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# Irrigation Water Management Tools and Alternative Irrigation Sources Trends and Perceptions by Farmers from the Delta Regions of the Lower Mississippi River Basin in South Central USA

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**Abstract:** This article describes the opinions and perceptions of farmers on water management tools that conserve groundwater and on alternative sources of water for irrigation. The analysis is based on a survey of producers ($N = 466$) across the Lower Mississippi River Basin (LMRB) areas of Arkansas, Louisiana, Mississippi, and Missouri. Summary statistics of practice usage across the region and for each state are presented. A Poisson count model is applied to the data to identify factors that influence the number of groundwater-conserving practices employed. The number of irrigated acres, years of farming, annual income level, perception of groundwater problems, and participation in conservation programs have statistically significant association with the number of practices employed. Years of farming experience is the only factor negatively associated with the number of practices employed, while participation in conservation programs has the largest magnitude effect on that number. These results provide evidence that sponsored conservation programs increase the number of conservation practices adopted by farmers. This insight is useful for producer collectives, policy makers, and program managers to design and target of conservation programs across the LMRB.

**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) underlies and sustains highly productive agricultural areas in the Lower Mississippi River Basin (LMRB) that include portions of Arkansas, Louisiana, Mississippi, and Missouri [1] (see Figure 1). Groundwater withdrawals that exceed the natural rate of aquifer recharge continue to reduce the stock of groundwater available in the MRVAA [2–5]. Groundwater conservation is a complex problem that requires careful irrigation and drainage management because, despite abundant annual rainfall, only a small fraction of total precipitation occurs in the growing season; when it does, it tends to be intense and rapid, which reduces precipitation effectiveness [2,6]. Curtailments of irrigation water resulting from groundwater shortages or regulation could have severe impacts on regional agricultural production and the economies and societies it supports [7,8].

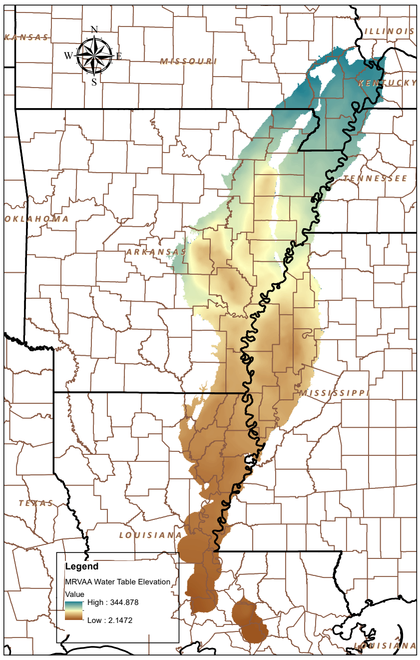



**Figure 1.** Potentiometric map of the Mississippi River Valley Alluvial Aquifer based on U.S. Geological Survey data from 2016.

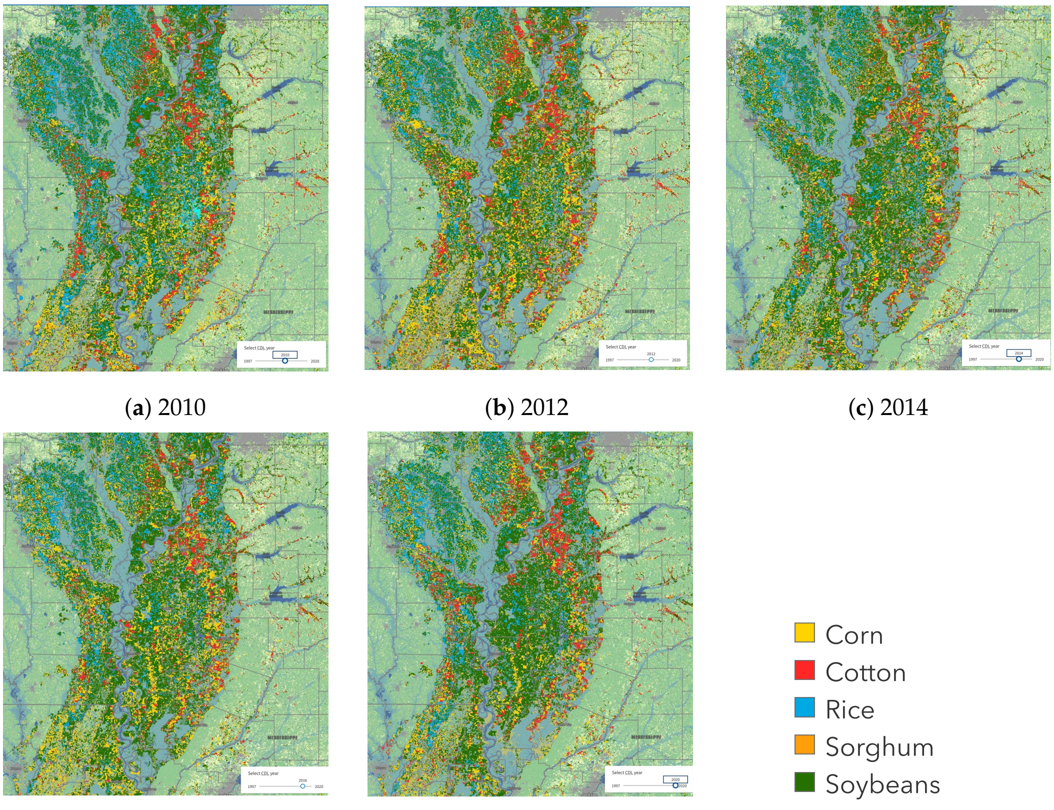
Consequently, an all-encompassing approach to water management is required to slow and reverse aquifer depletion. On the water supply side, artificial aquifer recharge projects [9,10] and the use of alternative surface and recycled water sources [11,12] are considered key components to the solution. On the water demand side, agricultural practices that increase water-use efficiency and reduce overall water use without significant reductions in yields or farmer profits have been proposed to slow the rates of depletion [13–16]. Conservation practices and alternative sources of irrigation water ameliorate aquifer conditions only if they are adopted by a sufficiently large number of producers.

This study aims to improve understanding of the factors driving producers in the LMRB to adopt a number of select conservation practices and employ sources alternative to groundwater for crop irrigation. The conservation practices considered in this study were selected based on their potential to reduce water use without injuring crop yield or farmer profitability, as demonstrated by published agronomic studies. Profitability is a necessary but not sufficient condition for adoption by producers in this region [8]. In a previous study, Quintana-Ashwell et al. [8] used data from an identical survey of Mississippi producers to examine factors associated with the adoption of individual conservation practices, finding that factors other than profitability significantly influence individual adoption. Notably, Quintana-Ashwell et al. [8] constructs adoption curves for individual practices which seem to correspond with increasing U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) conservation expenditures, but does not appear to significantly affect individual practice adoption in a statistical sense. Consequently, the focus in this article is on identifying the social, economic, and environmental factors that influence the number of practices adopted by producers across a broader and more diverse region across the LMRB. Furthermore, the summary statistics reported from the data are statistically tested to show which farmer characteristics present relative homogeneity or heterogeneity across the region.

Data on practice adoption and farmer characteristics from irrigators across the LMRB, including Arkansas, Louisiana, Mississippi, and Missouri are employed and summarized from a comprehensive survey carried out in 2016 with 466 valid responses. A Poisson count model identifies factors that are associated with determining the number of conservation practices employed by growers.

