and soil textures. Letters show significant differences at α=0.05.*

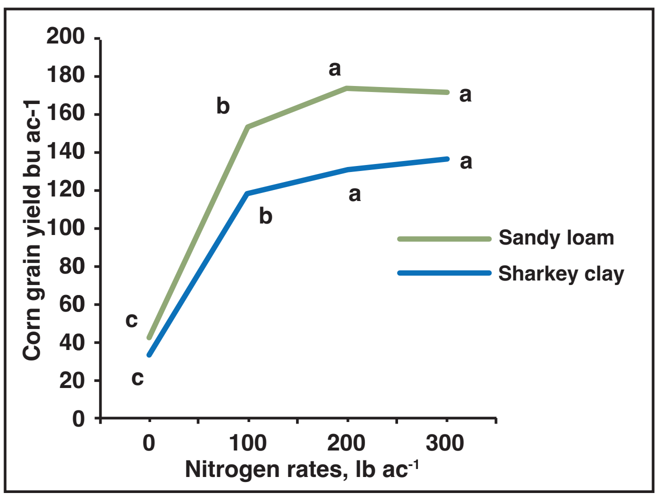

Figure 2. *Soil texture × nitrogen rates effects on corn yield. Data averaged over irrigation thresholds. Different letters within the same soil texture show significant differences at α=0.05.*

reached the irrigation threshold. Sensors at 6 and 12 inches were assigned 0.25 weight value each and 0.50 for the 24 inches depth sensor. Irrigation water use efficiency was calculated based on corn grain yield divided by the total amount of water applied to each plot. Irrigation was terminated when black layer was developed. The two middle rows from each plot were harvested using a plot combine. Corn grain weight per each plot was recorded. Corn grain yield was adjusted to 15.5% moisture. Analysis of variance was performed using the GLIMMIX procedure in SAS statistical software. Mean separations were performed using Fisher's protected LSD at α = 0.05.

Picture 1. *Corn research field irrigated with a sprinkler irrigation system (lateral move) located at the Delta Research and Extension Center, in Stoneville MS. Plots in lighter green did not receive nitrogen.*

Results and Discussion

Corn grain yield was affected by irrigation thresholds (**Figure 1**) and the two-way interaction between soil texture × nitrogen rates (**Figure 2**). Irrigation water use efficiency was influenced by the three-way interaction of soil type × irrigation threshold × nitrogen rate. There were no differences between the irrigation thresholds of -40 and -70 cb in corn grain yield, when averaged over soil texture and nitrogen rates. Using a lower irrigation threshold (i.e. -70 cb) will reduce the amount of water to irrigate corn and consequently preserve the Mississippi River Valley Aquifer. Overall, corn grown in a sandy loam soil had higher corn grain yield compared to corn grown in a Sharkey clay (**Figure 2**). Interestingly, there is no difference in corn grain yield when 200 or 300 lb ac^{-1} of nitrogen were applied in both sandy loam and Sharkey clay. For both soil textures, sandy loam and Sharkey clay the -100 cb had the highest IWUE. In a Sharkey clay soil, there were no differences in IWUE triggering irrigation at -70 and -40 cb. However, in a sandy loam soil triggering irrigation -40 cb had the lowest IWUE efficiency.

Irrigation and nutrient management practices that are site specific will increase corn productivity and water use efficiency and in the Mississippi Delta.

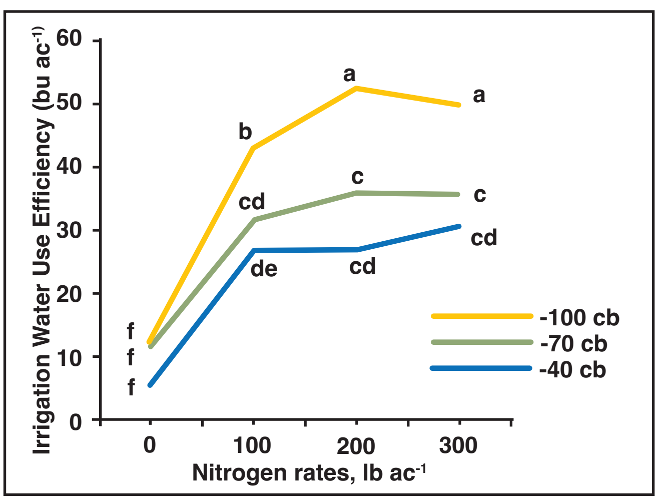

Figure 3. *Irrigation thresholds × nitrogen rates effects on irrigation water use efficiency in a Sharkey clay. Letters show significant differences at α=0.05.*

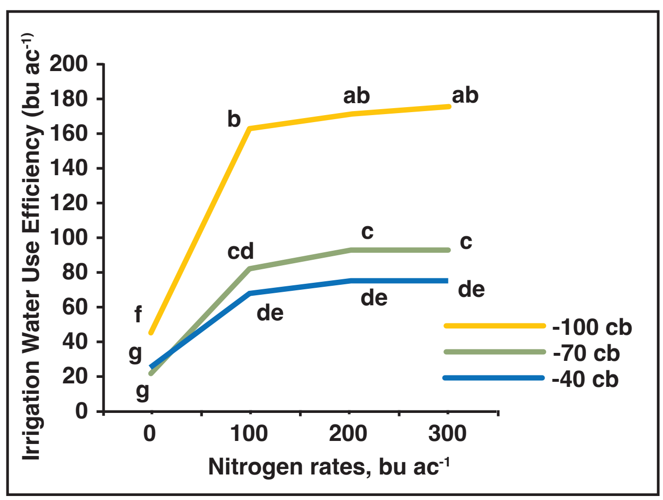

Figure 4. *Irrigation thresholds × nitrogen rates effects on irrigation water use efficiency in a Sandy loam. Letters show significant differences at α=0.05.*

Furrow Irrigation Spacing Impacts on Corn Production in Sharkey Clay Soils

Trey Freeland, Drew Gholson, Gurbir Singh, and Himmy Lo

Introduction

The Sharkey clay soil series, comprised mainly of 2:1 clay, is the dominant soil mapped in Mississippi, consisting of about 400 thousand hectares (Pettry, et al., 1996). More than 40% of the land is classified under clay soils in the Mississippi Delta. Clayey soils are prone to frequent flooding and waterlogging. Kaur, et al., 2020 reported that corn loses between 5-30% of yield with each day of waterlogging. Every row and one row skip irrigation spacing practiced by Mississippi growers often results in saturated conditions which can lead to lower corn yield. Therefore, the objective of this research was to evaluate if altering irrigation spacings on Sharkey clay soils can reduce the waterlogging damage to corn and subsequently provide a benefit in corn yield.

Clayey soils are prone to frequent flooding and waterlogging.

Materials and Methods

An on-station field experiment was conducted at the National Center for Alluvial Aquifer Research (NCAAR), Stoneville, MS (33°25′26″N, 90°54′54″W) in 2021. All treatments were established in a randomized complete design with four replications. Irrigation treatments included in this study were every row irrigation (ER), 1 row skip irrigation (1R; 80-inch spacing), 4 rows skip irrigation (4R-I; 160-inch spacing), and 8 rows skip irrigation (8R-I; 320-inch spacing) (**Figure 1**). For treatments 4- and 8- rows skip, yield data was collected from irrigated furrows designated as 4R-I and 8R-I (I, irrigated) and from rows furthest away from the irrigated furrows designated as 4R-NI and 8R-NI (NI, non irrigated). Corn hybrid DKC66-75 was planted at a seeding rate of 42,000 seeds/ac on April 7th, 2021, and 34,400 seeds/ac on May 9th, 2022 at 40 inch row spacing. Urea ammonium nitrate (32%) was applied at a rate of 244 lb/ac as a split application. Weeds were managed using a pre-emergence spray of Lexar @ 96 oz/ac plus paraquat @ 48 oz/ac plus 0.25% scanner in 15 gal/ac tank mix. Halex GT @ 3pt/ac plus round-

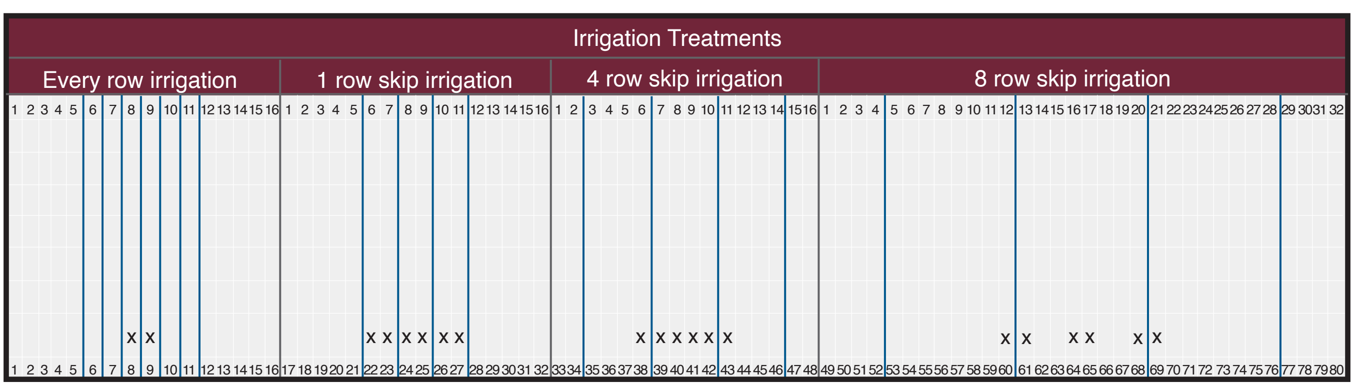

Figure 1. *Irrigation treatments used in our study. Blue lines indicate rows that were irrigated, an "X" indicates rows that were harvested for yield in 2021 and 2022.*

up powermax 3 @ 48 oz/ac plus 0.25% scanner was used for post-emergence weed management. Volumetric water content (VWC) was taken using a FieldScout TDR 350 Soil Moisture Meter (Aurora, IL) at a depth of 0-20 cm (**Figure 2**). Data was taken from every furrow before irrigation (event 1), after first irrigation (event 2), and after the second irrigation (event 3). Corn was harvested on August 28th, 2021 and September 9th, 2022, using a Kincaid 8XP plot combine equipped with a harvest master H2 grain gauge.

Results and Discussion

In 2021, the 4R-NI treatment yielded the highest in the trial at 177 bu/ac (**Figure 3**). The ER treatment had the second highest yield with 175 bu/ac (**Figure 3**), while the 8R-NI had the lowest yield at 161 bu/ac (**Figure 3**). In 2022, the trial was heavily diseased which lead to yield being to low to consider for statistical analysis. When looking at VWC% in 2021, the 4 - Row Skip treatments held the highest VWC% in both event 1 and 3. In event 1 the 8 Row Skip was the lowest (**Figure 4**). This shows that this irrigation treatment had sufficient subsurface lateral movement and that water moved efficiently through the plot for crop water demands without over saturating the soil in 2021. The VWC% data for 2022 shows that in event 1 Every Row and Skip Row treatment held the highest VWC%. In event 2 the Every row was again the highest, while the 8 Row Skip was the lowest in both events (**Figure 5**). Rainfall may be a significant factor in this study when looking at the amount that fell during the growing seasons. In 2021, 23 in. of rainfall helped to supplement the corn during peak water uptake timings. In 2022, VWC% was less in the 8-row skip compared to the Every Row for both irrigation events. For 2022, yield was low across all treatments and spacing due to disease issues and was not an-

Figure 2. *FieldScout TDR 350 was used for collecting soil volumetric water content data during the crop growing season (left) and 8 row skip irrigation treatment showing furrow irrigation water (right).*

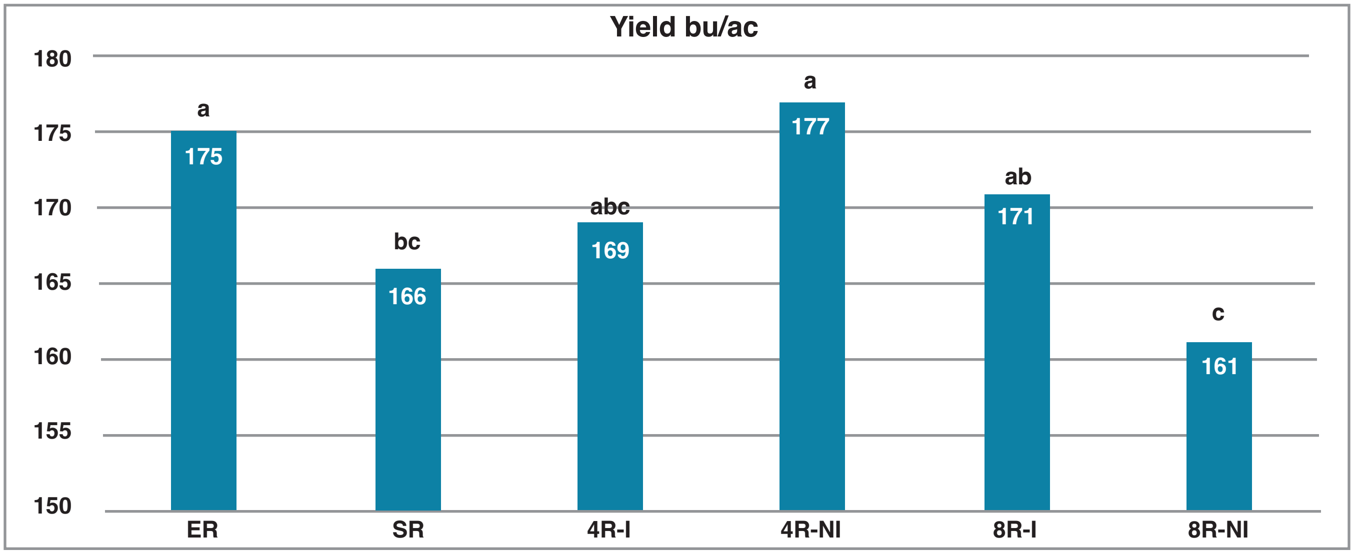

Figure 3. *Corn yield for 2021 shown in bu/ac. Same letter indicates no statistical difference.*

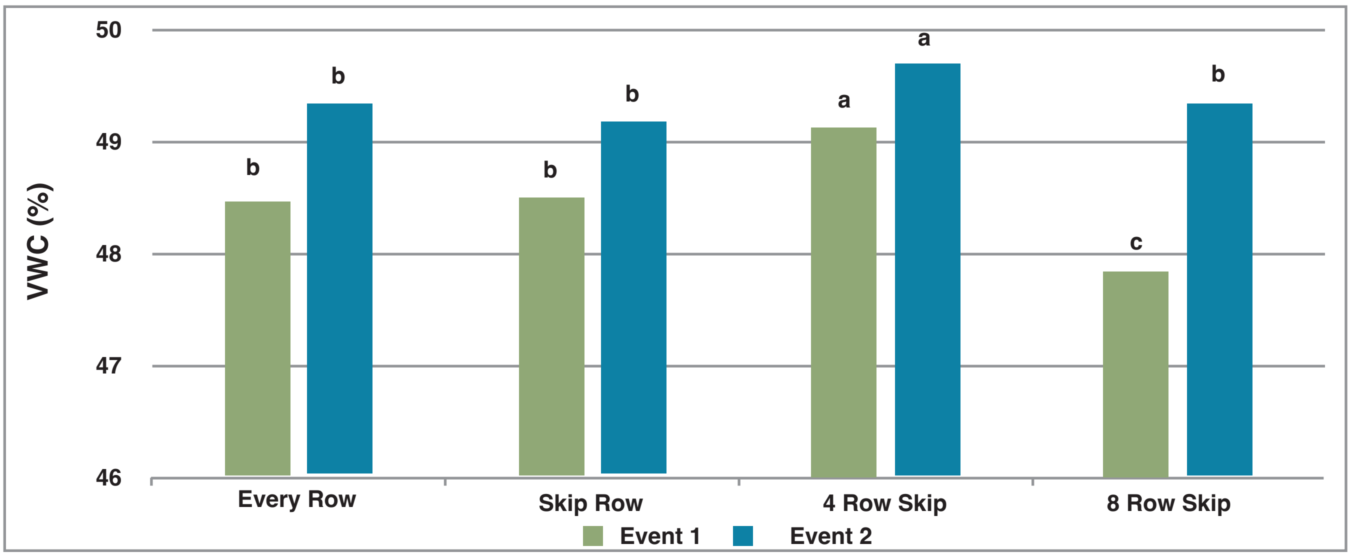

Figure 4. *Volumetric water content for 2021 taken from seven furrows in the middle of the plot. An "event" is taken five days after an irrigation. Same letter indicates no statistical difference.*

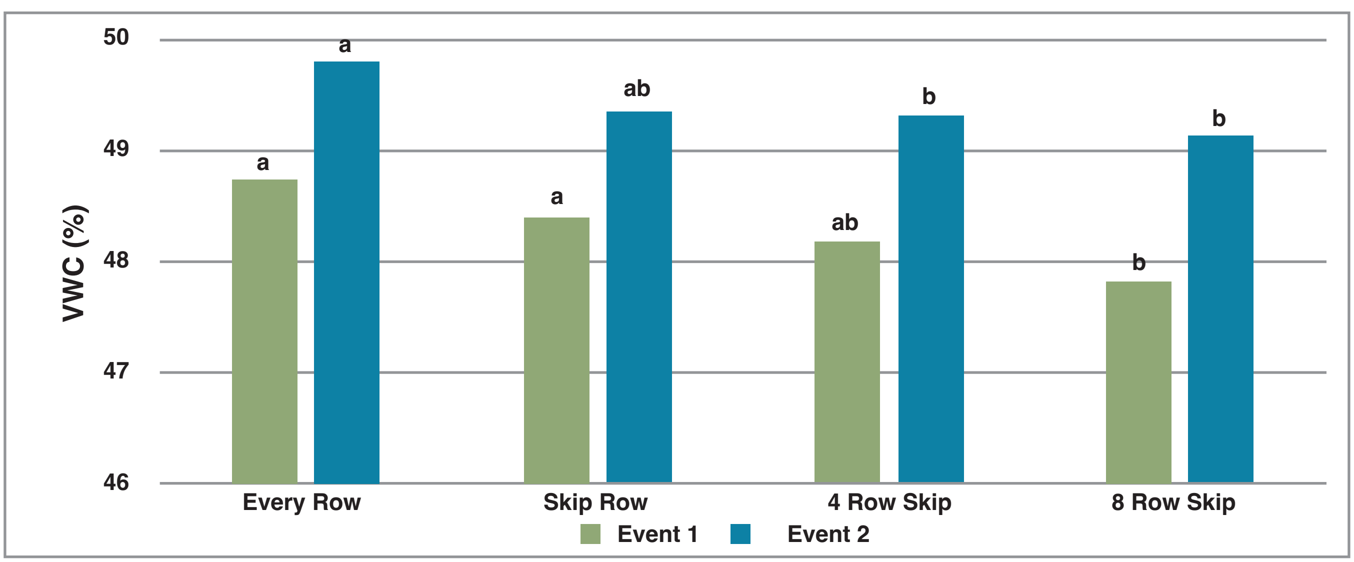

Figure 5. *Volumetric water content for 2022 taken from seven furrows in the middle of the plot. An "event" is taken five days after an irrigation. Same letter indicates no statistical difference.*

alyzed. Fifteen inches of rainfall fell during peak water uptake timing in 2022, which may also help explain why VWC% were different from the previous year.

