Article

Adoption of Water-Conserving Irrigation Practices among Row-crop Growers in Mississippi, USA

Nicolas Quintana-Ashwell [1,]*, **Drew M. Gholson [1]**, **L. Jason Krutz [2]**, **Christopher G. Henry[3] and Trey Cooke[4]**

[1]   National Center for Alluvial Aquifer Research, Mississippi State University, 4006 Old Leland Rd, Leland, MS,USA; n.quintana@msstate.edu (N.Q.); drew.gholson@msstate.edu (D.G.)

[2]   Mississippi Water Resources Research Institute, 885 Stone Blvd, Ballew Hall, Mississippi State, MS, USA; j.krutz@msstate.edu

[3]   Rice Research and Extension Center, University of Arkansas Cooperative Extension Service, Stuttgart, AR, USA; cghenry@uark.edu

[4]   Delta Farmers Advocating Resource Management, Delta F.A.R.M., Stoneville, MS, USA; trey@deltawildlife.org

*   Correspondence: n.quintana@msstate.edu; Tel.: 1-662-390-8508

Abstract: This article identifies irrigated row-crop farmer factors associated with the adoption of water conserving practices. The analysis is performed on data from a survey of irrigators in Mississippi. Regression results show that the number of *irrigated area*, years of *education*, perception of a *groundwater problem*, and participation in *conservation programs* are positively associated with practice adoption; while number of *years farming*, growing *rice* , and pumping *cost* are negatively associated with adoption. However, not all factors are statistically significant for all practices. Survey results indicate that only a third of growers are aware of groundwater problems at the farm or state level; and this lack of awareness is related to whether farmers noticed a change in the depth-to-water distance in their irrigation wells. This evidence is consistent with a report to Congress from the Government Accountability Office (GAO) that recommends policies promoting the use of: (1) more efficient irrigation technology and practices and (2) precision agriculture technologies, such as soil moisture sensors and irrigation automation.

Keywords: irrigation; groundwater; alluvial aquifer; water conservation adoption; row crops; Mississippi Delta; precision agriculture; Lower Mississippi River Valley

---

1. Introduction

The Mississippi River Valley Alluvial Aquifer (MRVAA) sustains irrigated agriculture in the Mississippi Delta. Almost 22,000 permitted wells [1] withdrawing more than 370 million m^3 of water per year [1] continue to reduce the stock of groundwater available in the MRVAA at an unsustainable rate [2]. A shortage of irrigation water would be a critical challenge to agricultural production in the region [3]. To address this threat, researchers, regulators and conservation agencies promote the adoption of water conserving practices in irrigated agriculture. However, little is known about what drives growers in Mississippi to adopt water conservation practices that improve irrigation efficiency.

Profitability is a primary concern in any sustainable enterprise. Hence, farmers would adopt new practices that result in higher profits or reduced risks. However, profitable practices are not

---

[1]   Dr. Don Christy, Executive Director, Yazoo Mississippi Delta Joint Water Management District, personal communication, June 6, 2020.

universally adopted; which suggests there are other factors related to the farmers and their ecosystem that influence their choice of agricultural practices. This implies that the combination of practices adopted and the factors that influence their adoption vary by practice and location [3]. In some cases, factors such as farmer age or practicality of the technology are more important than monetary factors [4]. Recent literature identifies factors likely to be associated with the adoption of certain water management and conservation practices at the state (for example, Nian *et al.* [3] for Arkansas) and national level [5]. But no recent study examines the factors driving conservation practice adoption in Mississippi.

This article describes water conservation practices that have the potential to profitably reduce the rate of depletion of the MRVAA and identifies social, economic, and environmental factors associated with the adoption of those practices among irrigators in Mississippi. The adoption of conservation practices and farmer characteristics are identified from a comprehensive survey of irrigators in Mississippi that achieved 148 valid responses. A choice model estimated using Probit regression on the dataset identifies which factors have a statistically significant association with each of the practices considered.

The predominant irrigation method in the Delta region of Mississippi is continuous flow furrow irrigation [6] on row-crops. This is a modified gravity irrigation system that employs pipes with holes aligned to deliver the flow of water on the furrows. The system is better suited to the relatively flat Delta area than it would be for other regions. Elevation goes from 62.5 m above sea level in the Northern tip just south of Memphis, TN, to 24.4 m above sea level at the Southern tip in Vicksburg, MS, while the center of the Delta averages an elevation of 38 m between Greenville and Greenwood. Also, the fields are often precision-leveled, which results in less "pooling of water" on the fields and more uniform irrigation. Consequently, the baseline case is a relatively inefficient gravity system in terms of costs and irrigation performance. The conservation practices assessed in this article are modifications, "add-ons" or substitutes to this baseline prevalent system.

There is compelling evidence that even minor modifications to existing irrigation and agronomic practices in the Mid-South USA region can result in noticeable water savings while achieving similar yields at harvest[6–9]. As anticipated, the practices evaluated in those studies and considered here are not universally adopted in the area. Despite the expected profitability of adoption, the costs of these practices occur at the time of adoption while their benefits accrue over time. Consequently, producers may require generous incentives or returns to the cost of investing in conservation practices to adopt them [10] or the assurance of witnessing several years of neighboring farmers employing them.

The adoption of conservation practices in the Delta area of Mississippi is partially driven by regulatory mandate. All wells drilled in the area with a casing diameter of 15 cm or greater are required to have a permit. The permits must be renewed every 5 years and require crop producers to file an Acceptable Agricultural Water Efficiency Practices (AAWEP) form. Irrigators must claim to employ a high efficiency irrigation system, such as a sprinkler irrigation system; or claim the use or proposed use of three water conservation practices—see https://www.ymd.org/permitting for the permit application and list of acceptable practices .

1.1. Conservation Practices

This article considers practices that show potential to profitably conserve irrigation water, are accepted in the AAWEP form and have been adopted by multiple respondents in the 2016 Survery of Misssissippi Irrigators. Although many irrigators may decide on adopting several practices simultaneously, this article analyses adoption practice by practice in order to maximize the number of valid observations for each case.

Soil Moisture Sensors (SMS) are used in irrigation event decision scheduling to prevent yield-limiting water deficit stress on a given crop. *SMS* gives producers the knowledge of the moisture within the soil profile to make informed and confident irrigation initiation and termination decisions [7] that typically result in increased irrigation efficiency [6,11].

The simplest and most inexpensive (free) upgrade to the baseline irrigation system is the **Computerized Hole Selection (CHS)**. Instead of punching uniform holes in layflat poly-tubing, *CHS* calculates relatively larger holes for parts of the field with long irrigation runs while shorter parts of the field receive smaller holes to allow water to uniformly reach the end of the field and minimize water runoff [7]. On-farm studies in the Delta area found that *CHS* achieves water savings of 20 to 25 percent in most situations [12].

"If it can be measured, it can be managed" goes the adage. Pumping **flow-meters (Meters)** are are an important irrigation water management tool compatible with all irrigation systems. Although it does not provide an intrinsic ability to conserve water, it is a crucial component, for example, to calculate the optimal size of the holes with CHS [13]. They are also required for cooperator farmers participating in NRCS conservation contracts.

Surge irrigation (Surge) allows fields to be divided in two in order to deliver a higher flow rate of water to each half. Water surges down one half of the field until the surge valve flips to deliver water to the other side of the field [7]. The wetting and soaking cycles reduce surface runoff and deep percolation loss while improving water application efficiency by up to 25 percent on the baseline systems with improved infiltration rates documented in sealing silt loam soils [14].