### *1.1. Crop Production Landscape in the LMRB*

Soybean production is predominant in the LMRB, followed by rice and corn above the 34th parallel (corn and rice below it) with significant acreage devoted to cotton production [1]. Nearly 5 million acres of soybean, 2 million acres of corn, about the same for rice, and a million acres of cotton were planted in the LMRB in 2016 [2]. The predominance of these four crops on the landscape seems well established since 2016 (see Figure 2). The need for irrigation is evidenced by the high evapotranspiration (ET) rates in the region, with the states that form it ranking fifth in US for annual ET rates [1]. These crops and the conditions they are grown under in the LMRB favor irrigation systems capable of delivering large volumes of water rapidly, which partly explains why continuous flow furrow irrigation on row-crops is the predominant irrigation method in this region [14]. This system, which employs pipes with holes aligned to deliver the flow of water on the furrows, is well suited to relatively flat fields [8]. Consequently, to identify practices that hold potential to conserve groundwater in the region, we assume that the baseline case is a relatively inefficient gravity irrigation system. The conservation practices considered in this article can be irrigation systems that replace the gravity systems or modifications that improve its efficiencies. Alternative sources of irrigation water are those related to the capture, storage, and reuse of pluvial and irrigation runoffs.




(**a**) 2010 (**b**) 2012 (**c**) 2014

(**d**) 2016 (**e**) 2020 (**f**) Legend

**Figure 2.** Evolution of cropping landscape in Mississippi Delta.

Agronomic research has shown that modifications to the existing irrigation and agronomic practices in the Mid-South USA region can result in significant water savings at the field level while achieving similar yields at harvest [13–16]. Most of the practices evaluated in those studies are included in this article. It has been established that producers require additional incentives to adopt these practices [17] or the assurance of witnessing several years of neighboring farmers employing them [8,18]. While Bailey et al. [18] focused on farmer peer network effects, and Quintana-Ashwell et al. [8] identified factors influencing the decision to adopt individual practices (in Mississippi), this article focuses on identifying factors influencing the number of conservation practices being adopted across the LMRB.

### 1.2. Irrigation Management Practices or Tools That May Conserve Groundwater

This article considers practices that show the potential to profitably conserve groundwater in irrigation. As irrigators may decide on adopting several practices simultaneously, this article focuses on the number of practices adopted. A brief description of the selected practices and how they may conserve groundwater follow.

Computerized Hole Selection (CHS) refers to software used to calculate the size of the holes on lay-flat poly-tubing based on field characteristics that include shape and slope to allow uniform water flow on the furrows across the field and to minimize water runoff [13]. Agronomic research has found that CHS can save 20 to 25 percent of water applied [19].

Micro-irrigation (Micro) is a high frequency and low pressure and volume system that can reduce overall irrigation water application by virtually eliminating runoff and non-beneficial evaporation by applying water directly in the root zone [20]. Another irrigation system that may conserve water in a similar way is pivot irrigation, which delivers water via sprinklers that simulate precipitation and are highly adjustable.

Irrigation pumping plant installed flowmeters are used to estimate the duration of pumping runs during the season and to keep track of the actual amounts of water applied for irrigation. Flowmeters are also needed to calculate the well pumping flows that are required to obtain the optimal size of the holes with CHS [21].

Pump timers (timer) automatically shut-off irrigation pumps after a prescribed time. They can help conserve groundwater by limiting excessive pumpage, particularly at night [3].

Soil Moisture Sensors (SMS) are used to avoid premature irrigation events. Avoiding irrigation events before they are necessary increases the chances of capturing additional rain, which can lower the amount of irrigation water applied over the growing season. Furthermore, it allows for informed irrigation termination decisions [13] that typically result in increased irrigation efficiency [14,22].

Surge irrigation (surge) consists of dividing an irrigating field 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 [13]. This creates wetting and soaking cycles that reduce water runoff and deep percolation losses. Surge irrigation has been documented to improve water application efficiency by up to 25 percent [23].

Agronomic management practices such as soil amendments, cover crops, or skipped-row irrigation are often considered tools for water conservation. Although cover crops are planted by about 30 percent of farmers in this region, we focus on irrigation management practices for which there is published evidence that they reduce irrigation water used in the LMRB, as those cited above. Pinnamaneni et al. [24] showed that skip-row irrigation can reduce water use in soybean production, and Quintana-Ashwell et al. [25] showed it can even be profitable, but the survey this work is based on did not collect data on skip-row irrigation.

### 1.3. Alternative Sources of Water for Irrigation

The use of water from sources alternative to groundwater helps conserve groundwater via substitution.

On-farm water storage systems (OFWS) are irrigation water-storage structures typically designed to supply 77 mm of water per hectare per season and meet irrigation requirements for 8 out of 10 years [12]. The U.S. Department of Agriculture (USDA) provides, through the Natural Resources Conservation Service (NRCS), technical and financial assistance to producers interested in building OFWS. These reservoirs require the use of tailwater recovery systems (TWS) because capture of precipitation on the surface area of OFWS alone is insufficient to provide reliable supplies for irrigation.

Tailwater Recovery Systems (TWS) collect irrigation and storm water runoff on the farm. The system typically includes a small storage capacity, but it can be combined with a larger reservoir (OFWS). TWS can reduce groundwater pumping by 25 percent [8].

For the purpose of the Poisson regression analysis, we consider the use of alternative water sources as an additional practice so that, for example, a producer who uses surge irrigation to deliver water from an OFWS is considered to have adopted two practices.

## 2. Materials and Methods

The climate of the LMRB is characterized as humid and sub-tropical, with highly variable convective rainfall occurring in the summer [26,27]. For example, daily rainfall amounts during the rice irrigation season at nine LMRB locations were not statistically different ($p > 0.05$) for the years 1985 to 2015 [28], although the north–south distance between rainfall stations exceeded 600 km. The soils of the region are also highly variable owing to being mostly of alluvial origin; they are dominated by Alfisols, Vertisols, Inceptisols, and Entisols [29]. The quality of water derived from the alluvial aquifer often has high concentrations of divalent cations [30] with some localized areas having high levels of sodium [31,32] that can negatively impact crop production. A primary contaminant of LMRB rivers is sediment [33].

This article reports data from a regional Crop Irrigation Survey that collected 466 valid responses on a variety of farmer practices, perceptions, attitudes, and socio-economic statuses. The empirical analysis applies a Poisson count model to the collected data in order to identify factors that influence the number of conservation practices adopted by producers.

The dependent variable in the analysis is the number of water-conserving practices employed by farmers as described in Sections 1.2 and 1.3. The selected explanatory variables are total *irrigated area* in the operation, crop choice (*rice*), number of *years farming*, years of formal *education*, whether the farmer perceives a groundwater *(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 explanatory variables have been shown to influence conservation practice adoption [7,8,34,35].

Next, we present the Poisson count model, succinctly followed by a more detailed presentation of the data employed in the analysis which further helps understand the similarities and heterogeneity among producers in the LMRB.

### 2.1. Empirical Count Model

The Poisson model is the most popular regression model for count data [36]. In this setting, the assumption is that the number of groundwater-conserving practices follows the Poisson distribution; in which the mean and variance are the same (equi-dispersion). When the data are not equi-dispersed (under or overdispersed) or when there are factors that artificially inflate the number of observations with a zero count, alternative formulations exist, such as the Negative Binomial model [37]. Regression results from the standard Poisson and Negative Binomial models are virtually identical, so we base the presentation of the framework and results on the standard Poisson.

In the Poisson regression, the logarithm of the expected value is estimated as a linear combination of the explanatory variables ($\lambda = E(Y;X) = e^{\beta' X}$). The probability mass function is:

$$p(y_i|x_i;\beta) = \frac{e^{y_i\beta' x_i} e^{-e^{\beta' x_i}}}{y_i!}; \quad (1)$$

and the coefficients of the linear predictor ($\beta$) can be estimated via maximum (log) likelihood:

$$\ell(\beta|y,x) = \sum_{i=1}^{N} \Big( y_i\beta' x_i - e^{\beta' x_i} - log(y_i!) \Big). \quad (2)$$

To predict the effect a change in the value of a variable would have on the number of adopted practices, the average marginal effects are calculated by obtaining each observation's marginal effect with each variable $k$:

$$\frac{\partial E[y_i|x_i]}{\partial x_{ik}} = \lambda_i \beta_k. \tag{3}$$

The standard errors are computed using the Delta method to test the statistical significance of the marginal effects.