Conclusions

In 2021, the result show that a 4 Row Skip Irrigation would be ideal for growers, while accounting for risks that are associated with over saturating the soil or soil waterlogging causing losses in corn grain yields with the Every Row or Skip Row irrigations. The 2022 results show that any irrigation can be used and still hold consistent yield across the board. This research will continue this year, 2023, to see how yield and VWC% correlate to either a wet or dry growing season.

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Skip-row irrigation produces corn yields equal to or better than all-row irrigations in farm-scale experiments

Saseendran S. Anapalli and Daryl Chastain

Introduction

Furrow irrigation, which pumps water from the Mississippi River Valley Alluvial Aquifer (MRVAA), dominates row-crop systems in the Mississippi Delta. The current rate of water removal from the aquifer surpasses natural recharge rates, thus threatening sustainable irrigated agriculture. In this study, corn (*Zea mays L.*) yield and water use (evapotranspiration; or ET) in all-furrow irrigation (FI), which is the primary irrigation practice, was compared to skip-furrow irrigation (SFI) and rainfed (RF) systems on farm-scale fields (10 ha; 25 ac) in 2017 and 2019 in a clay soil in the Lower Mississippi Delta. ET was monitored using eddy covariance (EC) towers (**Figure 1**).

Materials and Methods

Farm-scale, on-farm trials provide an opportunity to evaluate irrigation water management technologies under realistic farming conditions. Therefore, this farm-scale experiment allows for researchers to follow the pathway of water from soil— plant—atmosphere at the farm-scale. The experiment was a multiyear irrigated corn-soybean rotation conducted between 2016 and 2021 at the USDA-ARS Crop Production Systems Research Unit farm, in Stoneville, Mississippi. This investigation evaluated corn production responses, water use, and ET using cutting-edge science-based Eddy Covariance technology based on FI, SFI, and RF (control) systems. The corn cultivar 'Terral REV

24BHR99' was planted on 97-cm spaced ridges of about 80 m in a north-south orientation at a seeding rate of about 70,000 seeds ha^{-1}. Intra-row plant spacing on the ridges was about 14 cm. The fertilizer applied was urea ammonium nitrate injected into the ridge base at about 224 kg N ha^{-1} after corn seedling emergence.

Figure 1. *Eddy Covariance sensors installed on towers in a corn field.*

Results and Discussion

Average corn yield in the SFI was significantly (12.1 Mg ha^{-1}) higher (4.9%) than in the FI (11.7 Mg ha^{-1}), with yield in RF (10.2 Mg ha^{-1}) being lower (10.7%) than in the FI. Seasonal average ET was 556, 573, and 540 mm in FI, SFI, and RF, respectively. The average water use efficiencies (WUE) were 0.021, 0.021, and 0.019 Mg ha-1 mm-1, respectively (10.5 % lower in RF than FI and SFI). In the SFI system, the average corn harvested was about 4.3% higher than FI. Grain yield harvested in the RF was approximately 13.7% lower than the FI, emphasizing the importance of irrigating corn in the region for stabilizing yield and economic returns for farmers.

Conclusion

This investigation revealed that adapting the SFI irrigation regime in corn cropping systems could produce grain yields equal to or higher than corn grown under the conventional FI, while saving about 40% of irrigation water. The farm-scale studies conducted in this investigation gave better confidence to recommend SFI to replace traditional FI systems in the region for water conservation in corn cropping systems. Further investigations may be needed to evaluate the viability of SFI in other contrasting soils and climates and recommend the system for adoption by the farming community.

Table 1. *Corn yield harvested in the all-furrow and alternate-furrow irrigation and rainfed treatments from 2017—2019. The least-square means and 95% confidence intervals are shown. The same letters following standard error values within a column are not statistically different at $p < 0.05$.*

Irrigation treatments	Corn yield, Mg ha^{-1}		
	2017	2019	Mean ± 95% CFI
All-furrow irrigation (FI)	11.5	11.8	11.7 ± 0.03 b
Alternate-furrow Irrigation (SFI)	12.0	12.1	12.1 ± 0.04 a
Change due to SFI	4.9%	5.5%	5.2%
Rainfed (RF)	10.4	10.0	10.2 ± 0.09c
Change due to RF	-15.4%	-21.0%	-18.6%

The same letters following standard error values within a column are not statistically different at $p < 0.01$.
CFI = confidence interval.

Determining how polypipe hole size and field shape impacts cotton water use and yield

Amanda Nelson

Introduction

Programs such as the Delta Plastics Pipe Planner Program were designed to create efficient irrigation plans under an array of field shapes using variable hole sizes in polypipe irrigation. However, little is known about how these irrigation plans impact water-use efficiency and crop yield. Therefore, the objective of this study was to determine the effectiveness of this program on water-use and cotton yield from regular and irregularly shaped fields.

Materials and Methods

The site consists of four fields located in Washington County, Mississippi (33.429777, -90.948461) at the corner of Old Leland Rd and Potter Rd (**Figure 1**) at the NCAAR West Farm facility. Fields were planted with Delta Pine 1646 at 40” row spacing. The big rectangle and triangle (**A and B** in **Figure 1**) were irrigated according to the Delta Plastics Pipe Planner Program. The rhombus and little triangle (**C and D in Figure 1**) were irrigated under a “business as usual” plan to represent a plan that a farmer would use to irrigate similar fields in the Lower Mississippi Delta.

Each length of polypipe had its own flow meter (one per riser, plus one additional length using a T-pipe on the riser between the two rectangle fields). The rhombus and little triangle (**C and D** in **Figure 1**) utilized two risers, dividing the field into two. The southern end used one size hole in the polypipe until the field starts to taper, at which point it was tied off and the pipe from the second riser used (creating the little triangle). The pipe from the second riser used two sizes of holes; 3/8” for 135 rows, 7/16” for the remaining rows until the field started to taper again (~280 rows), then back to 3/8” for the remainder. The big rectangle (**Figure 1A**) used two hole sizes, per the Delta Plastics Pipe Planner output; 1/2” for 165 rows and 9/16” for the remaining ~230 rows. The triangle (**B in Figure 1**) used the hole size plan in **Table 1**. Water was applied 7-10 days after the last rainfall until the longest rows were wetted.

Table 1. *Hole size plan for the polypipe for the big triangle field (**B in Figure 1**).*

Hole Size	Furrow Count
5/16”	18
3/8”	8
7/16”	9
1/2”	10
9/16”	11
5/8”	11
11/16”	13
3/4”	47
11/16”	46
5/8”	37
9/16”	33
1/2”	28
7/16”	25
3/8”	21
5/16”	41

Results/ Current Status

In 2022, cotton was planted the end of June, putting this study about three weeks behind the recommended date the region. Three irrigation events were conducted during the year in accordance to the standards outlined in the Delta Plastics Pipe Program design, however late rains and technical difficulties (polypipe blowouts) limited the ability to meet the original objectives. However, preliminary results show that Pipe Planner used

Figure 1. *The Cotton Triangle Fields include: the big rectangle (A), the big triangle (B), the trapezoid (C), and the little triangle (D). Red dots indicate risers. The black dot is the well pump.*

an average of 26% less water on the triangular fields. Therefore, initial results are very promising for improved cotton water use under the Delta Plastics Pipe Planner Program.

The project was adapted mid-year to additionally investigate the efficacy of the Goanna Ag sensors (Queensland, Australia). The Goanna GoField comprehensive system integrates field sensor data, satellite imagery, and integrated algorithms that provides critical information for making field specific, precise irrigation scheduling decisions, thereby reducing water use and increasing water use efficiency. Preliminary results revealed issues with infiltration of irrigation water through this monitoring system. The comprehensive system will be fully implemented in the 2023 season.

Cottonseed was sampled for quality in November 2022, but harvesting did not occur until late December 2023 due to weather. This project will be repeated in the 2023 season, but with the Goanna sensor system guiding irrigation application timing. There is also a post-harvest project planned for these fields for February 2023 to monitor water movement and infiltration with the above pipe designs. This will allow us to better determine irrigation rates and application techniques in the Lower Mississippi River Basin.

Stepwise Addition and Deletion of Fertilizer Inputs In a Corn Production System Under Irrigated and Dryland Conditions

James Dew, Camden Oglesby, and Jagmandeep Dhillon

Introduction

Corn remains one of the top three cereals produced internationally. Demand for corn has increased over the years and the crop currently supplies 50% of total world food calories. If a balanced management strategy or solution for corn production is not realized uncertainty in crop production worldwide may occur. The objective of this study was to determine which nutrient management strategy was best suited for optimizing yield.

Materials and Methods

Trials were conducted at the Delta Research and Extension Center (DREC), from 2020 to 2022. The trials incorporated production factors for evaluation including 1) plant population (32,000 seeds ac-1 versus 40,000 seeds ac^{-1}) 2) row configuration (single vs twin row), and 3) six nutrient treatments. The six nutrient treatments were either incrementally added (Addition) or withheld (Deletion) separating two trials. Both trials were configured in a complete block design where fertilizer treatments were randomized and a full factorial between three factors resulted in a total of 24 treatments replicated four times. Poly pipe irrigation was utilized in Stoneville. Treatment means were estimated and separated at $P \leq 0.05$.

Results and Discussion

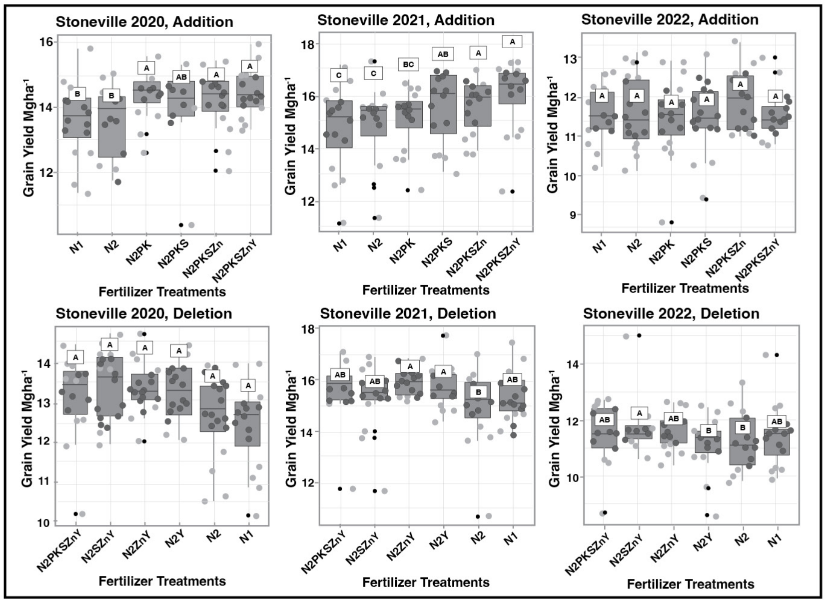
Grain yield responses to the addition and deletion of six nutrient treatments significantly differed by year (**Figure 1**). Where in 2020 application of phosphorus (P) and potassium (K) along with higher rates of nitrogen (N2) resulted in the highest grain yield. Whereas, in 2021 application of zinc (Zn) when applied with N2, P, K, and sulfur (S) resulted in the highest recorded yield. Finally, in 2022 no differences were observed among nutrient and fungicide applications between the two trials.

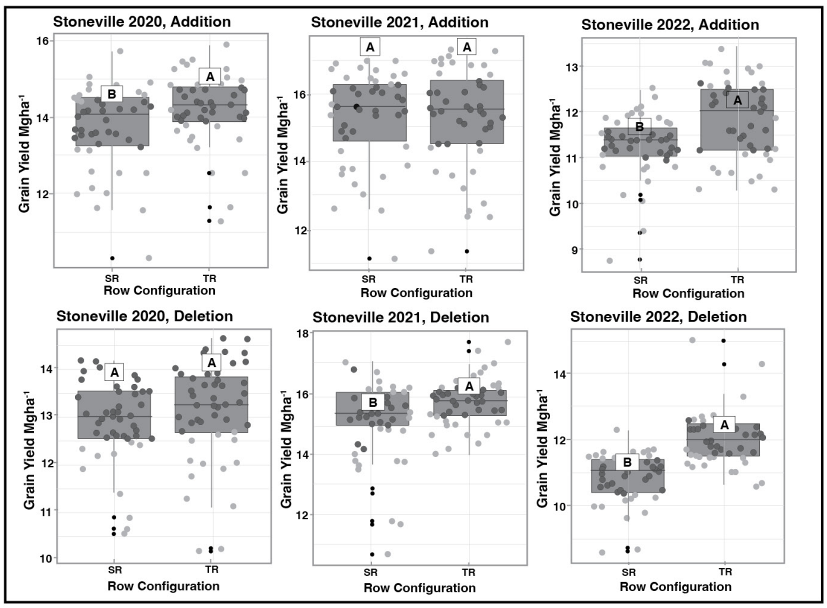
Row configuration including a single row (SR) and twin row (TR) was the second factor investigated within this study. In both trials in 2020 and 2022, TR out yields SR, whereas, no significant differences among row configurations were noted in 2021.

Lastly, we tested grain yield in response to plant population, where two populations of 32,000 seed ac^{-1} (79K ha^{-1}), and 40,000 seed ac^{-1} (99K ha^{-1}) were tested. In both 2020 and 2022, no significant differences among plant populations were noted. Whereas, in 2021 99K out yield 79K in both addition and deletion trials.

Conclusion

Results from three year and two trials show that the response of grain yield to fertilizer amendments are highly variable. Producers should conduct soil testing before applying any fertilizers to their fields to prevent economic and environmental losses. Furthermore, this study found that twin rows and higher plant populations resulted in higher yields. However, future research should be conducted to investigate site-specific optimum plant populations for single vs. twin-row configurations.





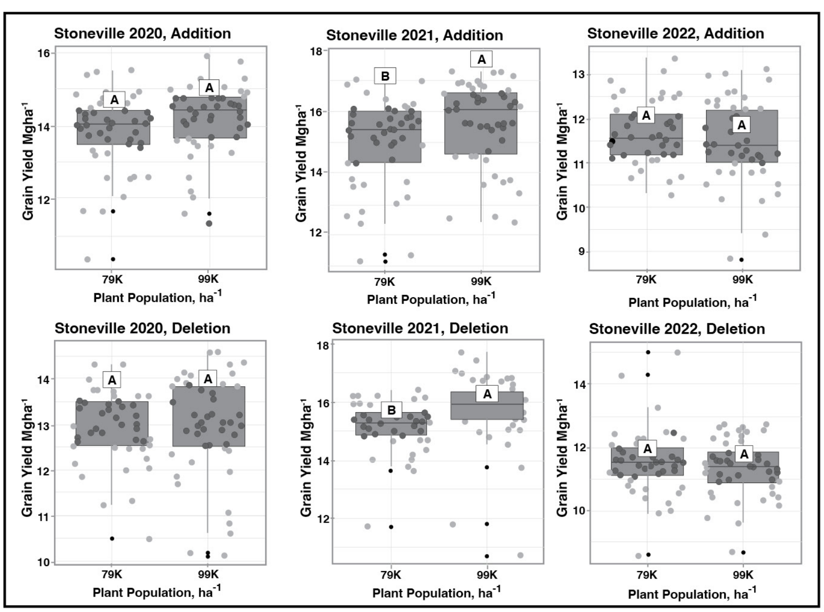


Figure 1. *Addition trial and deletion grain yield by fertilizer treatments. All years are represented by each chart within the figure. Dots represent individual data points. If upper case letters near the median are identical then there is no significant difference.*

Figure 2. *Addition trial and deletion trial grain yield by row configuration. All locations are represented by charts within the figure. Dots represent individual data points. If upper case letters near the median are identical then there is no significant difference.*

Figure 3. *Addition trial and deletion trial grain yield by plant population. All years and locations are represented by charts within the figure. Dots represent individual data points. If upper case letters near the median are identical then there is no significant difference.*

Identifying, Evaluating, and Demonstrating Sensor-Based Automation Irrigation Technologies in Corn and Soybean

Drew Gholson, Mark Henry, Himmy Lo, Trent Irby, Erick Larson, Nicolas Quintana Ashwell, and Alex Deason

Sponsored partially by Mississippi Soybean Promotion Board under project 13-2021, by Mississippi Corn Promotion Board under project 03-2021, and by the Conservation Innovation Grants program at USDA's Natural Resources Conservation Service under award number NR203A750008G007

Introduction

The RISER (Row-crop Irrigation Science Extension and Research) Program serves as the primary means to facilitate the widespread adoption of the latest irrigation management research findings across the Mississippi Delta. This program focuses on identifying and evaluating innovative sensor and automation technologies that can assist producers with improving their on-farm irrigation management strategies and scheduling.

Materials and Methods

An on-farm experiment was conducted from 2020 to 2022 on multiple production farm locations throughout the Mississippi Delta corn and soybean. Each demonstration farm consisted of two nearby irrigation wells and associated fields (irrigation sets) with similar soils and planting dates. One well served as a control (no change in technologies), and the other was equipped with pump controls, actuated valves (**Figure 1**), and soil moisture sensors enabled with telemetry capabilities (**Figure 2**). Predetermined templates set an irrigation time for each set and each field. These templates were programmed to the software, and the decision to irrigate was determined through field observations, soil moisture sensor readings, and weather outlook. The irrigation "spin" was initiated through the user interface. Sites were monitored throughout the growing season.