On-farm water storage systems (OFWS) are irrigation water storage structures that are typically designed by NRCS in the Mississippi Delta with the capacity to apply 77 mm of water per hectare per season and meet irrigation requirements for 8 out of 10 years [15]. Depending on seasonal conditions, storage capacity and farmed area, these systems can completely substitute groundwater pumping in some years. NRCS provides technical and financial assistance to producers interested in building OFWS, but many producers face a high opportunity cost to retire productive land to be used for water storage.

The **Tailwater Recovery System (TWS)** collects irrigation and storm water runoff on the farm in a reservoir (OFWS). TWS increases the amount of water available to irrigation compared to an OFWS filled only by precipitation. This allows OFWS to occupy a smaller surface area and more hectares to be farmed. NRCS estimates that TWS by itself can reduce groundwater pumping by 25 percent.

Micro-irrigation (Micro) is a low pressure, low volume, frequent application of water directly to the plant's root zone [16]. It can increase yields and decrease water use by drastically reducing non-beneficial evaporation and virtually eliminating irrigation water runoff. Micro-irrigation is rarely found in the Delta where the soil types and the water quality make the emitters (i.e., nozzles) prone to clogging.

Center pivot-irrigation (Pivot) is a type of irrigation that delivers water through sprinklers that create artificial precipitation and are attached to a wheel-driven frame that rotates radially (and arm pivoting on the center). They are highly configurable for a variety of field and crop requirements. Most center pivot systems in the Delta were installed in the 80s and designed for cotton [17]. However, the original designs are inappropriate to meet the maximum water demands of corn and soybeans. Consequently, there is both adoption and migration away from center pivot irrigation in the Delta. Similar to micro-irrigation, the soil types and water quality in the Delta present challenges in the form of nozzle clogging and wheels getting stuck in mud.

Pump timers (Timer) are a mechanism to program the time or amount of water at which a pump is shut-off. As it helps to automatically or remotely turn the pumps off, it conserves the excess water that might otherwise be pumped, particularly at night [1]. Timers can be employed across irrigation systems for a variety of crops.

Cover crops (Cover) are plants that are typically planted during the off season to cover the soil rather than for the purpose of being harvested. They can help sustain and improve soil health [18], microbial populations, and water infiltration as well as provide benefits in terms of weed control [19]. This is the only conservation practice being analyzed that is not part of AAWEP.

1.2. Factors Affecting Conservation Practices

This article analyzes data from a regional Crop Irrigation Survey that collected 148 valid observations and include data on farmer practices, perceptions & attitudes, and socio-economic status. The factors selected are *irrigated area* in the operation, groundwater *(GW) use* in irrigation, crop choice (*rice*), number of *years farming*, years of formal *education*, whether the farmer perceives a *GW problem* at the farm or state level, average *pumping cost* in the county of residence, participation in a *conservation program*, and annual *income* levels. These factors obtained a sufficient number of valid responses in the sample and are mentioned in two recent comprehensive reviews of the literature [5,20] that identify factors associated with the adoption of agricultural conservation practices or in a recent study of conservation practice adoption in Arkansas [3].

The empirical analysis consists of testing how these factors correlate with adoption of the identified practices. The hypotheses with respect to this association are drawn from the existing literature. Specifically, we draw from a study using similar data in an adjacent area by Nian et al. [3], a comprehensive review of 102 papers in the agricultural conservation practice adoption literature by Prokopy et al. [20], and a 129-page Government Accountability Office report to Congress on Irrigated Agriculture by Pearsons and Morris [5]. In terms of the signs of the regression coefficients, the hypotheses are as follow:

(a) *Irrigated area*: positive;
(b) *(GW) use*: positive;
(c) *rice* farming: negative[2];
(d) *years farming*: negative;
(e) *education*: positive;
(f) *GW problem*: positive;
(g) *pumping cost*: positive;
(h) *conservation program*: positive;
(i) *cracking soils*: negative for surge irrigation, undetermined for other practices; and
(j) *income*: positive.

2. Materials and Methods

2.1. Data

The data are from a survey of irrigators in Mississippi conducted by the Survey Research Laboratory at the Social Science Research Center in Mississippi State University [21]. A telephone-based survey secured a total of 148 completed interviews in Mississippi from a total 2,216 telephone numbers acquired (861 were disconnected or inaccessible after 10 attempts) with an overall cooperation rate of 27.6 percent. The sample is representative of the Delta area of Mississippi with 131 respondents residing in the area and 3 more in neighboring counties. The survey instrument contained questions on growers' characteristics, cultural practices, irrigation management practices, and perceptions & attitudes regarding groundwater availability.

Except for *irrigated area*, *years of education*, and *pumping cost*, the variables included in the analysis are coded as categorical or indicator (dummy) variables. The *pumping cost* is calculated as [22]:

$$p = \theta_e p_e d, \tag{1}$$

where p_e is the price of the energy source for the power unit, d is depth to water used as a proxy for pumping lift, and θ_e is the amount of energy from source e needed to lift a cubic meter of water a distance of one meter. The distance to water is obtained from U.S. Geological Survey [23] based on

---

[2]   Most conservation practices are geared towards row-cropping, so their adoption appears less likely for rice farmers.

respondent's claimed county of residence. Average energy prices were obtained from the U.S. Energy Information Administration (EIA).

Cracking soils is the percentage of soils with clay content dominated by smectite. Such soils crack on the surface when a moist soil shrinks due to drying. The data on soil composition is accessible through USDA-NRCS Websoil survey [24]. This is an important control variable. For example, surge irrigation programs are more difficult to manage in this type of soils because the programming of the alternating cycles is more complicated. The typical program relies on visual cues to switch from on side of the field to the next based on the time water takes to reach the tail of the section. In cracking soils, water infiltrates through the cracks and actual wetting occurs by 3 or more meters ahead of the wetting on the surface. The program is still applicable and carries the same water savings potential but becomes harder for the farmer to realize.

Number of *years of education* is calculated based on a question that was originally categorical. The assigned values are as follow: 10 for less than completed highschool, 12 for completed H.S., 13 for some college or vocational program, 14 for completed Associate degree, 16 for completed Bachelors, 18 for completed Masters and 20 for more than Masters. This transformation is helpful in the estimation and interpretation of regression results with a sample that is small relative to the number of variables considered.

The variable *GW problem* is a dummy variable based on the combination of categorical responses to two different questions in the survey: "In your opinion, do you have a groundwater shortage problem on your farm?" and "In your opinion, do you have a groundwater shortage problem in your state?." Lastly, *conservation program* is a dummy variable based on the combination of responses to 4 different questions that would have otherwise yielded 19 response categories (see appendix A).

2.1.1. Choice Model

There are several ways to motivate the empirical strategy. Due to the nature of the survey and structure of the data, a scenario that allows for irrigators to adopt a single practice or a number of them simultaneously is needed. Hence, a model of individual practice adoption is adequate. An irrigator i adopts a water conservation practice w if the grower expects to receive a greater utility from using the practice (U_{iw}) than they would not using it (U_{iNg}). The probability of adopting practice w is the probability that $y^*_{iw} = U_{iw} - U_{iNg} > 0$ and depends on a vector of n identified factors X_i. Following Maddala [25], y^*_i is a latent, unobservable, variable defined by the regression relationship:

$$y^*_{iw} = \beta' X_i + u_i \tag{2}$$

where u_i is the error term. The variable that is actually observed is whether a practice is adopted ($y = 1$) or not ($y = 0$).