Next, the data are presented with summary statistics of the most salient variables in the survey of irrigators.

*2.2. Data*

The data are from a survey of irrigators across the LMRB conducted by the Survey Research Laboratory at the Social Science Research Center at Mississippi State University at the end of the 2016 season [38]. Contact information for 8572 farmers in the LMRB was acquired from the Dun & Bradstreet Corporation: 3712 in Arkansas, 2138 in Louisiana, 2216 in Mississippi, and 506 in Missouri. A telephone-based survey resulted in 466 completed interviews (see Table 1 for breakdown by state with Pearson's chi-squared tests of independence across states). The survey collected data on farmers' characteristics, cultural practices, irrigation management practices, and perceptions and attitudes regarding groundwater availability. Table 1 summarizes the information gathered on growers' land tenure, education, and income.

**Table 1.** Summary statistic of farmer characteristics from an irrigation survey conducted in the Lower Mississippi River Basin (LMRB) in 2016.

| | Mississippi | | Arkansas | | Louisiana | | Missouri | | LMRB | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Farmer Characteristics** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| Responses | 148 | 31.8% | 199 | 42.7% | 93 | 20.0% | 26 | 5.6% | 466 | |
| Operator only | 31 | 20.9% | 37 | 18.6% | 21 | 22.6% | 4 | 15.4% | 93 | 20.0% |
| Owner and operator | 117 | 79.1% | 162 | 81.4% | 72 | 77.4% | 22 | 84.6% | 373 | 80.0% |
| **Education:** | | | | | | | | | | |
| Less than High School | 5 | 3.4% | 6 | 3.0% | 2 | 2.2% | 0 | 0.0% | 12 | 2.6% |
| Completed High School | 23 | 15.5% | 47 | 23.6% | 23 | 24.7% | 6 | 23.1% | 99 | 21.2% |
| Some college | 22 | 14.9% | 32 | 16.1% | 14 | 15.1% | 4 | 15.4% | 72 | 15.5% |
| Completed Associate's | 18 | 12.2% | 12 | 6.0% | 5 | 5.4% | 2 | 7.7% | 37 | 7.9% |
| Completed Bachelor's | 66 | 44.6% | 84 | 42.2% | 40 | 43.0% | 10 | 38.5% | 200 | 42.9% |
| Completed Master's | 11 | 7.4% | 10 | 5.0% | 7 | 7.5% | 2 | 7.7% | 30 | 6.4% |
| Beyond Master's | 2 | 1.4% | 8 | 4.0% | 2 | 2.2% | 2 | 7.7% | 14 | 3.0% |
| Agriculture-related ** | 63 | 42.6% | 109 | 54.8% | 44 | 47.3% | 18 | 69.2% | 234 | 50.2% |
| **Annual income:** | | | | | | | | | | |
| Less than USD50,000 | 13 | 8.8% | 25 | 12.6% | 5 | 5.4% | 3 | 11.6% | 46 | 9.9% |
| USD50,000 to USD100,000 | 41 | 27.7% | 55 | 27.6% | 16 | 17.2% | 2 | 7.7% | 114 | 24.5% |
| USD100,000 to USD150,000 | 17 | 11.5% | 28 | 14.1% | 10 | 10.8% | 3 | 11.5% | 58 | 12.5% |
| USD150,000 to USD200,000 | 9 | 6.1% | 18 | 9.1% | 6 | 6.5% | 1 | 3.9% | 34 | 7.3% |
| USD200,000 to USD250,000 | 6 | 4.1% | 7 | 3.5% | 5 | 5.4% | 1 | 3.9% | 19 | 4.1% |
| USD250,000 to USD300,000 | 5 | 3.4% | 4 | 2.0% | 2 | 2.2% | 0 | 0.0% | 11 | 2.4% |
| More than USD300,000 | 10 | 6.8% | 17 | 8.5% | 13 | 14.0% | 2 | 7.7% | 42 | 9.0% |
| Unsure or no-response | 47 | 31.8% | 45 | 22.6% | 36 | 38.7% | 14 | 53.9% | 142 | 30.5% |

Note: ** $\chi^2_3 = 8.4304$, Pr = 0.038: Mississippi respondents show lower-than-expected agricultural-related education.

Most respondents across the states own the land they operate (owners and operators) while about a fifth (15 to 23 percent across states) farm on land owned by someone else (operators only)—no valid response was recorded by an owner who does not also farm. The number of *years of education* is calculated based on a question that was originally categorical as follows: 10 years for less than completed highschool, 12 for completed highschool, 13 for some college or vocational program, 14 for completed associate degree, 16 for completed bachelor's, 18 for completed master's, and 20 for more than Master's. The median farmer across the region and each state has completed a bachelor's degree. Furthermore, the formal education for the median farmer in Arkansas and Missouri was agricultural-related in Arkansas and Missouri (54.8 and 69.2 percent of respondents), while the percentage of farmers in Mississippi with formal agricultural education is lower than expected from the overall statistics (42.6 percent of respondents).

Almost 70 percent of respondents reported their annual household income category (Missouri is significantly under-reported with less than 50 percent) with the median farmer income at between 100,000 and 150,000 U.S. dollars. Among respondents within each state, only Mississippi's median farmer income is different, at between 75,000 and 100,000 U.S. dollars per year (the survey included 8 income categories below 100,000 U.S. dollars per year). Arkansas respondents had the highest level of responses identifying an income category, with over three-fourths providing an income level.

Income level is expected to be positively correlated with the adoption of individual conservation practices [7,34]. Persons and Morris [34] also find that the level of farmer education positively influences the adoption of irrigation-related precision-agriculture practices. For Mississippi growers, Quintana-Ashwell et al. [8] found that level of education did have a significantly positive influence in the adoption of some conservation practices, with weaker results with respect to income levels.

Farming experience is often negatively associated with adoption of new practices. As farmers must continually adapt to changing environmental and market conditions, it is intuitive that farmers fine-tune their operations rather than become inflexible over time. However, to outright replace a "proven" practice on their farm, they would typically require substantial incentives of which economics is an important, but not sole, consideration. When looking at the overall number of practices adopted, this variable can be expected to positively affect the number of practices, as they can be adopted over an extended period. Data on years of farming experience and number of practices are summarized by state in Table 2.

**Table 2.** Farmer experience across the Lower Mississippi River Basin (LMRB).

| | N | Min | Max | Mean | Std. Deviation |
|---|---|---|---|---|---|
| **Years farming** | | | | | |
| Arkansas | 199 | 1 | 73 | 32.61 | 15.50 |
| Louisiana | 93 | 4 | 70 | 32.39 | 14.23 |
| Mississippi | 148 | 3 | 80 | 28.03 | 14.76 |
| Missouri | 26 | 5 | 60 | 35.62 | 13.83 |
| LMRB | 466 | 1 | 80 | 31.28 | 15.07 |
| **Number of practices** | | | | | |
| Arkansas | 199 | 0 | 12 | 4.39 | 2.28 |
| Louisiana | 93 | 0 | 8 | 2.62 | 1.52 |
| Mississippi | 148 | 0 | 11 | 5.05 | 2.55 |
| Missouri | 26 | 1 | 7 | 3.54 | 1.58 |
| LMRB | 466 | 0 | 12 | 4.20 | 2.37 |

Respondents represent a wide range of farming experience, from as little as a year to as many as 80 years of farming experience with a mean level of experience around 30 years, which is also the overall median and modal years of experience. Almost 90 percent of farmers had at least 10 years of farming experience across the surveyed region. Nearly three-fourths (73.1 percent) of the sample are farmers with more than 20 years of experience. Farmers are more similar across the states in terms of years of experience than in other variables of interest, which is consistent with what is known about the aging farming population in the United States.