Results and Discussion

Information on irrigation application, pumping energy requirement, crop growth, and yield was collected at each field to document and display the impact of implementing irrigation automation technologies on conserving water and maintaining/improving crop yield (**Figure 3; Table 1**). The functionality of actuated valves was also evaluated. If a low battery caused issues with valve

***Figure 1**. Actuated valve in a corn field.*

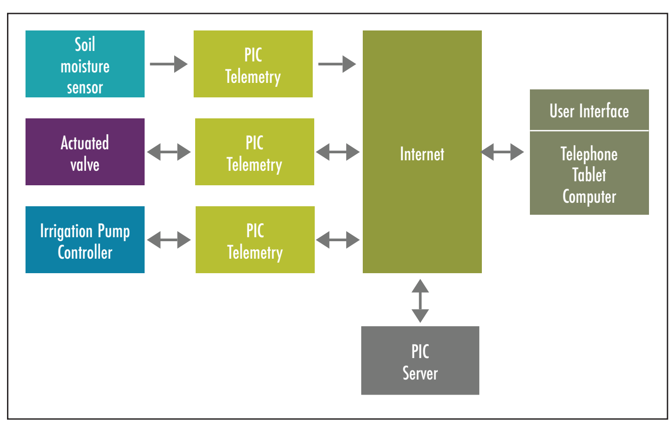


***Figure 2.** Schematic of automation telemetry communication.*

opening and closing, the battery was replaced. At each site for all irrigations, the automated system made a successful run.

Conclusion

This technology is early on in development, and certain changes have been made within the 3 years of evaluation. NCAAR has worked with companies to help increase user-friendly applications and dashboards to assist with the ease of operating the automation. As labor continues to become one of the most significant concerns across the farming community, investigating tools that can decrease labor, assist in decision-making, and save water is increasingly important. This study suggests that irrigation automation may be a beneficial tool for soybean and corn irrigation, saving water and time and ultimately conserving groundwater in the Mid-South. The next step will be to continue investigating the effectiveness of automation with the addition of more sites for statistical and economic analysis.

Table 1. *On-farm comparisons between automated irrigation and non-automated irrigation in terms of crop yield, seasonal irrigation, and irrigation water use efficiency; each value represents the average across sites in 2021 for corn or for soybean.*

	Yield (bu/ac)	Irrigation (inches)	Irrigation Water Use Efficiency (bu/ac-in; yield divided by irrigation)
Corn			
Automated	219	7.49	35
Non-Automated	220	10.84	21
Soybean			
Automated	85	6.77	15
Non-Automated	85	9.59	12

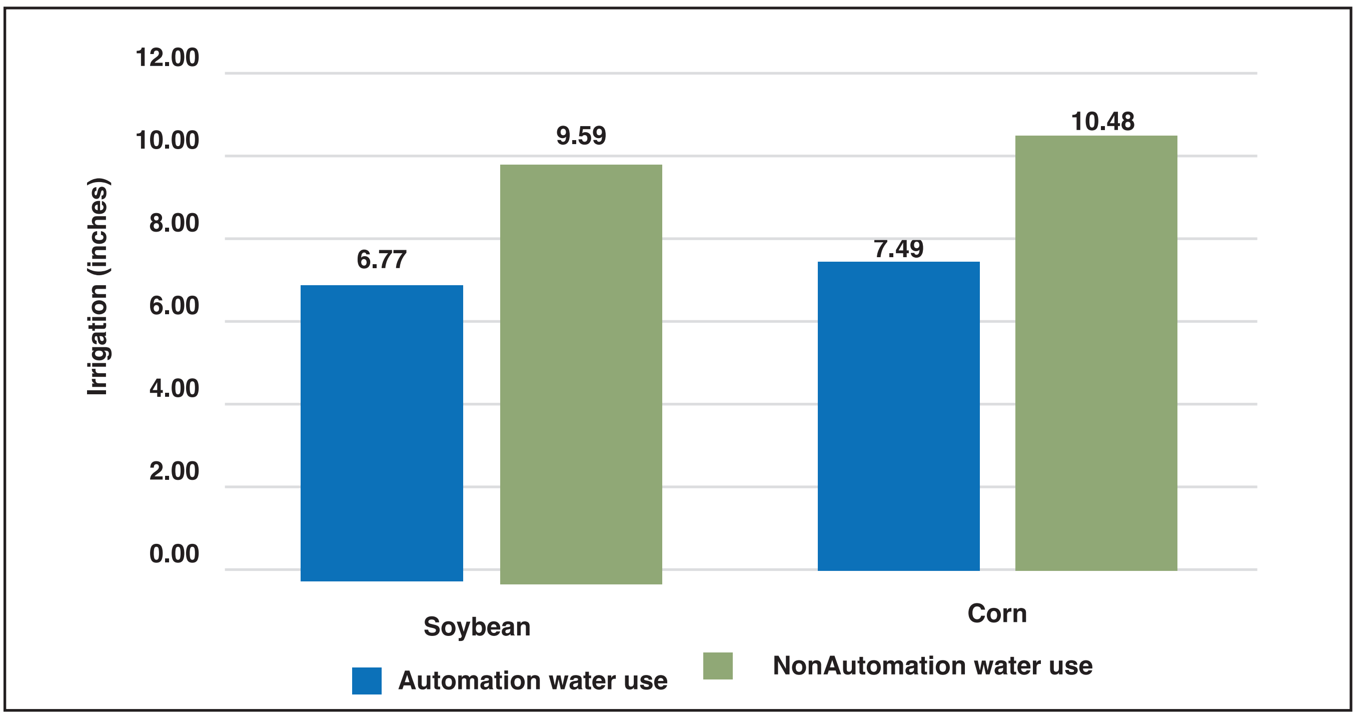


Figure 3. *Water applied from 2020 to 2022 by automated irrigation and by non-automated irrigation, respectively, averaging across on farm sites for corn and for soybean separately.*

HYDROLOGICAL & SOCIOECONOMIC ANALYSES

Exploring the role of off-season precipitation and irrigation water use in inter-season changes in well depth to water

Amer Al-Sudani, Nicolas E. Quintana Ashwell, and Drew M. Gholson

Introduction

The Mississippi Delta Region (Delta) receives over 52 inches of rain during the year, on average, but most of that precipitation occurs outside the growing season. Consequently, the region depends on irrigation to sustain agricultural production. The number of permitted wells increased from about 10,000 to over 21,000 between 2000 and 2022 (Mississippi Department of Environmental Quality), with rates of newly permitted wells of between 178 (2003) to more than 1,100 (2011-2013)—see **Figure 1**. Pumping from the Mississippi River Valley alluvial aquifer (MRVAA) exceeds its rate of recharge, which has led to declining water levels of between 2 feet to more than 13 feet between the years 2000 to 2020 (**Figure 2**). We analyze weather and water use data to assess whether off-season rainfall mitigates aquifer depletion.

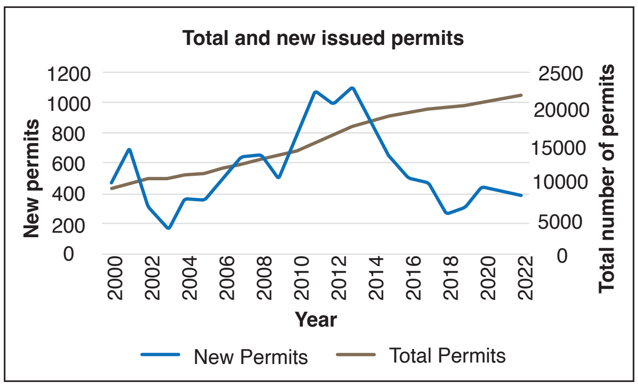


Figure 1: *Evolution of the number of permitted groundwater wells in the Delta (2000-2022)*

Groundwater's User Response to Climate and Depth to Water

We quantify the change in groundwater well depth to water (at the start of the season) due to user's reported past groundwater use and off-season precipitation using field-level data on over 1,900 wells over the 2014-2017 period. First, we estimate producer's groundwater use given seasonal aquifer and weather conditions, including total groundwater use, irrigated acreage and amount of groundwater applied per acre—see **Table 1** for regression results.

Groundwater users adjust the amount of water applied per acre and their total water use in response to changes in weather and aquifer conditions. In terms of irrigated acreage, the data suggests producers reduce the actual irrigated acreage with increased evapo-transpirative demand. Based on this regression analysis, we estimate groundwater use for all permitted wells in the Delta to understand the role of off-season precipitation in alleviating aquifer depletion. This first stage of analysis indicates that reported water use is sensitive to the depletion of the aquifer with average irrigation depth decreasing by a quarter-inch for every additional foot of pumping lift.

The Role of Water Use and Off-season Precipitation on Change in Depth to Water

The decline in groundwater level is a consequence of the expansion in total irrigated acreage and total groundwater use. However, the aquifer also depends on recharge from infiltration and percolation of precipitation. Therefore, off-season rainfall can curb groundwater depletion by restoring soil moisture profile and replenishing the aquifer. Our enriched dataset includes over 63,000 data points between 2014 and 2017 accounting for estimated total water use during the growing season and interpolated estimates of off-season precipitation along with a number of control variables (not reported). We regress the change in depth to water (inter-annual difference in depth to water measures) on estimated water use and preceding off-season precipitation (**Table 2**).

The results indicate that for every 100 acre-feet increase in pumping from a given well, the average change in depth to water increases by 0.13 feet—i.e., depletion accelerates by 0.13 feet per year. Similarly, a total of 100 acre-feet increase in pumping by wells located within 1 kilometer of a given well would be associated with the rate of depletion of that well accelerating by 0.019 feet per year. On the other hand, for every 4 inches (100mm) of additional off-season precipitation, the average rate of depletion decreases by 2.76" (0.23 feet). These effects indicate that aquifer conservation efforts involve a collective effect by which the actions from a given farmer affect other farmers.

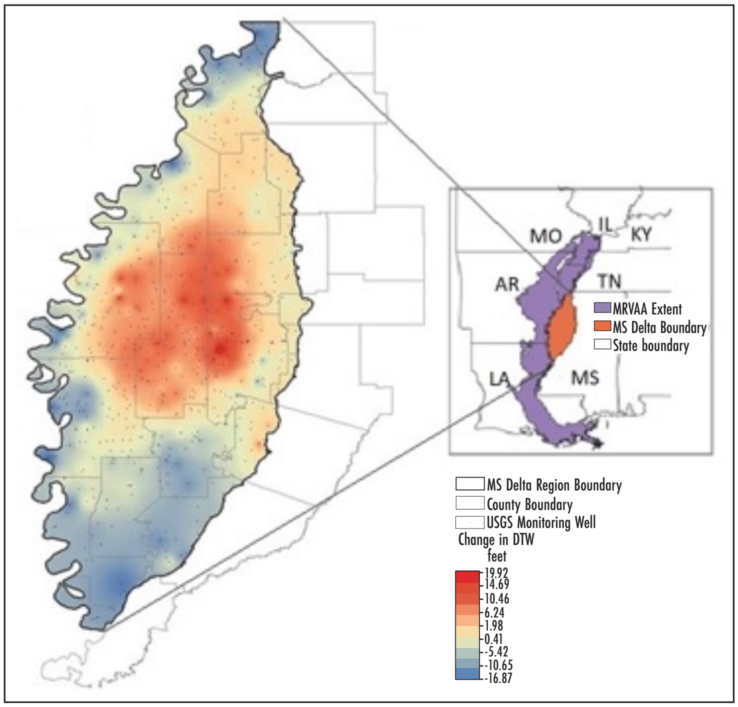


Figure 2: *Change in groundwater well depth to water in the Delta (2000-2020)*

Conclusion

The data confirms the intuition that greater water use speeds up depletion in every case while it also provides insights with respect to the role of off-season precipitation in alleviating depletion. The regression results indicate that off-season precipitation alleviates the rate of depletion of the aquifer. In terms of groundwater use, the results also indicate that collective action by farmers may be as important as individual action by farmers in conserving the aquifer given the statistically significant impact that pumping from neighboring wells have on the depth to water for any given well.

Table 1. *Groundwater user's response to climate and pumping lift.*

Variables	Irrigated acres	Irrigation depth (inches)
On-season precipitation Apr.-Aug. (mm)	**-0.024** (0.011)**	**-0.012** (0.000)**
On-season evapotranspiration Apr.-Aug. (mm)	**0.016 (0.016)**	**0.036*** (0.012)**
Depth to water (feet)	**-0.403 (0.264)**	**-0.756 *** (0.072)**
R-Squared	**0.867**	**0.768**
Observations	**4,677**	**4,677**
Standard errors in parentheses. Statistically significance test indicated by * for p<0.01, ** for p<0.05, and * for p<0.1**		

Table 2. *Change in depth to water response to water use and off-season precipitation*

Variable	Coefficient
Total water use/permit (acre/feet)	**0.00127*** (0.00035)**
Total water use/1-km (acre/feet)	**0.00019*** (0.00004)**
In-season precipitation Apr-Aug. (mm)	**-0.001876*** (0.000272)**
Off-season precipitation Sep-Mar. (mm)	**-0.002302*** (0.000148)**
Observations	**63,200**
R-squared	**0.16**
Bootstrapped standard errors in parentheses. Statistically significance test indicated by * for p<0.01, ** for p<0.05, and * for p<0.1.**	

Framework for Calibration, Sensitivity, and Uncertainty Analyses of an Agro-Hydrological Model

Mahesh L. Maskey and Amanda M. Nelson

Introduction

Researchers are constantly improving hydrological models in response to climate change stressors in crop systems. However, these models need accurate parameterization (i.e., tweaking certain parameters and equations for more accurate representation) prior to implementation. In addition, it is crucial to examine sensitive parameters and their range of uncertainty since they may be highly dependent on model output. For these tasks, this study considered the Agricultural Policy Environmental Extender (APEX) – a widely used farm and small watershed-scale process-based hydrological model. The objective of this study was to develop a generalized approach to calibrate the APEX model and perform sensitivity and uncertainty analyses to assess influential parameters and identify how grazing impacts farm-scale runoff from grassland and annual cropping systems.

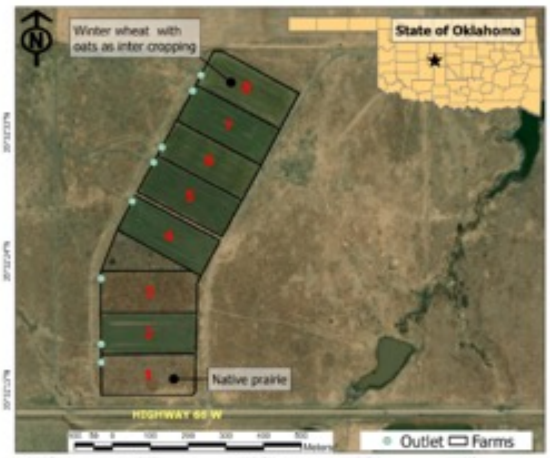


Figure 1a: *Location of study site within Water Resources and Erosion watersheds, indicating the outlet of each watershed by circles where runoff was measured via H-flume.*

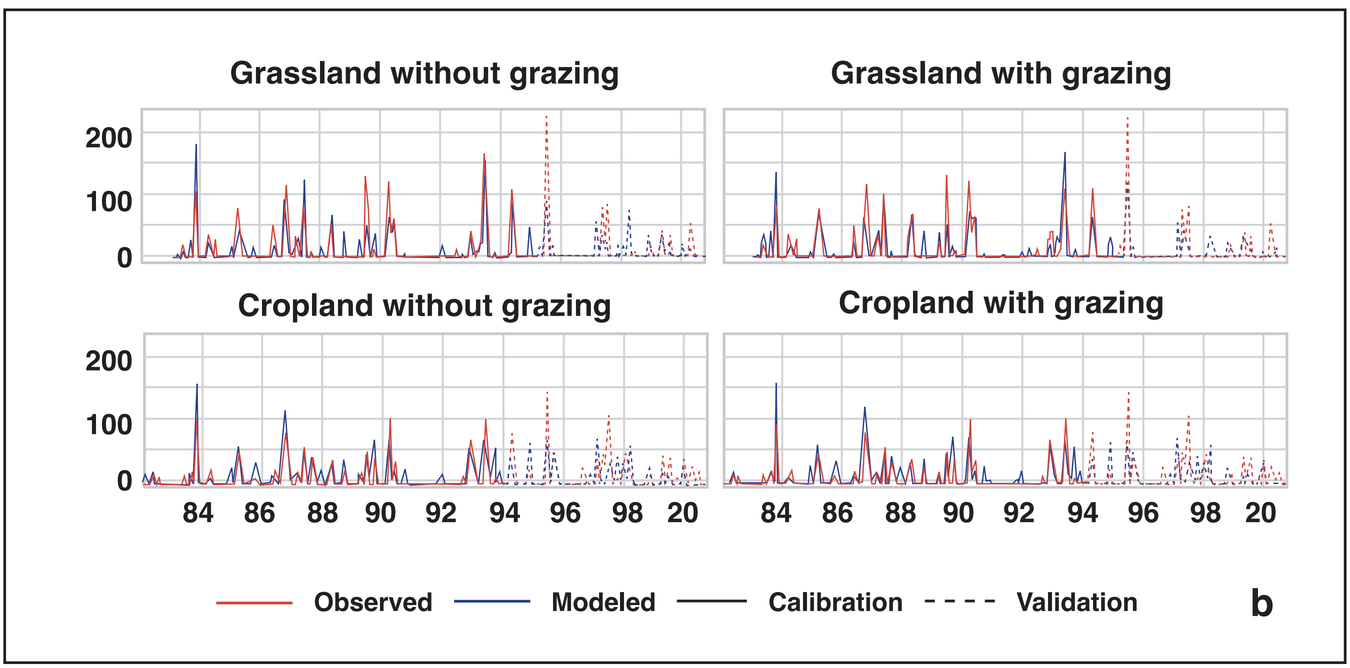


Figure 1b: *Monthly timeseries of best representations of surface runoff optimized at daily scale for grassland (top) and cropland (bottom) watersheds with (right) and without (left) grazing operation. Calibration period (solid) for grassland and cropland are 1983-1994 and 1982-1993, respectively, while validation period (dashed) ends in 2000 for each watershed.*

Table 1. *Percent changes in annual average physical quantities for grassland and cropland management.*

Physical quantities	Grassland	Cropland
Surface Runoff, mm	4.56	0.50
Biomass, t/ha	-91.53	-0.18
Sediment Yield, t/ha	78.81	11.57
Deep Percolation, mm	-92.18	-0.62
Forage (crop) yield, t/ha	71.44	-0.65
Total Nitrogen, kg/ha	60.75	7.03
Total phosphorus, kg/ha	21.70	10.93

Materials and Methods

We used APEX to compare water quality and quantity from a watershed managed with a native prairie grassland and another under an annual system (wheat and oats) based on a dataset with 20-years of measured data, including planting, tillage, fertilizer, pesticide, and surface runoff near El Reno, Oklahoma (**Figure 1a**).