From these relationships, the probability that any given practice w is adopted can be estimated using probit with the assumption that u_i follows a normal distribution:

$$Pr(y_w = 1) = Pr\left(\sum_j \beta_{jw} X_j > 0\right) = \Phi\left(\sum_j \beta_{jw} X_j\right), \tag{3}$$

where $\Phi(\cdot)$ is the cumulative normal distribution function.

To predict the effect a change in the value of a variable would have on the probability of adopting a given practice, the marginal effects are calculated as

$$\frac{\partial}{\partial x_{ik}} \Phi\left(X'_i \beta\right) = \phi\left(X'_i \beta\right) \beta_k, \tag{4}$$

where where $\phi(\cdot)$ is the normal probability density function. This marginal effect is denoted as dy/dx in the results.

3. Results and Discussion

3.1. The Sample

The survey instrument contained questions on growers' characteristics, cultural practices, irrigation management practices, and perceptions & attitudes regarding groundwater availability. Table 1 summarizes the information gathered on growers' land tenure, education and income. Responses are considered to be representative of irrigators operating in the Delta because 88.5 percent of respondents reside in that area and additional respondents live in neighboring counties. Cracking soils are present in 83.1 percent of the counties where irrigators claim residence with an average of 27.6 percent of soils classified as cracking.

Table 1. Summary statistic of farmer characteristics from an irrigation survey conducted in the Mississippi Delta in 2016.

Farmer characteristics	N	%
Delta	131	88.5
Cracking soil	123	83.1
Avg. percentage		27.6
Operator	31	20.9
Landowner and operator	117	79.1
Education:		
Less than Highschool	5	3.4
Completed Highschool or GED	23	15.5
Some college	22	14.9
Completed Associate	18	12.2
Completed Bachelors	66	44.6
Completed Masters	11	7.4
Beyond Masters	2	1.4
Agriculture-related	63	42.6
Income per year:		
Less than USD50,000	13	8.7
USD50,000 to USD100,000	41	27.7
USD100,000 to USD150,000	17	11.5
USD150,000 to USD200,000	9	6.1
USD200,000 to USD250,000	6	4.1
USD250,000 to USD300,000	5	3.4
More than USD300,000	10	6.8
Unsure or no response	47	31.7

Almost 80 percent of respondents are land-owner operators and the remaining growers are operators only. Nearly two-thirds of the farmers have completed a post-secondary degree (65.6 percent) and 42.6 percent of respondents indicated that part of their formal education was related to agriculture.

Growers also identified a range of income they have achieved the previous year. A total of 101 valid responses were recorded with 31.7 percent of respondents refusing to provide an answer or being unsure with respect to which income bracket they belong to. Amongst the valid responses, 53.5 percent of farmers claimed an annual income of less than USD100,000. The median income in the sample was between USD75,000 and USD100,000 per year.

Income level is expected to be positively correlated with the adoption of conservation practices [3,5]. Persons and Morris [5] also find that the level of farmer education positively influences the adoption of irrigation-related precision agriculture practices.

3.1.1. Farming practices

Table 2. Summary statistic of cultural practices.

	N	%	Min	Max	Mean	Std. Deviation
Years farming	148	100	3	80	28.03	14.761
			(Min, Max, and Mean in ha)			
Irrigated area (ha, all)	148	100.0	0	6,070	896	1,007
Irrigated crops						
Corn	106	71.6	2.02	1,821	305	337.7
Cotton	49	33.1	18.1	2,833	490	546.7
Rice	41	27.7	32.4	1,558	373	407.2
Soybeans	131	88.5	27.1	3,804	671	700.2
Cover crop	45	30.4	4.05	1,335	-	-
Land leveling	124	83.8				
Zero grade	26	17.6	2.02	971	177	239.6
Precision grade	116	78.4	3.24	4,654	733	848.5
Warped or optisurface	33	22.3	10.12	1,619	266	385.9
Not leveled	76	51.4	4.05	1,714	202	240.3
Conservation programs	111	75				
CRP	58	39.2	-	-	-	-
EQIP	87	58.8	-	-	-	-
RCPP	14	9.5	-	-	-	-
CSP	31	20.9	-	-	-	-
NRCS	8	5.4	-	-	-	-
Other	8	5.4	-	-	-	-

Note: CRP is NRCS Conservation Reserve Program; EQIP is NRCS Environmental Quality Incentives Program; RCPP is NRCS Regional Conservation Partnership Program; CSP is NRCS Conservation Stewardship Program; NRCS is USDA Natural Resources Conservation Service unspecified program.

Data on growers' agricultural experience and practices are summarized in Table 2. In terms of farming experience, respondents represent a wide range of experience, from as little as 3 years to as much as 80 years of farming experience. Every measure indicates that these are seasoned farmers. On average, growers had 28 years of farming experience with a median and mode of 29 and 30 years of experience, respectively. More than 84 percent of farmers had 10 years or more of farming experience. Approximately two-thirds of the sample are farmers with more than 20 years of experience. The number of years farming is expected to be negatively associated with the adoption of agricultural innovations.

The size of the farming operation is an important factor in deciding the adoption of agricultural practices in general. The average operation involved 896 ha of irrigated farmland with a median of 567 ha and as much as 6,070 irrigated ha. More than three-fourths of the responding growers operate 1,133 ha or less. Hence, the number of irrigated hectares is expected to be positively correlated with the adoption of conservation practices.

Crop choice is oftentimes associated with the choice of irrigation technology [26,27]. The largest number of growers report producing irrigated soybeans (N=131) which occupies the largest cultivated area among the irrigated crops reported: 671 ha on average and as much as 3,804 ha. Irrigated corn is the second most popular crop choice with 106 farmers reporting an average of 305 ha and as much as 1,821 ha of irrigated farmland dedicated to that crop. Cotton is a traditional crop in the Delta region of

Mississippi. About a third of the respondents grow cotton with irrigation dedicating an average of 490 ha and as much as 2,833 ha to its production. These are typically row-crops that employ the same or similar irrigation set-ups when the fields are prepared for furrow irrigation.

Kebede *et al.* [1] reports that irrigated rice consumes more water than any other crop in the region. Growers in this sample report an average of 373 ha of irrigated rice farmland with as much as 1,558 ha of rice under irrigation. Rice production is expected to be negatively correlated with the conservation practices considered in this article, which are better suited for row-crop irrigation.

Cover crops are typically not harvested. Consequently, these crops are not considered as part of crop choices but rather as a conservation practice in this article. Nearly a third (30.1 percent) of growers in the sample claim to plant cover crops. Responses to the survey very widely in terms of crop and area matching. Wheat and radishes received the highest reported area of 1,335 ha while the least was reported for Asian mustard greens (4 ha). The adoption of this practice is tested against the identified explanatory factors.

Land leveling is a relatively common practice in the area with 84 percent of growers reporting having at least a part of their fields land-leveled in some way. It is also no surprise that 51.4 percent of the participating growers report that some fields are not leveled because the Delta in Mississippi is unusually flat. Precision grade is the most common land leveling method with 78 percent of growers employing it on an average of 733 ha and in up to 4,654 ha of their operation.

Awareness and participation in conservation programs are expected to positively influence the adoption of irrigation water conservation practices [3,5]. Three fourths of the growers claimed participation in a conservation program. The program most commonly cited is the NRCS Environmental Quality Incentives Program (EQIP) with 59 percent participation.