In terms of the number of practices that farmers employ which can be seen as conserving groundwater, the responses range from none to twelve. The average across the region is 4.2 practices with a median and mode of 4 and 3, respectively. Arkansas respondents claimed an average of 4.39 practices, with a median of 4 and mode of 3. For Louisiana, the mean was 2.62 with median of 3 and mode of 2 water-conserving practices. Mississippi showed the highest level of conservation practice use with a mean of 5.05, median of 5, and a bi-modal 4 and 5 water-conserving practices. Similar to Louisiana, Missouri shows relatively low number of practices with an average of 3.54 practices, median of 3, and bi-modal of 2 and 3 water-conserving practices.

It has been well established that crop choice is intertwined with the choice of irrigation technology [39,40]. Table 3 summarizes the extension and popularity of the main crops in the LMRB as represented by survey respondents. The largest number of growers report producing irrigated soybean (N=403) which occupy the largest cultivated area among the irrigated crops reported: 901 acres on average and as much as 15,000 acres (Louisiana). All the respondents from Missouri claim to grow soybean, followed by 95.5 percent in Arkansas, 87.8 percent in Mississippi, and 60.2 percent in Louisiana.

**Table 3.** Summary statistics of irrigated crop choices and acreage.

| | **N** | **%** | **Min** | **Max** | **Mean** | **Std. Deviation** |
|---|---|---|---|---|---|---|
| | | | | **(in Acres)** | | |
| **Irrigated crops** | | | | | | |
| Arkansas | 198 | 99.5 | 35 | 20,050 | 2491.58 | 2501.80 |
| Louisiana | 88 | 94.6 | 5 | 20,000 | 1582.00 | 2346.13 |
| Mississippi | 143 | 96.6 | 5 | 15,000 | 2291.04 | 2501.40 |
| Missouri | 24 | 92.3 | 237 | 15,000 | 2664.46 | 3041.63 |
| LMRB | 453 | 97.2 | 5 | 20,050 | 2260.74 | 2519.09 |
| Corn | | | | | | |
| Arkansas | 114 | 57.3 | 30 | 2000 | 422.31 | 481.25 |
| Louisiana | 50 | 53.8 | 5 | 3400 | 680.60 | 812.39 |
| Mississippi | 106 | 71.6 | 5 | 4500 | 575.14 | 796.06 |
| Missouri | 24 | 92.3 | 130 | 3000 | 749.25 | 705.37 |
| LMRB | 294 | 63.1 | 5 | 4500 | 548.03 | 691.79 |
| Cotton | | | | | | |
| Arkansas | 34 | 17.1 | 50 | 3000 | 654.41 | 785.30 |
| Louisiana | 14 | 15.1 | 50 | 2000 | 684.93 | 722.10 |
| Mississippi | 49 | 33.1 | 45 | 7000 | 741.84 | 1207.67 |
| Missouri | 9 | 34.6 | 450 | 6000 | 1461.11 | 2007.45 |
| LMRB | 106 | 22.7 | 45 | 7000 | 767.35 | 1130.81 |
| Rice | | | | | | |
| Arkansas | 141 | 70.9 | 18 | 6250 | 1027.28 | 1046.27 |
| Louisiana | 40 | 43.0 | 24 | 3000 | 802.25 | 751.24 |
| Mississippi | 41 | 27.7 | 80 | 3850 | 629.39 | 933.87 |
| Missouri | 7 | 26.9 | 200 | 1600 | 514.29 | 587.16 |
| LMRB | 229 | 49.1 | 18 | 6250 | 901.60 | 980.24 |
| Soybean | | | | | | |
| Arkansas | 190 | 95.5 | 40 | 12,000 | 1415.64 | 1510.91 |
| Louisiana | 56 | 60.2 | 52 | 15,000 | 1120.80 | 2173.26 |
| Mississippi | 131 | 87.8 | 67 | 9400 | 1556.14 | 1722.80 |
| Missouri | 26 | 100.0 | 70 | 5000 | 514.29 | 751.24 |
| LMRB | 403 | 86.5 | 40 | 15,000 | 901.59 | 980.25 |

Irrigated corn is the second most popular crop choice overall, with 294 farmers reporting an average of 548.03 acres and as much as 4500 acres (Mississippi). This is also the second most popular crop in every state except Arkansas (57.3 versus 70.9 percent for rice), where respondents grow it as follows: 92.3 percent in Missouri, 71.6 percent in Mississippi, and 53.8 percent in Louisiana.

Heavily influenced by the greater number of respondents from Arkansas, rice is the third most widely reported crop grown across the LMRB (229 respondents or 49.1 percent) with an average of 901.6 acres grown with rice and as much as 6250 acres (Arkansas). In Louisiana, 43 percent of respondents grow rice, which is also the third most popular crop there. However, rice is the fourth most popular in Mississippi (27.7 percent) and Missouri (26.9 percent). According to Kebede et al. [3], irrigated rice consumes more water on a per acre basis than any other crop in the region. As many of the groundwater conservation practices considered in this study were developed for furrow irrigation, rice production, particularly when irrigated traditionally, may be negatively correlated with the number of groundwater conservation practices employed.

Finally, cotton is a traditional crop in the region and it still provides a good deal of status to its growers. “Cotton was king” in Mississippi, and its cultivation and trade helped shape some of the most iconic organizations in Memphis, TN [41]. More popular than rice in Mississippi (33.1 percent) and Missouri (34.6 percent), an overall 22.7 percent of respondents across the LMRB grow it, with an average of 767.35 acres grown and as much as 7000 acres (Mississippi).

Corn, cotton, and soybean are typically furrow-irrigated row-crops that employ the same or similar irrigation set-ups when the fields are prepared for furrow irrigation. Consequently, rice production is included as a control variable in the Poisson regression.

The size of the farming operation is an important factor in the decision to adopt agricultural practices in general. The average operation involved 2260.74 acres of irrigated farmland with a median of 1600 acres and as much as 20,050 irrigated acres (Arkansas). More than three-fourths of the responding growers operate 3000 irrigated acres or less. Arkansas respondents show a mean of 2491.58, median of 1830, and as much as 20,050 total irrigated acres. In Louisiana, the mean is 1582, median is 1125, and as much as 20,000 total irrigated acres were reported. For Mississippi, the mean reported irrigated acreage is 2291.04 acres, with a median of 1500 and maximum 15,000 acres. Missouri respondents have an average of 2664.46 total irrigated acres, median of 2200 acres, and as much as 15,000 total irrigated acres. The number of irrigated hectares is calculated as the sum of irrigated acres reported for each of the crops reported by respondents and is expected to be positively correlated with the number of groundwater conservation practices.

Table 4 summarizes responses to participation in select conservation programs and the planting of cover crops. The latter is not included in the analysis, but is an interesting indicator to track across the region. Almost three-fourths (73 percent) of the growers claimed participation in at least one conservation program. The program most commonly cited is the NRCS Environmental Quality Incentives Program (EQIP) with almost 54 percent participation across the LMRB and ranging from 49 percent participation in Louisiana to over 69 percent in Missouri (50.25 and 58.78 percent in Arkansas and Mississippi, respectively).

Groundwater is the lifeline of irrigated agriculture in the LMRB. Over 90 percent of respondents in each state in the LMRB claim to withdraw groundwater for irrigation. Table 5 summarizes statistics related to groundwater use and other sources of water for irrigation across the states in the region. The use of surface with OFWS, TWS, or captured water only are included as explanatory variables in the Poisson count model.