Model input files were initially developed using the Nitrogen Tracking Tool and then modified to suit a new version of APEX that accounts for grazing. During the development of the model, only parameters relevant to hydrology and sediment were selected based on the literature. Still, 20 parameters needed to be optimized, requiring many model-runs (1060 runs) to determine the possibilities of parameter value combinations. Running 100k simulations requires significant computational resources, therefore we utilized the high-performance computing facilities provided by USDA-SCINet's Office of Scientific Computing for calibration.

To improve the non-linear behaviors of parameters in the existing methods, the proposed method used a normal distribution during calibration. We changed the calibrated parameter set by 5% of the difference in parameter bounds in increments of 0.05 for sensitivity analysis. For uncertainty analysis, we chose the range of 20 parameters between ±3 standard deviations from the average parameter sets.

Results and Discussion

For both watersheds, the calibrated model produced reasonable representations of monthly runoff, while optimized at daily scale (**Figure 1b**). As seen, the model's monthly values (blue; **Figure 1b**) of aggregated runoff closely follow the observed ones (red). Further, during calibration, the reasonable values of performance metrics corroborate the model's goodness (Nash-Sutcliffe efficiency and coefficient of determination were higher than 0.70 and 0.69, respectively, but these metrics became less favorable at the validation level).

Results of the model revealed increased biomass and deep percolation in grassland systems (**Table 1**), but less in cropland. Grazing operations, therefore, resulted in reductions in runoff, sediment yield, and nutrient loading (nitrogen and phosphorus). Grazing reduced forage production from grasslands with slight biomass production increases from croplands.

Conclusion

In this project, we have developed a conceptual framework for calibration, sensitivity, and uncertainty analyses of a hydrological model and validated its ability to quantify runoff dynamics from grazing systems. We predict that the proposed framework could be possible to calibrate an agro-hydrological model capable of simulating different cropping patterns, climate conditions, and management regimes to support NCAAR research in the Mississippi Delta. Additionally, the model can be used to simulate deep percolation and lead to the development of a hydroeconomic model. As a result, we will use this tool to analyze the impact of climate change and population growth on the Mississippi River Valley Alluvial Aquifer.

Creating High-Resolution Soil Maps for NCAAR for Precision Soil-Water Management

Amanda J. Ashworth

Background and Goals

Digital soil property maps are being created for the West Farm to develop precision soil and water management recommendations to improve water quantity and quality in the Lower Mississippi Delta. Soil maps are created from digital elevation models, terrain attributes, and remote sensing and help illustrate the spatial distribution of soil properties for every 5 square meters (16 x 16 ft). This digital soil mapping method (patented by ARS scientists) is currently being used on 1.5 M acres in 16 states within the U.S. This mapping algorithm uniquely predicts continuous soil properties and groups these properties into patterns within the field that have similar response to fertilizer and herbicide applications within crop varieties. Use of this technology reduces operating costs by 8-12% and saves producers $25-$50/ac. However, because this mapping process is largely terrain-driven, little work has been to evaluate its application in flat and topographically homogeneous areas like the Mississippi Delta. SWMRU Scientists will also further using these continuous soil property maps as a data layer to evaluate potential aquifer recharge areas, reduce over-irrigation, and more precisely manage soil nutrients, thus improving surface water quality.

By applying a fuzzy logic model on soil sample points, USDA-ARS has produced geospatial property maps that estimate soil properties of alluvial soils in Mississippi.

Methodology

These soil property maps illustrate continuous soil property predictions for improved agricultural management. In general, maps are created by: (1) disaggregating Gridded Soil Survey Geographic Database (SSURGO) to develop a parent material map; (2) then, a 3-m resolution light detection and ranging (LiDAR)-based

Figure 1. *Soil sample collection at West Farm, NCAAR in November, 2022.*

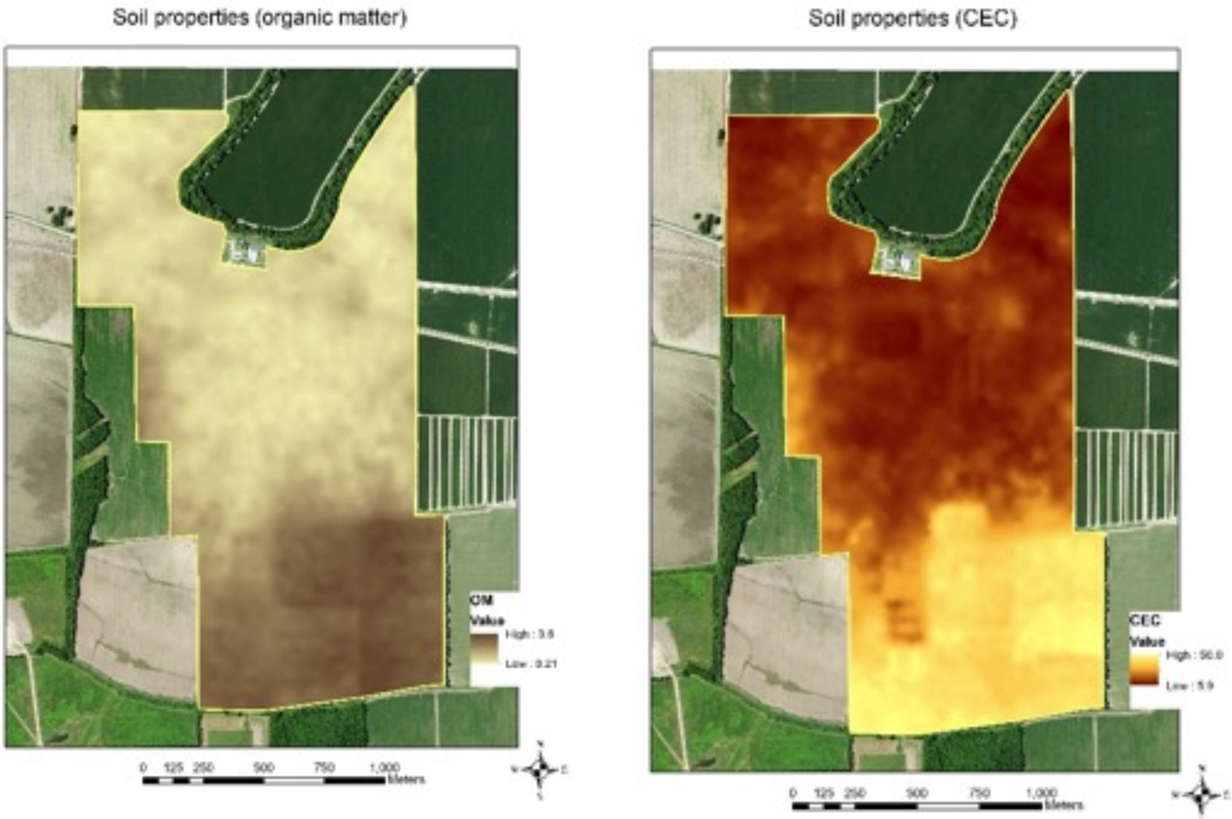


Figure 2. *Version 1 maps of soil organic matter (left) and cation exchange capacity (right) of West Farm, USDA-ARS.*

digital elevation model (DEM) is developed to determine terrain attributes and resampled to 5 m resolution; (3) followed by k-means clustering to develop generic soil classes developed within each PM; and, (4) fuzzy logic is then carried out to develop unique property predictions for each pixel within the area. From there a “smart sampling” campaign was undertaken to sample unique soil classes, thus minimizing sample numbers (**Figure 1**). For the 250 acre West Farm, 16 sample cores were collected to 90-120 cm (0-15; 15-30; 30-60; 60-90; 90-120). By applying a fuzzy logic model (patented by an ARS scientist) on soil sample points, USDA-ARS has produced geospatial property maps that estimate soil properties of alluvial soils in Mississippi.

Outcomes of Soil Mapping Products

• Allow producers and researchers to make real-time precision management decisions in the field using high resolution soil information.

• Respond to landscape-level agricultural issues that ultimately improved our understanding of spatial variability and related nutrient and water-use efficiency (**Figure 2**).

• Develop a mapping method for heterogeneous alluvial soil systems for broader use in the Mississippi Delta.

• Managing soil to manage water (focus on infiltration and recharge).

References

For more information on methodology please visit:

Fuentes, B. A.J. Ashworth, M. Ngunjiri, and P.R. Owens. 2021. Mapping soil properties to advance the state of spatial soil information for greater food security on US Tribal Lands. Frontiers in Soil Science. 1, 95386. doi.org/10.3389/fsoil.2021.695386

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Establishing the Water Budget of a Tailwater Recovery System

Amanda Nelson

Introduction

Tailwater recovery (TWR) systems are an important best management practice for addressing both water quality and quantity issues in the Mississippi Delta. TWRs are systems for capturing surface water runoff to be later used for irrigation. TWRs consist of 1) a ditch to capture runoff; sometimes an on-farm storage (OFS) reservoir to store captured water; and 2) pumps to move surface water from the ditch into the OFS reservoir and to irrigate nearby fields. To determine if TWR systems are an effective way to reduce water use and downstream nutrient loads, water quality and quantity data from a closed ditch TWR system in Sunflower County, MS, is being measured in a long-term evaluation. The objective of this study is to establish a water budget for a closed TWR system, where the TWR is used as the primary irrigation source. Seasonal and rainfall event runoff quantity and quality trends are also being analyzed. These data will later be used to model TWR systems to determine their impacts on aquifer dynamics.

Materials and Methods

The field experiment is being conducted at a TWR system in Sunflower County, MS. There are one or two outflow pipes from each eight, 40 acre fields contributing to the TWR, each

***Figure 1a (**left**)** Runoff water sample setup, April 2022; **Figure 1b (**right**)** pole with solar panel and storm box for electrical components for the velocity meters under water from November rains which overtopped the tailwater ditch in some places. (Note the flooded fields in the background).*

equipped with an automatic runoff sampler (ISCO GLS, Teledyne ISCO, Lincoln, Nebraska) and an area velocity flow sensor (ISCO 2150) to collect composite water samples and flow rates for each runoff event. Management of the fields are at the farmer's discretion and are recorded. Within 24 hours of rainfall or irrigation events, runoff samples are collected, placed on ice, immediately transported to NCAAR laboratories, and stored at 4°C until analysis. Variables measured include runoff volume, sediment, and nutrients. In addition, two rain gauges were installed at the site and a laser water level loggers was installed in the TWR ditch. Irrigation and pumping records and agronomic management information are provided by the cooperator.

Figure 1c *tailwater recovery ditch after heavy November rains. (Almost all the runoff pipes were under water at this point, often backing up into the field, making it difficult to record flow rates).*

Current Status

Beginning in November 2021, field installation began with the help of staff from C.C. Lynch, Inc. Installation of this project and was completed in the summer of 2022, with minor adjustments still being made. Runoff quantity was recorded throughout the 2022 growing season, with data and samples collected from nine irrigation events and thirteen rain events in 2022 (**Figure 2**).

Outcomes

This work is expected to demonstrate that TWR systems are an effective way to reduce water use and downstream nutrient loads from a closed ditch TWR system for the Mississippi Delta. Such results will be useful for minimizing Alluvial Aquifer withdraw.

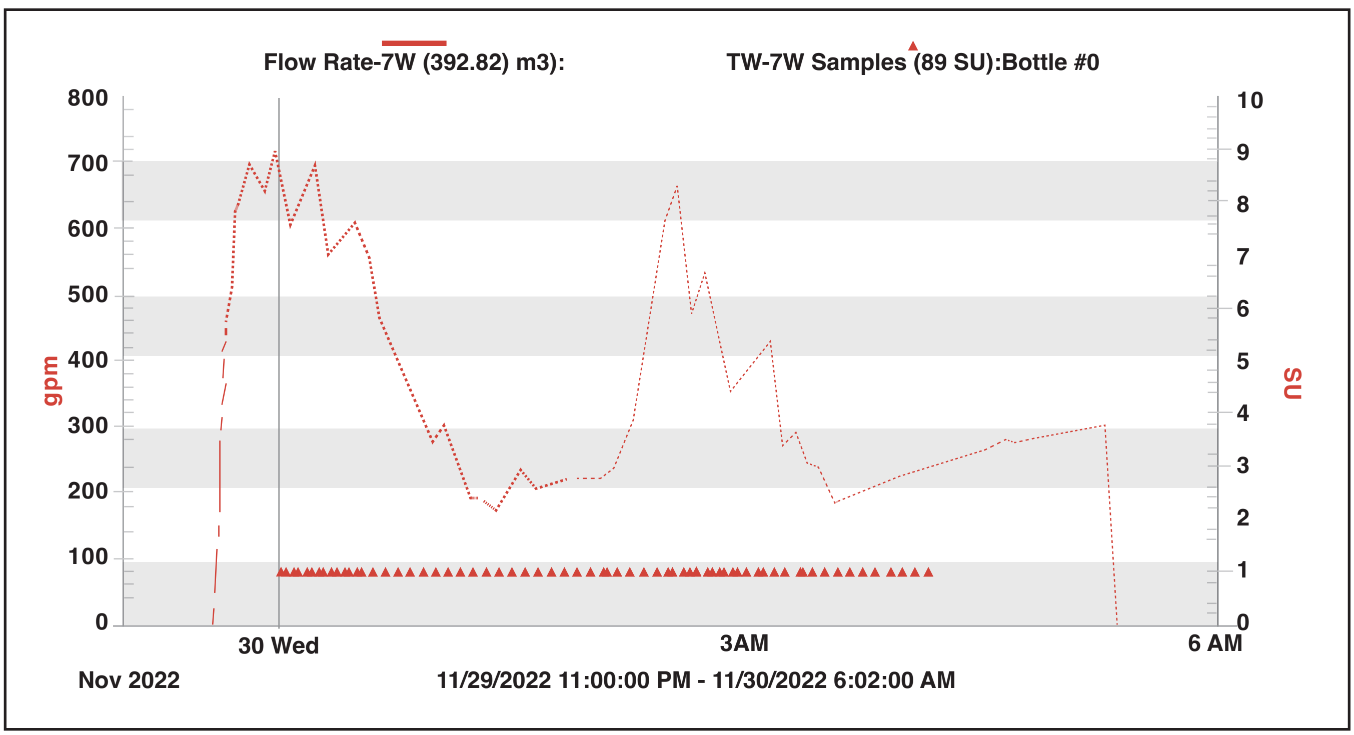


Figure 2*. A hydrograph showing the flow rate (in gpm) of one sampler (7W) over a 7 hour period on November 30th during a rain event. Each triangle represents an 80 mL sample being taken.*

And who's my neighbor? One with On-Farm Water Storage might be a real-life Good Samaritan!

Insights from water use reporting data and GIS analyses

Nicolas E. Quintana Ashwell, Amer Al-Sudani, and Drew M. Gholson

The use of alternative sources of water in the context of a declining aquifer has alleviating effects through substitution and interception. Surface water substitutes the amount of groundwater that would otherwise be pumped from a well. As groundwater slowly flows through an aquifer (from the rivers to the "cone of depression," for example), the interception occurs when pumping hinders the ability of other wells to replenish.

This article provides further insight into the ripple effects of employing surface water sources for irrigation in the Delta. This example illustrates the positive external effects of establishing on-farm water capture and storage infrastructure.

The calculations are based on data described in "Exploring the role of off-season precipitation and irrigation water use in inter-season changes in well depth to water" (**page 44 in this newsletter**) that estimates groundwater pumping for 17,467 wells. That article employs projections of aquifer water elevation and groundwater use between the years 2014 and 2017.

A regression analysis accounting for field-specific and year-specific fixed effects (two-way fixed effect regression). This method controls for any variable that is particular to a field (and does not change over time) or something particular to a given year that affected all wells. **Table 1** summarizes the main variables and the regression coefficients associated with water use and presence of surface water installations (either pumping from a stream, ditch or reservoir). In this type of regression, the coefficients are interpreted as the change in depth to water associated with a unit change in the explanatory variable.

In a future where more water use and crop productivity are expected, and needed, the ability to capture, store and re-use off-season precipitation could be a critical component of the agricultural production system in the Delta.

The first scenario evaluated estimates the localized effect (on a given well, all else equal) of establishing tailwater recovery and reservoir infrastructure in association with the existing irrigation well (Scenario 1). This incorporates the standard NRCS tailwater and reservoir plan for a 160-acre field, which involves approximately 12 acres of added infrastructure capable of providing 50% of irrigation needs with a 10% chance that surface water would be insufficient for 80 irrigated acres (in which case supplemental groundwater may be pumped). This infrastructure is capable of slowing-down change in depth to water by an average of 54% (to about 4 inches per year). This result is obtained from estimating the reduction in groundwater use that is substituted with surface water and the retention of off season rain and tailwater effect captured by the "Surface water" indicator variable effect.

Scenario 2 adds to Scenario 1, the establish-

Table 1. *Average levels for select variables across the Delta, two-way fixed effects regression coefficients for select explanatory variables and projected effects of change in levels under different tailwater and on-farm reservoir adoption scenarios. The estimated levels are based on interpolations from U.S. Geological Survey and Mississippi voluntary flow-meter reporting program. A positive number indicates faster decline (depth to water increases) and a negative number indicates aquifer recovery (depth to water decreases).*

	Average Level	Change in aquifer depletion (ft/year)	Scenario 1: tailwater and reservoir within permit	Scenario 2: tailwater and reservoir within permit and for 10% of pumps within 3km	Scenario 3: tailwater and reservoir within permit and for 10% of pumps within 5km
Change in Depth-to-water (ft/year)	0.72		0.33	-0.03	-0.09
Percentage slowdown in depletion Scenario 1			-54%	Replenish by 4%	Replenish by 12%
Average groundwater pumping (acre-ft/well)	70.31	0.0018632	-0.0655	-0.0655	-0.0655
Water use within 3km	2,517	0.00028	0	-0.03524	-0.03524
Water use between3km to 5km	5,080	0.0002225	0	0	-0.056518
Surface water within 1km	0.48	-0.3223	-0.3223	-0.64461	-0.64461

ment of similar water infrastructure for 10% of all wells within a 3km (little less than 2 miles) radius. This added infrastructure reverses depletion and a localized 4% repletion results. This is the good neighbor effect that can also be interpreted as a network effect. Because these on-farm investments have positive effects outside the farms where they are established, this practice becomes an attractive target for public policy or funds. It could, furthermore, be an avenue for collective action from private farmers who are, through this infrastructure, able to look at the issue of irrigation water from a basin scale rather than a field-level scale—possibly allowing cooperation or cost-sharing as one farmer's runoff could become another farmer's irrigation water. The third Scenario further illustrates the impact from even more distant neighbors.