3.1.2. Irrigation and water conservation practices

Grower irrigation practices are summarized in Table 3. Groundwater is the principal source of water for irrigation with 93 percent of respondents identifying it as a source. On average, 889 ha are irrigated with groundwater with a maximum of 4,856 ha relying in that source for irrigation. Surface water is also employed for irrigation including streams and bayous which are the source for 178 ha on average. The surface sources can also be complemented with OFWS, 11.5 percent of responses, and TWS in 14.2 percent of responses. Some growers built OFWS and TWS capable of fully supplying the irrigation water needs for some of their fields. Producers relying groundwater from a depletable aquifer are expected to be more inclined to adopt water conservation practices.

The predominant irrigation practice is furrow irrigation for row-crops, which is employed by 86 percent of respondents on an average of 823 ha. Practices that improve the performance of furrow irrigation are deep tilling, employed by 71 percent of the respondents, computerized hole selection (CHS), adopted by 59 percent of growers, and surge irrigation, adopted by 24 percent of farmers in the sample. The last two are considered water-conserving practices for which we seek to find determining adoption factors. Irrigation systems with higher application efficiency are also considered water conservation practices. Micro irrigation is very rare with only 3.4 percent of respondents employing it on an average of 65 ha; while center pivot sprinkler use is more widespread with 60 percent of respondents having used it on an average of 370 ha.

Irrigation scheduling is a crucial component of irrigation water management. The use of soil moisture sensors (SMS) for scheduling has the potential to save as much as 50 percent of total water applied [28]. Agronomic studies in the area have shown that SMS can help improve water use efficiency in furrow irrigated soybeans [6] and corn [9] by reducing water use without reductions in yields when compared to conventional farmer-managed scheduling.

Flow-meters at the irrigation wells are another important management tool. Nearly 70 percent of participant growers own them. A voluntary metering program in Mississippi encourages their use and participation in NRCS incentive programs makes participation in that program mandatory for their cooperators. Another pump accessory is the pump timer which allows the irrigation events to

Table 3. Summary statistic of irrigation practices.

	N	%	Min (ha)	Max (ha)	Mean (ha)	Std. Dev.
Irrigation by source of water						
Groundwater	137	92.6	2.83	4,856	889	909
Stream or bayou	39	26.4	7.69	599	178	142
Stream or bayou & OFWS	17	11.5	2.02	977	182	253
Stream or bayou & TWS	21	14.2	16.2	707	178	185
No outside source w/ OFWS/TWS	16	10.8	4.45	304	81	84
Irrigation by practice						
Flood rc (row-crops)	69	46.6	6.07	4,047	737	939
Furrow rc	127	85.8	1.62	4,452	823	942
Deep till (furrow)	104	70.7	1.62	2,428	512	522
Computerized ole selection	87	58.8	1.62	3,462	734	706
Surge	35	23.6	12.1	607	140	146
Border rc	26	17.6	10.1	769	158	274
Micro rc	5	3.4	2.02	223	65	106
Pivot rc	88	59.5	2.43	2,428	370	391
Irrigation scheduling						
Soil moisture sensors	72	48.6	0.4	6,070	554	1027
Visual crop stress	103	69.6	-	-	-	-
Computerized scheduling	5	3.4	80.9	243	146	102
Routine	29	19.6	-	-	-	-
Probe/feel	27	18.2	-	-	-	-
ET or Atmometer	4	2.7	0	202	99	84
Watch other farmer	6	4.1	-	-	-	-
			Min (units)	**Max (units)**	**Mean (units)**	**Std. Dev.**
Irrigation pumps	146	98.6	1	120	21	24.0
Pump timers	65	43.9	1	90	11	16.6
Flow-meters	103	69.6	1	46	8	7.9
Power unit						
Electric	126	85.1	1	80	11	14.8
Diesel	117	79.1	1	85	13	14.0
Propane	24	16.2	1	45	7	9.3
Natural gas	3	2.0	1	5	3	2.0
Pumping cost (USD/ML)	94	-	0.02	0.088	0.054	0.022

Note: OFWS is on-farm water storage; TWS is tailwater recovery system;

be started or stopped automatically. Almost 44 percent of respondents employ pump timers on an average of 11 pumps.

Finally, the energy source for the pump power units vary with most growers having more than one type of energy source. Electricity is the most common energy source with 85 percent of farmers claiming it. Diesel is the second most common source with almost 80 percent of respondents using it. The energy source mix is important in calculating irrigation pumping costs. The average cost of pumping is estimated at USD 0.0538 per megaliter.

3.1.3. Grower Perceptions and Attitudes

The data collected on farmer perceptions and attitudes towards groundwater availability issues are summarized in Table 4. Less than one-third of growers have observed a change in their wells' depth-to-water while over two-thirds of respondents indicate they perceive there is not a problem with the groundwater supply at their farm or in the state. A test of independence in these responses indicates that they have a statistically significant dependence: those who perceive there has been a

change in their wells depth-to-water are more likely to believe there is a groundwater problem in their farm or at the state level.

Table 4. Summary statistic of farmer perceptions and attitudes.

	Thinks there is a GW problem		
Frequency	**No**	**Yes**	**Total**
Well depth to water:			
No change	60	24	**84**
Increased	9	11	**20**
Decreased	12	13	**25**
Don't Know	16	2	**18**
Refused	1	0	**1**
Total	**98**	**50**	**148**

Percentage	**No**	**Yes**	**Total**
Change in depth to water:			
No/Can't tell	51	17	**68.9**
Changed	14	16	**30.4**
Refused	1	0	**0.7**
Total	**66.2**	**33.8**	**100**

Pearson χ_4^2 = 13.4 with Pr = 0.009.

Note: GW is groundwater.

Table 5. Aquifer "cone of depression" and farmer perceptions & attitudes.

	Cone of depression		
Percentages	**No**	**Yes**	**Total**
Depth to water:			
No change	56	14	69
Changed	20	11	31
Total	76	24	100

Pearson χ_1^2 = 4.3 with Pr = 0.038

Groundwater problem:			
No	54	12	**66**
Yes	22	12	**34**
Total	**76**	**24**	**100**

Pearson χ_1^2 = 5.6 with Pr = 0.018.

The U.S. Geological Survey (USGS) has recently published a map of Potentiometric Surface of the Mississippi River Valley Alluvial Aquifer for the Spring 2016 [23] that shows the location and gradient of the aquifer's cone of depression. A cross-tabulation of farmer perceptions and their location in the center of the cone of depression is presented in Table 5. A Pearson test of independence of the responses shows evidence that farmers located in the cone of depression are more likely to observe a change in their well levels and think there is a groundwater problem at the farm or state level. Half of those located in the center of the cone of depression believe there is a groundwater problem as opposed to 29 percent amongst those located outside that area. Similarly, 46 percent of those in the cone of depression area have observed a change in the depth-to-water in their wells while only 26 percent of those outside the area have noticed such a change.

3.2. Probit Regression Analysis

The estimated models of practice adoption fit the data relatively well with pseudo$-R^2$ (McFadden's) ranging between 0.156 to 0.545. Except for Micro irrigation (only 5 adopters), the conservation practices being analyzed have at least one factor with a statistically significant coefficient. The Probit regression coefficients are detailed in Table 6 for all factors except cracking soils and income–which are detailed in Table 7.

Tailwater recovery systems (TWS) adoption is positively and significantly influenced by the farmers perception that a groundwater problem exist (*GW prob.*). The marginal effect (dy/dx) indicates that that a producer that becomes aware of the groundwater problems in the Delta area would be associated with a 25 percent higher likelihood of adopting TWS. The data indicates that farmers who do not use groundwater for irrigation have not adopted *TWS*.

