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Use Patterns and Influencing Factors of Irrigation Best Management Practices in the Lower Mississippi River Basin

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Use Patterns and Influencing Factors of Irrigation Best Management Practices in the Lower Mississippi River Basin

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Abstract

This study uses the 2016 Irrigation Survey from Arkansas, Louisiana, and Mississippi to document the use of irrigation best management practices (IBMPs), analyze use patterns, and use quantitative methods to determine factors that influence producers' decisions regarding IBMPs. IBMPs included in the survey can be grouped as: field management practices (zero-grade leveling, precision-grade leveling, end blocking, warped surface, and deep tillage), water flow control practices (computerized pipe-hole selection, multiple-inlet irrigation, surge irrigation, alternate wetting and drying, cutback irrigation, flow meters, and pump timers), water recovery/storage practices (tail-water recovery system and on-farm storage reservoir), and advanced irrigation scheduling practices (soil moisture sensors, ET or atmometers, computerized scheduling, and Woodruff charts). We find that most of the sample producers use between one and four individual IBMPs from two or more groups. Explanatory variables consist of producer characteristics (being a landowner, education, years of farming experience, income), farm characteristics (total irrigated acres, percent of irrigated acres under gravity irrigation, percent of irrigation from ground water, farm location), and conservation variables (participation in conservation programs within the last five years), and producer perception of groundwater shortage on his or her own farm. Important findings from our study include the strong correlation between higher irrigated acres and water flow meters, and the use of many IBMPs. Our results indicate that more years of farming experience is negatively associated with use of advanced irrigation scheduling practices, and participation in conservation programs such as EQIP is associated with use of water recovery and storage practices, as well as land leveling practices. Being located in a critical groundwater area did not have any statistically significant effect on producers' decisions concerning IBMPs in this study.

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Chapter I. Introduction

A. Study Area

This study focuses on the Lower Mississippi River Basin (LMRB), also called the Mississippi River Alluvial Plain, which encompasses the eastern part of Arkansas, northeastern part of Louisiana, and western part of Mississippi. The Mississippi Delta refers to the region of the United States that is located between the Mississippi River and the Yazoo River.

The LMRB is a highly productive agricultural region in the mid-south and includes parts of seven states, including Arkansas, Louisiana, and Mississippi (Yang et al., 2019). The region sees substantial levels of precipitation throughout the year, however, much of this occurs outside of the regular growing season (Reba et al., 2017). This leads to many producers in the Lower Mississippi River Basin relying on irrigation for their crops (Yasarer et al., 2020). Because of proximity to the Mississippi River Valley Alluvial Aquifer (MRVAA), much of the groundwater used for irrigation in the region comes from this source. In 2015, Arkansas was responsible for about 70% of the irrigation withdrawals, and 14% was attributed to Mississippi (Reba and Massey, 2020). Steady increase in irrigation in the Lower Mississippi River Basin is depleting the aquifer, and there is now a significant gap in the sustainable level of the aquifer and the amount of groundwater being pumped from the aquifer annually (Reba and Massey, 2020). As noted in Reba et al. (2017), irrigated cropland increased by 7.7% in Arkansas, 14.5% in Louisiana, and 20.7% in Mississippi between 2007 and 2012. Annual rate of decline of the Mississippi River Valley Alluvial Aquifer has been determined to be anywhere between 0.15 and 0.45m (Massey et al., 2017).

Agriculture plays a major role in the economies of each of these states and the region as a whole (Yasarer et al., 2020). Arkansas ranks third in the nation for irrigated cropland area, and

Mississippi is ranked eighth (Massey et al., 2017). Collectively, Arkansas and Mississippi have over 60,000 wells that are used to pump groundwater for agricultural irrigation (Massey et al., 2017). The main crops grown in this region are soybeans, rice, corn, cotton, wheat, and grain sorghum, and the area as a whole is responsible for about 20% of total cotton production and about 70% of total rice production for the United States (Yasarer et al., 2020). Arkansas is the top producer of rice in the United States, as well as being a major producer of soybeans. Soybeans, rice, and corn are among the top crops produced in Louisiana. Mississippi is one of the top producers of cotton in the nation, as well as being a major producer of soybeans and corn. Conservation efforts in these states such as the Rice Stewardship Partnership, established by the USA Rice Federation and Ducks Unlimited, aim to increase and accelerate the adoption of best management practices, proving the importance of protecting natural resources (Reba et al., 2017).

More than 50% of the rice production in the United States is in Arkansas, which contributes significantly to the state's economy (Reba and Massey, 2020). Apart from being a major agricultural producer, Arkansas is also home to a large waterfowl population, which relies on harvested rice fields for habitat (Reba and Massey, 2020). Arkansas ranks third in the nation for irrigated acres and second in the nation for volume of water pumped (Massey et al., 2017). Therefore, water is a critical element in sustaining the economy of the state of Arkansas. Groundwater from the Lower Mississippi River Basin provides for approximately 80% of the irrigation demand of Arkansas producers (University of Arkansas Division of Agriculture, 2021). Groundwater declines in Arkansas were first measured in the early 1900s, and by 1980, a cone of depression had formed in the Grand Prairie region of the state (Reba and Massey, 2020).

Continued groundwater withdrawal at unsustainable rates caused another cone of depression to form in the Cache region in the 1990s (Reba and Massey, 2020).

The Arkansas Groundwater Protection and Management Program manages and protects the groundwater resources across the state through a system of monitoring and implementation of best management practices (Kresse et al., 2014; Arkansas Department of Agriculture, 2020). The Arkansas Natural Resources Commission is responsible for monitoring water levels and quality in aquifers as well as enforcing regulations regarding the construction of wells. The Groundwater Protection Program is responsible for monitoring the quality of groundwater sources across the state. This includes monitoring the numerous aquifers in the state through a network of water supply wells (Kresse et al., 2014; Arkansas Department of Agriculture, 2020). The Arkansas Groundwater Initiative targets the issue of declining aquifer levels in the Delta region of the state (Reba and Massey, 2020). The goals of the initiative are to address the issue of groundwater decline through the implementation of conservation practices and management plans, and this voluntary program provides both financial and technical assistance to producers throughout seven Arkansas counties. Funding for the initiative is available through the Environmental Quality Incentives Program (EQIP), a program which encourages the adoption of best management practices through financial assistance of producers (Tosakana et al., 2010).

In Louisiana, industries such as power generation and chemical manufacturing, as well as agricultural segments including aquaculture and rice farming, depend on water for survival (Louisiana Groundwater Resources Commission, 2012). Farmland accounts for more than a quarter of the land area of Louisiana, of which over half is cropland. Groundwater supply in Louisiana is provided by 11 aquifers across the state, and nearly half of the groundwater pumped in the state is used for irrigation (Louisiana Groundwater Resources Commission, 2012). In

2010, irrigation accounted for 4% of surface water used and 42% of groundwater withdrawals for the entire state of Louisiana (Louisiana Groundwater Resources Commission, 2012). Flood and furrow irrigation are the most common methods used in Louisiana (Kebede et al., 2014; Guatam et al., 2020). Approximately 65% of the rice produced in Louisiana is grown in the southwestern part of the state (Louisiana Groundwater Resources Commission, 2012). In these areas, annual declines in groundwater levels are estimated to be approximately 1 to 2 feet (Louisiana Groundwater Resources Commission, 2012).

In 2017, approximately 70% of the total cropland in Louisiana was irrigated (Guatam et al., 2020). In southwest Louisiana, the main source of groundwater is the Chicot Aquifer (LaHaye et al., 2021). Over 70% of the groundwater withdrawals in this area are used for aquaculture and rice production (LaHaye et al., 2021). The United States Environmental Protection Agency has referred to the Chicot Aquifer as a “sole-source aqifer” due to lack of readily available alternatives for freshwater and groundwater in southwest Louisiana (Louisiana Groundwater Resources Commission, 2012). Overall, the MRVAA provides for approximately 80% of total groundwater pumped for irrigation in Louisiana (Louisiana Department of Transportation, 2018). Roughly 85% of the groundwater used for irrigation purposes in northeastern Louisiana in is pumped from the MRVAA (Guatam et al., 2020). Approximately 66% of all water used for irrigation in Louisiana rice production is from groundwater sources, primarily from the Chicot Aquifer (Louisiana Department of Transportation and Development, 2018).

In the past, the assumption of abundant water resources in Louisiana has impacted the implementation of irrigation technologies and led to poor water management strategies for the state (Kebede et al., 2014). An abundance of precipitation and surface water coupled with the decline of aquifers throughout Louisiana creates an interesting paradox for the state (Adusumilli et al., 2016). It is likely that the abundance of resources creates a propensity to overuse and poorly manage water resources, especially those used for agricultural production. Kebede et al. (2014) reported inefficient agricultural water use in the southern portion of the state, and also associated the continuing depletion of aquifers with groundwater overdraft for cropland irrigation. Agricultural water use efficiency could be improved by shrewder management of water resources.

In 1999, prospective well owners were required to notify the Office of Conservation and consent to an evaluation prior to the actual construction and use of the well (Louisiana Groundwater Resources Commission, 2012). According to the Louisiana Groundwater Resources Commission, there are 130,000 registered and more than 100,000 active groundwater wells in the state. There are no state-level regulations regarding the use of groundwater in Louisiana. In the state of Louisiana, the "Rule of Capture" applies to the ownership of most natural resources, including groundwater; if one is able to capture the resource, one is able to own the resource (Louisiana Groundwater Resources Commission, 2012). However, local policies may be enforced to protect resources in areas of groundwater concern. In 2003, when evaluation of the Sparta Aquifer System showed trends of declining water levels in the aquifer, monthly reporting of groundwater and conservation education policies were implemented in four Louisiana Parishes. Over the past decade, rising water levels have been observed in parts of this region, likely due to decreased groundwater pumping in and around the area; however, some levels continue to fall (Louisiana Groundwater Resources Commission, 2012). In 2011, a temporary groundwater emergency was declared near Shreveport, Louisiana, due to drought-like conditions (Louisiana Groundwater Resources Commission, 2012). As a result, restrictions were placed on groundwater use and conservation measures were implemented to prevent further groundwater decline in the area (Louisiana Groundwater Resources Commission, 2012).

Nearly 80% of the water use in Mississippi is attributed to agricultural use in the Delta region. The majority of this water is supplied by the Mississippi River Valley Alluvial Aquifer, which continues to decline due to overuse (YMD, 2006). Declines in groundwater supply in Mississippi are associated with agricultural production (Reba and Massey, 2020). Crops grown in the Delta region account for more than 80% of the total crops produced in Mississippi (Kebede et al., 2014). The most severe decline in the MRVAA observed east of the Mississippi River is in the central Mississippi Delta, an area which is considered to be a major producer of rice, cotton, and catfish (Reba and Massey, 2020; Yasarer et al., 2020).

The Yazoo Mississippi Delta Joint Water Management District (YMD) was created in 1989 to establish a water supply system, protect current water resources, and develop additional resources. Mississippi's Water Management Plan aims to create balance in water supply and demand as well as improve and protect the quality of surface water. A primary objective of the Mississippi Water Management Plan is to stop the decline of the alluvial aquifer by reducing groundwater withdrawals. Mississippi regulates water use through a permitting system required to drill wells, along with establishing withdrawal limits and requiring use of practices to improve efficiency in agricultural irrigation (Bryant et al., 2017). The protection of groundwater resources in Mississippi is the responsibility of the Groundwater Assessment and Remediation Division. Producers are encouraged to use conservation practices through programs such as the Delta Voluntary Metering Program in which producers install approved flow meters on wells and report annual water usage (Massey et al., 2017).

In Mississippi, regulatory mandates are responsible in part for the adoption of IBMPs and other conservation practices (Quintana-Ashwell et al., 2020). Permits must be obtained to drill wells that are larger than 15cm in diameter and must be renewed every five years. Highly efficient irrigation systems or multiple IBMPs must be employed in order to retain the permit (Quintana-Ashwell et al., 2020). Mississippi is thought to be one of the most progressive states in the southeastern United States, due in part to regulation such as this (Reba and Massey, 2020).

B. Survey Data

The main dataset used in this study is the 2016 Irrigation Survey. The survey was part of the United Soybean Board Irrigation Project which was funded by the United Soybean Board and the Mid-south Soybean Board and conducted by irrigation specialists from the University of Arkansas, Mississippi State University, Louisiana State University, and the University of Missouri (Henry et al., 2020). Survey data was collected via phone interviews by enumerators from the Mississippi State University Social Science Research Center. The sample for the survey comes from a list of all commercial crop producers in each state, as identified by Dun and Bradstreet records, and contact information was acquired from Survey Sampling International (Henry et al., 2020). The survey collected information about the producers' use of IBMPs and irrigation technologies on their farm. Computerized pipe-hole selection (CHS), surge irrigation, irrigation scheduling using soil moisture sensors, and multiple inlet rice irrigation were of great importance and interest in this project, as these practices have been shown to be beneficial and there have been recent outreach efforts regarding the adoption of these practices through Extension (Henry et al., 2020).

The final sample for this study includes 470 randomly selected irrigators from three states: 229 from Arkansas, 93 from Louisiana, and 148 from Mississippi. Figure 1.1 highlights the locations of the sample counties from each state. Observations from Missouri were not included in this study due to the small number of responses. Four irrigation technologies are assessed in this study: flood, furrow, border, and center-pivot. The IBMPs can be categorized into one of four groups: water flow control practices, field management practices, water recovery and storage practices, and advanced scheduling irrigation practices. This study also observes the production of four crops by sample producers: corn, cotton, soybeans, and rice. According to Yang et al. (2019), the Lower Mississippi River Basin has become one of the most critical regions in the United States for the production of these crops.

Table 1.1 reports the number of both total and irrigated acres harvested of all four crops in each state using data from the 2017 Census of Agriculture (USDA, 2018). Arkansas has the most irrigated acres for all crops, with nearly 70% of all harvested acres in the state being irrigated. Arkansas also has more irrigated harvested acres for each crop observed in this study than Louisiana and Mississippi: corn (85.7%), cotton (90.0%), and soybeans (79.2%). All acres (100%) of rice harvested across Arkansas, Mississippi, and Louisiana were irrigated. Corn was the second-most irrigated crop in Louisiana and Mississippi, and cotton was the second-most irrigated crop in Arkansas. Of the four crops observed in this study, soybeans accounted for a larger share of irrigated acres in all three states.

Table 1.2 reports the number of sample producers by crop in each state in 2015. The majority of sample producers grew soybeans (85.7%) and corn (61.3%). Significantly more Arkansas producers grew soybeans and rice than Louisiana producers. The share of producers growing corn and cotton in Mississippi was significantly higher than Louisiana and Arkansas.

These findings are consistent with production patterns observed in Table 1.1 using the 2017 Census of Agriculture (USDA, 2018).

Table 1.3 reports irrigation technologies used by sample producers from Arkansas, Louisiana, and Mississippi in 2015. In this study, four technologies are observed: furrow irrigation, border irrigation, flood irrigation and center pivot. Furrow, border, and flood irrigation are types of gravity irrigation. Center pivot irrigation delivers water through a sprinkler system, initially designed for irrigation of cotton fields (Quintana-Ashwell et al., 2020). Irrigation technologies typically vary by field, so producers often use more than one technology in their operation. Producers in Arkansas used significantly more furrow, border, and flood irrigation than producers in Louisiana and Mississippi. Arkansas is the number one producer of rice in the United States, which is commonly irrigated using flood irrigation. Furrow irrigation is a common practice used in soybean production and is widely used across all three states (Massey et al., 2017). Mississippi producers use center pivots significantly more than those in Arkansas and Louisiana. This is expected, as Mississippi produces more cotton than the other two states, and center pivots were originally designed to irrigate cotton fields (Quintana-Ashwell et al., 2020). Farm location and producers' perception of groundwater concern are also reported in Table 1.3. Producers with no perception of a groundwater shortage for farms located outside of a critical groundwater area use significantly less flood irrigation and significantly more center pivots. This makes sense, as flood practices require large amounts of water and center pivots conserve water by application through sprinklers (Quintana-Ashwell et al., 2020).

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D. Tables and Figures

Table 1.1: *Total acres harvested and irrigated acres harvested by crop in 2017 for Arkansas, Louisiana, and Mississippi.*

	Arkansas		Louisiana		Mississippi	
	Total	Irrigated	Total	Irrigated	Total	Irrigated
Corn	594,773	509,819 (*85.7%*)	488,581	283,519 (*58.0%*)	499,944	273,105 (*54.6%*)
Cotton	439,582	399,559 (*90.9%*)	216,670	72,476 (*33.4%*)	627,212	322,788 (*51.5%*)
Soybean	3,498,157	2,770,211 (*79.2%*)	1,250,093	426,237 (*34.1*)	2,170,472	1,072,165 (*49.4%*)
Rice	1,103,773	1,103,733 (*100%*)	397,653	397,653 (*100%*)	114,104	114,104 (*100%*)
All crops	7,098,672	4,843,849 (*68.2%*)	3,314,955	1,209,249 (*36.5%*)	4,174,210	1,807,551 (*43.3%*)

Notes:

[a.] Shares of total acres harvested irrigated are reported in parentheses.

[b.] Source: 2017 Census of Agriculture (USDA, 2018)

Table 1.2: *Number of sample producers by crop in 2015 and percentage of producers by crop in Arkansas, Louisiana, and Mississippi.*

Crop	N Producers	% Producers			
		All Three States	Arkansas	Louisiana	Mississippi
Corn	288	61.3	57.6	53.8^{LAMS**}	71.6^{ARMS**}
Cotton	104	22.1	17.9	15.0^{LAMS***}	33.1^{ARMS***}
Soybean	403	85.7	94.3^{ARLA***}	60.2^{LAMS***}	88.5
Rice	244	51.9	71.2^{ARLA***}	43.0^{LAMS**}	27.7^{ARMS***}

Notes:

[a.] ARMS: The difference between Arkansas (AR) and Mississippi (MS) is statistically significant.

[b.] ARLA: The difference between Arkansas (AR) and Louisiana (LA) is statistically significant.

[c.] LAMS: The difference between Louisiana (LA) and Mississippi (MS) is statistically significant.

[d.] * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

[e.] Source: 2016 Irrigation Survey (Henry et al., 2020)

Table 1.3: *Irrigation technologies used by sample producers in Arkansas, Louisiana, and Mississippi in 2015.*

Irrigation technology	By state				Farm located inside or outside areas of groundwater concerns [a]		Producers' perception of groundwater shortage on own farms [b]	
	All	Arkansas	Mississippi	Louisiana	Inside	Outside	Shortage	No shortage
Furrow	81.9	$87.3^{\text{ARLA}***}$	85.8	$62.4^{\text{LAMS}***}$	79	84.2	89.6	81
Border	20.6	$26.2^{\text{ARLA}***}$	18.9	$9.7^{\text{LAMS}*}$	23.8	18.1	25	20.1
Flood	59.1	$76.9^{\text{ARLA}***}$	$37.8^{\text{ARMS}***}$	$49.5^{\text{LAMS}*}$	74.3	46.9^{***}	79.2	56.9^{***}
Center pivot	36.8	31	$54.1^{\text{ARMS}***}$	$23.7^{\text{LAMS}***}$	28.1	43.8^{***}	22.9	38.4^{**}

Notes:

[a.] Indicates whether farm is located inside or outside areas of groundwater concern.