In a future where more water use and crop productivity are expected, and needed, the ability to capture, store and re-use off-season precipitation could be a critical component of the agricultural production system in the Delta. While earth-moving and the land-cost of establishing the foot print of tailwater and reservoirs is high; the cost of retiring irrigated land in the future due to depleted aquifers could be much higher.

COVER CROPS, TILLAGE & SOIL CONSERVATION

NCAAR laboratory renovations and construction complete

Amanda Nelson and Andrea Simpson

In 2022, the construction and renovations of the NCAAR laboratories were completed. Begun in 2020, the project saw delays due to the COVID-19 pandemic, supply chain issues, staff turnover, and severe weather. Renovations included the formation of four laboratories with built-in gas, pressurized air, and vacuum lines, gas tank storage, isolated exhaust systems, and safety facilities such as emergency showers and eyewash stations.

In Building A, two labs were established: Lab A contains many of our analytical instruments and will be used for biogeochemical analyses of water, soil, and plant samples. Lab B will be NCAAR's wet chemistry lab where analyte extractions and preparations will be performed (**Figure 1**).

In building D, two additional labs were renovated including Lab C which has general lab facilities, such as a fume hood, and will be equipped with a vacuum manifold, and Lab D which will be more of a "dirty" lab in which much of the sample processing and physical soil and plant analyses will take place (**Figure 2**). A partial list of expected capabilities is below.

Soil

pH
Electrical Conductivity
Total (Organic) Carbon and Nitrogen
Extractable Phosphorus and Ammonium
Particle Size Analysis
Bulk Density
Ion Concentrations (Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, and Zn)
Anion Concentrations (Fl-, Cl-, NO3-, Br-, NO2-, SO4-)
Aggregate Stability
Soil Organic Matter Fractionation

Water

pH
Electrical Conductivity
Dissolved Oxygen
Suspended and Dissolved Solids
Dissolved Ammonium
Dissolved Reactive Phosphorus
Ion Concentrations (Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, and Zn)
Anion Concentrations (Fl-, Cl-, NO3-, Br-, NO2-, SO4-)

Plant Material

Total Carbon and Nitrogen
Dry Matter
Seed Count
Protein Content
Ion Concentrations (Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, and Zn)
Leaf Morphology
Extractable Phosphorus and Ammonium
Anion Concentrations (Fl-, Cl-, NO3-, Br-, NO2-, SO4-)

Current Status

With the construction completed, we have undertaken the task of moving and unpacking our laboratory equipment and supplies. We are setting up the equipment and have started training for processing and analyzing samples. Our collection of analytical protocols keeps growing as we continue establishing procedures for various biochemical measurements. We are hoping to hire a lab manager and have fully operational laboratories in 2023.

Figure 1a *Laboratory A with a Lachat flow injection analyzer (left) and ion chromatograph (right);* ***Figure 1b*** *Laboratory B, the wet chemistry lab.* ***Figure 2a*** *Laboratory C with a fume hood, emergency shower, and ample counter space;* ***Figure 2b*** *Laboratory D, the "dirty" lab to be used for physical soil and plant analyses.*

Cover Cropping in Cotton Can Save Irrigation Water in Dry Years

Carson Roberts, Drew Gholson, Martin Locke, Dave Spencer, Whitney Crow, and Brian Pieralisi, and Nicolas E. Quintana Ashwell

Sponsored partially by Cotton Incorporated under project 21-863

Introduction

Cover crops have been touted as a “miracle cure” for most soil and environmental issues in agriculture, but after years of research there remain only a handful of proven benefits. One of those is the conservation of water, specifically on arid and semi-arid dryland. Water saving in that setting have translated to improved yields. Often, however, ample water resources mask those benefits making the cover cropping expense unjustifiable in areas with irrigation or high precipitation. The Mississippi Delta has both. It is likely that the improved infiltration and water holding capacity in a cover crop system could translate to less irrigation water use, but in the past, it has been very difficult to quantify. This study was developed to investigate how conservation tillage and cover crop systems influence lint yield and irrigation water use efficiency. It is hypothesized that water use can be reduced, and yield can be maintained or improved under conservation systems in the Mid-South.

Materials and Methods

A study is being conducted in Stoneville, MS, from 2021 to 2023 on a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs). Study treatments include reduced tillage with subsoil (RT), strip tillage (ST), strip tillage with cover crops (ST,CC), strip tillage with cover crops and subsoil (ST,CC,SS), no tillage (NT), no tillage with cover crops (NT,CC), and no tillage with cover crops and minimal surface disturbance subsoil (NT,CC,SS). Cover crops in all treatments consist of a 50/50% blend of hairy vetch and cereal rye planted at 60 lbs/acre. This study is organized as a randomized

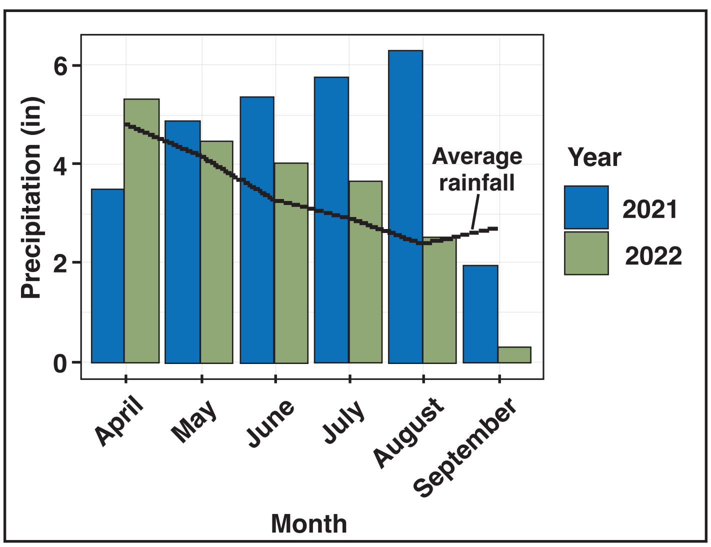


Figure 1. *Monthly precipitation between planting and harvest in 2021 and 2022, and average rainfall of the last 30 years.*

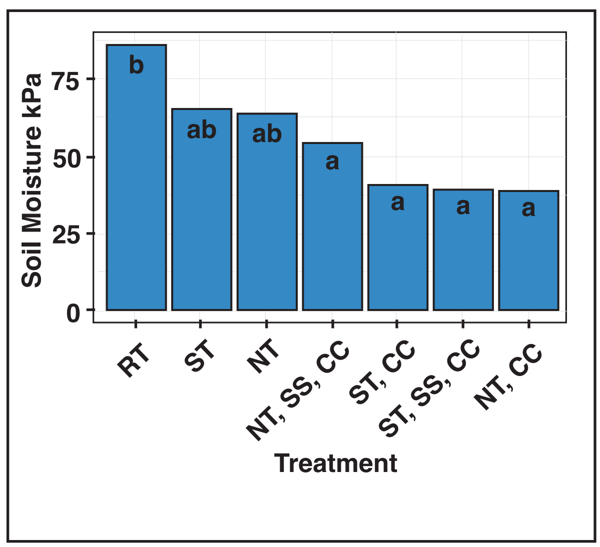


Figure 2. *Soil moisture (kPa) of seven tillage and cover crop combinations in 2022 prior to first irrigation (20 July). Values with the same letter are not statistically different (P<0.05)*

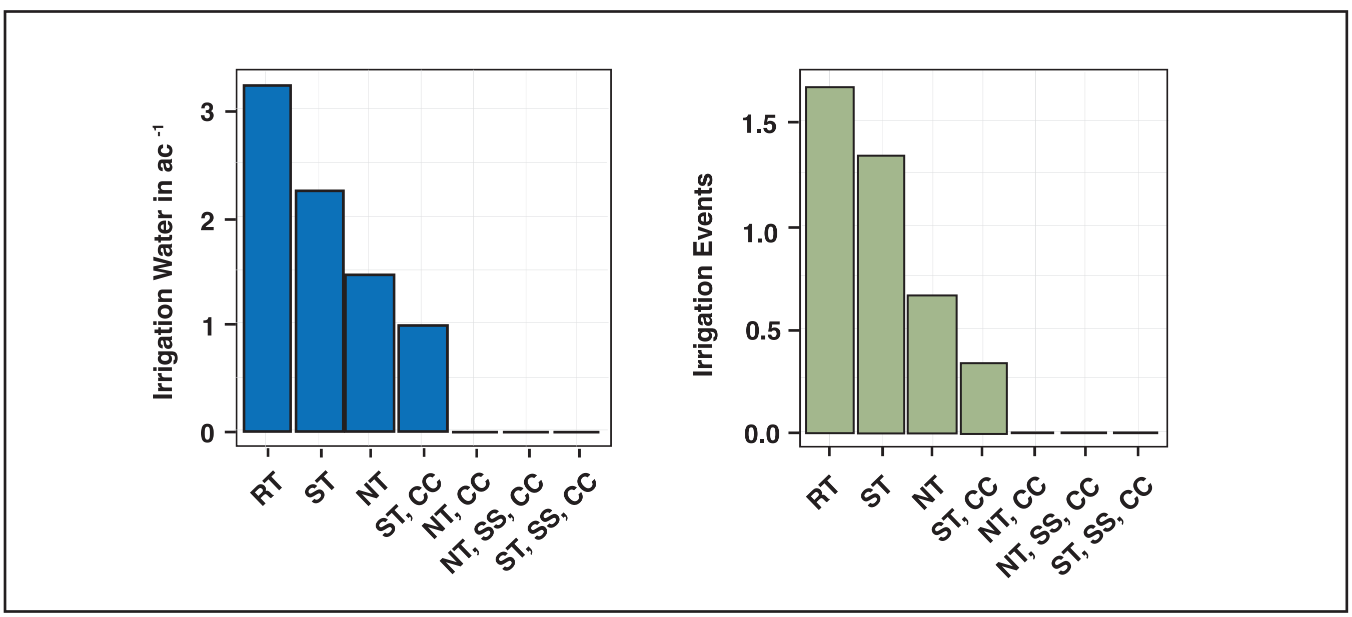


Figure 3. *Irrigation volume and number of events of seven tillage and cover crop combinations applied to cotton at Stoneville, Mississippi in 2022.*

complete block design with three replications. Plots consist of eight 40” rows that are 500’ in length.

Cover crop treatments were terminated two weeks prior to planting. After being terminated, ST plots were tilled using a strip tillage implement (**Figure 1**). The variety Deltapine® 2012 BX3 was planted, routine fertility, pesticide, and PGR applications were made. Watermark® soil moisture sensors were installed, and irrigation was triggered at -90 kPa. Data were analyzed in R studio using the lmer function in the lme4 package, and means were separated using unrestricted LSD.

Results and Discussion

Excessive rainfall occurred during the 2021 growing season (**Figure 1**). This resulted in the irrigation of only one RT plot after reaching the -90 kPa irrigation trigger, so no assumptions were made regarding irrigation water use efficiency in 2021. Precipitation in 2022 followed more normal patterns.

Soil moisture in 2022 differed across the treatments with the RT treatment being significantly drier than any of the treatments where winter cover crops were grown (**Figure 2**). All cover crop treatments contained more soil moisture when contrasted against winter fallow systems. This led to more irrigation water used in the winter fallow systems (**Figure 3**). It also caused the RT system to be irrigated more frequently than most of the other systems. When tilled and weathered, soils can form a crusty or platy structure that inhibits infiltration. That poor structure formation is likely to blame for the increase irrigation water use when the soil is not protected during the winter months.

Lint yields in 2021 were greatest where RT treatments were implemented and were comparable to ST,CC,SS and ST,CC treatments (**Figure 4**). The differences in yield are likely caused by other factors than water use since precipitation throughout the growing season provided ample water for the crop needs. In 2022, results were mixed with the yield of most treatments remaining similar to one-another. Although the NT,CC, NT,SS,CC, and ST,SS,CC treatments remained unirrigated, yield reductions did not occur.

Conclusion

No water-related benefits were realized in 2021 where precipitation was heavy and timely. In drier years like 2022 where irrigation was common, treatments where cover crops were sown needed little to no irrigation, and yield did not suffer. Further investigation at this site is needed to gain a deeper understanding of the results seen here.

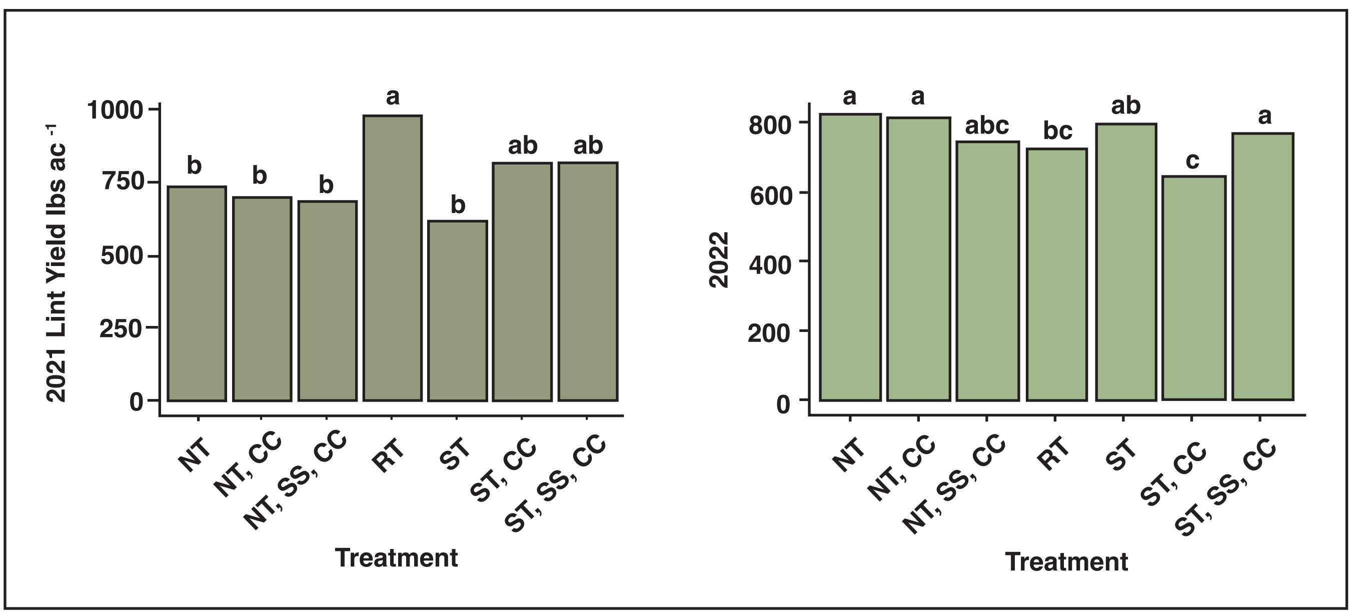


Figure 4. *Cotton lint yield (lbs. ac^{-1}) of seven tillage and cover crop combinations during 2021 and 2022. Values with the same letter are not statistically significant (P < 0.05).*

Cover Cropping Affects Herbicide Concentration in Runoff Water

Carson Roberts, Drew Gholson, Martin Locke, Dave Spencer, Whitney Crow, and Brian Pieralisi, and Nicolas E. Quintana Ashwell

Introduction

Waterways can become polluted by runoff water containing agricultural pesticides. These pesticides have the potential to harm wildlife ecologies in both fresh and saltwater. The Mississippi Delta region contributes more pesticides than any other basin in the Mississippi River drainage system, and some blame conventional agriculture practices for the large pesticide loads. Among the crops grown in the area, cotton has far greater pesticide use than any other crop. Conservation practices including no-till and cover crops have been championed as solutions to this problem. However, few studies in the Mid-South have quantified the potential to reduce pesticides in runoff water by using conservation systems in production. This study was developed to investigate how conservation tillage and cover crop systems influence runoff water quality. It is hypothesized that water quality can be improved under conservation systems in the Mid-South.

Materials and Methods

A study is being conducted in Stoneville, MS, from 2021 to 2023 on a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs). Study treatments include reduced tillage with subsoil (RT), strip tillage (ST), strip tillage with cover crops (ST,CC), strip tillage with cover crops and subsoil (ST,CC,SS), no seedbed tillage (NST), no seedbed tillage with cover crops

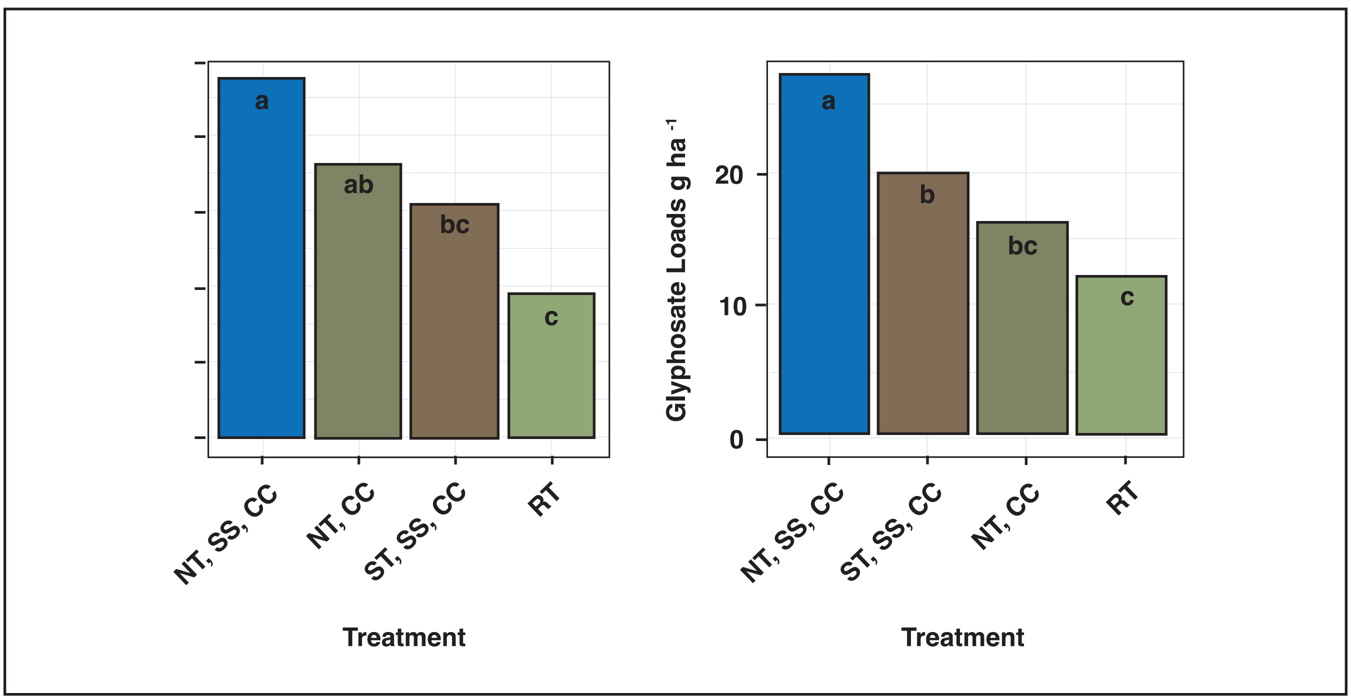


Figure 1. *Glyphosate concentration and loads of four treatments in 2021 following burndown application of glyphosate. Values with the same letter are not statistically different (P< 0.05).*

(NST,CC), and no seedbed tillage with cover crops and minimal surface disturbance subsoil (NST,CC,SS). This study is organized as a randomized complete block design with three replications. Plots consist of eight 40” rows that are 500’ in length.