For on-farm water storage systems (OFWS), the number of irrigated hectares under the operation (*Irr.area*) is positively and significantly associated with the adoption of OFWS. The calculated marginal effect indicates that for an additional 40 hectares of farmed land, the probability of a farmer adopting OFWS is 0.8 percent higher. The data indicates that farmers who do not use groundwater for irrigation have not adopted *OFWS*.

Computerized hole selection (CHS) is positively and significantly associated with the number of irrigated hectares, the perception of existence of a groundwater problem, and having an income between $100,000 and $150,000. The marginal effects indicate 0.5 percent higher probability of *CHS* adoption for an additional 40 ha of land irrigated and the probability of adoption increases by 30 percent when a farmer realizes there is a groundwater problem at the farm or state level.

The adoption of surge irrigation (Surge) is positively and significantly associated with the perception of existence of a groundwater problem and negatively by the pumping cost. The negative influence of the pumping cost variable is a departure from the hypothesized relations in the GAO report. Because this variable is a combination of various data with a fundamental rooting in the county of residence claimed by the farmer, there may be confounding of factors, the identification of which is beyond the scope of this study. However, the result is driven in part by the fact that nobody claiming to reside in the cone of depression (highest pumping cost) uses surge irrigation. Surge irrigation is harder to manage in the cracking clays that are a common soil type in that area [3] but this effect does not appear statistically significant in this regression. The marginal effect calculations suggest the probability of adoption of *Surge* increases by 0.2 percent for an additional 40 hectares of irrigated land added to the operation but an increase of 1 percent in the cost of pumping would decrease adoption probability by 0.55 percent. The data indicates that farmers who do not use groundwater for irrigation have not adopted *Surge*.

The use of soil moisture sensors (SMS) is significantly associated with *irrigated area* (positive at 5 percent), *Rice* production (negative at 5 percent), participation in a conservation program (positive at 5 percent), and increasing income (from baseline to the $100k to $150k income bracket, positive at the 5 percent). The estimates suggest that an increase of 40 hectares in irrigated land would result in 2 percent higher probability of adopting *SMS*, the choice of growing rice would reduce that probability by 50 percent, and the participation in a conservation program would add 45 percent to the *SMS* adoption probability. The data indicates that farmers who do not use groundwater for irrigation have not adopted *SMS*.

---

[3]   For details, see soil survey data at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Table 6. Results from Probit Regressions (coefficients by income level in Table 7).

	Irr. area	GW use	Rice	Years farm	Educ.	GW prob.	P.cost	Cons. pr.
TWS	0.0001	(a)	-0.398	0.009	0.177	0.857**	0.464	0.691
s.e.	(0.0001)		(0.435)	(0.015)	(0.132)	(0.448)	(1.052)	(0.588)
dy/dx	0.00003		-0.115	0.003	0.051	0.25**	0.134	0.199
McFadden's $R^2 = 0.228$								
OFWS	0.0003**	(a)	-0.007	0.027	0.214	0.779	1.45	0.186
s.e.	(0.005)		(0.507)	(0.018)	(0.159)	(0.54)	(1.18)	(0.67)
dy/dx	0.00008***		-0.002	0.006	0.052	0.189	0.353	0.045
McFadden's $R^2 = 0.324$								
CHS	0.0002*	0.59	-0.176	-0.01	0.153	1.13**	-0.58	-0.24
s.e.	(0.0001)	(1.11)	(0.49)	(0.015)	(0.124)	(0.51)	(1.03)	(0.495)
dy/dx	0.00005*	0.16	-0.048	-0.003	0.041	0.30**	-0.157	-0.065
McFadden's $R^2 = 0.271$								
Surge	0.00007	(a)	-0.516	-0.019	0.258	1.172*	-2.462**	0.735
s.e.	(0.00011)		(0.508)	(0.017)	(0.151)	(0.601)	(1.23)	(0.76)
dy/dx	0.00002		-0.116	-0.004	0.058**	0.26**	-0.55**	0.165
McFadden's $R^2 = 0.362$								
SMS	0.0009**	(a)	-2.72**	-0.016	0.03	-0.81	-1.1	2.45**
s.e.	(0.0003)		(0.94)	(0.019)	(0.168)	(0.9)	(1.31)	(1.06)
dy/dx	0.0002***		-0.5***	-0.003	0.005	-0.15	-0.204	0.45**
McFadden's $R^2 = 0.545$								
Micro	-0.00003	(a)	(b)	0.02	0.47	(b)	-4.42	(a)
s.e.	(0.0004)			(0.05)	(0.63)		(10.6)	
dy/dx				0.0003	0.009		-0.074	
McFadden's $R^2 = 0.464$								
Pivot	0.0001	(a)	-0.622	0.0005	0.24*	-0.028	1.28	-0.29
s.e.	(0.0001)		(0.471)	(0.015)	(0.13)	(0.48)	(1.08)	(0.58)
dy/dx	0.00003		-0.18	0.001	0.068**	-0.0087	0.363	-0.083
McFadden's $R^2 = 0.156$								
Timer	0.0003**	(a)	-0.84	0.003	-0.14	1.67**	-0.43	(b)
s.e.	(0.0001)		(0.52)	(0.016)	(0.13)	(0.54)	(1.23)	
dy/dx	0.00006**		-0.2*	0.001	-0.034	0.41***	-0.1	
McFadden's $R^2 = 0.355$								
Flow meter	0.0005**	0.181	-0.43	0.017	0.167	0.932	-0.56	0.33
s.e.	(0.0003)	(1.15)	(0.61)	(0.016)	(0.143)	(0.67)	(1.26)	(0.56)
dy/dx	0.0001**	0.037	-0.09	0.004	0.034	0.19	-0.12	0.068
McFadden's $R^2 = 0.34$								
Cover	0.0001	-0.76	0.43	-0.04**	0.068	-0.44	-0.015	0.78
s.e.	(0.0001)	(1.55)	(0.47)	(0.018)	(0.125)	(0.50)	(0.96)	(0.59)
dy/dx	0.00003	-0.21	0.12	-0.011**	0.02	-0.12	-0.004	0.22
McFadden's $R^2 = 0.21$								

Note: (a) negative cases predict failure ; (b) positive cases predict failure ; (c) positive cases predict success.

Table 7. Results from Probit Regressions (continued) on "cracking" soils and income levels .