[b.] Indicates producers' perception of groundwater shortage on own farm.

[c.] ARMS: The difference between Arkansas (AR) and Mississippi (MS) is statistically significant.

[d.] ARLA: The difference between Arkansas (AR) and Louisiana (LA) is statistically significant.

[e.] LAMS: The difference between Louisiana (LA) and Mississippi (MS) is statistically significant.

[f.] * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

[g.] Source: 2016 Irrigation Survey [e.] LAMS: The difference between Louisiana (LA) and Mississippi (MS) is statistically significant.

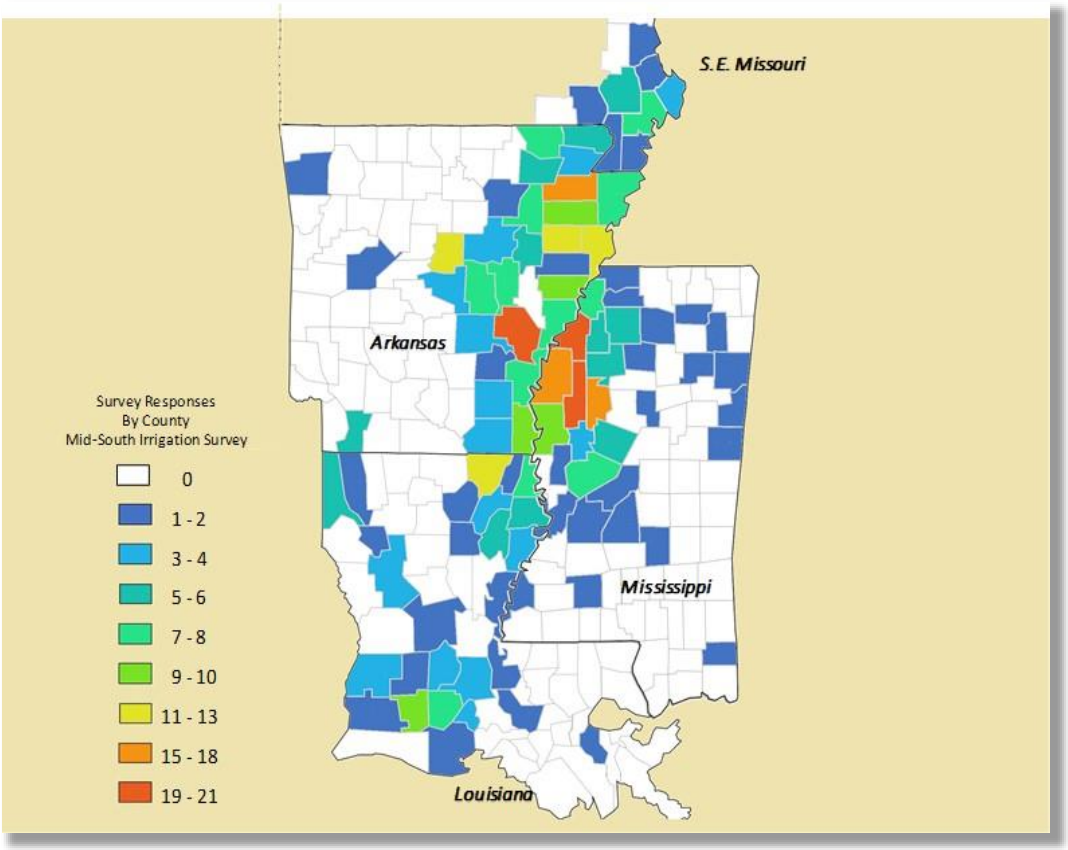

Figure 1.1: *Locations of the sample counties of the 2016 Irrigation Survey.*

Notes:

[a] Source: 2016 Irrigation Survey (Henry et al., 2020)

[b] Observations from Missouri not included in this study due to small number of responses

Chapter II. Irrigation Best Management Practices and Use Patterns in Arkansas, Louisiana, and Mississippi

A. Introduction

Several states in the mid-southern US have experienced significant expansions of irrigated cropland in the past decades. From 1950 to 2017, irrigated cropland in Arkansas increased more than 10 folds from 0.4 million acres to about 4.8 million acres acres (USDA, n.d.; USDA, 2021). During the same period, irrigated acres in Louisiana doubled to more than 1.2 million acres. The expansion in Mississippi occurred later but also registered an 11-fold increase between 1974 and 2017 (Reba and Massey 2020). Meanwhile, several other leading irrigation states such as California and Texas have experienced declines in irrigated acres (Reba and Massey 2020; Schaible and Aillery 2012). Data compiled from the Census of Agriculture indicate that irrigated cropland in the Delta has increased drastically from 1969 to 2017 (USDA, n.d.; USDA, 2021). Irrigation of cotton and soybeans has increased, even though total cropland production of the crops has decreased in parts of the Delta in the last three decades (Yasarer et al., 2020).

The Mississippi River Valley Alluvial Aquifer (MRVAA) provides most of the groundwater for the mid-southern United States, including Arkansas, Louisiana, Mississippi, Missouri, and Tennessee (Wood et al., 2019). Irrigation is the largest water user in the region, with over 90% of the groundwater used for irrigation in the Lower Mississippi River Basin (LMRB) coming from the Mississippi River Valley Alluvial Aquifer (Reba and Massey, 2020). Steady increase in irrigation in the LMRB is depleting the aquifer, and there is now a significant gap in the sustainable level of the aquifer and the amount of groundwater being pumped from the aquifer annually (Reba and Massey, 2020). The groundwater withdrawal rate for agricultural use exceeds the recharge rate of the aquifer. This has caused the formation of cones of depression in the delta region, along with declining water levels within the MRVAA (Wood et al., 2019). Withdrawals for irrigation have also been associated with depletion of streams in the Delta region, especially during summer months when rainfall is sparse (Barlow and Clark, 2011).

According to Yasarer et al. (2020), depletion of streams in the Delta have coincided with the upsurge of cropland irrigation in the region. Some areas have experienced more intense groundwater level decline, such as the Cache and Grand Prairie regions in Arkansas, where cones of depression developed between 1980 and the mid-1990s (Yasarer et al., 2020; Reba and Massey, 2020; Kresse et al., 2014). As a result, these areas have been designated as critical groundwater areas (Kresse et al., 2014). This region includes some of the leading rice-producing counties in the state of Arkansas, which are also areas of increased groundwater withdrawal due to irrigation demand. In addition to the MRVAA, the Sparta aquifer also underlies the Grand Prairie region in Arkansas, and has become an increasingly important source of groundwater due to the decline of the MRVAA (Kresse et al., 2014). Cones of depression have also developed in the center of the Delta, near the Sunflower River in Mississippi (Yasarer et al., 2020; Reba and Massey, 2020). The development of these cones of depression and continuing declines in groundwater levels throughout the region have peaked interest for irrigation specialists and agricultural economists (Yasarer et al., 2020).

Over the past 35 years, the total number of groundwater wells for agricultural use have increased exponentially (Bryant et al., 2017). Total annual withdrawals from the MRVAA are greater than the recharge rate of the aquifer, leading to increased depth to water in the Delta (Bryant et al., 2017). There are 27 Arkansas counties located over the MRVAA. Groundwater levels have increased in 11 counties over the past decade, due in part to excess precipitation

(Nian et al., 2020). However, groundwater levels have continued to decline in the other 16 counties, averaging more than 2 feet from 2008 to 2018 (Nian et al., 2020). In Mississippi, the annual gap between the supply and demand of groundwater is estimated at 370 million cubic meters and is mostly credited to agricultural irrigation in the Delta (Kebede et al., 2014).

The MRVAA is the largest aquifer underlying the Mississippi Embayment area (Kandpal et al., 2018). Also underlying this area is the Gulf Coast Plain aquifer, which is the most depleted aquifer in the United States (Yang et al., 2019). The depletion of the MRVAA and other aquifers in the Mississippi Delta threatens the sustainability of the economies and ecosystems that depend on them for survival. Though the depletion of the MRVAA affects the entire Lower Mississippi River Basin, the state of Arkansas has arguably been affected the most, with annual groundwater levels estimated to be declining at approximately 1 to 1.5 feet over the past 45 years (Kandpal et al., 2018).

Boosting irrigation application efficiency is viewed as a key solution to mitigate water shortage. For example, the 2014 Arkansas Water Plan Update identified adopting measures that improve on-farm application efficiency as one of the critical initiatives (Arkansas Natural Resources Commission, 2015). Adopting more efficient irrigation technologies such as sprinkler irrigation or drip irrigation are often the policy instruments recommended. However, this may not be the best approach for the mid-south states. The biggest challenge with adopting center pivots is the initial large capital investments, and hefty maintenance costs are often associated with more efficient irrigation technologies (Tacker and Vories, 1998). Soil type, a major consideration when apply center pivot irrigation, is not favorable. The most common soil in the region is clay, which is considered marginal soil for center pivot systems. The wheels on a center-pivot system often cut deep ruts and become stuck in the soil (Stevens, Rhine, and Vories, 2017).

Instead, using irrigation best management practices (IBMP) to improve the performance of gravity irrigation may be the more practical approach (Nian et al., 2020). According to Reba and Massey (2020), improving irrigation practices for agronomic crops such as rice and soybean offer an opportunity to reduce overdraft of the MRVAA almost immediately. For example, the experiment conducted by Bryan et al. (2017) in Arkansas and Mississippi show a 21% reduction in water use on soybean fields managed with computerized hole selection, surge irrigation, and soil moisture sensors, relative to fields with conventional furrow irrigation. Additionally, the water saving was obtained without adverse effects on soybean yields or on-farm profitability (Bryan et al., 2017). Policy makers are recognizing this too. The Arkansas Groundwater Initiative (AGWI), a USDA-NRCS program, will provide financial and technical assistance through the Environmental Quality Incentives Program (EQIP) to producers that adopt IBMP practices such as land grading, tail-water recovery pits and reservoirs (USDA, 2019). There is a consensus among researchers that considerable reductions in MRVAA overdraft could be achieved if IBMPs become more widely adopted throughout the LMRB (Wood et al., 2017; Reba and Massey, 2020). Construction of on-farm storage reservoirs and the improvement of existing irrigation technologies are just some of the suggested strategies that could potentially increase efficiency and mitigate declining aquifer levels by reducing groundwater withdrawals (Yang et al., 2019).

Using a producer survey collected in 2016, this study documents which IBMPs are currently in use in three mid-south states (Arkansas, Louisiana, and Mississippi) and how the use if IBMPs has changed over time. The study also analyzes the patterns of IBMP uses and examines whether some IBMPs tend to be used together.

This study fills in several gaps of the current literature on irrigation management. First, partly due to the lack of data, most studies only focus on a few IBMPs, which is not likely to exhaust the list of IBMPs producers can choose from. In contrast this study includes 16 different IBMPs and thus provides a much clearer and comprehensive picture of IBMP use by producers. Second, most studies on IBMPs are small in scale, including only experiment fields. Our study includes three states and covers a region that is leading in irrigated acres nationwide. Third, the study goes beyond the use of individual IBMPs and focuses on IBMPs that improve different aspects of the irrigation systems and whether producers use a suite of IBMPs in an integrated way. Such a system approach generate valuable insights for both producers and conservation agencies.

B. Irrigation Best Management Practices Used in Study Sites

Table 2.1 reports the use of irrigation best management practices by sample producers in the 2015. Significantly more producers used land leveling practices, multiple-inlet irrigation, and cutback irrigation in Arkansas than in Louisiana and Mississippi. Arkansas producers also used more water recovery and storage practices. Mississippi producers used more deep tillage, computerized pipe-hole selection, and soil moisture sensors. Producers in Mississippi also used significantly more flowmeters and timers on pumps than those in Louisiana and Arkansas. Louisiana as a whole used significantly less advanced scheduling irrigation practices than Arkansas and Mississippi. Table 2.1 also reports whether the farm is located inside or outside areas of groundwater concern and whether producers believe there is a groundwater shortage on their own farm. Producers with no perception of groundwater shortage located on farms outside of critical groundwater areas are significantly less likely to use land-leveling practices or water recovery and storage practices.

Table 2.2 reports IBMP use patterns by sample producers in 2015. The largest share of sample producers (38.3%) reported using IBMPs from two groups. Most of these used a combination of water flow control and field management practices. Louisiana producers used a grouping of water flow and field management IBMPs significantly more than producers in Arkansas and Mississippi. Significantly more producers in Mississippi used all four groups than in Louisiana and Arkansas. Producers in Arkansas used three groups more often than those in Mississippi and Louisiana. This was most often a blend of water flow control practices, field management practices, and water recovery and storage practices. Producers in Louisiana used one group of IBMPs significantly more than producers in Arkansas and Mississippi, most often field management practices.

Figure 2.1 shows the number of IBMPs used by sample producers from Arkansas, Louisiana, and Mississippi. Panel (a) shows the number of IBMPs used by sample producers from all three states. Most of the sample producers used between one and five water management practices in their operation. Very few producers report using more than nine IBMPs. Panel (b) shows the number of IBMPs used by producers in each state. The largest share of producers in Arkansas report using three IBMPs. In Louisiana, the largest share of producers report using two IBMPs. Mississippi has a greater share of producers using four or five IBMPs. Irrigation best management practices observed in this study can be categorized into four groups based on the facet of irrigation that is being controlled: field management practices, water flow control practices, water recovery/storage practices, and advanced irrigation scheduling practices. Appendix 1 defines and describes the individual water management practices in each category.

Zero-grade leveling systems are associated with some of the lowest water application rates, according to Massey et al. (2017) and Henry et al. (2016). Precision leveling is a common practice in the Lower Mississippi River Basin as it promotes the use of furrow irrigation, which is the predominant irrigation method used for soybeans in this region (Massey et al., 2017).

End blocking consists of blocking the ends of furrows to trap water on the field and reduce tail-water runoff (Kandpal et al., 2018). This practice is often used by producers employing furrow irrigation in rice to allow for accumulation of rainfall and other precipitation (Kelly et al., 2021).

One of the most cost-effective ways to upgrade conventional irrigation equipment to make it more efficient is through computerized pipe-hole selection (Reba and Massey, 2020). This tool allows water to be uniformly distributed over a field by taking into account the length and elevation of each furrow and allocating water flows and pressures accordingly through polyethylene pipe (Bryant et al., 2017; Spencer et al., 2019). Implementation of CHS reduces total surface water runoff, as well as total amount of water applied for irrigation (Spencer et al., 2019; Quintana-Ashwell et al., 2020). CHS software such as PHAUCET and the Delta Plastic Pipe Planner are available to producers in the Lower Mississippi River Basin (Kebede et al., 2014). As of 2019, nearly 30% of furrow-irrigated crops in Arkansas, and more than 60% in Mississippi, had been outfitted with CHS (Reba and Massey, 2020). Previous studies conducted on farms in the Mississippi Delta have found that including CHS as part of irrigation management may attain up to 25% water savings (Quintana-Ashwell et al., 2020).

Surge irrigation is one of the most common practices used in corn and soybean production in Louisiana (Adusumilli et al., 2016). The installation of surge valves can improve irrigation efficiency and uniformity of water application on fields using surface irrigation. Two issues that are often faced when using gravity irrigation methods such as furrow irrigation are loss of deep percolation and excess surface runoff (Spencer et al., 2019; Bryant et al., 2020; Adusumilli et al., 2016). Implementing surge valves can remedy these problems through discontinuous water distribution. Surge irrigation distributes water onto furrows in bursts, allowing time for the water on the field to infiltrate the soil before irrigating again (Spencer et al., 2019). The "on" and "off" cycles are implemented on alternate portions of the field until water reaches the ends of the furrows (Bryant et al., 2017). Research has shown that surge irrigation can result in water savings of anywhere from 20-50%, along with potential yield increases (Adusumilli et al., 2016; Quintana-Ashwell et al., 2020; Krutz, 2014). Though surge irrigation can significantly increase irrigation efficiency, there are also considerable labor and capital requirements to ensure that the system remains suitable for use (Bryant et al., 2020; Adusumilli et al., 2016). Even so, surge irrigation has been shown to provide net positive returns in the long run (Adusumilli et al., 2016).

Multiple inlet irrigation is a practice developed by rice producers in Arkansas in the 1990s, which allows for the uniform distribution of water to each paddy simultaneously through a system of holes in lay-flat poly-tubing (Reba and Massey, 2020; Reba et al., 2017). Compared to cascade flooding, multiple inlet irrigation may reduce water application by up to 25% (Reba et al., 2017).

In rice production, alternate wetting and drying is a method in which the flood water on a rice paddy is allowed to recede to near or below the soil surface before flooding the paddy once again (Linquist et al., 2015). This method was initially developed by the International Rice Research Institute to assist Asian farmers with conservation in instances of water scarcity (Bouman, 2007).

Cutback irrigation is another practice that increases irrigation efficiency while reducing surface water runoff. This method cuts back on the amount of water that is distributed onto a field to allow for deeper infiltration. This reduces the total amount of water that is applied to the field, as well as the amount of water that runs off at the end of the furrows (Kandpal et al., 2018).

Flowmeters are an important part of irrigation management, even though they do not actually conserve water on their own. For example, flowmeters are valuable in calculating the ideal size of holes used in CHS (Massey et al., 2017), as wells as helping producers keep record of the application of water across fields (Kebede et al., 2014). Flowmeters are a convenient tool in assisting with water conservation because they are compatible with nearly any irrigation system (Quintana-Ashwell et al., 2020). Throughout most of the Lower Mississippi River Basin, the use of flowmeters is not mandated by state law. Use of flowmeters has been most widespread in Mississippi, due to the requirement set forth by the Mississippi Department of Environmental Quality stating that no less than 10% of all agricultural wells in each county must have flowmeters (MDEQ, 2021).

Timers are another integral part of irrigation management that help producers conserve water. Installing timers allows producers to either set pumps to turn off at a designated time, or allow the producer to switch pumps on and off remotely (Kebede et al., 2014). Throughout most of the Lower Mississippi River Basin, the use of flowmeters is not mandated by state law. However, participation in some NRCS programs requires that flowmeters and pump timers be used. In some states, there are programs which encourage the use of such implements, but do not require them. For example, the Delta Voluntary Metering Program in Mississippi is a voluntary program funded by the NRCS which requires use of flowmeters and timers in order to participate (Quintana-Ashwell et al., 2020; MDEQ, 2021).

Tail-water recovery systems consist of catching surface water runoff and rainwater in a recovery ditch or canal and storing it in an on-farm reservoir to be used for reapplication (Kebede et al., 2014). These systems can improve irrigation efficiency, however, they require large initial investments of capital and land (Kandpal et al., 2018). Such systems have been implemented in Mississippi and Arkansas in areas where cones of depression have been located in an effort to slow depletion of the MRVAA (Omer, 2017; Reba and Massey, 2020). Increased awareness of declining groundwater levels encourages producers to save water any way that they can. Tail-water recovery systems have been estimated to reduce withdrawals by nearly one fourth by allowing increasing reliance on surface water for irrigation rather than groundwater (Quintana-Ashwell et al., 2020). Though the installation of TWS might reduce pumping rates, there is no evidence yet whether it will allow aquifer levels to improve (Yasarer et al., 2020).