Cover crop treatments were terminated using 44 oz acre^{-1} of glyphosate two weeks prior to planting. After being terminated, ST plots were tilled using a strip tillage implement (**Figure 1**). The variety Deltapine® 2012 BX3 was planted, and routine fertility and PGR applications were made. Preemergence herbicides included Glyphosate at 44 oz/acre, Glufosinate at 28 oz/acre, and Cotoran 4L and Dual Magnum at 24 oz/acre each. Layby applications included Cotoran 4L at 36 oz/acre and Dual Magnum at 24 oz/acre. Runoff water samples were collected during the runoff event following each application using an area velocity flow meter with an integrated, automatic composite water sampler. Samples were analyzed at Mississippi State University’s chemical laboratory; glyphosate, AMPA, glufosinate, s-metolachlor,

It is hypothesized that water quality can be improved under conservation systems in the Mid-South.

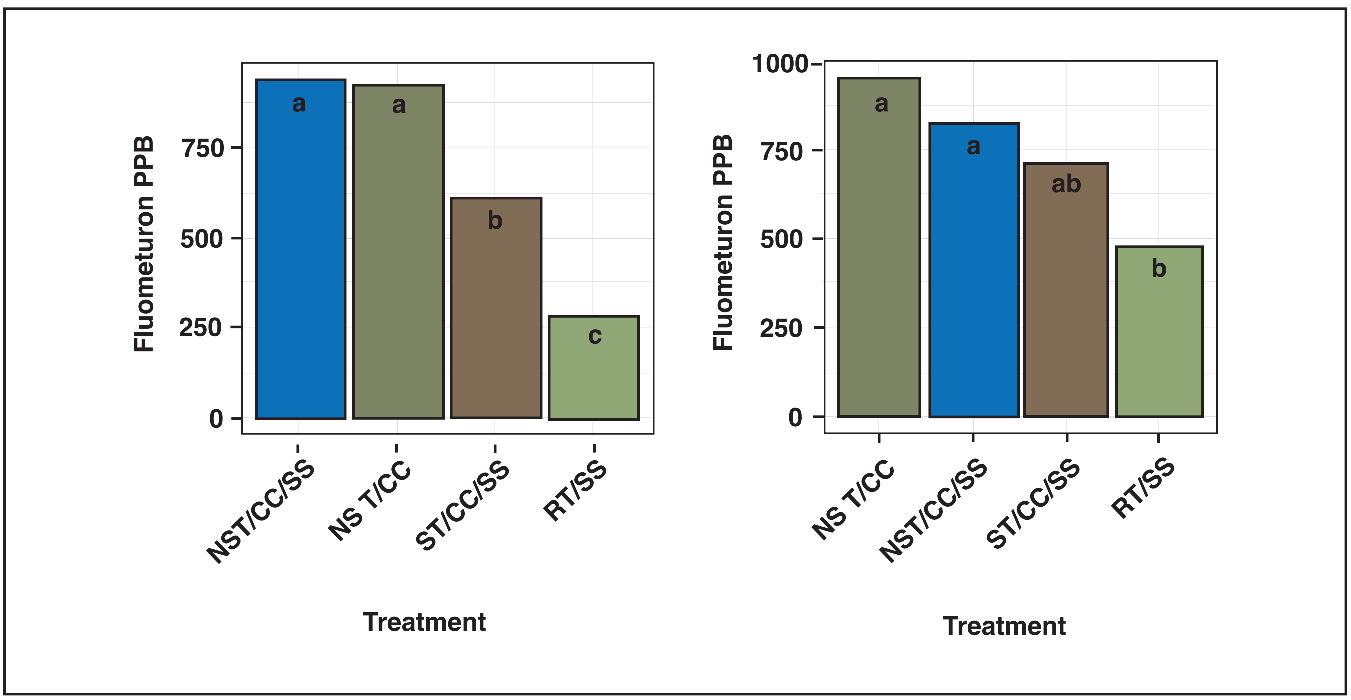


Figure 2. *Fluometuron and s-metolachlor concentrations (ppb) of four treatments in 2022 following layby application of glyphosate. Values with the same letter are not statistically different (P< 0.05).*

Figure 1. *Strip tillage implement in a terminated cover crop.*

Figure 2. *Runoff measurement and sampling equipment.*

fluometuron, total nitrogen, total phosphorus, and total solids were measured. Data were analyzed in R studio using the lmer function in the lme4 package, and means were separated using unrestricted LSD.

Results and Discussion

There were differences between the treatments in both concentration and quantity of glyphosate runoff following the burndown application of glyphosate in 2021. This event showed glyphosate concentrations in the runoff water being increased by more than 2-fold where no seedbed tillage and cover crops were implemented (**Figure 1**). Furthermore, the total quantity of glyphosate being exported from the field was double in the NST,SS,CC and ST,SS,CC when compared to the conventional, RT treatment.

In 2022 runoff concentrations of some of the runoff events were not calculated because of equipment malfunction. Of those that were calculated, glyphosate, AMPA, glufosinate, total nitrogen, total phosphorus, and total solids in each treatment did not differ from each other. Runoff concentrations of fluomenturon and s-metolachlor did differ across the treatments that were measured following the layby application (**Figure 2**). The trends here follow the same pattern as trends in 2021. During the rainfall event two days following the layby application, fluometuron concentrations in the runoff water were more than three times more in both treatments where no till and cover crops were implemented compared to the RT treatment. The ST,SS,CC treatment also produced concentrations that were two times greater than the RT,SS treatment. S-metolachlor concentrations were also different, but the most severe difference between RT and any other treatment was only two-fold, and it was comparable to the ST,SS,CC treatment.

The difference between the treatments in all these different cases is likely relative to the amount of biomass in each system. Since the RT treatment has little to no biomass the opportunity for the herbicide to adhere to the soil is greater than in the cover crop systems where the herbicide can fall on the cover crop residue where adhesive potential is limited. The runoff water quantity may also play a role in the elevated levels since runoff volume is usually less in the cover crop systems.

Conclusion

Herbicide as a runoff water pollutant was not reduced by implementing cover crop and no-till practices. Concentration differences between the treatments suggest that the herbicides are not adhering to the soil as strongly where cover crops are planted. Further investigation at this site is needed to determine the potential of these systems in the Mid-South.

Effects of Subsoiling Frequency and Irrigation Frequency on Delta Corn

Jacob Rix, Himmy Lo, Drew Gholson, Lyle Pringle, Dave Spencer, and Gurbir Singh

Introduction

In historically cotton-growing soils of the Delta, hardpans are prevalent as a consequence of long-term intensive tillage and equipment traffic. These compacted layers restrict root development and water infiltration. To combat this problem, subsoilers have been used to fracture hardpans once every year or longer. The goal is to enhance crop access to soil water and nutrients, thus improving yield on rainfed fields and reducing irrigation frequency on irrigated fields. In previous research on Delta cotton, the combination of annual subsoiling and high-frequency irrigation decreased yield and profit because of excessive soil water. More information is needed on how subsoiling frequency and irrigation frequency jointly affect Delta corn.

Methods

Scientists at NCAAR analyzed the corn portion of a corn-cotton rotation experiment near Tribbett, Mississippi. The soil was classified as silty clay loam, with a hardpan around 8-12 inches below the surface. Replicated across five blocks over five years, each of the 12 treatments in this experiment represented a unique combination of one in-row subsoiling frequency and one furrow irrigation frequency. The four evaluated subsoiling frequencies were no subsoiling (NS), subsoiling only before cotton (CS), subsoiling only before corn (MS), and every-year subsoiling (ES)—all using the low-till parabolic subsoiler in the fall or winter. The three evaluated irrigation frequencies were no irrigation (NI), low-frequency irrigation (LI), and high-frequency irrigation (HI).

Soil water was monitored using a set of Irrometer Watermark 200SS sensors at the depths of 6, 12, 18, and 24 inches in each NS × HI and ES × LI plot. Grain yield was measured

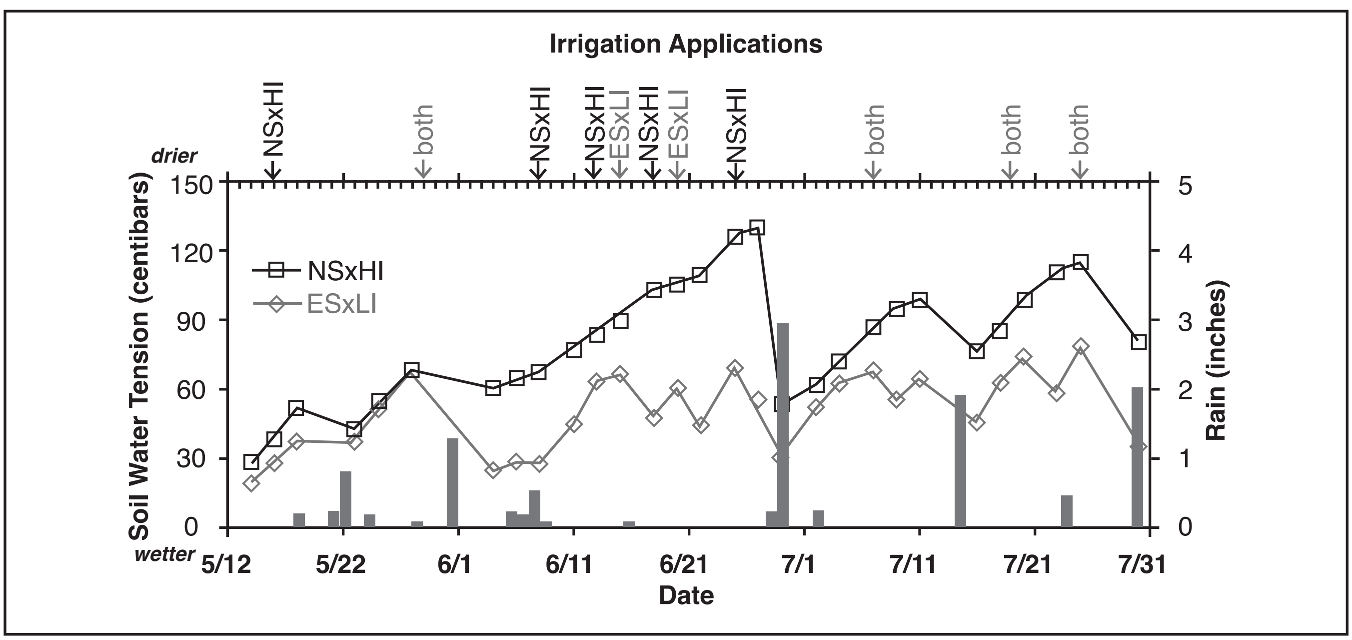


Figure 1. *Example of soil water response to rain and irrigation in the no subsoiling × high-frequency irrigation treatment (NS × HI) and the every-year subsoiling × low-frequency irrigation treatment (ES × LI) treatment; soil water tension increases as the soil dries.*

using a weigh wagon and was adjusted to a standard moisture content of 15.5%. Profitability was compared assuming corn price of $4.30 per bushel, subsoiling cost of $11 per acre per year, fixed irrigation cost of $44 per acre per year, and variable irrigation cost of $2 per acre-inch.

Results and discussion

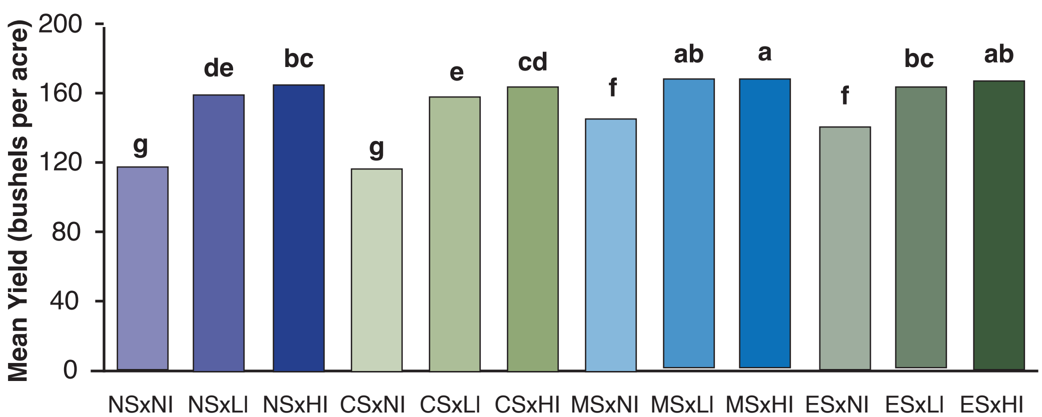
Subsoiling before corn increased the infiltration of irrigation water for irrigated corn. More soil water was maintained even with lower irrigation frequency. However, soil water data did not show that subsoiling before corn increased the infiltration of in-season rainfall for irrigated corn. Instead, heavy rains tended to reduce soil water differences between the NS × HI and ES × LI treatments. These findings were exemplified in **Figure 1** and were confirmed statistically using pairwise t tests.

At each irrigation frequency, NS and CS were statistically indistinguishable in corn yield just as MS and ES were statistically indistinguishable in corn yield (**Figure 2**). Without irrigation, subsoiling before corn maximized corn yield. Without subsoiling, high-frequency irrigation maximized corn yield. Low-frequency irrigation and high-frequency irrigation resulted in statistically indistinguishable corn yield only if subsoiling occurred before corn.

Subsoiling before corn and irrigation each increased average profit and decreased profit variability for corn production (**Figure 2**). The highest average profit was achieved by the MS × LI treatment, whose profit variability was also relatively small. By subsoiling before corn, similar profits could be earned with lower irrigation frequency.

Conclusion

To reap the benefits of subsoiling in Delta corn, subsoiling should be performed every off-season that precedes a corn crop. Subsoiling before corn is strongly recommended for both nonirrigated and irrigated corn in the Delta as an effective practice to preserve farm profits while conserving water resources.



	NSxNI	NSxLI	NSxHI	CSxNI	CSxLI	CSxHI	MSxNI	MSxLI	MSxHI	ESxNI	ESxLI	ESxHI
Average	507	616	630	493	607	619	622	652	647	598	631	636
Standard Deviation	184	120	129	195	117	111	135	104	99	133	88	106

Profit Above Specified Costs (dollars per acre per year)

Figure 2. *Corn yield and profit response to subsoiling frequency × irrigation frequency treatments; treatments sharing a grouping letter on top of their columns were not statistically different in yield according to Fisher's least significant difference test at alpha = 0.05.*

Effects of Conservation Practices on Corn Yield, Furrow Infiltration, and Water Content in Surface-Sealing Soils

Jacob Rix, Himmy Lo, Drew Gholson, Dave Spencer, and Gurbir Singh

Introduction

Surface sealing is a prevalent problem in historically cotton-growing soils of the Delta. These soils naturally contain a high silt content and were commonly subjected to decades of intensive tillage that destroyed soil aggregates and left the soil bare. Thus, the surface is prone to forming a dense crust that can hinder seedling emergence and water infiltration. Rain and irrigation become less effective at replenishing soil water, so more irrigation is required for protecting crop yields. To promote greater water sustainability in the Delta, conservation practices that might address surface sealing should be compared side by side.

Methods

The experiment was conducted near Stoneville, MS, in surface-sealing soils that range from very fine sandy loam to silt loam. Five conservation practices were evaluated in eight replicate blocks of continuous corn against a conventional tillage (CT) control that used a disk twice and then a pan hipper once in the fall and finally a do-all immediately before corn planting. The no-till (NT) treatment omitted each of these soil-disturbing operations. The cereal rye (CR) treatment modified CT by operating the do-all immediately behind the pan hipper and then planting this cover crop at 60 pounds per acre. The subsoiling (SS) treatment added to CT one pass of the low-till parabolic subsoiler in the row direction. The furrow diking (FD) treatment added to CT the creation of small pits and dams in alternate furrows during the early vegetative period. The polyacrylamide (PAM) treatment added to CT the sprinkling of granular polyacrylamide onto every furrow at 10 pounds per acre immediately after corn planting and again five weeks later. The CT, NT, SS, and CR treatments had been ongoing for multiple years, whereas the FD and PAM treatments were newly imposed.