	Cracking	50k to 100k	100k to 150k	150k to 200k	200k to 250k	250k to 300k	≥300k
TWS	0.18	-0.49	-0.5	-1.195	0.302	(dropped)	0.604
s.e.	(0.02)	(0.6)	(0.637)	(1.02)	(1.063)		(1.185)
dy/dx	0.005	-0.14	-0.144	-0.345	0.087		0.174
OFWS	-0.008	-1.021	-0.7	(dropped)	0.615	(dropped)	0.186
s.e.	(0.03)	(0.684)	(0.676)		(1.33)		(0.671)
dy/dx	-0.002	-0.248	-0.17		0.15		0.045
CHS	0.035	0.611	1.325*	0.59	0.273	0.613	1.33
s.e.	(0.02)	(0.625)	(0.694)	(0.878)	(1.05)	(1.25)	(1.24)
dy/dx	0.009	0.165	0.358**	0.159	0.074	0.166	0.359
Surge	0.028	-1.26*	-0.241	0.66	(dropped)	(dropped)	1.44
s.e.	(0.03)	(0.766)	(0.669)	(0.963)			(1.165)
dy/dx	0.006	-0.28*	-0.05	0.148			0.324
SMS	0.014	0.99	2.48**	-0.496	0.258	-0.019	-1.38
s.e.	(0.03)	(0.95)	(1.06)	(0.982)	(1.091)	(1.26)	(2.0)
dy/dx	0.003	0.183	0.458**	-0.092	0.048	-0.004	-0.255
Micro	-0.052	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
s.e.	(0.06)						
dy/dx	-0.001						
Pivot	0.021	-0.45	-0.49	-0.365	(d)	0.548	(a)
s.e.	(0.02)	(0.64)	(0.64)	(0.927)		(1.183)	
dy/dx	0.06	-0.13	-0.14	-0.1		0.156	
Timer	0.046	-0.486	-0.129	0.421	-0.028	(c)	(c)
s.e.	(0.029)	(0.711)	(0.78)	(0.9)	(1.03)		
dy/dx	0.01	-0.12	-0.03	0.1	-0.01		
Flow meter	0.03	-0.88	0.09	-1.15	(c)	(c)	(c)
s.e.	(0.03)	(0.78)	(0.87)	(1.07)			
dy/dx	0.005	-0.18	0.02	-0.24			
Cover	-0.003	0.15	0.55	0.36	1.97*	0.57	1.23
s.e.	(0.019)	(0.68)	(0.68)	(0.94)	(1.06)	(1.15)	(1.16)
dy/dx	-0.001	0.041	0.155	0.1	0.554**	0.16	0.34

Note: Base income is $50,000 or less.
(a) negative cases predict failure; (b) positive cases predict failure; (c) positive cases predict success.

With respect to *Micro* irrigation, the Probit regressions do not find statistically significant effects. This may be due in part to the relatively few respondents who have claimed to practice it. For *center pivot* irrigation, however, there is enough variability to show a statistically significant and positive effect of the number of years of farmer formal education. For every additional year of formal education completed, the farmer is 0.68 percent more likely to adopt center pivot irrigation. The data indicates that farmers who do not use groundwater for irrigation have not adopted *center pivot*.

The adoption of a pump *Timer* is positively and significantly associated with the number of irrigated hectares and the perception that a groundwater problem exists at the farm or state level. An additional 40 hectares or irrigated land is associated with 0.6 percent higher probability of adoption and the realization that a problem with groundwater stock exists in the state implies 41 percent higher probability of employing a pump *Timer*. All farmers in the sample with incomes above $250,000 use pump timers.

Flow meter adoption is also positively and significantly associated with the number of irrigated hectares. An additional 40 hectares or irrigated land is associated with 1 percent higher probability of adoption. All farmers in the sample with incomes above $200,000 use flow meters.

Growing *Cover* crops is negatively and significantly associated with farmer experience as represented by number of years farming and positively associated with the $200,000 to $250,000 income bracket. An additional year of farming experience is associated with 1.1 percent lower probability of growing cover crops. Since the agronomic benefits of cover crops payoff over a longer time-horizon, a farmer getting closer to retirement may be less eager to invest on a practice for which she will not see most of the benefits.

In terms of identifying factors that are associated with the adoption of conservation practices, the results indicate the following: *Irrigated area* (positive), *GW use* (positive), *Rice* (negative), *Years farming* (negative), *Education years* (positive), perception of *GW problem* (positive), *Pumping costs* (negative), *Conservation program* participation (positive), and *Income* (positive). These results confirm the stated hypotheses with respect to factor association except for the effect of *pumping cost* which was expected to have a positive association with adoption of conservation practices. It is not clear from the data what drives this result which is limited to the adoption of *surge* irrigation only and does not appear statistically significant for other practices.

4. Discussion

Promoting the adoption of water conservation practices in irrigated agriculture has been a principal initiative to slow-down the decline of the Mississippi River Valley Alluvial Aquifer (MRVAA). Ongoing agronomic research from scientists at Mississippi State University's Delta Research and Extension Center (DREC) and the USDA Agricultural Research Service in Stoneville, MS, continue to show the potential for these practices to reduce water use while maintaining farm yield and revenue levels. The Mississippi Department of Environmental Quality and the Yazoo Mississippi Delta Joint Water Management District require the use of a minimum number of these practices to issue groundwater well drilling and use permits in the area. Grower associations such as the Delta Farmers Advocating Resource Management (F.A.R.M.) sponsors and promotes the use of these practices among their members. Financial and technical assistance from USDA Natural Resource Conservation Service (NRCS) is geared towards minimizing farmer risk exposure associated with the implementation of these conservation practices. However, little is known about the farmer factors that drive their decision to adopt any given conservation practice. This article provides insights that help identify and understand the determinants of conservation practice adoption in the Delta region in Mississippi.

The regression analyses indicate that no single factor consistently predicts the adoption of every conservation practice, but many factors influence a farmer's decision to adopt a given practice. The size of the farming operation is an important factor in deciding the adoption of agricultural practices in general. Indeed, it is the factor with the most statistically significant coefficients (positive) in the regression analyses. From an economic perspective, this may be attributed to the fact that practices that are marginally beneficial on a per hectare basis may not be worth the managerial cost to small operations but could add-up to significant economies of scale for larger operations in which fixed and overhead costs associated with a practice can be spread over more hectares.

Results from the 2016 Mississippi Irrigation Survey indicate that groundwater is a source for irrigation for almost 93 percent of growers in the sample. Yet, only a third of the growers think there is a groundwater problem at the farm or state level. The analysis presented suggests that this lack of awareness is significantly related to whether the growers observe a change in the depth-to-water in their wells or not.

Perception of the existence of *GW problem* at the farm or state level is the second most important factor identified. This is an encouraging finding because the results show a strong influence of this variable on the probability of adoption of several adoption practices and because this is, essentially, an awareness issue. Perception of water quantity issues in regions of high rainfall can be difficult to
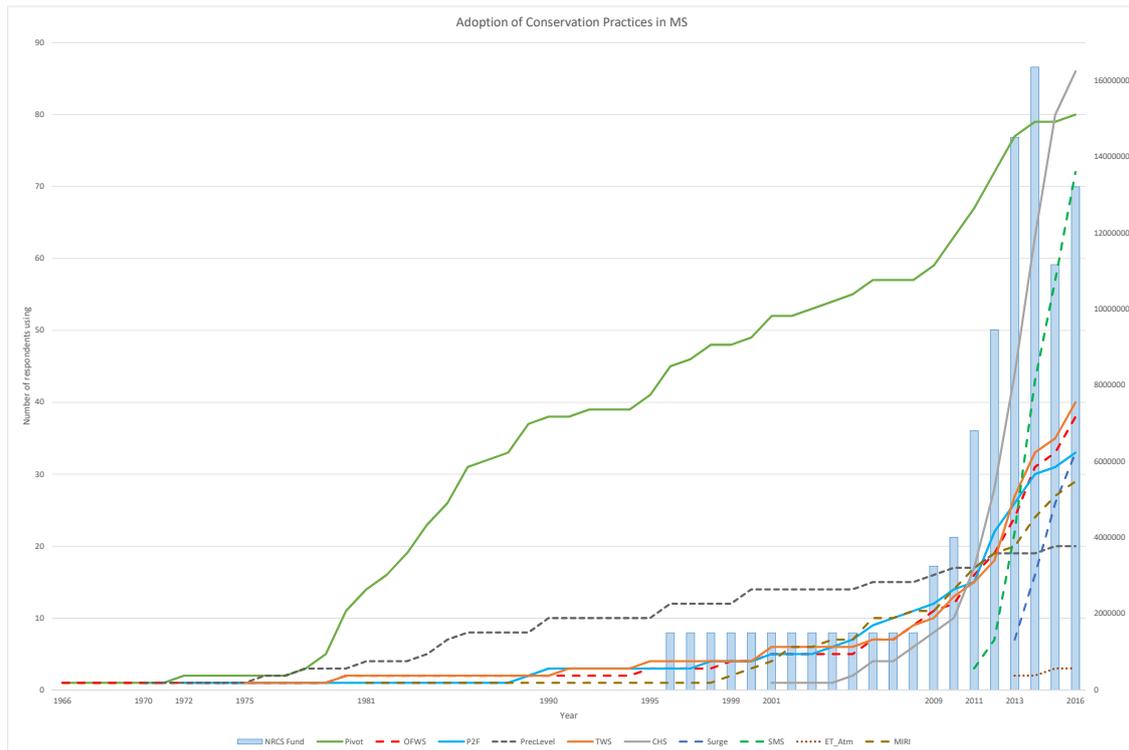
Figure 1. Timeline of adoption of conservation practices and USDA-NRCS EQIP expenditures in MS Delta area.