**Table 4.** Summary statistics of farmers growing cover crops and participating in government-sponsored conservation programs in the Lower Mississippi River Basin (LMRB) in 2016.

| | Mississippi | | Arkansas | | Louisiana | | Missouri | | LMRB | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Program** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| Cover crops | 45 | 30.41 | 60 | 30.15 | 20 | 21.51 ** | 15 | 57.69 ** | 140 | 30.04 |
| CRP | 58 | 39.19 | 90 | 45.23 | 33 | 35.48 | 10 | 38.46 | 191 | 40.99 |
| EQIP | 87 | 58.78 | 100 | 50.25 | 46 | 49.46 | 18 | 69.23 | 251 | 53.86 |
| RCPP | 14 | 9.46 | 29 | 14.57 | 5 | 9.8 | 1 | 3.85 | 49 | 10.52 |
| Other | 41 | 27.7 | 60 | 30.15 | 25 | 26.88 | 7 | 26.92 | 133 | 28.54 |

Note: ** Denotes statistically significant departure from expected proportion. CRP is NRCS Conservation Reserve Program; CSP is NRCS Conservation Stewardship Program; EQIP is NRCS Environmental Quality Incentives Program; RCPP is NRCS Regional Conservation. Partnership Program; and NRCS is USDA Natural Resources Conservation Service unspecified program.

**Table 5.** Summary statistics of irrigation water sources in the Lower Mississippi River Basin (LMRB) in 2016.

| Irrigation by Source of Water | N | % | Min (ac) | Max (ac) | Mean (ac) | Std. Dev. |
|---|---|---|---|---|---|---|
| **Groundwater:** | | | | | | |
| Arkansas | 183 | 91.9 | 40 | 20,050 | 2079.2 | 2415.5 |
| Louisiana | 84 | 90.3 | 5 | 160,00 | 1330.9 | 1973.5 |
| Mississippi | 137 | 92.6 | 7 | 12,000 | 2196.2 | 2245.6 |
| Missouri | 25 | 96.2 | 237 | 15,000 | 2623.7 | 3053.9 |
| LMRB | 429 | 92.1 | 5 | 20,050 | 2006.3 | 2343.9 |
| **Surface direct:** | | | | | | |
| Arkansas | 77 | 38.7 | 10 | 9000 | 750.0 | 1133.4 |
| Louisiana | 36 | 38.7 | 40 | 4000 | 677.0 | 952.0 |
| Mississippi $^{a}$ | 39 | 26.4 | 19.2 | 1480 | 439.7 | 352.1 |
| Missouri $^{a}$ | 1 | 3.9 | | | | |
| LMRB | 153 | 32.8 | 10 | 9000 | 653.7 | 952.3 |
| **Surface with OFWS:** | | | | | | |
| Arkansas $^{b}$ | 41 | 20.6 | 25.5 | 2200 | 446.5 | 455.4 |
| Louisiana | 4 | 4.3 | 120 | 1900 | 715.0 | 808.5 |
| Mississippi | 17 | 11.5 | 5 | 2415 | 449.3 | 625.7 |
| Missouri | 1 | 3.9 | | | 340 | |
| LMRB | 63 | 13.5 | 5 | 2415 | 465.2 | 520.9 |
| **Surface with TWS:** | | | | | | |
| Arkansas $^{b}$ | 59 | 29.7 | 36 | 3075 | 456.6 | 509.6 |
| Louisiana | 3 | 3.2 | 300 | 1800 | 966.7 | 763.8 |
| Mississippi | 21 | 14.2 | 40 | 1748 | 440.3 | 456.25 |
| Missouri | 1 | 3.9 | | | 102 | |
| LMRB | 84 | 18.0 | 36 | 3075 | 468.0 | 508.2 |
| **Captured only:** | | | | | | |
| Arkansas $^{b}$ | 47 | 23.6 | 28 | 2800 | 339.8 | 44.9 |
| Louisiana | 4 | 4.3 | 22 | 1200 | 653.8 | 489.8 |
| Mississippi | 16 | 10.8 | 11 | 750 | 229.1 | 205.3 |
| Missouri | 1 | 3.9 | | | 536 | |
| LMRB | 68 | 14.6 | 11 | 2800 | 338.2 | 407.3 |

Note: $^{a/b}$ indicates proportion significantly less/more than expected; OFWS is on-farm water storage; TWS is tailwater recovery system.

About a third of respondents employ surface water sources directly for irrigation with Mississippi and Missouri showing a significantly lower proportion of growers using direct surface water sources. Arkansas distinguishes itself by showing a larger portion of growers employing alternative sources of water for irrigation. On average, 2006.3 acres are irrigated with groundwater with a maximum of 20,050 acres relying on it. Surface water from streams and bayous is applied to 654 acres on average. OFWS accounts for 13.5

percent of responses and TWS in 18 percent of responses, with average acreage of 447 and 457 acres receiving irrigation from these sources on average across the region. Producers relying on groundwater from a depleting aquifer are expected to adopt a higher number of water conservation practices and use alternative sources of water for irrigation.

Table 6 summarizes the use of different irrigation water management and delivery systems. As expected, flood or furrow irrigation is the predominant irrigation system across the LMRB, with an overall usage of 87.7 percent among respondents. Missouri shows a lower proportion relative to what would be expected from the overall sample at 69.2 percent usage. Flood (including furrow) irrigation is the system not only used by the majority of growers, but it is also applied to most of their acres: 2779 acres on average and as much as 26,000 acres. To calculate total acreage under flood or furrow irrigation, three survey questions were aggregated that encompass acreage under exclusive flood, exclusive furrow, and alternating flood and furrow irrigation.

**Table 6.** Summary statistics of irrigation practices for row crops in the Lower Mississippi River Basin (LMRB) in 2016.

| Irrigation Practice | N | % | Min (ac) | Max (ac) | Mean (ac) | Std. Dev. |
|---|---|---|---|---|---|---|
| **Flood/furrow** | | | | | | |
| Arkansas | 183 | 92.0 | 29 | ‡ 25,300 | 3326.5 | 3663.8 |
| Louisiana | 59 | 88.1 | 20 | ‡ 26,000 | 2178.7 | 3717.1 |
| Mississippi | 126 | 85.1 | 4 | 14,000 | 2243.6 | 2771.6 |
| Missouri [a] | 18 | 69.2 | 150 | 13,600 | 2923.9 | 3183.3 |
| LMRB | 386 | 87.7 | 4 | ‡ 26,000 | 2778.8 | 3414.9 |
| **Computerized hole selection** | | | | | | |
| Arkansas | 66 | 33.5 | 10 | 13,300 | 1411.8 | 2404.2 |
| Louisiana | 21 | 31.8 | 2 | 3100 | 1013.3 | 852.8 |
| Mississippi [b] | 87 | 59.2 | 4 | 9000 | 1812.7 | 1744.7 |
| Missouri [a] | 4 | 19.2 | 150 | 2700 | 1410.0 | 958.1 |
| LMRB | 179 | 41.1 | 2 | 13,300 | 1557.6 | 1929.3 |
| **Surge** | | | | | | |
| Arkansas | 38 | 19.3 | 1 | 3000 | 368.8 | 592.0 |
| Louisiana | 11 | 17.2 | 25 | 1000 | 273.2 | 314.8 |
| Mississippi | 35 | 23.7 | 30 | 1500 | 345.9 | 361.9 |
| Missouri [b] | 9 | 34.6 | 1000 | 2000 | 1660.0 | 421.9 |
| LMRB | 93 | 21.4 | 1 | 3000 | 434.6 | 564.5 |
| **Border** | | | | | | |
| Arkansas [b] | 52 | 26.5 | 25 | 2500 | 628.8 | 797.6 |
| Louisiana [a] | 8 | 12.1 | 12 | 1400 | 381.2 | 544.6 |
| Mississippi [a] | 26 | 17.7 | 25 | 1900 | 390.7 | 677.3 |
| Missouri | 5 | 19.2 | 1800 | 4600 | 3200.0 | 1979.9 |
| LMRB | 91 | 20.9 | 12 | 4600 | 684.1 | 996.5 |
| **Micro** | | | | | | |
| Arkansas | 2 | 1.0 | 60 | 200 | 130.0 | 99.0 |
| Louisiana | 2 | 3.0 | 40 | 200 | 120.0 | 113.1 |
| Mississippi | 5 | 3.4 | 5 | 550 | 160.8 | 261.8 |
| Missouri | 1 | 3.9 | | | 400.0 | |
| LMRB | 10 | 2.3 | 5 | 550 | 171.4 | 190.3 |
| **Pivot** | | | | | | |
| Arkansas | 77 | 38.7 | 1 | 3000 | 368.8 | 592.0 |
| Louisiana | 29 | 43.3 | 25 | 1000 | 273.2 | 314.8 |
| Mississippi | 88 | 59.5 | 30 | 1500 | 345.9 | 361.9 |
| Missouri [a] | 21 | 80.8 | 1000 | 2000 | 1660.0 | 421.9 |
| LMRB | 215 | 48.9 | 1 | 3000 | 434.6 | 564.5 |