To highlight any treatment differences in

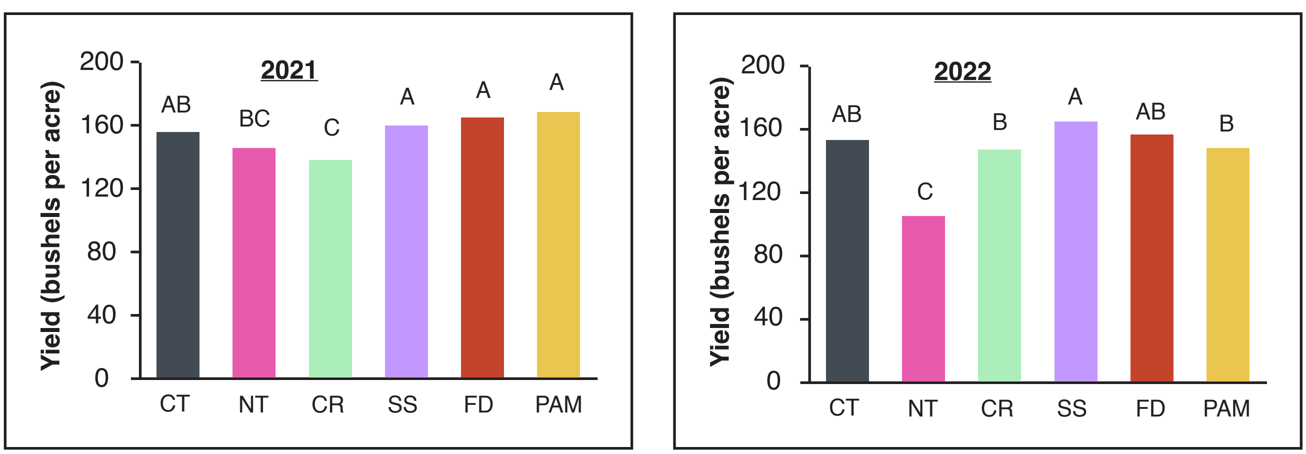


Figure 1. *Grain yield of rainfed corn under conventional tillage (CT), no-till (NT), cereal rye (CR), subsoiling (SS), furrow diking (FD), and polyacrylamide (PAM) treatments; treatments sharing a grouping letter on top of their columns were not statistically different in yield according to Fisher's least significant difference test at alpha = 0.05.*

water availability, 118-day corn was planted around mid-April and was not irrigated. For all treatments in both 2021 and 2022, grain yield was measured using a plot combine around early September and was adjusted to a standard moisture content of 15.5%. For CT and NT in 2021 and for CT, CR, SS, and PAM in 2022, furrow infiltration was measured twice a year at three locations per plot using a 1-hour ponded test with a 12-inch single-ring infiltrometer. For CT, SS, and FD in 2022, soil water content was measured eight times using a calibrated neutron probe at depths of 4, 12, 20, 28, and 36 inches on both shoulders of a raised bed.

To promote greater water sustainability in the Delta, conservation practices that might address surface sealing should be compared side by side.

Results and discussion

None of the five conservation practices achieved a statistically higher rainfed yield than the CT control in either year (**Figure 1**). In both years, SS and FD outyielded CT numerically, but the yield of these three treatments were statistically indistinguishable.

There were no statistical differences in furrow infiltration between CT and NT in 2021 and between CT, CR, SS, and PAM in 2022. In fact, the infiltration rate of the CT control was numerically the fastest at every measurement time.

For soil water content in the top 40 inches, there were also no statistical differences between CT, SS, and FD in 2022. Numerically, SS was wettest at six of eight measurement times while FD was driest at every measurement time (**Figure 2**).

Conclusion

The five conservation practices are known to have the potential to enhance water availability to crops. As implemented in this experiment, however, these practices did not significantly improve rainfed yield, furrow infiltration, and water content in surface-sealing soils. Further work is needed to adapt these practices and to assess other practices for advancing both farm economic viability and natural resource stewardship under the environmental conditions of the Delta. In the meantime, subsoiling is most recommended based on its observed benefits across decades of local research for corn production in historically cotton-growing soils.

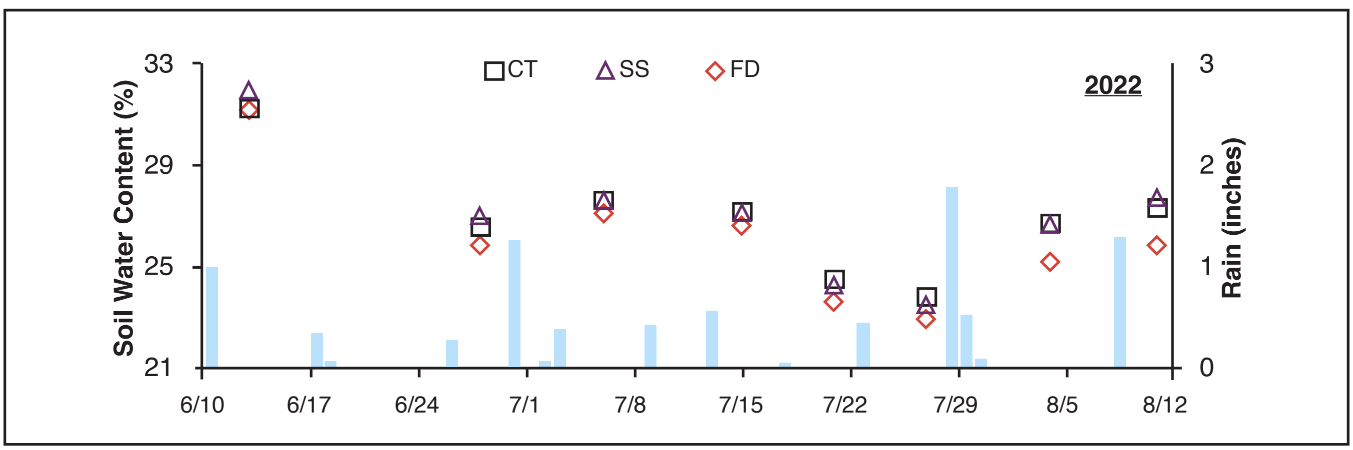


Figure 2. *Soil water content in the top 40 inches for the conventional tillage (CT), subsoiling (SS), and furrow diking (FD) treatments; rainfall records were provided by the Delta Agricultural Weather Center (http://deltaweather.extension.msstate.edu).*

DECISION TOOLS, EXTENSION RESOURCES & EDUCATION

DECISION TOOLS, EXTENSION RESOURCES & EDUCATION

Enhancing Producer Knowledge of Irrigation Water Management Through a Comprehensive Educational Course

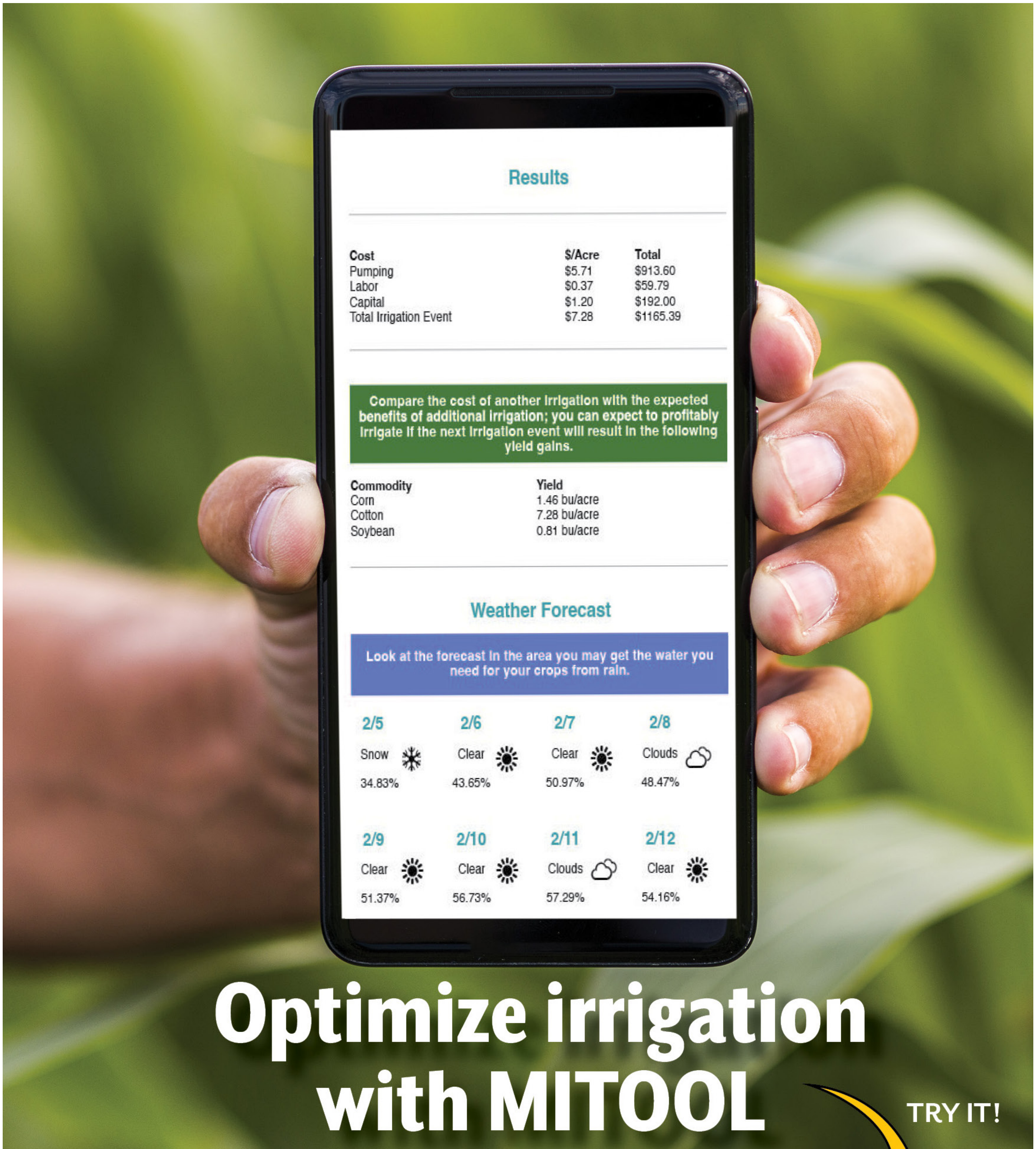
Dillon Russell, Drew M. Gholson, Nicolas E. Quintana Ashwell, and Himmy Lo

Motivation

Scheduling irrigation events using soil moisture sensors has proven to reduce irrigation water applied while maintaining or improving crop yield and profitability. On the other hand, producers are hesitant to adopt soil moisture sensors because they either have had a bad experience or simply do not understand how to comprehend the readings being given. This course is designed to address all facets of irrigation water management, including irrigation water management practices (IWM), soil health, agronomics, irrigation scheduling, irrigation systems, and equipment maintenance, the economics of irrigated agriculture, and policy and management. Our goal is to equip producers with the knowledge they need to make the right irrigation water management decisions that improve their water use efficiency and, ultimately, their on-farm profitability.

Development of the Mississippi Master Irrigator program began in May 2022. This program is being modeled after the original Master Irrigator course offered by the North Plains Groundwater Conservation District. The program is being delivered through a hybrid approach via online modules and in-person training. Instructional videos are being produced, and we expect to have approximately 12 credit hours of content created by the end of spring 2023. Throughout the second half of 2022, promotional materials such as a logo and a website containing program information were developed. The website can be found here: http://extension.msstate.edu/agriculture/crops/master-irrigator

Once our online modules are complete, we will launch the online portion of the course. Participants will be required to complete online modules in a 12-month period to become eligible for our in-person training, a two-day event held at the Delta Research and Extension Center in Stoneville, MS, sometime in the off-season. The online modules and in-person training days are being conducted by MSU Extension Specialists, as well as other individuals/entities with specialized experience in each discussion topic. A Mississippi Irrigation Manual has been developed and will be given to each program participant at the conclusion of the two-day event. At the conclusion of the two in-person meetings, participants will be granted a certificate titling them a “Mississippi Master Irrigator,” which we expect will grant them funding and/or priority ranking from NRCS programs and discounts on soil moisture monitoring equipment.



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USDA United States Department of Agriculture

MISSISSIPPI STATE UNIVERSITY

Increasing Mississippi Youth Interest in and Entry to Sustainable Agriculture Practices and Careers

Tinuola Osho, Himmy Lo, Drew Gholson, Leslie Burger, Beth Baker, Mary Love Tagert, Manola Erby, Carolyn Banks, Jacqueline McComb, Sonia Eley, Karla Turner-Bailey, and Steele Robbins

Sponsored by USDA-NRCS under award NR204423XXXXC116

Introduction

Mississippi agriculture is facing increases in the rate of technological advancement, the intensity of economic competition, and the complexity of environmental challenges. To propel the continued success of this important industry, Mississippi must develop a skilled and motivated workforce to fill agricultural jobs and must cultivate a conservation-minded citizenry to support improvements in sustainability. Therefore, educational efforts that stimulate Mississippi youth interest in and entry to agriculture are essential to securing a thriving future for Mississippi agriculture and the rural communities that depend on it.

To amplify such efforts, a collaboration was formed between Mississippi State University, Alcorn State University, Hinds Community College, and Mississippi Delta Community College. The project focuses on three goals. First, high school students will better understand the scientific principles and societal importance of soil and water conservation. Second, high school students will become more aware of the breadth and prospects of college and employment options in agriculture and natural resources. Third, disadvantaged high school students will gain greater opportunities for hands-on learning related to agriculture and natural resources.

Educational efforts that stimulate Mississippi youth interest in and entry to agriculture are essential to securing a thriving future for Mississippi agriculture.

Classroom Program

In 2022, the project reached roughly 1,000 high school students in and around the Delta through a classroom program. Students were taught two interactive lesson modules. The first module focuses on sustainable agriculture, emphasizing soil and water conservation and also sharing knowledge about plants, animals, and food. The second module focuses on career pathways and introduces students to the diverse jobs in agriculture and the education required to pursue them.

Questionnaire responses from participating students proved clearly that the classroom program raised their interest in agriculture and its careers. Before the program, 19% of respondents indicated that they were interested in agriculture and its careers while 48% indicated that they might be interested. After the program, 42% of respondents stated that they were more interested in agriculture and its careers, 76% stated that they were more aware of the diverse jobs in agriculture, and 85% stated that they were more aware of how agriculture is related to STEM. Furthermore, 37% of respondents marked that they were more likely to take classes related to agriculture, and 37% marked that they were more likely to join extracurricular activities related to agriculture. Given such positive results,

the project team looks forward to expanding this proven program across the state in the upcoming years.

Field Trip

In 2022, the project organized its first field trip, hosting a total of about 65 students from O'Bannon High School, Yazoo County High School, and Greenville Christian School at Mississippi State University's Delta Research and Extension Center in Stoneville, MS. The first part of this field trip followed a career fair format, where students rotated between nine booths to learn from agriculture and natural resources professionals about careers in their respective disciplines. These professionals included employees in government, university, and industry and discussed careers in USDA-NRCS, hydrology, forestry, apiology/apiculture, Cooperative Extension, plant pathology, aquaculture, food science, and cotton processing. The second part of the field trip was a multi-stop tour that demonstrated and explained agricultural equipment and operations. Students experienced soil moisture sensing, sprinkler irrigating, drone flying, GPS-guided planting, and catfish feeding. The project team is committed to arranging additional field trips that broaden youth exposure to agriculture and natural resources.

Other Efforts

In 2022, the project also launched its digital outreach program on Facebook (www.facebook.com/MSYouth4Ag) and Instagram (www.instagram.com/msyouth4ag). Educational information and links about various topics related to agriculture were shared with social media followers. The project team is grateful for its successes thus far and will continue to strive to increase Mississippi youth interest in agriculture and its careers.

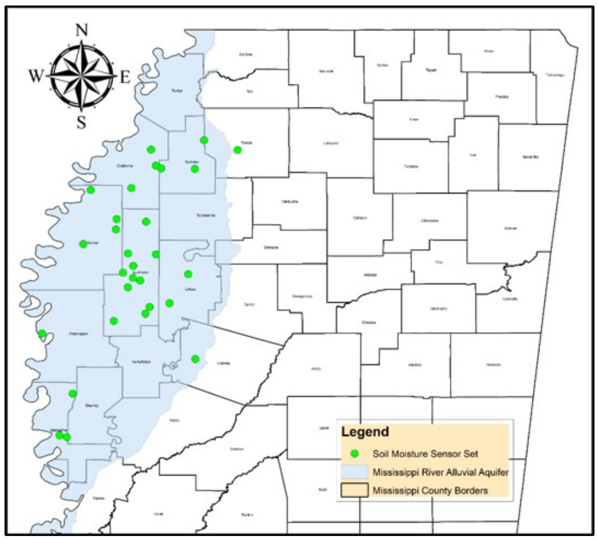
Advancing Adoption of Soil Moisture Sensors Through On-Farm Training and Demonstration

Drew Gholson, Himmy Lo, Alex Deason, Mark Henry, and Dillon Russell

Sponsored partially by Mississippi Soybean Promotion Board under project 13-2022, by Mississippi Corn Promotion Board under project 03-2022, and by Cotton Incorporated State Support Program under project 17-526MS.

Motivation

On-station and on-farm research have shown that soil moisture sensors can help producers irrigate less while maintaining or even improving yield and profit. However, hesitation to adopt soil moisture sensors remains common in Mississippi and nationwide. Some producers assume that their irrigation scheduling is already near optimal and thus will not benefit from the information reported by sensors. Some other producers are reluctant to continue using sensors because of a negative past experience, such as suspicious sensor readings and malfunctioning telemetry systems. In either case, one-on-one guidance from MSU Extension professionals over multiple seasons can assist Mississippi producers in gaining the skills and confidence necessary to adopt soil moisture sensors on their own.



Program

To empower producers to integrate soil moisture sensors fully into their farming operations, we launched an agent-led, multi-year on-farm education program. With generous funding from Mississippi commodity promotion boards and NCAAR, we give telemetry-enabled soil moisture monitoring systems and technical support to interested MSU Extension county agents. These agents recruit producers from their respective counties and provide participants with hands-on training and troubleshooting to deliver the best user experience. Agents then gradually decrease their involvement with day-to-day sensor data interpretation until the participants become active and capable independent users of soil moisture sensors. More than 30 producers across Mississippi participated in 2022, and the crops at the sensor locations included soybean, corn, cotton, and rice. (**Figure 1**).

Outcomes

Some program participants were convinced of sensors' usefulness so quickly that they bought soil moisture monitoring systems before the first year was over. Some participants ignored the sensors during the first year and were shocked to discover at their end-of-season meeting how much they had overirrigated. This realization motivated them to pay closer attention to the sensors during the second year.

In 2022, 33 producers were in the program and 7 of those were year three participants. Post-training evaluation data not only indicate 100% of participants increased their knowledge and trust in soil moisture sensors. All also intend to adopt soil moisture sensors into their operation while around 30% had already adopted prior to the completion of the program. The program aims to help growers use less water and spend less money irrigating and to understand their role in protecting their water supply and groundwater resources.