overcome. It suggests that additional incentives are necessary to bring those who do not perceive a problem to the realization that it actually exists.

Increasing producer awareness is a task that fits, for example, the mission of University Extension services which can aid the communications efforts of federal and state research and regulatory entities in that regard. Regulatory agencies and universities can work together to have a consistent message regarding the projection of groundwater in the state and to increase grower awareness of the issue with a focus on county-based expected changes in wells' depth-to-water distances. However, such efforts have been carried out by these organizations which suggests there is a need for an additional signal to help convince farmers of the seriousness of the situation.

At nearly 70 percent of respondents, this sample far surpasses the national average of 30 percent flow-meter use [29]. However, only 10 to 15 percent of permittees report individual water-use every year. There is promising evidence from areas with mandatory water use reporting that producers become better informed and more concerned with the health of the aquifer.

For example, growers near Sheridan county in Kansas widely supported a self-imposed Local Enhancement Management Area to create a 5-year allocation of groundwater that resulted in a 26 percent reduction in water use [30]. A similar case where the threat of regulation from the state level, induced irrigators to form the Groundwater Subdistrict no.1 in the San Luis Valley of Colorado and "formulate a homegrown governance response" that reduced water use by 33 percent in the district [31].

The survey results in our study indicate that farmers may require stronger signals that the aquifer problem is real and important. Furthermore, the experience documented in the aforementioned studies suggest that aquifer problem awareness, resulting largely from individual water use monitoring, and the threat of top-down regulation, can induce more active farmer participation in water conservation.

Although participation in conservation programs is a statistically significant factor for only one of the practices (SMS), Figure 1 shows how NRCS expenditures [32] and practice adoption in the region track similar time trends. In particular, the rate of adoption of *CHS, SMS*, and *SURGE* starting in 2009

Table 8. Impact of conservation practice adoption factors compared to existing literature.

Factor	Results	Nian et al. Morris (2020)	Prokopy et al. (2019)	Pearsons and (2019)
Irrigated area	Pos	Pos	Pos	Pos
GW use	Pos	Pos	Pos	
Rice farming	Neg		Mix	
Years farming	Neg	Neg	Neg	Neg
Education	Pos		Mix	Pos
Perceives GW problem	Pos	Pos	Pos	Pos
Pumping cost	Neg		Pos	Neg
Participation in conservation programs	Pos	Pos	Pos	Pos
Cracking soils	Mix			Neg
Farmer income	Mix	Pos	Pos	Pos

Note: *Pos* denotes a positive influence of the factor on adoption; *Neg* denotes a negative influence of the factor on adoption; *Mix* denotes mixed or undetermined influence of the factor on adoption.

are noteworthy. This suggests there is an effect to NRCS technical and financial assistance in terms of adoption. However, perhaps due to insufficient data, this association can not be validated empirically in this study.

These results can inform policy makers, regulatory entities, university extension services and producers about the salient aspects of conservation practice adoption in Mississippi. Conservation agencies can use the insights in this study to better target their incentive programs, for instance focusing on incentivizing relatively young farmers to adopt practices with long-term benefits such as cover crops. Similarly, further research, extension and incentives are necessary to devise incentives and training to facilitate practice adoption by smaller farms. Lastly, periodic surveys (2-5 year intervals) may be necessary to track trends and assess the effectiveness of conservation practice adoption programs.

Our results are largely consistent with the most recent literature [3,5,20]—see Table 8 for a comparison. The GAO report in particular, describes policy options at the federal level including their benefits and challenges. With respect to irrigation technology, it recommends that policy makers promote: (1) the use of more efficient irrigation technology and practices, in conjunction with appropriate agreements to use the technology and practices to conserve water; and (2) the use of precision agriculture technologies, in conjunction with appropriate agreements to use the precision agriculture technologies to conserve water. These recommendations are consistent with the ongoing efforts mentioned above and this study lends empirical validity to the recommendations for the case of Mississippi.

The main limitation of this study is the small sample relative to the number of practices and factors being considered. This limitation determined the choice of Probit regression models rather than multivariate and sequential modeling. There is evidence that practices, especially add-ons to furrow irrigation, are adopted in bundles. This feature is not incorporated in this study and constitutes a promising avenue for future research.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AAWEP	Acceptable Agricultural Water Efficiency Practices
AWEP	Agricultural Water Enhancement Program
ARS	USDA Agricultural Research Service
CHS	Computerized hole selection
CRP	Conservation Reserve Program
DREC	Mississippi State University Delta Research and Extension Center
EIA	U.S. Energy Information Administration
EQIP	NRCS Environmental Quality Incentives Program
F.A.R.M.	Delta Farmers Advocating Resource Management
FSA	Farm Service Agency
GAO	Government Accountability Office
GW	Groundwater
MRVAA	Mississippi River Valley Alluvial Aquifer
NRCS	USDA Natural Resources Conservation Service
OFWS	On-farm water storage
RCPP	Regional Conservation Partnership Program
SMS	Soil moisture sensors
TWS	Tailwater recovery system
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
WRP	Wetlands Reserve Progra

Appendix A Conservation programs in Mississippi

The Delta region in Mississippi has a diversity of habitats in which urban, agricultural and wildlife habitat landscapes coexist. Growers and landowners in the area actively seek guidance in attaining land and water resource stewardship. Hunting and fishing clubs are among the most priced memberships in the areas. Agricultural land and water projects often include wildlife habitat enhancing features that further increase the value of such clubs. The National Wildlife Federation work in the area focuses on protecting and restoring healthy rivers and estuaries; conserving wetlands, springs, and aquifers; and protecting wildlife habitats. These goals overlap with producer interests and are prominent features in existing conservation programs in the area. Table A1 contains a list and brief description of the conservation programs survey respondents claimed to participate in.