Note: [a/b] indicates proportion significantly less/more than expected. ‡ Exceeds total irrigated acreage in Table 3, possibly due to double counting by respondents on 3 questions related to flood and furrow irrigated acreage.

Comparing the maximum acreage of flood or furrow irrigation with the maximum acreage of total irrigated acreage, a disparity is evident. This is most likely due to double-counting on behalf of the respondents regarding the acreage under different irrigation systems. The total irrigated acreage estimates were produced aggregating acres of irrigated crops, which is likely more accurate in a producer's mind. The acreage under an irrigation system is not used in the statistical analysis.

In contrast, other irrigation delivery systems are less popular. Pivot irrigation was practiced by almost half of the respondents, with Missouri having a significantly larger proportion of respondents using this system than the overall sample (80.1 percent). Border irrigation was employed by almost 21 percent of respondents on an average of 684 irrigated acres.

Computerized hole selection (CHS) and surge valve irrigation are practices that improve water use efficiency and uniformity in furrow irrigation systems. CHS was employed by 41.1 percent of all respondents, covering an average of 1557.6 irrigated acres. The practice is significantly more popular in Mississippi (59.2 percent on 1813 acres) and significantly less popular in Missouri (19.2 percent and 1410 acres) relative to the overall sample. Surge irrigation was claimed by 21.4 percent of all respondents with an average of 435 acres across the LMRB. Missouri growers show a significantly higher incidence, with 35 percent of respondents employing it on an average of 1660 acres.

Irrigation scheduling has important implications for both irrigation water use as well as for profitability, regardless of water source. The primary goal of irrigation is to deliver water to the crops when and in the volume they need it. Applying irrigation after crops require it or in insufficient amounts adversely affects yields. Early and over-application could also have that effect in some cases. Table 7 summarizes the methods employed by growers to schedule irrigation events.

**Table 7.** Summary statistics of irrigation scheduling.

| Irrigation Scheduling | N | % | Min (ac) | Max (ac) | Mean (ac) | Std. Dev. |
|---|---|---|---|---|---|---|
| Soil moisture sensors | | | | | | |
| Arkansas | 77 | 38.7 | 1 | 3000 | 368.8 | 592.0 |
| Louisiana | 29 | 43.3 | 25 | 1000 | 273.2 | 314.8 |
| Mississippi | 88 | 59.5 | 30 | 1500 | 345.9 | 361.9 |
| Missouri [b] | 21 | 80.8 | 1000 | 2000 | 1660.0 | 421.9 |
| LMRB | 215 | 48.9 | 1 | 3000 | 434.6 | 564.5 |
| Visual crop stress | | | | | | |
| Arkansas | 144 | 72.4 | - | - | - | - |
| Louisiana | 51 | 76.1 | - | - | - | - |
| Mississippi | 19 | 73.1 | - | - | - | - |
| Missouri | 103 | 69.6 | - | - | - | - |
| LMRB | 317 | 72.1 | - | - | - | - |
| Computerized | | | | | | |
| LMRB | 18 | 4.1 | - | - | - | - |
| Routine | | | | | | |
| Arkansas | 67 | 33.7 | - | - | - | - |
| Louisiana | 16 | 23.9 | - | - | - | - |
| Mississippi | 29 | 19.6 | - | - | - | - |
| Missouri | 10 | 38.5 | - | - | - | - |
| LMRB | 122 | 27.7 | - | - | - | - |
| Probe/feel | | | | | | |
| Arkansas | 48 | 24.1 | - | - | - | - |
| Louisiana | 12 | 17.9 | - | - | - | - |
| Mississippi | 27 | 18.2 | - | - | - | - |
| Missouri | 9 | 34.6 | - | - | - | - |
| LMRB | 96 | 21.8 | - | - | - | - |
| ET or atmometer | | | | | | |
| LMRB | 11 | 2.5 | - | - | - | - |
| Watch another farmer | | | | | | |
| LMRB | 24 | 5.5 | - | - | - | - |

Note: [b] indicates proportion significantly more than expected.

The most common method to schedule irrigation on a given field is by visually scanning for cues of crop stress. Across the region, 72.1 percent of respondents employ this scheduling system with small variations across states (from 70 percent in Missouri to 76 percent in Louisiana). As this irrigation scheduling system is highly subjective, it cannot be considered as a practice capable of conserving groundwater, because implementation and results are hard to evaluate systematically.

Almost 50 percent of respondents claim to trigger irrigation events based on soil moisture sensor (SMS) readings on an average of 434.6 acres. A higher-than-expected share of Missouri respondents claim to schedule irrigation events based on SMS (80.8 percent) on a much larger acreage on average (1660 acres). Mississippi growers also employ SMS in a larger share than the overall sample at 59.5 percent. Agronomic research shows that irrigation scheduling based on SMS readings can save up to 50 percent of total water applied [42] without reductions in yields when compared to conventional scheduling [14,16]. SMS use is considered a groundwater-saving practice for the purposes of this study. Similarly, the use of computerized scheduling, used by 4.1 percent of growers, and ET- or atmometer-based scheduling (2.5 percent) are considered groundwater saving practices in the empirical analysis.

Table 8 summarizes responses associated with groundwater pumping. Each grower in the LMRB manages an average of 22 and as many as 220 (Arkansas) irrigation pumps. This signals the difficulty in efficiently managing irrigation at the farm level so that it delivers needed irrigation water to crops while avoiding excessive water application. Revisiting the scheduling discussion, lacking automation, growers need to incorporate the start and end of pumping routines for a number of pumps that can be large and distant from each other. Consequently, it is natural to presume that pumping starts early in many cases and ends late in others due to logistical and time demands of managing irrigation for all those fields. A practical solution to this challenge is the use of pump timers (timer) which allows irrigators to automatically stop pumpage after a prescribed time or volume of water has been pumped. More than a fourth of respondents in the LMRB employ pump timers, with Mississippi having a significantly larger portion of users (44.5 percent) than the overall sample, while Louisiana growers use it at a significantly lower proportion (11.4 percent).