NCAAR

YEAR-END REVIEW OF SERVICE AND EDUCATION

35K
SOCIAL MEDIA INTERACTIONS

121
ONE-ON-ONE CONSULTATIONS

13 FIELD DAY TOURS
NCAAR hosted field days at grower farms and tours through our research plots.

34 ON-FARM DEMONSTRATIONS
We focused on demonstrating proven technology and working one-on-one with growers throughout the season to show how to use technology for their benefit.

21 ON-FARM RESEARCH SITES
We conducted 21 on-farm research projects to evaluate new technologies on a farm-size scale.

1,200 YOUTH REACHED
We reached 1,200 Mississippi youth with 196 presentations at 21 area high schools. We taught at 5 summer youth camps, initiating connections to agriculture and water-based STEM.

15 EXTENSION & TECHNICAL PUBLICATIONS

53 REFEREED JOURNAL PUBLICATIONS
Co-authored one book chapter

16 POPULAR PRESS ARTICLES

76 PRESENTATIONS

NCAAR ON THE NET

4800 WEBSITE PAGEVIEWS
www.ncaar.mstate.edu

2200
Youtube views of instructional videos and presentations

3 WEBINARS
10 BLOGPOSTS

THREE EPISODES
Crop Doctors' Mississippi Crop Situation Podcast

The snapshot of 2022 outreach encapsulates part of the NCAAR mission, which is to conduct research and provide information for issues surrounding water use for agriculture and natural resources in the Lower Mississippi River Basin (LMRB).

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DECISION TOOLS, EXTENSION RESOURCES & EDUCATION

Graduate Student Showcase

Trey Freeland

M.S. student in Agronomy
Advised by Dr. Drew Gholson

Trey was born and raised in Leland, Mississippi. He earned his bachelor's degree in Agronomy from Mississippi State University. Growing up here, Trey has always known of the great research at Delta Research and Extension Center. When he learned of NCAAR's work in irrigation and water management, he knew he had to further his education at NCAAR. Trey's thesis research examines the effects of furrow irrigation spacing on Sharkey clay soils when planting corn. The clay soils in the Delta are extremely prone to flooding, often resulting in loss of yield for corn that is grown on this type of soil. This study will help show how to effectively space irrigation to reduce the amount of flooding on the clay soils.

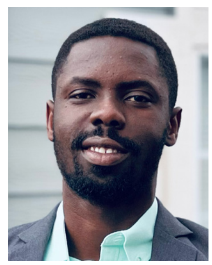
Amrinder Jakhar

M.S. student in Agronomy
Advised by Dr. Gurpreet Kaur

Amrinder comes from the state of Punjab in India. He received his bachelor's degree in Agricultural Science from Punjab Agricultural University. He has always been passionate about the sustainability of natural resources, which matches the mission of NCAAR. Amrinder's thesis intends to quantify the impact of biochar and gypsum on soil properties, water quality, and crop production in the soybean and cotton production systems of the Delta. The declining groundwater levels in the Mississippi River Valley Alluvial Aquifer have created the need to increase soil infiltration and groundwater recharge. Amrinder is eager to contribute to developing the best possible solutions as a member of the NCAAR team.

Eugene Oku

M.S. student in Agricultural Economics
Advised by Nicolas E. Quintana Ashwell



Eugene Oku is a driven and ambitious graduate student at Mississippi State University, where he is currently pursuing a master's degree in Agricultural Economics. Born in Ghana and now living in the USA, he obtained both his Bachelor's and Master's degrees in economics from the University of Ghana.

Eugene's academic interests lie in applied econometrics and water resource economics, fields that address pressing global challenges related to agriculture and resource management. He aspires to leverage his education and skills to create real-world solutions to these challenges and make a meaningful impact on the world. With his determination and commitment to creating positive change, Eugene is poised to make a significant contribution to the fields of economics and agricultural science.

Outside of his academic pursuits, Eugene is an avid soccer player and enjoys playing the piano. His passion for these hobbies reflects his dedication to excellence and his drive to pursue all areas of his life with enthusiasm and diligence.

Jacob Rix

M.S. student in Agronomy
Advised by Drs. Drew Gholson and Himmy Lo

Jacob is a native of Omaha, Nebraska. He earned his bachelor's degree in Mechanized Systems Management at University of

Nebraska-Lincoln. His earliest memories of irrigation were center pivot startups with his grandfather. Jacob's thesis research examines furrow infiltration on surface sealing loam soils in corn. A surface seal limits infiltration, increases runoff, and accelerates depletion of groundwater resources. Practical biological, chemical, and mechanical treatments are being investigated as potential remedies. Jacob has also contributed to NCAAR's Soil Moisture Monitoring Showcase. His career goal is to be a water & integrated cropping systems extension educator.

Carson Roberts

Ph.D. student in Agronomy
Advised by Dr. Drew Gholson

Carson grew up in rural Idaho on a small alfalfa and barley farm. He earned a bachelor's degree in Crop and Soil Science from Brigham Young University-Idaho and a master's degree in Plant Science from Utah State University. Carson is taking a critical look at cropping practices like no-till, strip-till, subsoil tillage, and cover crops in cotton production and their impact on water use efficiency, soil erosion, soil compaction, and water runoff quality. Preliminary results after the first year of study implementation show reductions in yield where some conservation practices were implemented. Carson hopes for a career where his research and outreach will improve farmer efficacy and profitability.

Dillon Russell

M.S. student in Agronomy
Advised by Dr. Gurpreet Kaur

Dillon is a native of Greenville, Mississippi. He earned his bachelor's degree in Agronomy from Mississippi State University in 2019. After working as a summer worker under Dr. Jason Krutz from 2015 to 2017, Dillon knew that he wanted to pursue graduate studies in irrigation research. Dillon's thesis research examines the effect of irrigation scheduling thresholds and cover crops on corn and soybean production. Dillon is determined to produce research that will help producers increase their farm profitability, as well as conserve and restore natural groundwater levels. His dream career is becoming a research agronomist for a private research company.

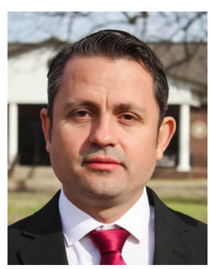
Anna Smyly

Ph.D. student in Agronomy
Advised by Dr. Drew Gholson

Anna is from Stuttgart, Arkansas, where she grew up on a rice, soybean, and corn farm. She earned her bachelor's degree in Crop & Soil Sciences from the University of Arkansas and her master's degree in Plant & Soil Sciences from Louisiana State University. Anna is evaluating how different irrigation frequencies in furrow-irrigated rice affect rice grain yield, water sensing levels, water usage, and nitrogen applications and timing. Determining an irrigation strategy that effectively delivers water to the rice crop is important to the sustainability of our water sources. Anna hopes her research will provide rice growers with an efficient irrigation system utilizing less water in furrow-irrigated rice production systems.

Amilcar Vargas

Ph.D. student in Agronomy
Advised by Dr. Drew Gholson



Amilcar is from Guatemala. He earned his bachelor's degree in Agriculture from Zamorano University in Honduras and his master's degree in Plant Pathology from The Ohio State University. Ever since he was at Zamorano University, he wanted to pursue graduate studies in irrigation water management practices. The groundwater levels in the Mississippi River Valley Alluvial Aquifer are declining, and research is needed to improve irrigation water use efficiency. Amilcar's research evaluates the effects of irrigation systems (i.e., sprinkler and furrow), row spacings, and nitrogen rate applications on row crops. He looks forward to presenting his results and sharing the benefits of water conservation strategies for the Delta.

NCAAR's former students on the move

Jacob Rix, Amrinder Jakhar, and Dillon Russell

Jacob Rix

Hometown

Omaha, Nebraska

Education

Bachelor of Science in Mechanized Systems Management (Minors in Agronomy & Mathematics), University of Nebraska – Lincoln

Master of Science in Agronomy, Mississippi State University

Current title and employer

Irrigation Design Engineer, Pacific SouthWest Irrigation Corporation, Stockton, California

How did MSU prepare you for your current role?

With the encouragement of my committee members, I took a few selected courses outside of my department that further honed the skills needed for my current role.

What was the most valuable lesson you learned during your time at NCAAR?

The most valuable lesson I received is how to effectively communicate science verbally and written to any audience.

How did your experience here lead you to your current role?

The opportunity to attend conferences as a graduate student such as the 2021 Irrigation Association Show expanded my professional connections and broadened my career exploration.

Is there anything you'd like to say to a colleague or supervisor at NCAAR?

I personally would like to thank my former supervisor and great friend, Dr. Himmy Lo, for his strong mentorship to mold me into the individual I am today.

Amrinder Jakhar

Hometown

Abohar, Punjab, India

Education

Bachelor of Agriculture, Punjab Agricultural University

Master of Science, Mississippi State University

Current title and employer

Graduate Research Assistant, Dr. Leonardo Bastos, University of Georgia

How did MSU prepare you for your current role?

Yes; I learned a lot of skills which helped me get this position.

What was the most valuable lesson you learned during your time at NCAAR?

Using equipment, learning how to research, thinking analytically, making good friends

How did your experience here lead you to your current role?

I did a side project which help me grow my interest in precision agriculture, and I came to this position to build my knowledge related to GIS.

Is there anything you'd like to say to a colleague or supervisor at NCAAR?

Everybody was super helpful to me at NCAAR; if in the future I get a chance back to work [with] these guys, I will definitely take it.

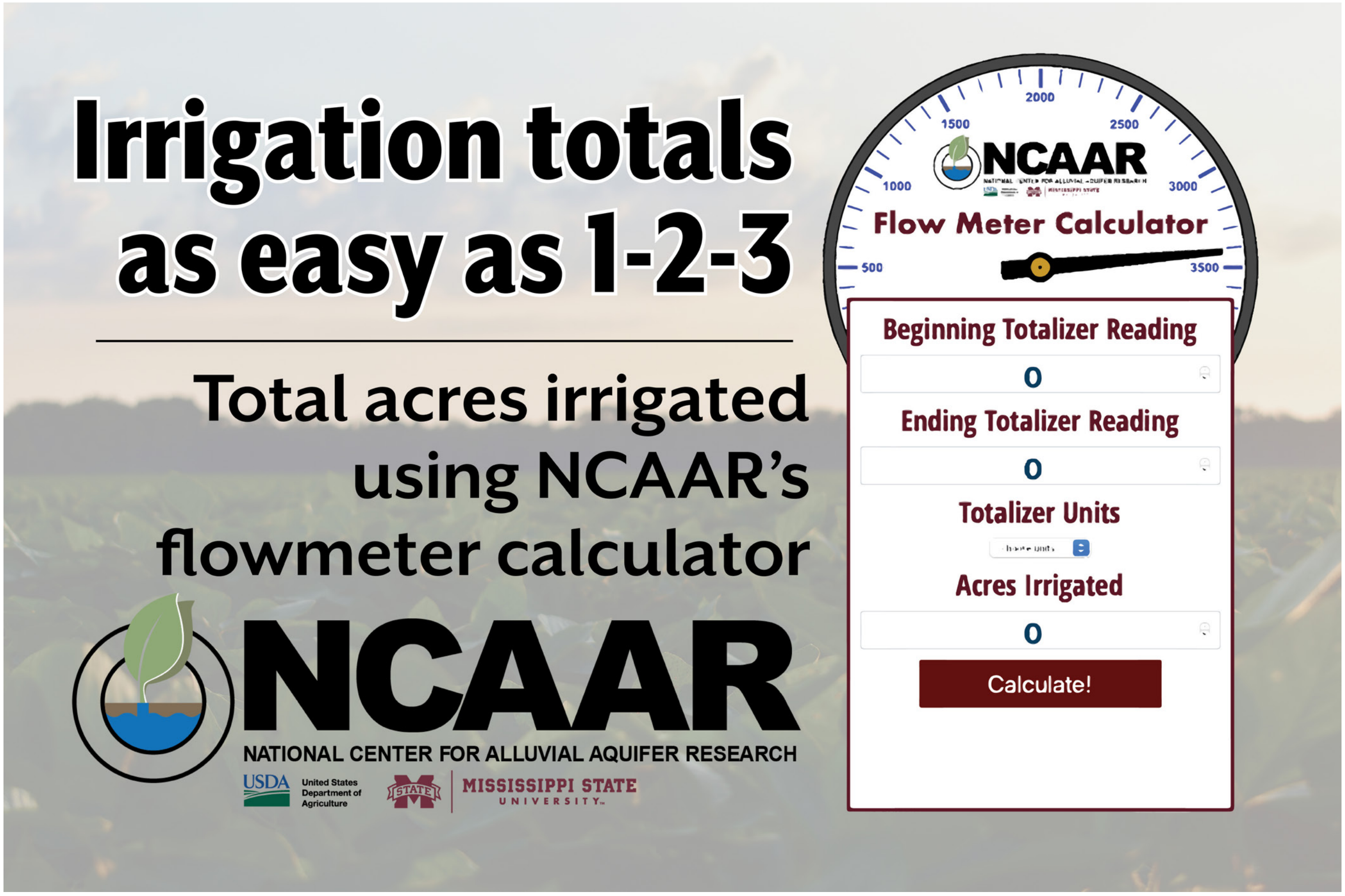
Dillon Russell

Hometown

Greenville, Mississippi

Education

Bachelor of Science, Plant and Soil Sciences-Agronomy, Mississippi State University



Master of Science, Plant and Soil Sciences-Agronomy, Mississippi State University

Current title and employer

Extension Associate II, NCAAR, Mississippi State University

How did MSU prepare you for your current role?

Mississippi State University's dedicated professors and extensive agronomy program equipped me with the knowledge I needed to effectively communicate and provide solutions to growers all across the Mississippi Delta.

What was the most valuable lesson you learned during your time at NCAAR?

Make building relationships and connections a priority. Before my time at NCAAR, I mainly stayed in my inner circle and was hesitant to speak up and introduce myself to others. At NCAAR, you get so many opportunities to connect with growers and research professionals from all around the world. Eventually, you realize that each relationship you build with another person adds another beam of support to what you're building for yourself.

How did your experience here lead you to your current role?

NCAAR provided me with numerous opportunities to connect with others through field days, workshops, conferences, etc. I now use these skills through Extension to collaborate with growers and teach them about the importance of irrigation water management.

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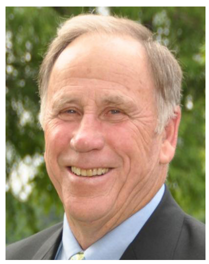

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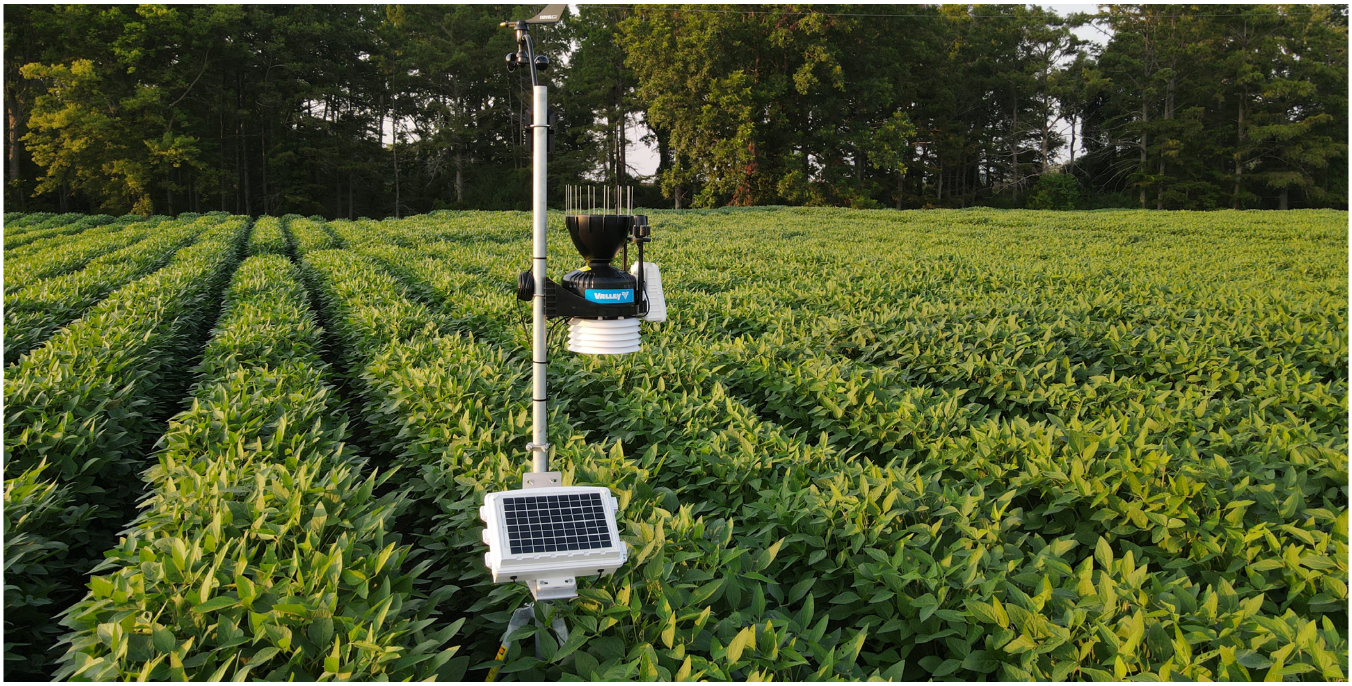

National Center for Alluvial Aquifer Research

Background

The Lower Mississippi River Basin is one of the most productive and intensively irrigated agricultural regions in the nation with 90 percent of the irrigation water pumped coming from the Mississippi River Valley Alluvial Aquifer. Overdrawing this shallow productive aquifer is negatively impacting agricultural productivity and profitability, base flows of streams, water quality, and aquatic and riparian habitats. Currently, scientists from USDA-ARS and Mississippi State University are conducting research and extension activities on water-related issues.

History

The National Center for Alluvial Aquifer Research (NCAAR) was established by Congress in 2017 as a cooperative program between USDA's Agricultural Research Service and the Mississippi Agricultural and Forestry Experiment Station at Mississippi State. NCAAR was created to address the water resources challenges in Mississippi River Alluvial Aquifer.

Our Mission

The mission of NCAAR is to conduct research and provide information for issues surrounding water use for agriculture and natural resources in the Lower Mississippi River Basin (LMRB).

Objectives

NCAAR aims to produce and communicate research directed at the conservation and sustainability of water resources for agriculture that include: developing water-efficient cropping systems, improving water capture, improving water distribution systems and irrigation efficiencies, use of water-saving irrigation management options, and developing economic risk assessment tools that enable producers to identify profitable, water-efficient production options.

Support

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