The use of advanced irrigation scheduling tools such as soil moisture sensors and computerized schedulers can increase water use efficiency in crops without negatively impacting yields (Bryant et al., 2017; Wood et al., 2020). Irrigation scheduling using soil moisture sensors has been shown to reduce water application by up to 40% for rice, soybeans and corn, and up to 63% for cotton (Spencer et al., 2017; Wood et al., 2020; Bryant et al., 2017; Spencer et al., 2019). However, in the mid-south, fluctuating weather conditions and a variety of soil types make it more difficult to use irrigation scheduling tools (Kebede et al., 2014). In the Delta, the Arkansas Irrigation Scheduler and the Mississippi Irrigation Scheduling Tool are two web-based programs that allow producers to schedule irrigation (Kebede et al., 2014). Even with the availability of these tools, less than 15% of producers in the Delta region of Arkansas and Mississippi use advanced scheduling practices (Spencer et al., 2017). In Louisiana, the Smart Technologies for Agricultural Management and Production (STAMP) Irrigation Scheduling Tool is a decision tool developed to aid producers in determining how much water to apply to crops and when to apply it (Davis and Fromme, 2017). Producer perception of impacts on yield and profit might be one reason why producers in the mid-south are reluctant to adopt the more advanced irrigation technologies (Wood et al., 2020).

Evidence shows that even making small adjustments to current irrigation systems might result in water savings or increased efficiency of existing technologies without harming crop yields (Quintana-Ashwell et al., 2020). According to Henry et al. (2013), using surge valves with CHS may improve irrigation efficiency. Implementing multiple inlet irrigation on precision graded fields may also improve irrigation efficiency in rice production (Henry et al., 2013).

Spencer et al. (2019) reported that implementing practices such as CHS, surge irrigation, and scheduling using soil moisture sensors decreased water application by nearly 40% in corn production. This study was conducted on 18 paired fields from 2013 to 2017, with one field assigned as the control and the other being irrigated. Flowmeters were used to monitor water application on each field (Spencer et al., 2019). Relative to conventional irrigation practices, CHS, surge valves, and sensor-based scheduling have all been shown to reduce water application in irrigation of soybeans (Bryant et al., 2017; Krutz et al., 2014). Kebede et al. (2014) suggests that using CHS together with surge valves could further increase efficiency of furrow irrigation. Other studies suggest that using these two practices in conjunction with each other reduces the application of water to soybeans in clay soil by nearly 25% (Reba and Massey, 2020; Wood et al., 2017).

C. Use of Irrigation Technologies and IBMPs over Time

Figure 2.2 reports the use of irrigation technologies and water management practices by sample producers over time, from 1950 to 2015. Use of all practices observed in this study have increased over time, some more so than others. Grading, center pivots, and water storage practices have seen a gradual increase in use from around 1980 forward. The trends of tail-water recovery systems and storage reservoirs follow each other, as they are often used together. More advanced technologies such as advanced irrigation scheduling practices, as well as surge irrigation and multiple-inlet irrigation, have seen a more abrupt increase in use beginning around 2010.

Figure 2.3 reports the adoption of IBMPs by year. Panel (a) shows the adoption of grading and center pivots. Adoption of land leveling practices such as precision and zero grading began around 1970 and started to increase around 1980. The adoption of center pivots began to take off a little later, around 1985.The use of both of these practices has increased over tome. Nearly 40% of the sample producers used one of these in their operation by 2015. Panel (b) shows the adoption of water flow control practices. The number of producers adopting practices such as surge irrigation, multiple-inlet irrigation, and computerized pipe-hole selection began to increase slightly around 2000 and increased even more around 2010. Adoption of CHS skyrocketed in the last decade, with nearly 150 sample producers reporting adoption of this practice. Panel (c) shows the adoption of tail-water recovery systems and storage reservoirs. Again, the trends of these two practices move together. Producer adoption of these practices began to increase in the early 2000s. Adoption of more advanced technologies and IBMPs is still relatively low compared to adoption of other practices among sample producers. Sample producers began adopting computerized scheduling as early as 1995, however, atmometers, Woodruff charts, and soil moisture sensors were not adopted until after 2010. Soil moisture sensors are the most widely adopted advanced practice, with approximately 100 sample producers reporting adoption between 2010 and 2015.

D. Correlations

Correlations between irrigation technologies and IBMPs are reported in Table 2.3. Positive (negative) coefficients are interpreted as positive (negative) correlations. Flood irrigation is positively correlated with land leveling practices and multiple inlet irrigation. This makes sense, because all of these practices are commonly implemented in rice production. Furrow irrigation is positively correlated with using deep tillage and computerized pipe-hole selection. Border irrigation and center pivots are not very highly correlated (>0.30) with any individual IBMPs.

Table 2.4 reports correlations among IBMPs. These results are fairly consistent with the results reported in Table 2.3. For example, grading (zero- and precision-grade leveling) is positively correlated with multiple-inlet irrigation, and deep tillage is positively correlated with CHS. Surge irrigation is associated with use of flow meters and soil moisture sensors. Timers and soil moisture sensors are supplementary as well. There are no highly significant negative correlations (>0.30) observed in these results. This could indicate and further validate the assumption that most sample producers using IBMPs in their operation use more than one.

E. Discussion

Chapter II uses the 2016 Irrigation Survey to analyze IBMP use patterns of producers from Arkansas, Louisiana, and Mississippi. Sample producers use more flood, furrow, and center-pivot irrigation technologies than border irrigation. More than 70% of sample producer report using IBMPs from two or more groups. The largest share of sample producers use IBMPs from the field management practices group, followed by water flow control practices. The data do not indicate any major differences among the use of individual IBMPs in Arkansas, Louisiana, and Mississippi. The adoption of IBMPs corresponds with the increasing number of irrigated acres in all three states over time. This indicates a positive relationship between IBMP adoption and irrigated acres.

One method of encouraging the adoption of water management practices and other conservation practices is through the implementation of federal, state, and locally funded programs that aid producers. The 2017 Census of Agriculture enumerates the number of farms that received financial and technical assistance in the previous five years for irrigation and drainage improvements in their operation. In 2017, there were 294,235 irrigated farms in the United States. 10,138 of these farms were located in Arkansas, Louisiana, and Mississippi. Only 1,439 (14.19%) of these farms received either financial or technical assistance during the previous five years (USDA 2018). The development of new programs to support and educate producers, and the increasing awareness of such programs, may improve the number of producers who adopt water management practices and participate in conservation efforts in their area.

Similar use patterns among producers from all three states may indicate similar use patterns among producers in the Lower Mississippi River Basin, in general. The majority of producers in this region also draw groundwater from the Mississippi River Valley Alluvial Aquifer. Therefore, policies targeting users of the MRVAA as a whole may be more effective in battling the depletion of the aquifer than policies targeting irrigators from individual states. The factors that influence producer decisions regarding IBMPs will also need to be considered by policymakers. Though the data indicates similar use patterns, there may be differences in influencing factors for producers in each state that could affect the success of new policies.

The next step in this research will be to identify which factors influence the producers' choice of specific IBMPs and groups. Irrigator characteristics such as being a landowner, education, and years of farming experience, and household income, as well as farm characteristics such as total irrigated acres, percent of irrigated acres under gravity irrigation, percent of irrigated water from groundwater and flow meters use will be analyzed. Participation in conservation programs and perception of groundwater shortage will also be examined.

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G. Tables and Figures

Table 2.1: *Use of IBMPs by sample producers in 2015*

Groups of IBMP	Individual IBMP	By state				Farm located inside or outside areas of groundwater concerns [a]		Producers' perception of groundwater shortage on own farms [b]	
		All	Arkansas	Mississippi	Louisiana	Inside	Outside	Shortage	No shortage
Field Manage-ment practices	Zero or Precision leveling	40.2	58.1$^{\text{ARLA***}}$	18.2$^{\text{ARMS***}}$	31.2$^{\text{LAMS**}}$	54.8	28.5***	66.7	37.2***
	Warped surface	24	25.3	22.3	23.7	24.3	23.8	29.2	23.5
	End blocking	28.7	30.6$^{\text{ARLA***}}$	35.1	14.0$^{\text{LAMS***}}$	30	27.7	33.3	28.2
	Deep tillage	51.5	47.2$^{\text{ARLA**}}$	70.3$^{\text{ARMS***}}$	32.3$^{\text{LAMS***}}$	48.1	54.2	47.9	51.9
Water Flow Control practices	Multiple-inlet irrigation (rice)	27.4	37.6$^{\text{ARLA**}}$	13.5$^{\text{ARMS***}}$	24.7$^{\text{LAMS**}}$	40	17.3***	35.4	26.5
	Alternate wetting and drying (rice)	5.5	5.2	4.7	7.5	7.1	4.2	6.3	5.5
	Computerized pipe-hole selection	38.1	31	58.8$^{\text{ARMS***}}$	22.6$^{\text{LAMS***}}$	37.6	38.5	39.6	37.9
	Surge irrigation	18.5	17.9	23.6	11.8$^{\text{LAMS**}}$	16.2	20.4	20.8	18.2
	Cutback irrigation	10.2	13.5$^{\text{ARLA***}}$	9.5	3.2$^{\text{LAMS*}}$	10.5	10	14.6	9.7
	Water flow meter	41.7	34.5$^{\text{ARLA***}}$	69.6$^{\text{ARMS***}}$	15.1$^{\text{LAMS***}}$	44.8	39.2	54.2	40.3*
	Pump timer	26.6	21.8$^{\text{ARLA**}}$	43.9$^{\text{ARMS***}}$	10.8$^{\text{LAMS***}}$	26.7	26.5	27.1	26.5
Recovery /storage	Tail-water recovery system	34.3	45.4$^{\text{ARLA***}}$	28.4$^{\text{ARMS***}}$	16.1$^{\text{LAMS**}}$	41.9	28.1***	75	29.6***
	Storage reservoir	28.1	34.5$^{\text{ARLA***}}$	27.7	12.9$^{\text{LAMS***}}$	35.2	22.3***	58.3	24.6***
Advanced scheduling	Soil moisture sensor	21.7	9.2	48.6$^{\text{ARMS***}}$	9.7$^{\text{LAMS***}}$	16.7	25.8**	18.8	22
	ET or Atmometer	2.8	3.5$^{\text{ARLA*}}$	3.4	0.0$^{\text{LAMS*}}$	3.8	1.9	2.1	2.8
	Computerized scheduling	3.8	5.7$^{\text{ARLA**}}$	3.4	0.0$^{\text{LAMS*}}$	4.3	3.5	2.1	4
	Woodruff chart	0.9	1.3	0.7	0	0.5	1.2	2.1	0.7

Notes:

[a] ARMS: The difference between Arkansas (AR) and Mississippi (MS) is statistically significant.

[b] ARLA: The difference between Arkansas (AR) and Louisiana (LA) is statistically significant.

[c] LAMS: The difference between Louisiana (LA) and Mississippi (MS) is statistically significant.

[d] * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

[e] Source: 2016 Irrigation Survey

Table 2.2: *IBMP use patterns by sample producers in 2015*

N groups	Water Flow Control	Field Manage -ment	Water Recovery / Storage	Advanced Irrigation Scheduling	By state				Farm located inside or outside areas of groundwater concerns ^{a}		Producers' perception of groundwater shortage on own farms ^{b}	
					All	Arkansas	Mississippi	Louisiana	Inside	Outside	Shortage	No shortage
4	Yes	Yes	Yes	Yes	10	7.9^{ARLA*}	$18.2^{ARMS***}$	$2.2^{LAMS***}$	11.9	8.5	16.7	9.2
3	Yes	Yes	Yes		18.5	$29.7^{ARLA***}$	$8.8^{ARMS***}$	6.5	25.2	13.1^{***}	43.8	15.6^{***}
	Yes	Yes		Yes	10.2	4.8	$23.0^{ARMS***}$	$3.2^{LAMS***}$	7.1	12.7^{**}	4.2	10.9
		Yes	Yes	Yes	0.4	0.9	0	0	0.5	0.4	2.1	0.2*
	Yes		Yes	Yes	0.6	0.0^{ARLA**}	0.7	2.2	0	1.2	0	0.7
				Subtotal	29.8	$35.4^{ARLA***}$	32.4	$11.8^{LAMS***}$	32.9	27.3	50	27.5^{***}
2	Yes	Yes			27.2	26.2	24.3	34.4^{LAMS*}	28.1	26.5	6.3	29.6^{***}
		Yes	Yes		5.1	6.1	3.4	5.4	3.3	6.5	14.6	4.0^{***}
		Yes		Yes	0.4	0	0.7	1.1	0	0.8	0	0.5
	Yes		Yes		2.6	3.1	0.7	4.3^{LAMS*}	4.3	1.2^{**}	2.1	2.6
	Yes			Yes	2.3	1.7	4.7^{ARMS*}	0.0^{LAMS**}	0.5	3.8^{**}	0	2.6
			Yes	Yes	0.6	0	1.4^{ARMS*}	1.1	0	1.2	0	0.7
				Subtotal	38.3	37.1	35.1	46.2^{LAMS*}	36.2	40	22.9	40.0^{**}
1		Yes			8.7	8.7^{ARLA**}	3.4^{ARMS**}	$17.2^{LAMS***}$	8.6	8.8	4.2	9.2
	Yes				5.3	4.4^{ARLA**}	3.4	10.8^{LAMS**}	4.3	6.2	6.3	5.2
			Yes		1.7	2.2	2	0	0.5	2.7*	0	1.9
				Yes	0.2	0.4	0	0	0	0.4	0	0.2
				Subtotal	16	15.7^{ARLA**}	8.8^{ARMS*}	$28.0^{LAMS***}$	13.3	18.1	10.4	16.6
0					6	$3.9^{ARLA***}$	5.4	11.8^{LAMS*}	5.7	6.2	0	6.6^{*}
				Total	***100***							

Notes:

a. Indicates whether farm is located inside or outside areas of groundwater concern.

b. Indicates producers' perception of groundwater shortage on own farm.

c. ARMS: The difference between Arkansas (AR) and Mississippi (MS) is statistically significant.

d. ARLA: The difference between Arkansas (AR) and Louisiana (LA) is statistically significant.

e. LAMS: The difference between Louisiana (LA) and Mississippi (MS) is statistically significant.

f. * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

g. Source: 2016 Irrigation Survey

Table 2.3: *Correlations between irrigation technologies and IBMPs*

Groups of IBMP	Individual IBMP	Irrigation technologies			
		Flood	Border	Furrow	Center Pivot
Field management practices	Zero or Precision leveling	0.54***	0.20***	0.01	-0.16***
	Warped surface	0.02	0.02	0.16***	0.01
	End blocking	0.14**	0.15***	0.24***	-0.06
	Deep tillage	-0.12**	0.04	0.36***	0.18***
Water flow control practices	Multiple-inlet irrigation (rice)	0.46***	0.18***	0.03	-0.15***
	Alternate wetting and drying (rice)	0.14**	0.11*	-0.03	-0.05
	Computerized pipe-hole selection	-0.05	0.10*	0.32***	0.16***
	Surge irrigation	-0.02	0.05	0.14**	0.08
	Cutback irrigation	0.05	0.04	0.12**	-0.02
	Water flow meter	0.00	0.08	0.23***	0.10*
	Pump timer	-0.04	0.03	0.08	0.14**
Water recovery /storage	Tail-water recovery system	0.25***	0.13**	0.15***	-0.10*
	Storage reservoir	0.13**	0.08	0.07	-0.08
Advanced scheduling	Soil moisture sensor	-0.14**	0.01	0.17***	0.21***
	ET or Atmometer	0.03	0.01	0.08	0.06
	Computerized scheduling	0.01	0.01	0.04	0.08
	Woodruff chart	0.03	0.07	-0.02	0.03

Notes:

[a] * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

[b] Source: 2016 Irrigation Survey

Table 2.4: *Correlations among IBMPs*

IBMP	Field management practices				Water flow control practices						Water recovery /storage		Advanced scheduling		
	Grading	Warp	End	Till	Minlet	CHS	Surge	Cut	Meter	Timer	Tail-water	Reservoir	SoilMoiSt	Atmometer	Comp
Warped surface (Warp)	0.03	1.00													
End blocking (End)	0.17***	0.06	1.00												
Deep tillage (Till)	-0.12*	0.20***	0.18***	1.00											
Multiple-inlet irrigation (Minlet)	0.58***	0.09	0.19***	-0.05	1.00										
Alternate wetting and drying (AWD)	0.22***	-0.03	0.07	-0.06	0.29***	1.00									
Computerized pipe hole selection (CHS)	-0.03	0.08	0.11*	0.30***	-0.01	-0.02	1.00								
Surge irrigation (Surge)	-0.02	0.03	0.11*	0.10*	0.01	0.03	0.19***	1.00							
Cutback irrigation (Cut)	0.07	0.04	0.25***	0.07	0.06	-0.02	0.01	0.16***	1.00						
Water flow meter (Meter)	0.01	0.06	0.21***	0.29***	0.06	0.04	0.39***	0.15***	0.01	1.00					
Pump timer (Timer)	0.03	0.02	0.18***	0.12**	0.01	0.06	0.22***	0.16***	0.05	0.28***	1.00				
Tail-water recovery (Tail-water)	0.24***	0.08	0.21***	0.10*	0.25***	0.02	0.10*	0.15***	0.11*	0.22***	0.08	1.00			
Storage reservoir (Reservoir)	0.12*	0.06	0.15**	0.07	0.17***	-0.07	0.06	0.07	0.01	0.19***	0.07	0.62***	1.00		
Soil moisture sensor (SoilMoist)	-0.12*	-0.07	0.08	0.20***	-0.06	-0.04	0.42***	0.20***	0.03	0.40***	0.21***	0.09	0.12**	1.00	
ET or Atmometer (Atmometer)	0.07	0.09	0.12**	0.11*	0.04	0.02	0.16***	0.02	-0.01	0.15**	0.13**	0.01	0.04	0.19***	1.00
Computerized scheduling (Comp)	0.04	0.02	0.07	0.13**	0.00	-0.05	0.03	-0.04	0.04	0.06	0.08	-0.00	0.02	0.08	0.30***
Woodruff chart (Woodruff)	0.02	0.00	0.04	0.09	-0.01	-0.02	0.07	0.02	0.05	0.06	0.05	0.13**	0.15**	0.06	0.13**

Table 2.4 (Cont.)

Notes:

[a] * denotes statistical significance at 10%, ** statistical significance at 5% and *** statistical significance at 1%.