**Table 8.** Summary of irrigation groundwater pumping statistics.

| | N | % | Min (Units) | Max (Units) | Mean (Units) | Std. Dev. |
|---|---|---|---|---|---|---|
| **Irrigation pumps** | | | | | | |
| Arkansas | 193 | 97.0 | 1 | 220 | 27.1 | 28.0 |
| Louisiana | 88 | 94.6 | 1 | 42 | 9.7 | 9.9 |
| Mississippi | 146 | 98.6 | 1 | 120 | 21.0 | 24.1 |
| Missouri | 21 | 80.8 | 3 | 167 | 28.6 | 37.8 |
| LMRB | 448 | 96.1 | 1 | 220 | 21.7 | 25.5 |
| **Pump timers** | | | | | | |
| Arkansas | 43 | 22.3 | 2 | 60 | 13.4 | 12.9 |
| Louisiana [a] | 10 | 11.4 | 1 | 15 | 4.0 | 5.0 |
| Mississippi [b] | 65 | 44.5 | 1 | 90 | 12.6 | 16.9 |
| Missouri | 6 | 28.6 | 2 | 167 | 42.6 | 70.1 |
| LMRB | 124 | 27.7 | 1 | 167 | 13.6 | 20.9 |
| **Flowmeters** | | | | | | |
| Arkansas | 72 | 37.3 | 1 | 110 | 8.3 | 16.0 |
| Louisiana | 14 | 15.9 | 1 | 40 | 5.4 | 10.7 |
| Mississippi [b] | 103 | 70.5 | 1 | 45 | 8.3 | 8.0 |
| Missouri | 0 | | | | | |
| LMRB | 189 | 42.2 | 1 | 110 | 8.1 | 11.7 |

Note: [a/b] indicates proportion significantly less/more than expected.

Flowmeters to measure actual amount of water applied in irrigation are an important irrigation management tool. Across the LMRB, 42.2 percent of respondents employ them. Mississippi is, by a large margin, the state with the highest proportion of users at

70.5 percent. Possible explanations are that the Mississippi Department of Environmental Quality (MDEQ) has a voluntary metering program that encourages flowmeter use and reading reporting. In addition, NRCS programs require their cooperating farmers to install flowmeters and report readings to MDEQ. No respondents from Missouri employ flowmeters, while only 15.9 percent of Louisiana respondents claim the practice. Flowmeters do not conserve groundwater per se, but are often important components of practices that do. Consequently, we include it among the groundwater conserving practices considered in the empirical analysis.

For completeness in pumping characteristics, Table 9 summarizes the energy sources employed by pumps across the region. A growing set of the literature explores the links between water and energy use, which is beyond the scope of this article. Most growers use more than one type of energy source. Electric and diesel motors are the most common types of pumping power units at 83.4 and 81.2 percent, respectively. Missouri has a markedly lower portion of electric pump users at 61.9 percent, while Louisiana has a lower proportion of diesel-driven pumps at 68.2 percent. Electric pumps are associated with lower operating costs and easier integration with automation and remote management technologies, but growers often face challenging conditions or prohibitive costs of drawing power lines from the grid to the well location.

**Table 9.** Summary statistics of groundwater pumping energy sources.

| Power Unit | N | % | Min (Units) | Max (Units) | Mean (Units) | Std. Dev. |
|---|---|---|---|---|---|---|
| Electric | | | | | | |
| Arkansas | 166 | 86.0 | 1 | 75 | 13.3 | 13.0 |
| Louisiana | 71 | 80.7 | 1 | 38 | 6.7 | 8.4 |
| Mississippi | 126 | 86.3 | 1 | 80 | 11.1 | 14.9 |
| Missouri [a] | 13 | 61.9 | 1 | 80 | 17.7 | 23.1 |
| LMRB | 376 | 83.4 | 1 | 80 | 11.4 | 13.6 |
| Diesel | | | | | | |
| Arkansas | 169 | 87.6 | 1 | 160 | 15.5 | 19.3 |
| Louisiana [a] | 60 | 68.2 | 1 | 21 | 5.4 | 5.1 |
| Mississippi | 117 | 80.1 | 1 | 85 | 13.0 | 14.0 |
| Missouri | 18 | 85.7 | 1 | 87 | 14.0 | 19.9 |
| LMRB | 364 | 81.2 | 1 | 160 | 12.9 | 16.4 |
| Propane | | | | | | |
| Arkansas [a] | 11 | 5.7 | 1 | 16 | 5.1 | 5.4 |
| Louisiana [a] | 4 | 4.6 | 2 | 7 | 3.3 | 2.5 |
| Mississippi | 24 | 16.4 | 1 | 45 | 6.9 | 9.3 |
| Missouri [b] | 11 | 52.4 | 1 | 23 | 5.7 | 6.6 |
| LMRB | 50 | 11.2 | 1 | 45 | 5.9 | 7.6 |
| Natural gas | | | | | | |
| Arkansas | 30 | 15.5 | 1 | 50 | 7.4 | 9.8 |
| Louisiana | 10 | 11.4 | 1 | 8 | 2.9 | 2.5 |
| Mississippi [a] | 3 | 2.1 | 1 | 5 | 3.0 | 2.0 |
| Missouri | 2 | 9.5 | 25 | 30 | 27.5 | 3.5 |
| LMRB | 45 | 10.0 | 1 | 50 | 7.0 | 9.5 |

Note: [a/b] indicates proportion significantly less/more than expected.

Propane and natural gas powered pumps are less common, with 11.2 and 10 percent of respondents claiming to use those energy sources across the LMRB, respectively. Missouri has a significantly higher-than-expected proportion of growers using propane for their pumps at 52.4 percent, while Mississippi has a significantly lower proportion of respondents claiming natural gas as energy source for their pumps when compared to the overall sample. The energy source mix is an important consideration when estimating the costs of groundwater pumping.

The survey of irrigators collected data on their perceptions and attitudes toward groundwater availability. Table 10 compares grower perception of groundwater scarcity with their perceived change of groundwater level at their wells across the LMRB. Across the LMRB, most growers do not perceive there is groundwater problem at their farm or in their state (53 percent). More than two-thirds of respondents do not perceive a change in their wells' depth-to-water distance (68.9 percent). A Pearson's chi-square test indicates that perceiving a change in their well's depth-to-water make farmers more likely to believe there is a groundwater problem on their farm or at the state level. Table 11 reveals that there is great heterogeneity in these perceptions across the states.

**Table 10.** Summary statistics of farmer perceptions and attitudes regarding changes in aquifer levels and presence of groundwater problems in the LMRB.

| | Thinks There Is a GW Problem | | |
|---|---|---|---|
| **Frequency** | **No** | **Yes** | **Total** |
| **Well depth to water:** | | | |
| No change | 152 | 118 | **270** |
| Increased | 24 | 30 | **54** |
| Decreased | 31 | 57 | **88** |
| Don't Know | 38 | 13 | **51** |
| Refused | 2 | 1 | **3** |
| **Total** | **247** | **219** | **466** |
| **Percentage** | **No** | **Yes** | **Total** |
| **Change in depth to water:** | | | |
| No/Can't tell | 41 | 28 | **68.9** |
| Changed | 12 | 19 | **30.5** |
| Refused | 0.4 | 0.2 | **0.6** |
| **Total** | **53** | **47** | **100** |
| **Pearson $\chi^2_4$ = 23.6 with Pr = 0.000.** | | | |

Note: GW is groundwater.

**Table 11.** Difference in farmer perceptions and attitudes regarding changes in aquifer levels and presence of groundwater problems across the LMRB.

| | Percentage Agreeing That There Is a Groundwater Problem | | | | |
|---|---|---|---|---|---|
| | **Arkansas** | **Louisiana** | **Mississippi** | **Missouri** | **LMRB** |
| **Change in depth to water:** | | | | | |
| No/Can't tell | 43 | 19 | 17 | 7 | 28 |
| Changed | 30 | 3 | 16 | 0 | 19 |
| Refused | 0.5 | 0.0 | 0.0 | 0.0 | 0.2 |
| Total | 73.4 | 22.6 | 33.8 | 7.7 | 47 |

Almost three-fourths of growers in Arkansas perceived that there was a problem at their farm or state level. In contrast, only 7.7 percent of Missouri irrigators thought so. Over a third of Mississippi respondents perceived a groundwater problem, and so did 22.6 percent of participants from Louisiana. This highlights that the solution for basin-wide problems may need to be addressed locally in a coordinated manner. The map of Potentiometric Surface of the Mississippi River Valley Alluvial Aquifer published by the U.S. Geological Survey (USGS) for the Spring 2016 [43] shows the location and gradient of the aquifer's cone of depression, indicating that there is a great variability in the aquifer conditions in the region—see Figure 1.