References

1. Kebede, H.; Fisher, D.K.; Sui, R.; Reddy, K.N.; others. Irrigation methods and scheduling in the Delta region of Mississippi: Current status and strategies to improve irrigation efficiency. *American Journal of Plant Sciences* **2014**, *5*, 2917.
2. Barlow, J.R.; Clark, B.R. *Simulation of water-use conservation scenarios for the Mississippi Delta using an existing regional groundwater flow model*; US Department of the Interior, US Geological Survey, 2011.
3. Nian, Y.; Huang, Q.; Kovacs, K.F.; Henry, C.; Krutz, J. Water Management Practices: Use Patterns, Related Factors and Correlations with Irrigated Acres. *Water Resources Research* **2020**, *56*.
4. Balogh, P.; Bujdos, Á.; Czibere, I.; Fodor, L.; Gabnai, Z.; Kovách, I.; Nagy, J.; Bai, A. Main Motivational Factors of Farmers Adopting Precision Farming in Hungary. *Agronomy* **2020**, *10*, 610.
5. Persons, T.M.; Morris, S.D. Irrigated Agriculture: Technologies, Practices, and Implications for Water Scarcity. *Report to Congressional Requesters, Technology Assessment. GAO-20-128SP: Published: Nov 12, 2019. Publicly Released: Nov 12, 2019.* **2019**.

Table A1. List and brief description of the conservation programs survey respondents claimed to participate in.

Program	Sponsor	Description
AWEP	NRCS	Agricultural Water Enhancement Program is a conservation initiative that provides financial and technical assistance to agricultural producers to implement agricultural water enhancement activities on agricultural land for the purposes of conserving surface & groundwater and improving water quality.
CRP	FSA	Conservation Reserve Program is a land conservation program to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality.
CSP	NRCS	Conservation Stewardship Program participants earn performance-based CSP payments: higher payment to higher performance.
Delta FARM	Public-private partnership	Farmers Advocating Resource Management is an association of growers and landowners that strive to implement recognized agricultural practices which will conserve, restore, and enhance the environment.
EQIP	NRCS	Environmental Quality Incentives Program provides incentive payments and cost-sharing for conservation practice adoption.
RCPP	NRCS	Regional Conservation Partnership Program promotes coordination of NRCS conservation activities with partners that offer value-added contributions to expand their collective ability to address on-farm, watershed, and regional natural resource concerns.
Rice stewardship	Public-private partnerships	USA Rice-Ducks Unlimited Rice Stewardship Partnership provides financial assistance for conserving water and wildlife in ricelands.
Soil erosion	Unspecified	Unspecified
Unspecified	USACE	The U.S. Army Corps of Engineers may enroll farmers adjacent to their projects as part of environmental or habitat enhancement features.
WRP	NRCS	Wetlands Reserve Program offers landowners the opportunity to protect, restore, and enhance wetlands on their property.

6.   Bryant, C.; Krutz, L.; Falconer, L.; Irby, J.; Henry, C.; Pringle, H.; Henry, M.; Roach, D.; Pickelmann, D.; Atwill, R.; others. Irrigation water management practices that reduce water requirements for Mid-South furrow-irrigated soybean. *Crop, Forage & Turfgrass Management* **2017**, *3*.

7.   Henry, W.B.; Krutz, L.J. Water in agriculture: Improving corn production practices to minimize climate risk and optimize profitability. *Current Climate Change Reports* **2016**, *2*, 49–54.

8.   Wood, C.; Krutz, L.; Falconer, L.; Pringle, H.; Henry, B.; Irby, T.; Orlowski, J.; Bryant, C.; Boykin, D.; Atwill, R.; others. Surge irrigation reduces irrigation requirements for soybean on smectitic clay-textured soils. *Crop, Forage & Turfgrass Management* **2017**, *3*.

9.   Spencer, G.; Krutz, L.; Falconer, L.; Henry, W.; Henry, C.; Larson, E.; Pringle, H.; Bryant, C.; Atwill, R. Irrigation Water Management Technologies for Furrow-Irrigated Corn that Decrease Water Use and Improve Yield and On-Farm Profitability. *Crop, Forage & Turfgrass Management* **2019**, *5*.

10. Carey, J.M.; Zilberman, D. A model of investment under uncertainty: modern irrigation technology and emerging markets in water. *American Journal of Agricultural Economics* **2002**, *84*, 171–183.

11. Krutz, L. Utilizing Moisture Sensors to Increase Irrigation Efficiency. *Mississippi State University Extension Service* **2016**.

12. Krutz, L. Pipe planner: The foundation water management practice for furrow irrigated systems. *Mississippi State University Extension Service* **2016**.

13. Roach, D. On-Farm Water Storage Systems and Surface Water for Irrigation. *Mississippi State University Extension Service* **2018**.

14. Krutz, L. Surge Valves Increase Application Efficiency. *Mississippi State University Extension Service* **2016**.

15. Tagert, M.L.; Paz, J.; Reginelli, D. On-Farm Water Storage Systems and Surface Water for Irrigation. *Mississippi State University Extension Service* **2018**.

16. Zotarelli, L.; Fraisse, C.; Dourte, D. Agricultural Management Options for Climate Variability and Change: Microirrigation. *EDIS, UF/IFAS (HS1203)* **2015**.

17. Coblentz, B.A. Pivot irrigation, not furrows, is most economical for Delta. *Mississippi State University Extension Service* **2014**.

18. Burdine, B. Cover Crops: Benefits and Limitations. *Mississippi State University Extension Service* **2019**.

19. Coblentz, B.A. Cover crops present challenges, advantages. *Mississippi State University Extension Service* **2018**.

20. Prokopy, L.S.; Floress, K.; Arbuckle, J.G.; Church, S.P.; Eanes, F.; Gao, Y.; Gramig, B.M.; Ranjan, P.; Singh, A.S. Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. *Journal of Soil and Water Conservation* **2019**, *74*, 520–534.

21. Edwards, J.F. Crop Irrigation Survey. Final Report. *Mississippi State University, Social Science Research Center, Survey Research Laboratory* **2016**.

22. Rogers, D.H.; Alam, M. *Comparing irrigation energy costs*; Agricultural Experiment Station and Cooperative Extension Service, Kansas . . . , 2006.

23. McGuire, V.L.; Seanor, R.C.; Asquith, W.H.; Kress, W.H.; Strauch, K.R. Potentiometric surface of the Mississippi River Valley Alluvial Aquifer, Spring 2016. Technical report, US Geological Survey, 2019.

24. USDA-NRCS. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. *Soil Survey Geographic (SSURGO) Database for Sunflower County Mississippi.* **2010**.

25. Maddala, G.S. *Limited-dependent and qualitative variables in econometrics*; 3, Cambridge university press, 1986.

26. Pfeiffer, L.; Lin, C.Y.C. Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. *Journal of Environmental Economics and Management* **2014**, *67*, 189–208.

27. Fenichel, E.P.; Abbott, J.K.; Bayham, J.; Boone, W.; Haacker, E.M.; Pfeiffer, L. Measuring the value of groundwater and other forms of natural capital. *Proceedings of the National Academy of Sciences* **2016**, *113*, 2382–2387.

28. Hassanli, A.M.; Ebrahimizadeh, M.A.; Beecham, S. The effects of irrigation methods with effluent and irrigation scheduling on water use efficiency and corn yields in an arid region. *Agricultural Water Management* **2009**, *96*, 93–99.

29. USDA. Irrigation: Results from the 2013 Farm and Ranch Irrigation Survey. *Census of Agriculture Highlights ACH12-16.* **2014**.

30. Drysdale, K.M.; Hendricks, N.P. Adaptation to an irrigation water restriction imposed through local governance. *Journal of Environmental Economics and Management* **2018**, *91*, 150–165.

31. Smith, S.M.; Andersson, K.; Cody, K.C.; Cox, M.; Ficklin, D. Responding to a groundwater crisis: The effects of self-imposed economic incentives. *Journal of the Association of Environmental and Resource Economists* **2017**, *4*, 985–1023.

32. USDA-NRCS. The PROTRACTS Database, Mississippi **2019**.