[b] Source: 2016 Irrigation Survey

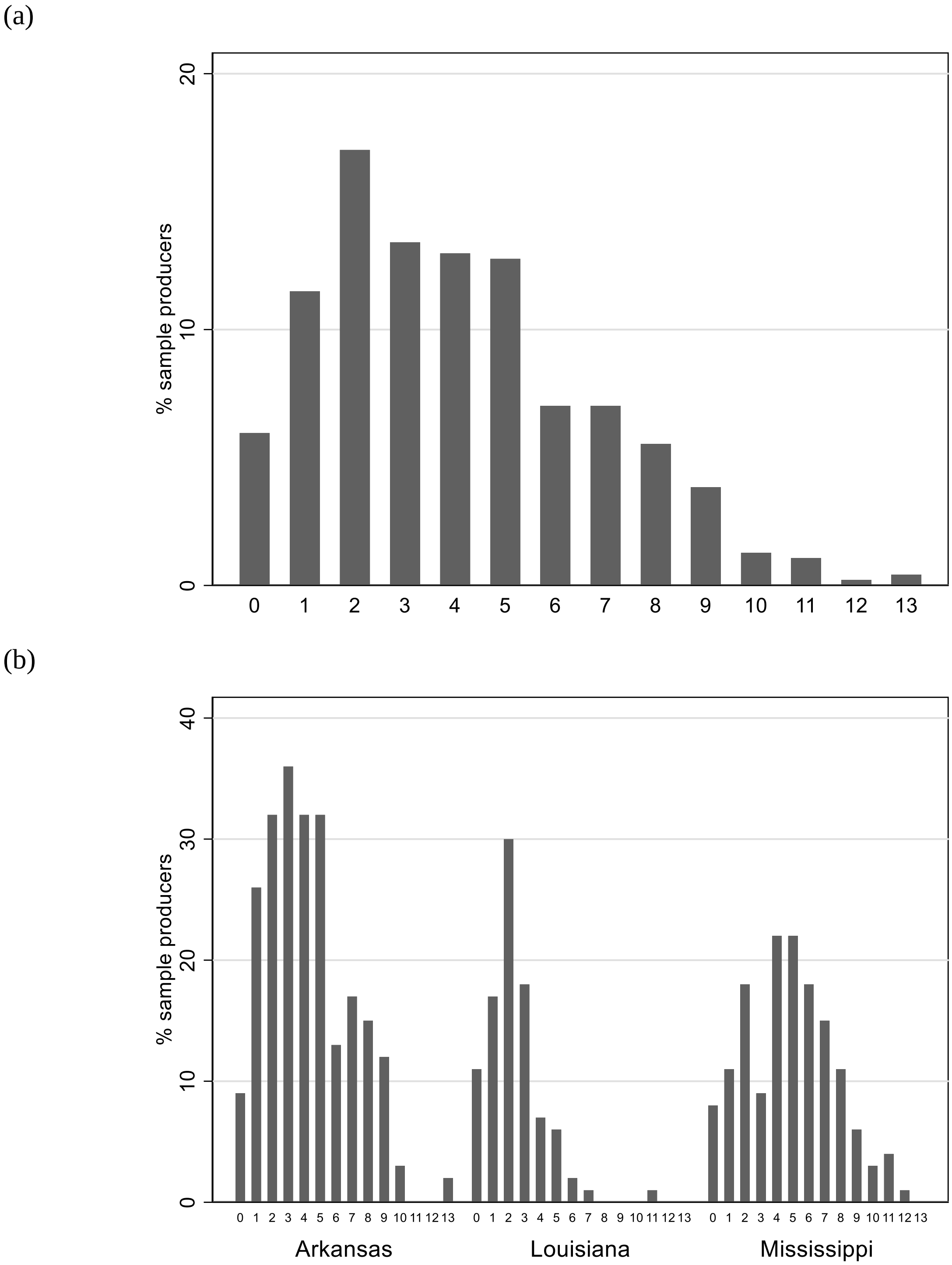


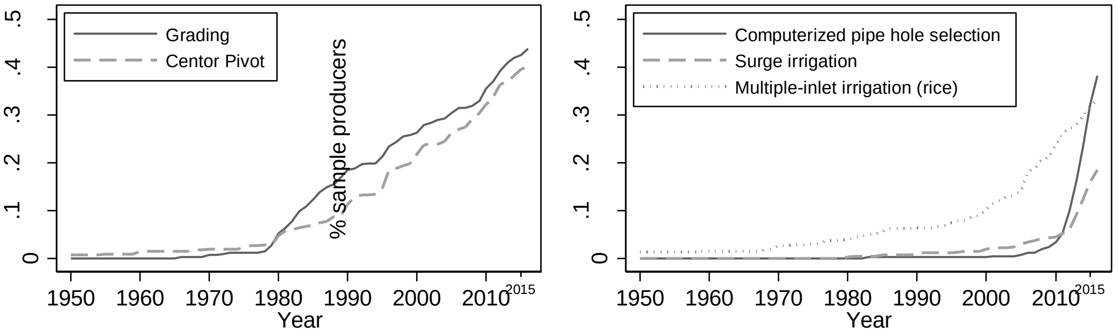
Figure 2.1: *Number of IBMPs used by sample producers in 2015*

Notes:

[a.] Panel (a) shows the percentage of all sample producers using *N* IBMPs.

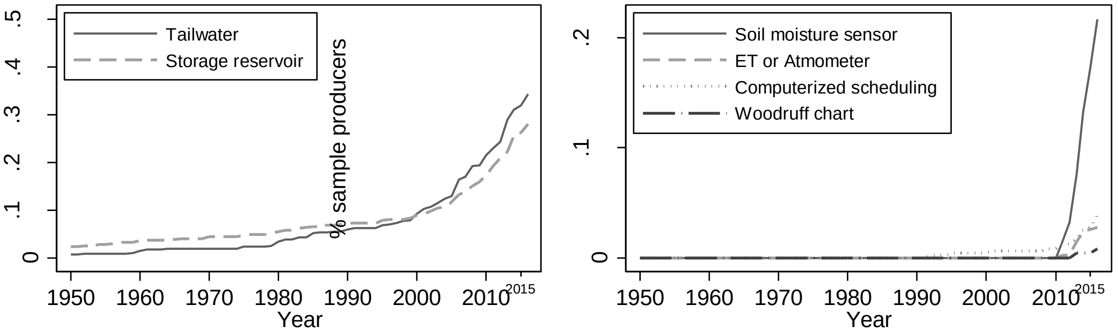
[b.] Panel (b) shows the percentage of sample producers using *N* IBMPs by state.

[c.] Source: 2016 Irrigation Survey (Henry et al., 2020)



Panel a. Center Pivot and Grading

Panel b. Water flow control practices



Panel c. Water storage practices

Panel d. Scheduling practices

Figure 2.2: *Use of irrigation technologies and IBMPs, 1950-2015*
Notes:

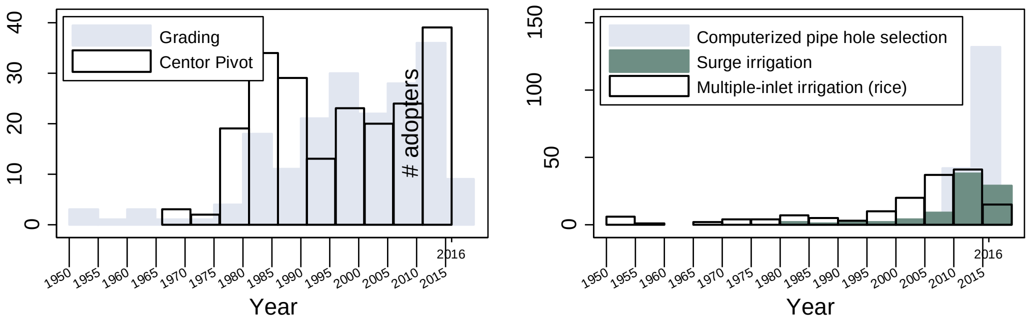
[a.] Panel (a) shows percentage of sample producers using center pivots and grading practices from 1950 to 2016.

[b.] Panel (b) shows percentage of sample producers using water flow control practices from 1950 to 2016.

[c.] Panel (a) shows percentage of sample producers using water recovery and storage from 1950 to 2016.

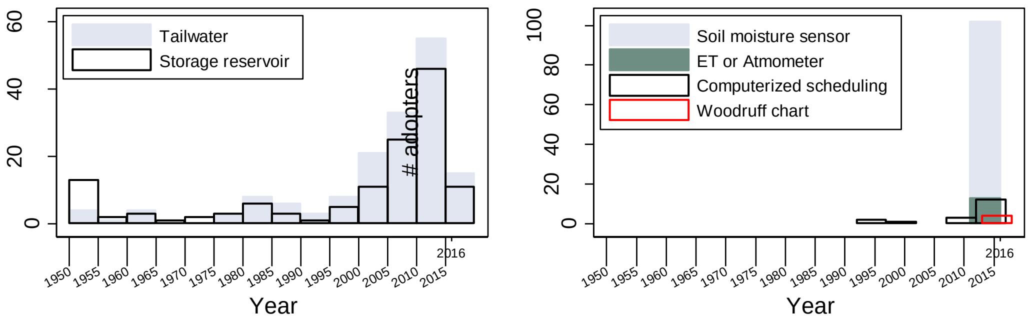
[d.] Panel (d) shows percentage of sample producers using advanced irrigation scheduling practices from 1950 to 2016.

[e.] Source: 2016 Irrigation Survey (Henry et al., 2020)



Panel a. Center Pivot and Grading

Panel b. Water flow control practices



Panel c. Water storage practices

Panel d. Scheduling practices

Figure 2.3: *Number of producers adopting IBMPs by year.*

Notes:

[a.] Panel (a) shows adoption of center pivots and grading practices from 1950 to 2016.

[b.] Panel (b) shows adoption of water flow control practices from 1950 to 2016.

[c.] Panel (a) shows adoption of water recovery and storage from 1950 to 2016.

[d.] Panel (d) shows adoption of advanced irrigation scheduling practices from 1950 to 2016.

[e.] Source: 2016 Irrigation Survey (Henry et al., 2020)

Chapter III. Influencing Factors of Irrigation Best Management Practices in Arkansas, Louisiana, and Mississippi

A. Introduction

Production agriculture is faced with many challenges. While trying to feed a growing population and sustain life in an ever-changing world, the longevity of natural resources is a mounting concern of producers and environmentalists alike. Soil and water conservation is an important part of preserving the resources needed in the production of crops and other agricultural commodities. The use of more efficient irrigation technologies and water management practices have been implemented all over the world in efforts to conserve water resources, which are vital in crop production and other agricultural enterprises. However, implementation of new technologies and practices can sometimes be costly, profitability is a concern for producers. Though it might be intuitive to assume that producers will adopt practices that increase profitability, this is not always the case. This implies that there are important factors other than price and profit that influence producers' decisions (Quintana-Ashwell et. al., 2020). In order to encourage the long-term use of best management practices, it is important to understand why producers choose to use them in the first place.

The economics literature investigating the factors that drive farmers' decisions regarding water resources focuses largely on the adoption of irrigation technologies rather than water management practices. Studies concerning the adoption of irrigation best management practices tend to produce conflicting results, likely due to the irregularities in socio-economic factors, as well as the variation in practices that are suitable for specific regions. Some studies suggest that being a landowner and having a higher household income will increase the likelihood of adoption (Karidjo et al., 2018), while others report mixed results (Mariano et al., 2012). Producer characteristics such as age and education have also been shown to have mixed effects on producer decisions (Mutua-Mutuku et al, 2017; Nian et al., 2020; Manyeki et al, 2013; Bett, 2004). One study performed in Canada suggests that farmers who rely more on on-farm income are more likely to adopt management practices than those who rely on off-farm income (Bjornlund et al., 2009). Many studies concerning water management in the United States have been done using data collected primarily in the Southwestern states, where water scarcity is a greater concern due to population growth, severe droughts, and rising temperatures (Mpanga and Idowu, 2021). In the southern United States, it has been found that irrigated yield and weather variation were also statistically significant factors in explaining the adoption of water management practices by cotton producers (Pokhrel et al., 2018).

There are many factors that could potentially influence producers' decisions regarding the use of irrigation technologies and water management practices. These include socio-economic factors such as farm or household income and level of education, as well as farming experience. Other factors such as suitability of the environment may also impact a producer's choice in IBMPs. For example, areas with predominately clay soils are not ideal for the use of center pivot irrigation, as the heavy systems can often become stuck in the soil (Bryant et al., 2020). Consideration of soil type and other environmental factors also play a role in the producer's choice of crop production, which in turn could have an impact on choice of irrigation technologies and IBMPs used. The use of more cost-effective practices such as furrow irrigation and precision grade leveling is often more suitable in the LMRB (Bryant et al., 2020).

Although there is ample research on how different factors can influence producer decisions, relatively few economics studies have been conducted in the Lower Mississippi River Valley. Huang et al. (2016), Knapp and Huang (2017), and Nian et al (2020) observe the influencing factors concerning choice in IBMPS by producers in Arkansas, and Quintana-Ashwell et al. (2020) observes the adoption of water conserving irrigation practices in Mississippi. However, none have evaluated use patterns and analyzed influencing factors in multiple states throughout the entire Mississippi Delta. Additionally, this study aims to identify factors that might influence producers' decisions among individual IBMPs within different IBMP groups.

In the past two decades, the total number of irrigated acres in the Lower Mississippi Delta has considerably increased, even surpassing the total number of irrigated acres in the Southern Plains region (Schaible and Aillery 2012). The Lower Mississippi Alluvial Valley is an area which relies heavily on agricultural production to sustain its economy and is considered the largest floodplain in the United States. 85% of this area is located within Arkansas, Louisiana, and Mississippi (Yang et al., 2019). Underlying this area is the Mississippi River Valley Alluvial Aquifer, which supplies the majority of the groundwater to the region. Almost 90% of the groundwater pumped from the MRVAA is used for irrigation in the LMRB (Reba and Massey, 2020). Groundwater pumping rates for the MRVAA are currently unsustainable (Reba and Massey, 2020). Previous studies suggest that overusing water resources for irrigation purposes might result in a net benefit today but will inevitably cause irreversible damage to the environment and decrease net benefits for future generations (Yaserer et al., 2020).

The objectives of this study are to identify influencing factors in producer decision regarding which IBMPs are used and how many IBMPs are used. The following sections of this chapter describe the data set and study area, discuss empirical methods and models, present estimation results, and conclude with policy implications.

B. Materials and Methods

Data

The primary dataset used in this chapter is the 2016 Irrigation Survey, which collected data from producers in Arkansas, Louisiana, Mississippi, and Missouri (Henry et al., 2020). The survey was part of the United Soybean Board Irrigation Project which was funded by the United Soybean Board and the Mid-south Soybean Board (Henry et al., 2020). Enumerators collected the data via a phone survey which asked producers about their use of irrigation technologies and water management practices in crop production. For this analysis, the final sample includes 229 observations from Arkansas, 93 observations from Louisiana, and 148 observations from Mississippi.

The dataset used in this study consists of information on the use of irrigation technologies and water management practices used by producers in each state. Other practices used in these states are unique to the mid-south and were not documented in the 2016 Irrigation Survey (Henry et al., 2020). The data allows us to identify and analyze patterns of IBMP use across the Lower Mississippi River Basin. The irrigation management practices observed in this study can be categorized as: water flow control practices, water recovery/storage practices, field management practices, and advanced irrigation scheduling practices. This is the same classification method used by Nian et al. (2020).

Field management practices consist of zero and precision grade leveling, warped surface leveling, end blocking, and deep tillage. Leveling practices involve grading the field to a desired slope of 0% or another specified slope, or using GPS enabled equipment to adjust grading for the contour of the field, as in warped surface. Zero grade leveling systems are associated with some of the lowest water application rates (Massey et al., 2017). Precision grading is a common practice used in both soybean and corn production (Massey et al., 2017). End blocking involves blocking the low ends of furrows to keep water from running off the field. This system allows for the reduction of water application but can also have negative impacts such as chemical leaching and poor infiltration (Kandpal et al., 2018). Water flow control practices include multiple inlet irrigation, computerized hole-selection, surge irrigation, and cutback irrigation. Computerized hole-selection software allows for the even distribution of water down rows through the computation of water flows and pressures (Bryant et al., 2017) and is considered one of the simplest upgrades to irrigation systems already in place (Quintana-Ashwell et al.., 2020). Surge irrigation has been shown to improve the efficiency of gravity irrigation and increase uniformity in water distribution on fields (Adusumilli et al. 2016). Water recovery and storage practices include tail-water recovery systems and on-farm storage reservoirs. These two practices are often used simultaneously to collect and reallocate surface water runoff (Omer, 2017). Advanced irrigation scheduling practices include soil moisture sensors, atmometers, computerized scheduling, and Woodruff charts. An atmometer is a water filled tube that is placed into a field and provides evapotranspiration information as the water level drops to marked levels on the tube. Woodruff charts use a variety of information such as crop type, soil type, and irrigation method to draw a paper chart that estimates soil moisture (Nian et al., 2020).

Table 3.1 reports use of irrigation best management practice by sample producers in 2015. Field management practices are the most widely used practices, with 40.2% of sample producers using land leveling and 51.5% using deep tillage. 41.7% of sample producers reported using flow meters and 38.1% used computerized pipe-hole selection. Advanced irrigation scheduling practices are the least used among sample producers, with less than 4% using computerized scheduling or atmometers and less than 1% using Woodruff charts. However, 21.7% of producers reported using soil moisture sensors. Figure 3.1 shows the use patterns of sample producers using irrigation best management practices and groups in 2015. Panel (a) reports the number of groups used by sample producers. Nearly 80% of producers reported using two or more groups, and less than 10% reported using none. Panel (b) shows the number of individual practices used by sample producers. The majority of sample producers reported using between one and five water management practices. This suggests that producers often use several irrigation best management practices, managing multiple aspects of irrigation. Very few producers report using more than nine practices. Panel (c) shows that producers tend to use one or two water flow IBMPs. Panel (d) shows that most producers do not use any water recovery and storage practices. Those that do tend to use two practices more often than one. This is most likely because tail-water recovery systems and storage reservoirs are often used in conjunction with one another. Panel (e) shows that a greater share of producers use one or two field management practices versus three or four. Panel (f) shows that the vast majority (>70%) of producers use zero advanced irrigation scheduling practices.