Following Quintana-Ashwell et al. [8], *irrigated area* and *years of education* are continuous variables, while the rest are coded as categorical or indicator (dummy) variables. The explanatory variable *GW problem* is a dummy variable based on the combination of categorical responses to two different questions: "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).

## 3. Regression Results and Discussion

The Poisson count model is estimated where the dependent variable is the number of groundwater-conserving practices and alternative water sources used by irrigators across the LMRB. The explanatory variables are the farm size, as represented by the number of *irrigated acres*, the number of *years of farming experience*, the number of *years of formal education*, the *annual household income level* category (where less than USD50,000 per year is the baseline category), whether the respondent *perceives groundwater problems* at the farm or state level, whether farmers *participate in conservation programs*, and whether the farmer *grows rice* as a control variable, given the large number of practices associated with row-crop production. The regression is performed using the *poisson* command in *Stata 15.1 S.E.* with standard errors clustered by state. Alternative specifications included the negative binomial regression and alternative robust standard error specifications. Another routine allowing for over and underdispersion (as the negative binomial does) is the generalized Poisson regression, but it does not accept categorical variables (income). Table 12 summarizes the regression results.

**Table 12.** Results from Poisson Regressions.

| | Coefficient | Robust Std.Err. | Marginal Effect | Delta Method Std.Err. (ME) |
|---|---|---|---|---|
| Irrigated acres (×1000) | 0.0617 *** | 0.0119 | 0.2629 *** | 0.0652 |
| Years of farming experience | −0.0048 ** | 0.0016 | −0.0203 ** | 0.0061 |
| Years of formal education | 0.0171 | 0.0112 | 0.0729 | 0.0507 |
| Annual income level (baseline is less than USD 50 k) | | | | |
| USD 50 k to 100 k | 0.0156 | 0.0758 | 0.0643 | 0.3164 |
| USD 100 k to 150 k | 0.1298 ** | 0.0502 | 0.5663 ** | 0.2442 |
| USD 150 k to 200 k | 0.0425 | 0.0481 | 0.1772 | 0.2069 |
| USD 200 k to 250 k | 0.1361 | 0.1606 | 0.5958 | 0.7706 |
| USD 250 k to 300 k | 0.2167 *** | 0.0341 | 0.9884 *** | 0.1806 |
| More than USD 300 k | −0.0725 | 0.0979 | −0.2859 | 0.3631 |
| Perceives groundwater problems | 0.2037 ** | 0.0876 | 0.8676 ** | 0.3308 |
| Participates in conservation program | 0.3280 *** | 0.0772 | 1.3971 ** | 0.4439 |
| Grows rice | 0.0123 | 0.1584 | 0.0523 | 0.6722 |
| Constant | 0.7822 | 0.1377 | - | - |
| Log pseudo-likelihood = −655.9; Pseudo $R^2$ = 0.083; AIC = 1317.81; BIC = 1329.11. | | | | |

Note: **, and *** denote significance at $p < 0.05$, and $p < 0.001$, respectively.

The Poisson regression identifies six6 of the selected explanatory variables as having a statistically significant relation with the number of groundwater-conserving practices adopted by farmers: the number of *irrigated acres*, the number of *years of farming experience*, a couple of *annual income levels*, if a farmer *perceives groundwater problems*, and whether the irrigator *participates in conservation programs*.

The number of *irrigated acres* is identified as highly significant ($p < 0.001$) and the average marginal effects estimation indicates that an additional groundwater-conserving practice is adopted for every 3800 additional acres operated, all else being equal. This result does not necessarily indicate that large operators are more conservation-inclined than smaller farmers. It rather likely means that large operations may require a broader range of practices to address a wide array of farm conditions (e.g., edaphic, irrigation infrastructure, labor, logistics, etc.). Another possibility is that this may be due to economies of scale for larger operations that are able to spread some of the fixed and overhead costs over more acres, resulting in lower average costs. This insight suggests that a further refinement in this type of study would be to account for the "intensity" of groundwater-conserving practices that account for both the number of practices and how prevalent they are on each cropping field.

The number of *years of farming experience* is negatively associated with the number of groundwater-conserving practices employed (significant at the $p < 0.05$ level). This result was observed in Quintana-Ashwell et al. [8] for the adoption of individual practices, in which case it was possible that a farmer who has fine-tuned their operation over time would be less likely to adopt a relatively unproven practice. However, the formulation of the Poisson model contradicts the fine-tuning hypothesis. Over the years, the farmer would have been exposed to the opportunity to try and adopt a higher number of practices, which would suggest a greater, not smaller, overall number of practices employed across their operation. The interpretation of the marginal effects indicate that an additional year of farming experience is associated with dropping more currently employed groundwater-conserving practices than new practices being adopted. Even though promoting the adoption of water conservation practices has been a principal initiative to slow the decline of the MRVAA [8], this result suggests an opportunity, and challenge, for targeted outreach and extension programs directed at an aging farmer population.

The interpretation of the coefficients and marginal effects of the household *annual income level* is more difficult because the data were collected as a categorical variable. However, it can be stated that all statistically significant coefficients are positive and for income brackets higher than the baseline bracket. This suggests that higher levels of income are associated with a higher number of practices employed. Further insight is more difficult because it may well be that higher levels of income allow the ability to afford the risk of adopting new practices, but it may well be that these practices can indeed improve farming profitability as suggested by previous research.

The perception of groundwater problems is positively associated with the number of groundwater-conserving practices employed ($p < 0.05$). Previous studies have identified this factor as a determinant in the decision to adopt a conservation practice, and this result expands that finding by identifying it as a determinant of the number of practices to adopt.

Finally, farmer participation in conservation programs is a statistically significant factor associated with the number of groundwater-conserving practices employed by farmers in this sample. A previous analysis of Mississippi farmers' adoption of individual practices could not establish a statistically significant relationship between program participation and adopting any individual practices. Consequently, this study provides a refined understanding about the role of conservation programs in the adoption of conservation practices. The combined analysis suggests that conservation programs may not convince farmers to adopt a practice, but once they decide to implement conservation practices, the availability of these programs has a larger influence on the farmers' decision regarding the suite of practices, as represented by the number of conservation practices employed.

These results provide further insight into understanding what drives the adoption and spread of groundwater-conserving irrigation practices. An important point is that the factors we explore here affect two aspects of practice adoption. One way these factors affect decisions is with respect to the number of practices in the conservation suite to adopt. The second aspect is with respect to which practices to select for the adoption set. This insight can help fine-tune research, education, outreach, and regulatory approaches to the problem, for example, assessing whether recruiting producers into conservation programs is a better use of resources as compared to expanding and intensifying practice adoption among farmers already participating in conservation efforts. It may well be that more groundwater is saved by promoting intensification of conservation practices than extending them more widely, especially if targeting cropland overlaying the cone of depression [5].

This survey is limited in that the data for the analysis are from the last independent survey of irrigators in the area, signaling the importance of conducting periodic surveys (2–5 year intervals) to update these insights and track possible trends.

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## 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 Program |

## Appendix A. Conservation Programs Mentioned in Survey

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

**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 and groundwater and improving water quality. |

**Table A1.** *Cont.*

| Program | Sponsor | Description |
|---|---|---|
| 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. |

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