Models for Use of IBMPs

The adoption and use of agricultural best management decisions are often modeled using random utility framework in economics (McFadden, 1981). Here, we utilize this framework to model the producer decisions concerning the use of irrigation best management practices. Let i represent a utility-maximizing producer, and let g represent a group of IBMPs. If the utility obtained from using IBMPs from group g (U_{ig}) is greater than the utility obtained from not using IBMPs from group g (U_{iNg}), then the producer will choose to adopt. The utilities are unobservable characteristics, making the net benefit to the producer a latent variable:$y_{ig}^{*} = U_{ig} -$

$U_{iNg} > 0$. The latent variable y_{ig}^* is a function of the observable characteristics ($\mathbf{x}_i$) and an error term (u_{ig}). Since in the study area, multiple groups of IBMPs are available to producers, producer decisions regarding any group of IBMPs is not likely made in isolation. Therefore, it is not appropriate to use a single equation model for each group of IBMPs. Producer choices among the four groups of IBMPs are estimated simultaneously using a system of equations. A multivariate probit model is used:

$$
\begin{aligned}
&y_{ig}^* = \mathbf{x}_i'\boldsymbol{\beta}_g + u_{ig}, \qquad g = 1,2,3,4 \\
&Y_{ig} = 1 \; if \; y_{ig}^* > 0 \\
&Y_{ig} = 0 \; if \; y_{ig}^* \leq 0
\end{aligned}
\tag{1}
$$

A multivariate probit model is also used to estimate producer choices among nine individual irrigation best management practices. Let *p* represent a specific IBMP. If the utility obtained from using practice *p*, U_{ip}, is greater than the utility obtained from not using practice *p*, U_{iNp}, then the producer will choose to adopt. The utilities are unobservable characteristics, making the net benefit to the producer a latent variable: $m_{ip}^* = U_{ip} – U_{iNp} > 0$. The latent variable m_{ip}^* is a function of the observable characteristics ($\mathbf{x}_i$) and an error term e_{ip}. Again, because it is likely that decisions concerning the use of an individual IBMP are correlated with those regarding other IBMPs, a single equation model is not appropriate. The multivariate probit model estimates decisions regarding nine practices simultaneously in a system of equations.

$$
\begin{aligned}
&m_{ip}^* = \mathbf{x}_i' \, \boldsymbol{\gamma}_p + e_{ip}, \qquad p = 1,2,3,4,5,6,7,8,9 \\
&M_{ig} = 1 \; if \; m_{ip}^* > 0 \\
&M_{ig} = 0 \; if \; m_{ip}^* \leq 0
\end{aligned}
\tag{2}
$$

The random utility framework is also used to model producers' choices of the number of groups of IBMPs. The ordered model has a latent variable N_i^* and the observed number of groups of IBMPs used N_i.

$$\begin{aligned} N_i^* &= \mathbf{x}_i^{\prime}\,\boldsymbol{\delta} + \varepsilon_i \\ N_i &= n \quad if \;\; s_{n-1} \leq N_i^* \leq s_n \end{aligned} \tag{3}$$

where s_n is the cut-off points. If the error term ε_i is logistically distributed with the CDF: $F(z) = e^z / (1+e^z)$, then (3) represent an ordered logit model. The marginal effect of the k^{th} explanatory variable, x_{ik}, on the number of IBMPs groups used is computed as:

$$\frac{\partial P(N_i=n)}{\partial x_{ik}} = [F'(s_{n-1} - \mathbf{x}_i'\boldsymbol{\delta}) - F'(s_n - \mathbf{x}_i'\boldsymbol{\delta})]\delta_{ik}$$

One of the potential drawbacks of the ordered logit model is that parameters in $\boldsymbol{\delta}$ are assumed to be the same for each value of N_i. Wald tests are performed to test the null hypotheses that δ_{ik}s are equal across each value of N_i. The tests for most explanatory variables generated large *p*-values, except for four variables. The generalized ordered logit models are also estimated using the STATA command **`gologit2`** (Williams, 2006), in which the constraints of equal parameters across all values of N_i are relaxed for these four variables. Another option is to treat N_i as a multinomial instead of ordinal outcome and estimate a multinomial logit model. This will increase the number of parameters by four folds since there is a set of parameters for each alternative of N_i (0, 1, 2, 3, 4, 5). The estimated coefficients as well as marginal effects across the three models, (ordered logit, generalized logit and multinomial logit) are consistent with small differences for a few variables. In this study, we used AIC to determine that ordered logit is the best fit model.

Ordered logit models with fixed effects at the county level are also estimated using the STATA command **`feologit`** (Baetschmann et al., 2020). The estimated coefficients are consistent between the ordered logit model with or without fixed effects model. The estimated coefficients of a few explanatory variables are statistically significant in the ordered logit model but lose their statistical significance when fixed effects are added. This is not surprising since fixed effects models only using variations within county in estimation. County level fixed effects models control for any unobserved characteristics that do not vary at the county level. As a result, variables such as rates of conservation program participations at the county level and soil type are removed from the regression because they do not vary within the same county. In addition, since the county fixed effects are not directly estimated, marginal effects cannot be estimated. These considerations have led to the decision of only reporting the results from the ordered logit models.

Ordered logit models are also used several other variables of interest: the total number of IBMPs used, the number of water flow control IBMPs used, the number of field management IBMPs used, the number of water recovery/storage IBMPs used, and the number of advanced scheduling IBMPs used.

Selection of Explanatory Variables

The explanatory variables used in this study are similar to those used in previous studies, such as Nian et al. (2020) and Quintana-Ashwell et al. (2020). Unlike the aforementioned studies, however, weather variables and fuel sources are not measured because these variables do not vary much across the three states included in the study. Summary statistics and descriptions of each variable used in this study are provided in Table 3.2. Explanatory variables can be divided into three categories: producer characteristics, farm characteristics, and conservation variables.

The first category of explanatory variables describes characteristics of the sample producers. Dummy variables were used to indicate whether the producer is a landowner and operator (versus operator only), whether the producer has formal education at the level of a bachelor’s degree or above, and whether the producer has any formal education related to agriculture. Dummy variables were also used to differentiate between producers earning an annual income greater than $100,000 less than $100,000. The base group for income consists of those who either did not know or refused to report income, which is about 28.5% of the sample producers. Years of farming experience a producer has is also included. Most sample producers (80%) are landowners and operators. On average, the sample producers have 31 years of farming experience. Being a landowner might increase the likelihood that a producer will adopt new irrigation technologies or water management practices. While there are potential short-term benefits, such as increased yield, decreased water use, and increased profits, there are also potential long-term benefits such as increased land value. Years of farming experience may increase or decrease likelihood of using IBMPs. On one hand, producers who have many years of farming experience and have used IBMPs for a long period of time are likely to continue using those and even adopt similar practices. On the other hand, years of farming experience is highly correlated with age of the producer and could decrease the likelihood of a producer adopting more complex IBMPs and advanced technologies with which they are unfamiliar (Koundouri et al., 2006; Olen et al., 2016). On average, 76% of producers have at least a bachelor’s degree, and 50% have formal education related to agriculture. Producers who are more educated might be better able to understand the benefits of new irrigation technologies and IBMPs and how they work, and therefore, might be more likely to adopt such practices. On average, 36% of producers earn more than $100,000 and 36% of producers earn less than

$100,000 annually. Higher levels of income could be positively correlated with the adoption of IBMPs because producers would have more access to liquid assets and more capital to invest in new technologies and practices.

Farm characteristics include total irrigated acres, the percentage of irrigated acres in corn and rice, the percentage of irrigated acres with gravity irrigation systems, and the percentage of irrigation water from a groundwater source. Larger operations with more irrigated acres may benefit more than smaller operations with fewer irrigated acres due to economies of scale. Sources of water for irrigation and use of gravity irrigation are helpful determinants of how beneficial certain IBMPs will be. For example, IBMPs that catch or stop surface runoff, such as tail-water recovery systems and end blocking, will be more effective on gravity irrigated fields. However, the same IBMPs that collect and redistribute surface water are also likely to be less beneficial if groundwater is the main source of irrigation supply. Shares of irrigated acres in soybean or cotton were not included here due to their high correlations with those of corn and rice. Dummy variables were used to indicate whether the producer owns a flow meter, and whether pumps had timers.

The third category of explanatory variables is conservation variables. The first two variables measure the need for saving water. A dummy variable was constructed using producers' answers to the survey question "In your opinion, do you have a groundwater shortage problem on your farm?" Only 10% of sample producers answered YES to this question. Producers who are concerned about groundwater shortage in their own farms and/or farm in counties with critical groundwater shortages might be more likely to adopt such practices in an attempt to quell water shortage. An alternative dummy variable was constructed to indicate whether a sample county is located in areas of groundwater concerns designated by water management authorities in each state.[1] In sharp contrast to producers' perception of groundwater shortage on their farms, 45% of sample producers are located in areas of groundwater concerns. The second set of variables in this category measure the prevalence of conservation programs such as Conservation Reserve Program, Environmental Quality Incentives Program, Conservation Stewardship Program, and Regional Conservation Partnership Program with Natural Resources Conservation Service. The percentage of sample producers that participated in one or more of these programs at the county level is used. Conservation programs offer educational information and insights on the benefits of using irrigation best management practices. Those that also offer tax credits or other incentives to adopt can also increase the likelihood of IBMP adoption for producers within the applicable county or region.

Lastly, Dummy variables are used to indicate which state the farm is located in. This will help capture any characteristics that do not vary at the state level. One such important variable is the extent of groundwater regulations and implementation efforts. Since soil is an important consideration is in water management, a variable is included to measure county averages of the percentage of soil that is clay.

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[1] In Arkansas, three critical groundwater areas covering the main regional cones of depression in the Mississippi River Valley alluvial and the Sparta aquifers have been designated. The Grand Prairie critical groundwater area, designated in 1998, includes Arkansas, Jefferson, and Prairie Counties and parts of Lonoke, Pulaski, and White Counties (Arkansas Natural Resources Commission, 1998). The Cache critical groundwater area, designated in 2009, includes Clay, Craighead, Cross, Greene, Lee, Poinsett, and St. Francis Counties lying west of Crowleys Ridge as well as Phillips and Monroe Counties (Arkansas Natural Resources Commission, 2009). The South Arkansas critical groundwater area, designated in 1996 includes Bradley, Calhoun, Columbia, Ouachita, and Union Counties. Since the 1996 designation, education, conservation, and development and usage of excess surface water have caused water levels within the areas to stabilize or rise (Arkansas Natural Resources Commission, 1996). In Mississippi, counties located in the cones of depression that have developed in the Mississippi delta region are considered areas of concerns (Barlow and Clark, 2011). In Louisiana, several counties in the Sparta aquifer have been declared to be areas of groundwater concerns (State of Louisiana Office of Conservation, 2005). In addition, water level declines have been as much as one to two feet per year in the Chicot aquifer in southwest Louisiana, which is the largest provider of groundwater of the state (Tomaszewski, 2011).

C. Estimation Results

This section reports two sets of estimation results. The first sub-section reports estimation results of models on producers' choice among different IBMP groups as well as among individual IBMPs. The second sub-section reports estimation results of models on producer decision concerning how many IBMPs to use. This includes the number of groups of IBMPs used, the total number of individual IBMPs used, and the number of IBMPs used from each IBMP group.

Factors Related to Which IBMPs Are Used

Multivariate probit models of producers' choices among IBMPs are estimated with the STATA command **`mvprobit`** (Capellari and Jenkins, 2003). Table 3.3 reports the multivariate probit models of choices among four IBMP groups: water flow control practices, water recovery/storage, field management and advanced scheduling practices. Since the grouping of IBMPs into different aspects of irrigation management is done by the authors, not by producers explicitly, analyzing individual IBMP may generate additional insights. Table 3.4 reports the multivariate probit model of nine individual IBMPs. Some IBMPs such as alternate wetting and drying and computerized scheduling are only used by a few producers (Table 3.1) and thus are not included in Table 3.4. The use of tail-water recovery systems and that of on-farm reservoirs are highly correlated with a correlation coefficient of 0.62. Since they are often used together, separating them into individual IBMPs does not generate any additional insights. Because of this, the results on tail-water recovery systems and/or on-farm reservoirs are similar across Tables 3.3 and 3.4.

In both Tables 3.3 and 3.4, the null hypothesis that all regression coefficients are jointly zero is rejected by the near zero *p*-value of the Wald test. In both Tables, correlation matrices, reported at the bottom, support the joint estimation of IBMP groups and individual IBMPs. Table 3.3 shows a positive and statistically significant correlation between the water flow control group and the field management group. Table 3.4 shows this may be due to the strong correlation between multiple inlet irrigation and IBMPs such as grading and end blocking. This is consistent with the recommendation that multiple inlet irrigation is more easily managed on precision graded fields (Henry et al. 2018). Table 3.3 reveals a positive and statistically significant correlation between the water flow control group and the advanced irrigation scheduling group. Table 3.4 shows that this is driven by the positive correlations between soil moisture sensor and computerized hole selection and surge irrigation. This is consistent with previous findings including Spencer et al. (2019) that the integrated use of computerized hole selection, surge irrigation, and irrigation scheduling based on soil moisture sensors reduced total water applied by almost 40% while increasing corn grain yield. Both Tables 3.3 and 3.4 also point to a positive correlation between water recovery and storage practices and advanced irrigation scheduling practices.

In probit models, the signs of the estimated coefficients would be the same as the signs of marginal effects of the same explanatory variable. Therefore, we focus only on the signs and levels of statistical significance of coefficients. In addition, because we lack sufficient data to estimate the causal effects of any explanatory variables on the use of IBMPS, we refrain from making any causal claims. A positive (negative) coefficient indicates a positive (negative) correlation between an explanatory variable and the dependent variable.

Results show that some characteristics of producers are associated with their choices of IBMPs. There are no statistically significant correlations between the use of IBMPs and being a landowner (Tables 3.3 and 3.4). The coefficients of years of farming experience is negative and statistically significant in the equations for water flow control and advanced irrigation scheduling practices (Table 3.3). This is supported by the negative and statistically significant correlations between years of farming experience and computerized hole selection (CHS), surge irrigation and the use of soil moisture sensor in Table 3.4. More experienced producers are likely better at timing irrigation based on weather, crop and soil conditions without the aid of devices such as CHS or soil moister sensor. More experienced producers also tend to be older producers who may be less familiar with newer technologies. Younger producers, on the other hand, may benefit more from advanced scheduling practices and are more likely to be open-minded about new technologies. The coefficients of the two education variables are positive but are not statistically significant in any equation (Table 3.3). Table 3.4 shows that education is relevant for some IBMPs. This may be attributed to the positive correlation between education and the use of computerized pipe-hole selection. Having a Bachelor's or above degree and or having formal education relating to agriculture are positively correlated with the use of CHS. The latter is also positively correlated with the use of multiple inlet irrigation. We do not have good explanations why having agriculture-related education is associated with some IBMPs but not others. Choices of IBMP groups do not seem to vary with levels of income (Table 3.3). However, Table 3 shows that producers with lower income (income less than $100,000) are more likely to use multiple inlet irrigation. This income effect also needs further exploration.

Characteristics of farm seem to play a more important role in the choices of IBMPs. The coefficients for total irrigated acres is positive and statistically significant in all four equations of

IBMP groups (Table 3.3). Its coefficients are also positive and statistically in six out of nine IBMP equations in Table 3.4. Crop mix also matters. The percentage of irrigated acres in rice is positively correlated with the use of water flow control and field management practices (Table 3.3). Table 3.4 reveals positive correlations between rice irrigated acreage and water flow IBMPs such as multiple inlet irrigation and field management IBMPs such as zero or precision grading. This is consistent with the recommendations for rice irrigation in the study areas (e.g., Henry et al. 2013). Using data from the University of Arkansas' rice research and verification trials conducted between 2005 and 2012, Henry et al. (2016) reported that Arkansas rice producers with zero-grade systems had the lowest irrigation application rates. The negative association with CHS is probably because CHS is used often with furrow irrigation and flood irrigation is still the dominant way to irrigate rice in the sample areas. Although the percentage of irrigated acres in corn does not have strong correlations with the choice of IBMP groups (Table 3.3), it is positively correlated with the use of surge irrigation and negatively correlated with the use of grading IBMPs (Table 3.4). In both Mississippi and Louisiana, data from corn demonstration plots have shown that using surge value reduced irrigation costs relative to continuous irrigation while also improving yields (Krutz, 2014; Burns, 2014). The negative correlation with grading is a bit puzzling and calls for further investigation.

Irrigation systems also matter. The share of irrigated acres that use gravity irrigation is positively correlated with the use of water recovery and storage practices (Tables 3.3 and 3.4). This makes sense because such practices are utilized to collect and store irrigation runoffs from gravity irrigation for future irrigation (Omer, 2017). The results also reveal a positive and statistically significant correlation between gravity irrigation and field management practices (Table 3.3), especially grading and end blocking (Table 3.4). This is consistent with the observed trend of using raised beds on precision-leveled cropland in the mid-south region (Massey et al., 2017). Gravity irrigation is also strong correlated with the use of multiple inlet irrigation (Table 3.4). This is not surprising given that multiple inlet has long been promoted as a key tool for improving irrigation efficiency in rice (Vories et al., 2005). The share of irrigation water supplied by groundwater is negatively correlated with the use of water recovery and storage practices and is positively correlated with the use of field management practices (Table 3.3).

One of the most significant results is the positive and statistically significant correlations between having water flow meters and all four groups of IBMPs (Table 3.3). The coefficients of water flow meters and positive for all nine IBMPs and statistically significant for five of them (Table 3.4). Water flow meters allow producers to keep track of the quantity of water used on farm. Such knowledge can motivate producers to cut down water use if meter readings revealed much higher levels of water use than what producers thought they were using. It may also be that producers who use IBMPs tend to install water flow meters to aid the operation of IBMPs or to measure the performance of IBMPs. We do not have data that can provide evidence to substantiate any causal effects. However, our results show that water flow meters are important part of irrigation water management. The coefficient for having a timer on pumps is positive in the equation for use of water flow control practices (Table 3.3), especially CHS and surge irrigation (Table 3.4). This makes sense because the purpose of a timer is to control the flow of water out of pumps. Using a pump timer can boost the effectiveness of other water flow IBMPs.

The perception of groundwater shortage on farm is positively related to the use of some groups of IBMPs but not all. If a producer thinks there is a groundwater shortage on his/her farm, he/she is more likely to use water recovery systems and/or on-farm reservoirs (Tables 3.3 and 3.4). This makes sense since such practices allow producers to hedge again the risks of future groundwater shortages. The producer is also more likely to use field management practices (Table 3.3), especially precision grading (Table 3.4). The producer is not more likely to use water flow control or advanced scheduling IBMPs. This is an interesting finding because the costs of water recovery systems and/or on-farm reservoirs and field management practices such as grading are generally higher than water flow control practices or scheduling devices. Another important finding is that producers located in critical groundwater areas are no more likely to use any groups of IBMPs than producers elsewhere (Tables 3.3 and 3.4). Furthermore, the coefficient of the dummy variable indicating critical groundwater areas is negative and statistically significant in the equation for advanced irrigation scheduling practices (Table 3.3).

Among all the conservation programs, the Environmental Quality Incentives Program (EQIP) is probably the most relevant because some of its programs target water management practices directly. For example, the Arkansas Groundwater Initiative targets the issue of declining aquifer levels and provides both financial and technical assistance through EQIP to producers in seven Arkansas counties that adopt IBMP practices such as land grading, tail-water recovery pits and reservoirs (USDA, 2019). The Mississippi Water Conservation Management Project was also funded through EQIP to incentivize the adoption of irrigation water management practices such as Phaucet, pump timers, surge irrigation, pump automation, soil moisture sensors, side inlet irrigation, and flowmeters (Crop Protection News Reports, 2015). Our estimation results support the argument that EQIP programs have increased IBMP uses. The coefficients of the percentage of producers participating in EQIP at the county level is positive in all four equations for IBMP groups, although it is only statistically significant in the equation for advanced irrigation scheduling practices (Table 3.3). Table 3.4 shows that higher participation rates in EQIP programs are strongly correlated with increased uses of surge irrigation, warped surface, deep tillage and soil moisture sensor. The percentage of producers participating in the Conservation Stewardship Program (CSP) at the county level is also positively associated with the use of water flow control practices (Table 3.3), especially surge irrigation. This result is a bit puzzling since CSP does not provide assistance for any water flow control IBMPs.

Some differences in the choice of IBMPs are observed across states. Since Arkansas serves as the base group, the coefficients of the state dummy variables represent the differences between Arkansas and Mississippi or Louisiana, respectively. The differences between Mississippi and Louisiana are analyzed through *t* tests of the two state dummies. Both Tables 3.3 and 3.4 show that producers in Louisiana are less likely to employ IBMPs than their counterparts in Arkansas and Mississippi. Producers in Mississippi are more likely to use advanced irrigation scheduling practices than those in Arkansas and Louisiana. No difference is observed regarding the likelihood to use water flow control practices. The percentage of the soil that is clay does not seem to correlate with the choices of IBMPs.

Factors Related to How Many IBMPs Are Used

Table 3.5 reports the Ordered Logit models of six categorical dependent variables that measure the number of IBMPs used: the number of IBMP groups used, the total number of individual IBMP used, the number of water flow control IBMPs used, the number of water recovery/storage IBMPs used, the number of field management IBMPs used, and the number of advanced scheduling IBMPs used. The average marginal effects of these models are reported in Appendices 1-6. For all six models, the directions of the average marginal effects are consistent with the signs of the estimated coefficient in the Ordered Logit. For example, the positive and statistically significant coefficient of the irrigated acres variable in the model for the number of

IBMP groups used (*N*, Table 3.5, column 1) means the average marginal effects of irrigated acres (Appendix 1) are negative on the probability of using a small number of groups (*N*=0, 1, 2) and positive on the probability of using a larger number of groups (*N*= 3, 4). The negative and statistically significant coefficient of the Louisiana dummy variable (Table 3.5, column 1) means the average marginal effects of being in Louisiana (Appendix 1) are positive on the probability of using a small number of groups and negative on the probability of using a larger number of groups with the same turning point for N ($N \leq 2$ versus $N \geq 3$). The same patterns apply to other models (Table 3.5, columns 2-6) but with different turning points for *N*. For example, for the total number of individual IBMP used (Table 3.5. Column 2 and Appendix 2), the turning point is $N \leq 3$ versus $N \geq 4$. Because of this, we only report the estimated coefficients in Table 3.5 since they are easier to compare across different models and only focus on the signs and the levels of statistical significance.

The coefficients of most explanatory variables have the same signs and levels of statistical significance between the regression for the number of IBMP groups (Table 3.5, column 1) and the regression for the total number of IBMPs used (column 2). The sizes of most coefficients are also within the same order of magnitude. Larger irrigated acres, a larger share of irrigated acres allocated to rice, a larger share of irrigated acres under gravity irrigation, the use of water flow meters, the use of pump timers, perception of groundwater shortage on farm, and a higher rate of participation in EQIP programs are the factors that have positive and statistically significant correlations with using more IBMP groups as well as more individual IBMPs. The coefficients of having a Bachelor’s or above degree and a larger share of irrigated acres allocated to corn are positive in both columns 1 and 2 but are only statistically significant for the number of IBMP groups used. Producers in Louisiana are associated with lower number of IBMP groups and individual IBMPs. Many results make sense. For example, the positive correlation between IBMP uses and irrigated acres could be due to economies of scale: the more irrigated acres a producer has, the lower the cost per unit (per acre) of implementing the irrigation best management practice, and thus, the marginal benefit is greater. More irrigated acres could also be closely related to more fields. As the landscape of fields tends to differ, so do the water needs and the practices that are appropriate for each field. A greater variety of IBMPs means that the producer will likely need to use IBMPs from different groups. Having agriculture-related education and being in areas of groundwater critical areas do not seem to be associated with more IBMP uses.

The coefficients of larger irrigated acres and the use of water flow meters are positive and statistically significant for the number of water flow control IBMPs used (Table 3.5, columns 3), the number of water recovery/storage IBMPs used (column 4), the number of field management IBMPs used (column 5), and the number of advanced scheduling IBMPs used (column 6). The coefficient of producers in Louisiana is negative for number of IBMPs in all four groups but is not statistically significant for number of advanced scheduling IBMPs (Table 3.5, column 6). This means that producers in Louisiana are associated with using a lower number of water flow, recovery and storage, and field management IBMPs.

The coefficients of having a Bachelor’s or above degree, larger irrigated acres, a larger share of irrigated acres allocated to rice, the use of water flow meters, and the use of pump timers are positive and significant for the number of water flow IBMPs used (Table 3.5, column 3). The coefficient for more years of farming experience is negative. Producers in Louisiana are associated with a lower number of water flow IBMPs. The coefficients of perception of groundwater shortage on farm and location of farm in a critical groundwater area are positive and significant for the number of water recovery and storage IBMPs (Table 3.5, column 4). These results make sense. Tail-water recovery systems and on-farm storage reservoirs capture excess surface water for use and can reduce groundwater pumping. The coefficients of a larger share of irrigated acres allocated to rice and the use of water flow meters are positive and significant for the number of field management IBMPs (Table 3.5, column 5). The coefficient of a larger share of irrigated acres under gravity irrigation is positive and statistically significant in columns 4 and 5. Producers in Mississippi are associated with a higher number of advanced irrigation scheduling IBMPs (Table 3.5, column 6). This is not surprising, as producers in Mississippi have access to advanced irrigation tools such as the Mississippi Irrigation Scheduling Tool (MIST).

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E. Tables and Figures

Table 3.1: *Use of individual Irrigation Best Management Practices (IBMP) by sample producers in 2015*

	IBMP	% Sample producers
Field Manage-ment practices	Zero or Precision leveling	40.2
	Warped surface	24
	End blocking	28.7
	Deep tillage	51.5
Water Flow Control practices	Multiple-inlet irrigation (rice)	27.4
	Alternate wetting and drying (rice)	5.5
	Computerized pipe-hole selection	38.1
	Surge irrigation	18.5
	Cutback irrigation	10.2
	Water flow meter	41.7
	Pump timer	26.6
Recovery /storage	Tail-water recovery system	34.3
	Storage reservoir	28.1
Advanced scheduling	Soil moisture sensor	21.7
	ET or Atmometer	2.8
	Computerized scheduling	3.8
	Woodruff chart	0.9

Notes:

[a.] Source: 2016 Irrigation Survey (Henry et al., 2020)

Table 3.2: *Variable Description and Summary Statistics*

Variable Name	Description	Mean	Std. dev.	Min	Max
Landowner	Land owner and operator	0.80	0.40	0	1
YRS_farming	Years of farming experience	31.22	15.14	1	80
Bachelor	Highest degree is Bachelor or above	0.76	0.43	0	1
Ag_Edu	Education agriculture-related	0.50	0.50	0	1
More 100K	Income more than 100K	0.36	0.48	0	1
Less 100K	Income less than 100K	0.36	0.48	0	1
Irri_Acres	Total irrigated acres in 1000 acres	2.33	2.62	0	25
PT_Corn	% irrigated acres in corn	0.17	0.25	0	1
PT_Rice	% irrigated acres in rice	0.20	0.28	0	1
PT_Gravity	% gravity irrigated acres	0.85	0.27	0	1
PT_GW	% irrigation water from groundwater	0.78	0.32	0	1
Meter	Used a flow meter	0.42	0.49	0	1
Timer	Used a timer on pumps	0.27	0.44	0	1
F_GW_Short	Producer thinks own farm has groundwater shortage	0.10	0.30	0	1
Critical_GW	County is in area of groundwater concerns	0.45	0.50	0	1
PT_CRP	% producers that participated in Conservation Reserve Program at county level	0.41	0.23	0	1
PT_EQIP	% producers that participated in Environmental Quality Incentives Programs at county level	0.50	0.24	0	1
PT_NRCS	% producers that participated in Regional Conservation Partnership Program or other	0.14	0.14	0	1
PT_CSP	% producers that participated in Conservation Stewardship Program at county level	0.24	0.21	0	1
Louisiana	Louisiana	0.20	0.40	0	1
Mississippi	Mississippi	0.31	0.46	0	1
Clay	Percent soil that is clay	0.32	0.11	0.13	0.57
Observations		470			

Notes:

[a.] Source: 2016 Irrigation Survey (Henry et al., 2020)

Table 3.3: *Multivariate Probit Model of Choices Among Groups of IBMPs*

	Water Flow Control	Water Recovery/Storage	Field Management	Advanced Irrigation Scheduling
Landowner	-0.082	0.065	0.177	-0.225
	(0.173)	(0.176)	(0.185)	(0.182)
YRS_farming	**-0.009***	0.003	-0.002	**-0.010***
	(0.005)	(0.005)	(0.005)	(0.005)
Bachelor	0.233	0.022	0.041	0.205
	(0.162)	(0.159)	(0.177)	(0.189)
Ag_Edu	0.154	0.196	-0.015	0.066
	(0.137)	(0.134)	(0.155)	(0.147)
More 100K	-0.017	0.173	0.246	0.112
	(0.168)	(0.165)	(0.187)	(0.188)
Less 100K	-0.007	0.041	0.125	-0.035
	(0.173)	(0.167)	(0.182)	(0.185)
Irri_Acres	**0.157*****	**0.084****	**0.137****	**0.089*****
	(0.047)	(0.035)	(0.057)	(0.026)
PT_Corn	0.148	0.380	0.412	0.475
	(0.282)	(0.274)	(0.321)	(0.309)
PT_Rice	**1.075*****	0.288	**1.291*****	-0.469
	(0.319)	(0.302)	(0.364)	(0.430)
PT_Gravity	0.311	**0.612****	**0.773*****	-0.166
	(0.260)	(0.261)	(0.271)	(0.284)
PT_GW	0.248	**-1.330*****	**0.600*****	-0.196
	(0.208)	(0.234)	(0.223)	(0.260)
Meter	**0.588*****	**0.263***	**0.352****	**0.644*****
	(0.153)	(0.154)	(0.174)	(0.157)
Timer	**0.319***	-0.030	0.126	0.255
	(0.164)	(0.156)	(0.186)	(0.160)
F_GW_Short	0.164	**0.961*****	**0.584****	-0.068
	(0.210)	(0.238)	(0.268)	(0.234)
Critical_GW	0.160	0.128	-0.048	**-0.298***
	(0.147)	(0.148)	(0.153)	(0.161)
PT_CRP	0.163	0.433	-0.106	-0.053
	(0.313)	(0.307)	(0.323)	(0.348)
PT_EQIP	0.053	0.083	0.498	**0.809****
	(0.308)	(0.320)	(0.330)	(0.347)
PT_NRCS	-0.112	-0.152	-0.347	-0.099
	(0.491)	(0.476)	(0.514)	(0.543)
PT_CSP	**0.633***	-0.429	-0.056	0.430
	(0.342)	(0.332)	(0.346)	(0.375)
Louisiana	-0.145	**-0.672*****	**-0.470****	-0.371
	(0.188)	(0.200)	(0.202)	(0.236)
Mississippi	0.137	-0.143	0.036	**0.488****
	(0.192)	(0.180)	(0.211)	(0.197)
Clay	0.112	0.483	0.659	0.083
	(0.650)	(0.693)	(0.750)	(0.723)
Constant	-1.149***	-0.765	-1.459***	-1.313**
	(0.442)	(0.469)	(0.474)	(0.517)
Observations	468			
AIC	1921	BIC	2327	

Table 3.3 (Cont.)

	Water Flow Control	Water Recovery/Storage	Field Management	Advanced Irrigation Scheduling
Correlation matrix of error terms				
Water Flow Control		0.054	**0.419*** **	**0.202***
		(0.090)	(0.104)	(0.105)
Water Recovery /Storage			0.077	**0.191***
			(0.104)	(0.101)
Field Management				-0.022
				(0.114)

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Table 3.4: *Multivariate Probit Model of Choices among Individual IBMPs*

	CHS	Minlet	Surge	Tail_res	Grading	End	Warp	DeepTill	SoilMoiSen
Landowner	-0.172	0.124	0.104	0.060	0.146	0.230	0.048	0.097	-0.257
	(0.178)	(0.202)	(0.183)	(0.177)	(0.206)	(0.172)	(0.172)	(0.167)	(0.184)
YRS_farming	**-0.012****	-0.003	**-0.013*****	0.003	-0.007	-0.002	-0.002	-0.000	**-0.011***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)	(0.006)
Bachelor	**0.331***	-0.034	0.000	0.016	0.135	0.020	-0.129	-0.195	0.276
	(0.170)	(0.183)	(0.173)	(0.160)	(0.197)	(0.160)	(0.157)	(0.160)	(0.207)
Ag_Edu	**0.247***	**0.373****	0.065	0.193	0.214	0.031	0.158	-0.173	-0.019
	(0.138)	(0.158)	(0.147)	(0.135)	(0.154)	(0.132)	(0.132)	(0.130)	(0.158)
More 100K	0.187	0.055	-0.187	0.176	0.208	-0.070	0.245	0.181	0.200
	(0.165)	(0.196)	(0.175)	(0.165)	(0.191)	(0.167)	(0.163)	(0.163)	(0.198)
Less 100K	-0.047	**0.367****	-0.227	0.040	0.340*	-0.031	0.041	0.100	-0.036
	(0.174)	(0.185)	(0.176)	(0.167)	(0.203)	(0.168)	(0.171)	(0.161)	(0.193)
Irri_Acres	**0.100*****	**0.136*****	-0.006	**0.083****	**0.141*****	0.030	0.008	**0.061****	**0.094*****
	(0.032)	(0.031)	(0.025)	(0.034)	(0.036)	(0.028)	(0.023)	(0.025)	(0.026)
PT_Corn	-0.154	-0.752	**0.532***	0.392	**-1.053*****	0.405	0.149	0.427	0.532
	(0.302)	(0.585)	(0.303)	(0.274)	(0.372)	(0.302)	(0.295)	(0.281)	(0.331)
PT_Rice	**-1.021*****	**2.583*****	-0.003	0.286	**3.139*****	0.303	-0.008	**-1.516*****	-0.333
	(0.308)	(0.380)	(0.337)	(0.303)	(0.413)	(0.319)	(0.300)	(0.351)	(0.515)
PT_Gravity	0.172	**0.993****	-0.101	**0.614****	**0.716***	**1.225*****	0.154	0.369	0.024
	(0.265)	(0.459)	(0.264)	(0.264)	(0.385)	(0.383)	(0.261)	(0.235)	(0.294)
PT_GW	**0.468****	-0.324	-0.190	**-1.328*****	0.265	-0.111	0.331	0.223	-0.180
	(0.236)	(0.252)	(0.242)	(0.234)	(0.263)	(0.219)	(0.210)	(0.211)	(0.267)
Meter	**0.714*****	0.122	0.245	**0.281***	0.139	**0.320****	0.150	**0.505*****	**0.724*****
	(0.150)	(0.173)	(0.161)	(0.155)	(0.168)	(0.149)	(0.150)	(0.146)	(0.166)
Timer	**0.290***	0.022	**0.427*****	-0.045	0.223	**0.357****	0.084	-0.012	0.045
	(0.157)	(0.179)	(0.158)	(0.156)	(0.178)	(0.153)	(0.160)	(0.155)	(0.166)
F_GW_Short	0.050	0.036	0.054	**0.958*****	**0.837*****	-0.005	0.064	-0.155	0.040
	(0.223)	(0.220)	(0.246)	(0.233)	(0.222)	(0.205)	(0.205)	(0.199)	(0.249)
Critical_GW	0.152	0.249	-0.183	0.144	-0.034	-0.110	-0.055	0.030	-0.286
	(0.150)	(0.166)	(0.156)	(0.146)	(0.160)	(0.141)	(0.147)	(0.141)	(0.181)
PT_CRP	0.277	0.497	-0.133	0.440	**0.798****	0.382	-0.290	-0.147	0.404
	(0.334)	(0.404)	(0.325)	(0.307)	(0.368)	(0.324)	(0.312)	(0.288)	(0.344)
PT_EQIP	-0.008	0.111	0.767**	0.052	-0.346	-0.047	**0.787****	**0.628****	**0.647***
	(0.323)	(0.393)	(0.351)	(0.317)	(0.360)	(0.312)	(0.314)	(0.294)	(0.364)
PT_NRCS	0.743	-0.269	-0.717	-0.159	0.408	-0.250	-0.624	0.550	0.145
	(0.508)	(0.543)	(0.505)	(0.474)	(0.555)	(0.487)	(0.486)	(0.437)	(0.529)

Table 3.4 (Cont.)

	CHS	Minlet	Surge	Tail_res	Grading	End	Warp	DeepTill	SoilMoiSen
PT_CSP	0.084	0.191	0.660*	-0.403	-0.006	0.250	0.444	0.229	0.158
	(0.347)	(0.389)	(0.371)	(0.333)	(0.398)	(0.351)	(0.327)	(0.309)	(0.393)
Louisiana	0.003	**-0.534****	**-0.440****	**-0.675*****	**-0.780*****	**-0.561*****	-0.166	**-0.475****	0.001
	(0.204)	(0.239)	(0.210)	(0.199)	(0.240)	(0.204)	(0.186)	(0.190)	(0.250)
Mississippi	0.229	-0.227	-0.202	-0.138	**-0.558****	0.071	**-0.308***	0.010	**0.929*****
	(0.189)	(0.208)	(0.201)	(0.180)	(0.222)	(0.195)	(0.186)	(0.181)	(0.204)
Clay	0.955	0.826	-0.074	0.483	-0.513	0.730	0.221	0.914	0.487
	(0.660)	(0.799)	(0.724)	(0.690)	(0.785)	(0.719)	(0.679)	(0.648)	(0.743)
Constant	-1.883***	-3.135***	-0.748	-0.765	-2.256***	-2.411***	-1.538***	-1.141***	-2.135***
	(0.471)	(0.668)	(0.483)	(0.466)	(0.569)	(0.530)	(0.440)	(0.437)	(0.541)
Observations	468	AIC	4279	BIC	5287				

Correlation matrix of error terms

	Minlet	Surge	Tail_res	Grading	End	Warp	DeepTill	SoilMoiSen
CHS	0.044	**0.257****	0.038	0.082	0.025	0.080	**0.246*****	**0.435*****
	(0.116)	(0.101)	(0.093)	(0.116)	(0.093)	(0.092)	(0.090)	(0.107)
Minlet		0.039	**0.254****	**0.674*****	**0.264****	**0.210****	**0.208****	0.088
		(0.111)	(0.101)	(0.118)	(0.106)	(0.098)	(0.104)	(0.138)
Surge			**0.186****	-0.067	0.128	0.011	0.123	**0.216****
			(0.094)	(0.106)	(0.094)	(0.093)	(0.095)	(0.109)
Tail_res				-0.054	0.129	0.081	0.120	**0.184***
				(0.108)	(0.087)	(0.092)	(0.084)	(0.101)
Grading					**0.265****	0.031	0.160	-0.095
					(0.105)	(0.098)	(0.099)	(0.133)
End						0.067	**0.263*****	-0.035
						(0.088)	(0.085)	(0.098)
Warp							**0.372*****	**-0.176***
							(0.091)	(0.106)
DeepTill								-0.001
								(0.098)

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

[c.] CHS stands for Computerized pipe-hole selection. Minlet stands for Multiple-inlet irrigation (rice). Surge stands for Surge irrigation. Tail_res includes both Tail-water recovery system and storage reservoir. Grading includes zero or Precision leveling. End stands for End blocking. Warp stands for warped surface. DeepTill stands for deep tillage.

Table 3.5: *Ordered Logit Models of Number of IBMPs Used*

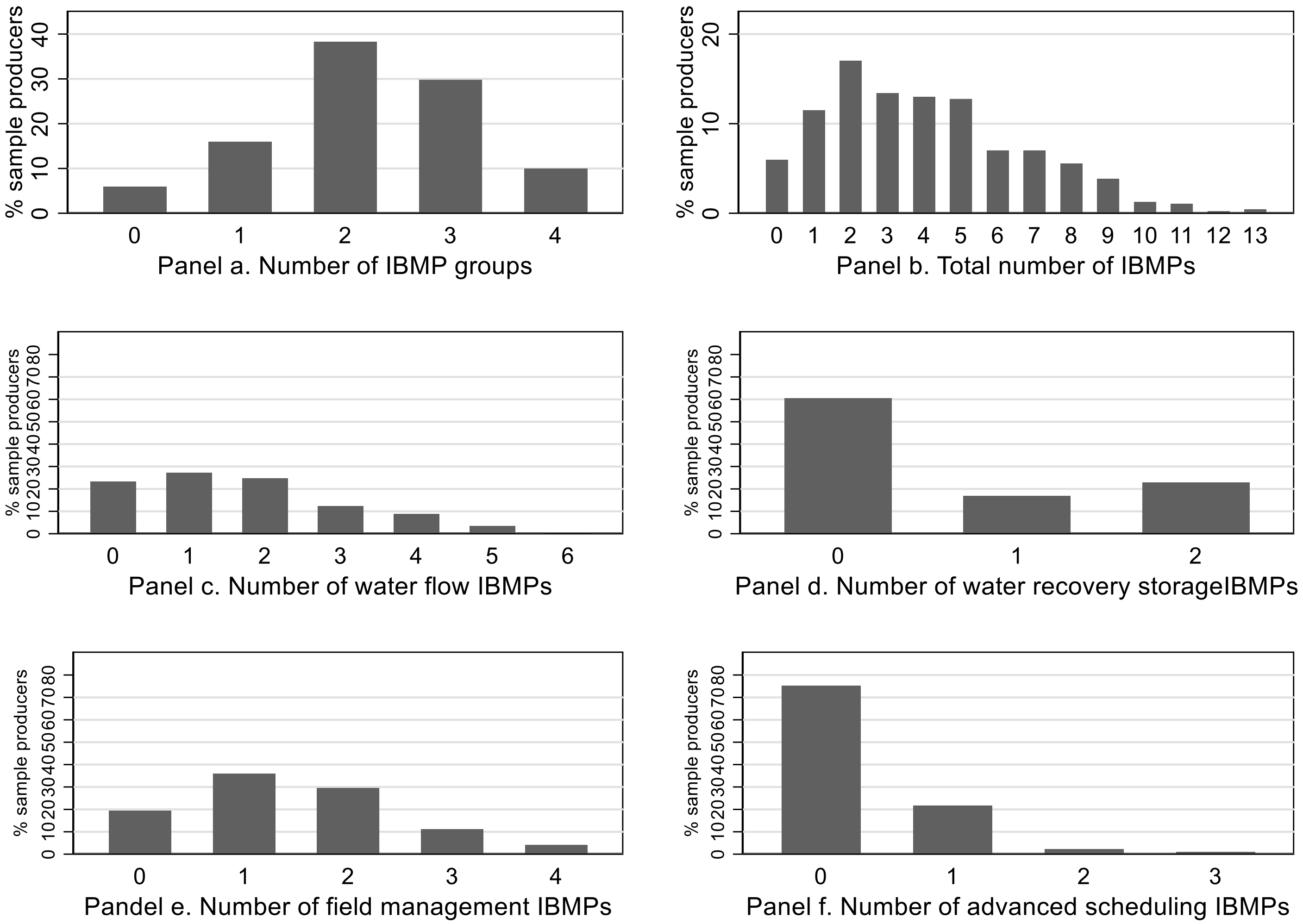
	N IBMP groups	N individual IBMPs	N water flow IBMPs	N water recovery/storage IBMPs	N field Management IBMPs	N Advanced Scheduling IBMP
Landowner	-0.0426	0.119	0.0565	0.0963	0.241	-0.491
	(0.269)	(0.236)	(0.244)	(0.280)	(0.224)	(0.311)
YRS_Farming	-0.00538	-0.00766	**-0.0155****	0.00675	-0.00393	-0.0146
	(0.00608)	(0.00599)	(0.00639)	(0.00702)	(0.00612)	(0.00940)
Bachelor	**0.366***	0.239	**0.403***	0.0286	-0.123	0.346
	(0.216)	(0.209)	(0.233)	(0.251)	(0.220)	(0.347)
Ag_Edu	0.0862	0.225	0.246	0.303	0.0770	0.130
	(0.192)	(0.178)	(0.185)	(0.214)	(0.183)	(0.248)
More100K	0.348	0.331	-0.0692	0.304	0.307	0.175
	(0.219)	(0.212)	(0.226)	(0.269)	(0.228)	(0.330)
Less100K	0.0409	0.0913	0.00164	0.0449	0.197	-0.123
	(0.231)	(0.209)	(0.226)	(0.269)	(0.223)	(0.316)
Irri_Acres	**0.220*****	**0.200*****	**0.151*****	**0.149****	**0.110*****	**0.118*****
	(0.0607)	(0.0410)	(0.0286)	(0.0607)	(0.0297)	(0.0362)
PT_Corn	**1.167*****	0.617	0.0617	0.567	0.404	0.764
	(0.451)	(0.387)	(0.412)	(0.412)	(0.441)	(0.508)
PT_Rice	**1.819*****	**1.659*****	**2.094*****	0.307	**1.258*****	-0.781
	(0.447)	(0.436)	(0.490)	(0.478)	(0.404)	(0.717)
PT_Gravity	**0.649***	**1.007*****	0.535	**1.071****	**1.219*****	-0.311
	(0.337)	(0.331)	(0.424)	(0.450)	(0.389)	(0.493)
PT_GW	-0.531	-0.508	0.155	**-2.338*****	0.386	-0.261
	(0.325)	(0.320)	(0.328)	(0.365)	(0.309)	(0.447)
Meter	**1.667*****	**2.141*****	**0.909*****	**0.615****	**0.650*****	**1.177*****
	(0.228)	(0.222)	(0.214)	(0.244)	(0.226)	(0.276)
Timer	**0.774*****	**1.536*****	**0.594*****	0.0184	0.373	0.418
	(0.213)	(0.225)	(0.219)	(0.254)	(0.237)	(0.273)
F_GW_short	**0.886*****	**0.818*****	-0.0562	**1.361*****	0.313	-0.216
	(0.276)	(0.245)	(0.328)	(0.286)	(0.254)	(0.413)
Critical_GW	-0.0743	0.0178	-0.0306	**0.397***	-0.0520	-0.355
	(0.206)	(0.192)	(0.205)	(0.241)	(0.197)	(0.262)
PT_CRP	0.0574	0.324	-0.00116	0.786	0.250	0.154
	(0.433)	(0.427)	(0.492)	(0.487)	(0.450)	(0.670)
PT_EQIP	**1.012****	**0.990****	0.680	0.329	0.626	1.070
	(0.449)	(0.427)	(0.447)	(0.518)	(0.410)	(0.804)
PT_NRCS	-0.183	-0.0561	0.0405	0.0129	0.134	0.736
	(0.731)	(0.655)	(0.698)	(0.793)	(0.642)	(1.357)
PT_CSP	0.588	0.663	0.915*	-0.771	0.521	0.705
	(0.477)	(0.468)	(0.486)	(0.530)	(0.504)	(0.664)
Louisiana	**-1.078*****	**-1.243*****	**-0.551***	**-1.181*****	**-0.973*****	-0.496
	(0.279)	(0.265)	(0.300)	(0.360)	(0.261)	(0.467)
Mississippi	0.208	-0.131	0.00197	-0.338	-0.309	**0.777***
	(0.261)	(0.267)	(0.269)	(0.296)	(0.290)	(0.403)
Clay	1.143	1.369	0.866	1.094	1.067	-0.233
	(0.914)	(0.916)	(0.967)	(1.195)	(1.000)	(1.247)
N	468	468	468	468	468	468
AIC	1115.7	1766.8	1104.9	767.4	1271.2	552.4
BIC	1223.6	1895.4	1212.8	866.9	1379.1	656.1

Table 3.5 (Cont.)

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.



Panel a. Number of IBMP groups

Panel b. Total number of IBMPs

Panel c. Number of water flow IBMPs

Panel d. Number of water recovery storageIBMPs

Pandel e. Number of field management IBMPs

Panel f. Number of advanced scheduling IBMPs

Figure 3.1: *Number of IBMPs used by Sample Producers*

Notes:

[a.] Source: 2016 Irrigation Survey

Chapter IV. Conclusions and Policy Implications

A. Discussion

This study uses the 2016 Irrigation Survey from Arkansas, Louisiana, and Mississippi to analyze factors that are associated with producers' decisions concerning use of irrigation best management practices. Many factors that characterize the sample areas including increasing irrigated acres, a high share of irrigated acres allocated to rice, heavy reliance on gravity irrigation are positively correlated with IBMP uses both in the number of IBMP groups and also the number of individual IBMPs used. Producers' perception of groundwater shortage on their own farm will prompt more efforts to use IBMPs. However, producers that rely more heavily on groundwater are not more likely to use IBMPs. Being located in an area of critical groundwater is not associated with increased use of IBMPs either. It is possible that producers are not aware of the critical status of groundwater resource in their areas. Because most aquifers in the area are recharged by precipitation or runoffs (Barlow and Clark, 2011), depth-to-water fluctuates over years. In some years, groundwater levels may rise closer to land surface. This may have masked the long-term declining trends of groundwater resources. An information campaign to educate producers about groundwater resource status may help. It may also be the case that producers do not believe that their individual conservation efforts will make a difference if other producers continue to pump groundwater since groundwater is a common pool resource. In this case, only financial incentives will be effective in eliciting water conservation efforts. More studies on the effects of IBMPs on farm profitability and more technical assistance on the appropriate operation of IBMPs could fill in the information gap. Targeting producers in critical groundwater areas is an important step too.

Another important policy instrument to promote IBMP use is the financial assistance provided through conservation programs. EQIP is one of the main conservation programs managed by NRCS in the mid-south that offers financial and technical assistance to agricultural producers in the implementation of conservation practices (USDA, 2021). A main priority of this program is the conservation of surface and groundwater. Practices such as land leveling, tail-water recovery systems, and on-farm storage reservoirs are IBMPs discussed in this study which are also among the irrigation practices funded by the EQIP program (USDA, 2021). Our results show that a higher participation rate in the EQIP program at the county level is positively correlated with using more individual IBMPs as well as more groups of IBMPs. However, not all IBMPs seem to be boosted by EQIP. Nationally funded EQIP initiatives often require a systems approach, which requires producers to implement more than one practice at a time in order to receive assistance (USDA, 2021). Such a systems approach has raised concerns among producers because they could not get financial assistants for some IBMPs they want to adopt because they have voluntarily adopted other required practices (Adusumilli et al, 2016). A change in program requirements to fit the reality of the mid-south that many producers have used one or more IBMPs, allowing more flexibility and supporting the adoption use of individual IBMPs might be more inclusive and therefore more effective.

Another important finding from our study is the strong correlation between water flow meters and the use of many IBMPs. Promoting the use of flow meters could be an important prerequisite to using more IBMPs. Expanding voluntary metering programs is one way to do this. The Delta Voluntary Metering Program implemented by the Mississippi Department of Environmental Quality is one such program. There are currently no voluntary metering programs in Arkansas or Louisiana. This could be something especially important in increasing adoption of

IBMPs in Louisiana, since producers in Louisiana have been shown to use fewer IBMPs in general. Developing more affordable and smarter water flow meters could aid in this effort.

Our research also identifies some potential barriers to adopting IBMPs. Years of farming experience seems to be negatively correlated with some IBMPs. Targeting these producers could reverse the relationship. Having agriculture- related education is only strongly correlated with a few IBMPs. Since irrigation is such an important part of the agriculture sector in the region, expanding the curriculum to include more IBMPs as well as more in-depth instruction on the costs and benefits associated with different types of practices is an important step in educating current producers and fostering future generations of producers.

Evaluating the performance of IBMPs for producers and for water resources is an important area for future research. Demonstrating the effectiveness of IBMPs in reducing water use and conveying these findings to producers is essential in inducing further adoption of these conservation practices. For example, advanced irrigation scheduling tools have been shown to increase efficiency of water use for agricultural purposes (Bryant et al., 2017; Wood et al., 2020). The Arkansas Irrigation Scheduler and the Mississippi Irrigation Scheduling Tool (MIST) are web-based scheduling programs available to producers in the Delta (Kebede et al., 2014). The Smart Technologies for Agricultural Management and Production (STAMP) Irrigation Scheduling Tool is another tool that was developed to assist producers in scheduling times and amounts of water application in Louisiana (Davis and Fromme, 2017). Even though these tools are available, they have not been widely adopted by producers (Spencer et al., 2017). Additional data collection and analysis of factors influencing adoption of such programs will be useful in developing more tools and encouraging producer adoption of these implements in their own operation. One potential drawback, however, is that the producer’s priority will remain profit maximization. Conserving water in one area might result in more water being used in another area, rather than achieving actual water savings.

There are limitations to this study. Even though our sample is representative, the size of our sample is small with only 470 producers from all three states. Securing more funding to continue to follow up producers and increase sample size will increase the accuracy of our research finding. A longer panel of data will also allow us to analyze causal effects of these factors.

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Appendix

Appendix 1. Ordered Logit Model of the Number of Groups of IBMPs (N)

	Ordered Logit	Average Marginal Effects				
		N = 0	N = 1	N = 2	N = 3	N = 4
Landowner	-0.043	0.002	0.003	0.001	-0.004	-0.003
	(0.269)	(0.013)	(0.021)	(0.008)	(0.023)	(0.018)
YRS_Farming	-0.005	0.000	0.000	0.000	-0.000	-0.000
	(0.006)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Bachelor	0.366*	-0.018*	-0.028*	-0.011	0.032*	0.025*
	(0.216)	(0.011)	(0.016)	(0.007)	(0.019)	(0.015)
Ag_Edu	0.086	-0.004	-0.007	-0.002	0.008	0.006
	(0.192)	(0.009)	(0.015)	(0.006)	(0.017)	(0.013)
More 100K	0.348	-0.017	-0.027	-0.010	0.030	0.024
	(0.219)	(0.011)	(0.017)	(0.007)	(0.019)	(0.015)
Less 100K	0.041	-0.002	-0.003	-0.001	0.004	0.003
	(0.231)	(0.011)	(0.018)	(0.007)	(0.020)	(0.016)
Irri_Acres	0.220***	-0.011***	-0.017***	-0.006**	0.019***	0.015***
	(0.061)	(0.003)	(0.005)	(0.002)	(0.006)	(0.004)
PT_Corn	1.167***	-0.057**	-0.090***	-0.034*	0.102**	0.079**
	(0.451)	(0.022)	(0.035)	(0.018)	(0.040)	(0.032)
PT_Rice	1.819***	-0.089***	-0.141***	-0.053**	0.158***	0.124***
	(0.447)	(0.024)	(0.034)	(0.022)	(0.042)	(0.032)
PT_Gravity	0.649*	-0.032*	-0.050*	-0.019	0.057*	0.044*
	(0.337)	(0.017)	(0.026)	(0.012)	(0.030)	(0.024)
PT_GW	-0.531	0.026	0.041	0.015	-0.046	-0.036
	(0.325)	(0.016)	(0.025)	(0.010)	(0.028)	(0.022)
Meter	1.667***	-0.081***	-0.129***	-0.048***	0.145***	0.113***
	(0.228)	(0.017)	(0.020)	(0.012)	(0.019)	(0.019)
Timer	0.774***	-0.038***	-0.060***	-0.022***	0.067***	0.053***
	(0.213)	(0.012)	(0.017)	(0.008)	(0.018)	(0.015)
F_GW_Short	0.886***	-0.043***	-0.069***	-0.026**	0.077***	0.060***
	(0.276)	(0.015)	(0.022)	(0.010)	(0.025)	(0.019)
Critical_GW	-0.074	0.004	0.006	0.002	-0.006	-0.005
	(0.206)	(0.010)	(0.016)	(0.006)	(0.018)	(0.014)
PT_CRP	0.057	-0.003	-0.004	-0.002	0.005	0.004
	(0.433)	(0.021)	(0.034)	(0.012)	(0.038)	(0.030)
PT_EQIP	1.012**	-0.049**	-0.078**	-0.029*	0.088**	0.069**
	(0.449)	(0.023)	(0.034)	(0.017)	(0.040)	(0.031)
PT_NRCS	-0.183	0.009	0.014	0.005	-0.016	-0.012
	(0.731)	(0.036)	(0.057)	(0.021)	(0.064)	(0.050)
PT_CSP	0.588	-0.029	-0.046	-0.017	0.051	0.040
	(0.477)	(0.023)	(0.037)	(0.015)	(0.042)	(0.032)
Louisiana	-1.078***	0.053***	0.083***	0.031**	-0.094***	-0.073***
	(0.279)	(0.014)	(0.021)	(0.014)	(0.026)	(0.020)
Mississippi	0.208	-0.010	-0.016	-0.006	0.018	0.014
	(0.261)	(0.013)	(0.020)	(0.008)	(0.023)	(0.018)
Clay	1.143	-0.056	-0.088	-0.033	0.100	0.078
	(0.914)	(0.045)	(0.071)	(0.029)	(0.080)	(0.063)
Observations	468					
AIC	1115.7	BIC	1223.6			

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Appendix 2. Ordered Logit of the Total Number of IBMPs Used (N)

	Ordered Logit	Average Marginal Effects									
		N = 0	N = 1	N = 2	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N ≥ 9
Landowner	0.119	-0.006	-0.007	-0.004	-0.000	0.001	0.002	0.002	0.003	0.003	0.005
	(0.236)	(0.011)	(0.013)	(0.009)	(0.001)	(0.002)	(0.005)	(0.004)	(0.006)	(0.006)	(0.011)
YRS_Farming	-0.008	0.000	0.000	0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bachelor	0.239	-0.011	-0.013	-0.009	-0.001	0.002	0.005	0.004	0.006	0.006	0.011
	(0.209)	(0.010)	(0.012)	(0.007)	(0.001)	(0.002)	(0.004)	(0.004)	(0.005)	(0.005)	(0.010)
Ag_Edu	0.225	-0.011	-0.013	-0.008	-0.001	0.002	0.004	0.004	0.006	0.006	0.010
	(0.178)	(0.009)	(0.010)	(0.007)	(0.001)	(0.002)	(0.004)	(0.003)	(0.005)	(0.005)	(0.008)
More 100K	0.331	-0.016	-0.018	-0.012	-0.001	0.003	0.007	0.006	0.008	0.009	0.015
	(0.212)	(0.010)	(0.012)	(0.008)	(0.001)	(0.002)	(0.004)	(0.004)	(0.005)	(0.006)	(0.010)
Less 100K	0.091	-0.004	-0.005	-0.003	-0.000	0.001	0.002	0.002	0.002	0.002	0.004
	(0.209)	(0.010)	(0.012)	(0.008)	(0.001)	(0.002)	(0.004)	(0.004)	(0.005)	(0.005)	(0.010)
Irri_Acres	0.200***	-0.010***	-0.011***	-0.007***	-0.001	0.002***	0.004***	0.004***	0.005***	0.005***	0.009***
	(0.041)	(0.002)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
PT_Corn	0.617	-0.030	-0.034	-0.022	-0.002	0.006	0.012	0.011	0.016	0.016	0.028
	(0.387)	(0.019)	(0.021)	(0.015)	(0.003)	(0.004)	(0.008)	(0.007)	(0.010)	(0.011)	(0.018)
PT_Rice	1.659***	-0.079***	-0.093***	-0.060***	-0.006	0.015***	0.033***	0.029***	0.042***	0.044***	0.076***
	(0.436)	(0.023)	(0.024)	(0.018)	(0.006)	(0.004)	(0.009)	(0.009)	(0.013)	(0.014)	(0.023)
PT_Gravity	1.007***	-0.048***	-0.056***	-0.036**	-0.004	0.009**	0.020***	0.018***	0.025***	0.026***	0.046***
	(0.331)	(0.017)	(0.019)	(0.014)	(0.004)	(0.004)	(0.008)	(0.007)	(0.009)	(0.010)	(0.016)
PT_GW	-0.508	0.024	0.028	0.018	0.002	-0.005	-0.010	-0.009	-0.013	-0.013	-0.023
	(0.320)	(0.016)	(0.018)	(0.012)	(0.002)	(0.003)	(0.006)	(0.006)	(0.008)	(0.009)	(0.015)
Meter	2.141***	-0.103***	-0.119***	-0.078***	-0.008	0.020***	0.043***	0.038***	0.054***	0.056***	0.097***
	(0.222)	(0.019)	(0.018)	(0.011)	(0.006)	(0.005)	(0.006)	(0.007)	(0.010)	(0.011)	(0.016)
Timer	1.536***	-0.074***	-0.086***	-0.056***	-0.006	0.014***	0.031***	0.027***	0.039***	0.040***	0.070***
	(0.225)	(0.015)	(0.015)	(0.011)	(0.005)	(0.004)	(0.006)	(0.006)	(0.008)	(0.008)	(0.014)
F_GW_Short	0.818***	-0.039***	-0.046***	-0.030***	-0.003	0.007***	0.016***	0.014***	0.021***	0.021***	0.037***
	(0.245)	(0.013)	(0.015)	(0.009)	(0.003)	(0.003)	(0.005)	(0.005)	(0.007)	(0.007)	(0.012)
Critical_GW	0.018	-0.001	-0.001	-0.001	-0.000	0.000	0.000	0.000	0.000	0.000	0.001
	(0.192)	(0.009)	(0.011)	(0.007)	(0.001)	(0.002)	(0.004)	(0.003)	(0.005)	(0.005)	(0.009)
PT_CRP	0.324	-0.015	-0.018	-0.012	-0.001	0.003	0.006	0.006	0.008	0.009	0.015
	(0.427)	(0.020)	(0.024)	(0.016)	(0.002)	(0.004)	(0.009)	(0.008)	(0.011)	(0.011)	(0.019)
PT_EQIP	0.990**	-0.047**	-0.055**	-0.036**	-0.004	0.009**	0.020**	0.017**	0.025**	0.026**	0.045**
	(0.427)	(0.021)	(0.024)	(0.016)	(0.004)	(0.004)	(0.009)	(0.008)	(0.011)	(0.012)	(0.020)
PT_NRCS	-0.056	0.003	0.003	0.002	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003
	(0.655)	(0.031)	(0.037)	(0.024)	(0.002)	(0.006)	(0.013)	(0.012)	(0.017)	(0.017)	(0.030)

Appendix 2. Ordered Logit of the Total Number of IBMPs Used (N)

	Ordered	Average Marginal Effects									
	Logit	N = 0	N = 1	N = 2	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9
PT_CSP	0.663	-0.032	-0.037	-0.024	-0.002	0.006	0.013	0.012	0.017	0.017	0.030
	(0.468)	(0.022)	(0.026)	(0.017)	(0.003)	(0.005)	(0.009)	(0.008)	(0.012)	(0.013)	(0.022)
Louisiana	-1.243***	0.060***	0.069***	0.045***	0.005	-0.011***	-0.025***	-0.022***	-0.031***	-0.033***	-0.057***
	(0.265)	(0.014)	(0.015)	(0.012)	(0.004)	(0.003)	(0.006)	(0.006)	(0.009)	(0.009)	(0.014)
Mississippi	-0.131	0.006	0.007	0.005	0.000	-0.001	-0.003	-0.002	-0.003	-0.003	-0.006
	(0.267)	(0.013)	(0.015)	(0.010)	(0.001)	(0.002)	(0.005)	(0.005)	(0.007)	(0.007)	(0.012)
Clay	1.369	-0.066	-0.076	-0.050	-0.005	0.013	0.027	0.024	0.035	0.036	0.062
	(0.916)	(0.044)	(0.052)	(0.034)	(0.005)	(0.009)	(0.018)	(0.016)	(0.024)	(0.025)	(0.043)
Observations	468										
AIC	1852.7	BIC	1997.9								

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Appendix 3. Ordered Logit Model of the Number of Water Flow Control Practices Used (N)

	Ordered	Average Marginal Effects				
	Logit	N = 0	N = 1	N = 2	N = 3	N = 4
Landowner	0.057	-0.010	0.001	0.005	0.003	0.001
	(0.244)	(0.044)	(0.006)	(0.023)	(0.011)	(0.004)
YRS_Farming	-0.016**	0.003**	-0.000*	-0.001**	-0.001**	-0.000*
	(0.006)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
Bachelor	0.403*	-0.073*	0.009	0.038*	0.019	0.006
	(0.233)	(0.041)	(0.006)	(0.022)	(0.011)	(0.004)
Ag_Edu	0.246	-0.044	0.006	0.023	0.011	0.004
	(0.185)	(0.033)	(0.005)	(0.017)	(0.009)	(0.003)
More 100K	-0.069	0.012	-0.002	-0.007	-0.003	-0.001
	(0.226)	(0.041)	(0.005)	(0.022)	(0.010)	(0.004)
Less 100K	0.002	-0.000	0.000	0.000	0.000	0.000
	(0.226)	(0.041)	(0.005)	(0.022)	(0.010)	(0.003)
Irri_Acres	0.151***	-0.027***	0.004**	0.014***	0.007***	0.002***
	(0.029)	(0.005)	(0.002)	(0.003)	(0.002)	(0.001)
PT_Corn	0.062	-0.011	0.001	0.006	0.003	0.001
	(0.412)	(0.074)	(0.010)	(0.039)	(0.019)	(0.006)
PT_Rice	2.094***	-0.378***	0.049**	0.200***	0.097***	0.032**
	(0.490)	(0.080)	(0.020)	(0.045)	(0.028)	(0.014)
PT_Gravity	0.535	-0.097	0.013	0.051	0.025	0.008
	(0.424)	(0.076)	(0.011)	(0.041)	(0.020)	(0.007)
PT_GW	0.155	-0.028	0.004	0.015	0.007	0.002
	(0.328)	(0.059)	(0.008)	(0.031)	(0.015)	(0.005)
Meter	0.909***	-0.164***	0.021**	0.087***	0.042***	0.014**
	(0.214)	(0.037)	(0.010)	(0.020)	(0.012)	(0.006)
Timer	0.594***	-0.107***	0.014*	0.057***	0.027**	0.009**
	(0.219)	(0.039)	(0.008)	(0.021)	(0.011)	(0.004)
F_GW_Short	-0.056	0.010	-0.001	-0.005	-0.003	-0.001
	(0.328)	(0.059)	(0.008)	(0.031)	(0.015)	(0.005)
Critical_GW	-0.031	0.006	-0.001	-0.003	-0.001	-0.000
	(0.205)	(0.037)	(0.005)	(0.020)	(0.010)	(0.003)
PT_CRP	-0.001	0.000	-0.000	-0.000	-0.000	-0.000
	(0.492)	(0.089)	(0.012)	(0.047)	(0.023)	(0.008)
PT_EQIP	0.680	-0.123	0.016	0.065	0.031	0.010
	(0.447)	(0.079)	(0.011)	(0.043)	(0.021)	(0.008)
PT_NRCS	0.041	-0.007	0.001	0.004	0.002	0.001
	(0.698)	(0.126)	(0.016)	(0.067)	(0.032)	(0.011)
PT_CSP	0.915*	-0.165*	0.022	0.087*	0.042*	0.014
	(0.486)	(0.086)	(0.014)	(0.046)	(0.024)	(0.009)
Louisiana	-0.551*	0.100*	-0.013*	-0.053*	-0.026*	-0.009
	(0.300)	(0.053)	(0.008)	(0.029)	(0.015)	(0.006)
Mississippi	0.002	-0.000	0.000	0.000	0.000	0.000
	(0.269)	(0.049)	(0.006)	(0.026)	(0.012)	(0.004)
Clay	0.866	-0.156	0.020	0.083	0.040	0.013
	(0.967)	(0.174)	(0.023)	(0.092)	(0.045)	(0.016)
AIC	1104.934	BIC	1212.794			

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Appendix 4. Ordered Logit Model of the Number of Field Management Practices Used (N)

	Ordered	Average Marginal Effects				
	Logit	N = 0	N = 1	N = 2	N = 3	N = 4
Landowner	0.241	-0.033	-0.018	0.022	0.019	0.009
	(0.224)	(0.030)	(0.017)	(0.021)	(0.018)	(0.009)
YRS_Farming	-0.004	0.001	0.000	-0.000	-0.000	-0.000
	(0.006)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
Bachelor	-0.123	0.017	0.009	-0.011	-0.010	-0.005
	(0.220)	(0.030)	(0.016)	(0.020)	(0.017)	(0.008)
Ag_Edu	0.077	-0.010	-0.006	0.007	0.006	0.003
	(0.183)	(0.025)	(0.013)	(0.017)	(0.014)	(0.007)
More 100K	0.307	-0.042	-0.023	0.028	0.024	0.012
	(0.228)	(0.031)	(0.017)	(0.021)	(0.018)	(0.009)
Less 100K	0.197	-0.027	-0.014	0.018	0.016	0.007
	(0.223)	(0.030)	(0.016)	(0.021)	(0.018)	(0.009)
Irri_Acres	0.110***	-0.015***	-0.008***	0.010***	0.009***	0.004***
	(0.030)	(0.004)	(0.002)	(0.003)	(0.002)	(0.001)
PT_Corn	0.404	-0.055	-0.030	0.037	0.032	0.015
	(0.441)	(0.060)	(0.033)	(0.041)	(0.035)	(0.017)
PT_Rice	1.258***	-0.171***	-0.092***	0.116***	0.100***	0.048**
	(0.404)	(0.057)	(0.029)	(0.039)	(0.033)	(0.019)
PT_Gravity	1.219***	-0.166***	-0.089***	0.113***	0.096***	0.046**
	(0.389)	(0.051)	(0.032)	(0.037)	(0.032)	(0.018)
PT_GW	0.386	-0.053	-0.028	0.036	0.031	0.015
	(0.309)	(0.042)	(0.023)	(0.029)	(0.025)	(0.012)
Meter	0.650***	-0.088***	-0.048***	0.060***	0.051***	0.025**
	(0.226)	(0.031)	(0.016)	(0.021)	(0.018)	(0.010)
Timer	0.373	-0.051	-0.027	0.034	0.030	0.014
	(0.237)	(0.032)	(0.018)	(0.022)	(0.019)	(0.009)
F_GW_Short	0.313	-0.043	-0.023	0.029	0.025	0.012
	(0.254)	(0.035)	(0.018)	(0.024)	(0.020)	(0.010)
Critical_GW	-0.052	0.007	0.004	-0.005	-0.004	-0.002
	(0.197)	(0.027)	(0.014)	(0.018)	(0.016)	(0.007)
PT_CRP	0.250	-0.034	-0.018	0.023	0.020	0.009
	(0.450)	(0.061)	(0.033)	(0.042)	(0.036)	(0.017)
PT_EQIP	0.626	-0.085	-0.046	0.058	0.050	0.024
	(0.410)	(0.056)	(0.030)	(0.037)	(0.033)	(0.017)
PT_NRCS	0.134	-0.018	-0.010	0.012	0.011	0.005
	(0.642)	(0.087)	(0.047)	(0.059)	(0.051)	(0.024)
PT_CSP	0.521	-0.071	-0.038	0.048	0.041	0.020
	(0.504)	(0.068)	(0.037)	(0.046)	(0.040)	(0.020)
Louisiana	-0.973***	0.132***	0.071***	-0.090***	-0.077***	-0.037***
	(0.261)	(0.035)	(0.021)	(0.024)	(0.022)	(0.013)
Mississippi	-0.309	0.042	0.023	-0.029	-0.024	-0.012
	(0.290)	(0.039)	(0.021)	(0.026)	(0.023)	(0.011)
Clay	1.067	-0.145	-0.078	0.099	0.084	0.040
	(1.000)	(0.136)	(0.074)	(0.093)	(0.079)	(0.039)
Observations	468					
AIC	1271.2	BIC	1379.1			

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Appendix 5. Ordered Logit Model of the Number of Water Recovery/Storage Practices Used (N)

		Average Marginal Effects		
	Ordered Logit	N = 0	N = 1	N = 2
Landowner	0.096	-0.017	0.004	0.012
	(0.280)	(0.049)	(0.012)	(0.036)
YRS_Farming	0.007	-0.001	0.000	0.001
	(0.007)	(0.001)	(0.000)	(0.001)
Bachelor	0.029	-0.005	0.001	0.004
	(0.251)	(0.044)	(0.011)	(0.032)
Ag_Edu	0.303	-0.053	0.013	0.039
	(0.214)	(0.037)	(0.010)	(0.028)
More 100K	0.304	-0.053	0.013	0.039
	(0.269)	(0.047)	(0.012)	(0.035)
Less 100K	0.045	-0.008	0.002	0.006
	(0.269)	(0.047)	(0.012)	(0.035)
Irri_Acres	0.149**	-0.026**	0.007**	0.019**
	(0.061)	(0.010)	(0.003)	(0.008)
PT_Corn	0.567	-0.098	0.025	0.073
	(0.412)	(0.071)	(0.019)	(0.053)
PT_Rice	0.307	-0.053	0.014	0.040
	(0.478)	(0.083)	(0.021)	(0.062)
PT_Gravity	1.071**	-0.186**	0.048**	0.138**
	(0.450)	(0.077)	(0.020)	(0.058)
PT_GW	-2.338***	0.405***	-0.104***	-0.302***
	(0.365)	(0.054)	(0.018)	(0.042)
Meter	0.615**	-0.107**	0.027**	0.079**
	(0.244)	(0.042)	(0.011)	(0.031)
Timer	0.018	-0.003	0.001	0.002
	(0.254)	(0.044)	(0.011)	(0.033)
F_GW_Short	1.361***	-0.236***	0.060***	0.176***
	(0.286)	(0.048)	(0.016)	(0.034)
Critical_GW	0.397*	-0.069*	0.018*	0.051*
	(0.241)	(0.042)	(0.011)	(0.031)
PT_CRP	0.786	-0.136	0.035	0.101
	(0.487)	(0.084)	(0.022)	(0.063)
PT_EQIP	0.329	-0.057	0.015	0.042
	(0.518)	(0.090)	(0.023)	(0.067)
PT_NRCS	0.013	-0.002	0.001	0.002
	(0.793)	(0.138)	(0.035)	(0.102)
PT_CSP	-0.771	0.134	-0.034	-0.100
	(0.530)	(0.092)	(0.023)	(0.069)
Louisiana	-1.181***	0.205***	-0.052***	-0.152***
	(0.360)	(0.060)	(0.016)	(0.045)
Mississippi	-0.338	0.059	-0.015	-0.044
	(0.296)	(0.051)	(0.013)	(0.038)
Clay	1.094	-0.190	0.049	0.141
	(1.195)	(0.207)	(0.053)	(0.155)
Observations	468			
AIC	767.4	BIC	866.9	

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.

Appendix 6. Ordered Logit Model of the Number of Advanced Scheduling Practices Used (N)

		Average Marginal Effects			
	Ordered Logit	N = 0	N = 1	N = 2	N = 3
Landowner	-0.491	0.067	-0.053	-0.009	-0.005
	(0.311)	(0.042)	(0.033)	(0.006)	(0.004)
YRS_Farming	-0.015	0.002	-0.002	-0.000	-0.000
	(0.009)	(0.001)	(0.001)	(0.000)	(0.000)
Bachelor	0.346	-0.047	0.038	0.006	0.004
	(0.347)	(0.047)	(0.038)	(0.006)	(0.004)
Ag_Edu	0.130	-0.018	0.014	0.002	0.001
	(0.248)	(0.034)	(0.027)	(0.004)	(0.003)
More 100K	0.175	-0.024	0.019	0.003	0.002
	(0.330)	(0.045)	(0.036)	(0.006)	(0.003)
Less 100K	-0.123	0.017	-0.013	-0.002	-0.001
	(0.316)	(0.043)	(0.034)	(0.006)	(0.003)
Irri_Acres	0.118***	-0.016***	0.013***	0.002**	0.001**
	(0.036)	(0.005)	(0.004)	(0.001)	(0.001)
PT_Corn	0.764	-0.104	0.083	0.014	0.008
	(0.508)	(0.069)	(0.055)	(0.010)	(0.006)
PT_Rice	-0.781	0.106	-0.085	-0.014	-0.008
	(0.717)	(0.098)	(0.078)	(0.013)	(0.008)
PT_Gravity	-0.311	0.042	-0.034	-0.006	-0.003
	(0.493)	(0.067)	(0.053)	(0.009)	(0.005)
PT_GW	-0.261	0.036	-0.028	-0.005	-0.003
	(0.447)	(0.061)	(0.049)	(0.008)	(0.005)
Meter	1.177***	-0.161***	0.128***	0.021***	0.012*
	(0.276)	(0.035)	(0.027)	(0.008)	(0.006)
Timer	0.418	-0.057	0.045	0.007	0.004
	(0.273)	(0.037)	(0.029)	(0.005)	(0.004)
F_GW_Short	-0.216	0.029	-0.023	-0.004	-0.002
	(0.413)	(0.056)	(0.045)	(0.007)	(0.004)
Critical_GW	-0.355	0.048	-0.039	-0.006	-0.004
	(0.262)	(0.036)	(0.029)	(0.005)	(0.003)
PT_CRP	0.154	-0.021	0.017	0.003	0.002
	(0.670)	(0.091)	(0.072)	(0.012)	(0.007)
PT_EQIP	1.070	-0.146	0.116	0.019	0.011
	(0.804)	(0.111)	(0.089)	(0.016)	(0.008)
PT_NRCS	0.736	-0.100	0.080	0.013	0.007
	(1.357)	(0.184)	(0.146)	(0.024)	(0.015)
PT_CSP	0.705	-0.096	0.077	0.012	0.007
	(0.664)	(0.090)	(0.071)	(0.012)	(0.007)
Louisiana	-0.496	0.068	-0.054	-0.009	-0.005
	(0.467)	(0.065)	(0.051)	(0.009)	(0.005)
Mississippi	0.777*	-0.106**	0.084**	0.014*	0.008
	(0.403)	(0.053)	(0.043)	(0.008)	(0.005)
Clay	-0.233	0.032	-0.025	-0.004	-0.002
	(1.247)	(0.170)	(0.135)	(0.022)	(0.013)
AIC	552.4	BIC	656.1		

Notes:

[a.] Robust standard errors are reported in parentheses.

[b.] *, **, *** indicate levels of statistical significance at 10%, 5%, and 1%, respectively.