Factors Motivating Producer Use of Soil Sensor Technology

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Abstract: Agricultural producers in the Southeast United States face significant production risks due to crop water needs and variable weather patterns. Legal and regulatory risk also exist related to water use with the ongoing U.S. Supreme Court litigation between Georgia and Florida. Advanced irrigation scheduling methods help producers make better water management decisions to increase their water use efficiency (WUE). The adoption of soil sensor technology (SST) is one method that can mitigate risks and improve environmental outcomes by increasing WUE. However, producer adoption remains low or inconsistent in regions that would benefit from these methods. Using a dataset of survey responses from Georgia agricultural producers, we use a logistic regression model to estimate factors motivating a producer's use of SST for their operation. Initial results indicate that producer age, size of operation, and their concern about water-related issues are significant predictors of using SST. These results suggest a pattern of SST usage in Georgia that is consistent with literature on technology diffusion in agriculture in which wealthier, less risk-averse producers are the first to adopt new technologies. These findings can help guide future Extension programing to increase producer adoption and improve water use efficiency in the region.

1. Introduction

Current climate change models suggest that drought events are likely to increase in frequency, severity and spatial extent across the Southeastern United States in the coming decades (Mishra, N. et al., 2017). Within this context of increasing uncertainty about future regional water availability, the U.S. states of Georgia and Florida are currently engaged in ongoing litigation concerning upstream water extraction for agricultural use in the Apalachicola-Chattahoochee-Flint River (ACF) basin, thus leading to potentially increased legal and regulatory risks for Georgia producers. Soil sensor technology (SST), which relies on the use of soil probes to indirectly calculate the volumetric water content in soil, has the potential to significantly mitigate these drought-related risks for farmers by allowing them to more efficiently manage their irrigation systems. Multiple studies have highlighted the important contributions of SST to overall water-use efficiency (WUE), thus emphasizing the technology's potential financial and environmental benefits (Leib et al., 2003; Laikos et al., 2015; Liang et al., 2016; Vellidis et al., 2016).

For these reasons, increasing producer adoption of SST has been identified by extension services as a potential aspect of mitigating agricultural production risk in regions where future water availability is likely to be a concern. Additionally, recent technical advances in wireless technology have greatly expanded the capabilities of SST while reducing their associated production costs (Ruiz-Garcia et al., 2009). Given these developments, it is somewhat surprising that that the adoption of SST remains low in the United States. The USDA observed in the 2013 Irrigation and Water Management Survey (formerly known as the Farm and Ranch Irrigation Survey) that SST was only adopted by 9% of Georgia agricultural irrigators. In contrast, 40% of Georgia irrigators relied on observing the condition of the soil when deciding irrigation scheduling despite research (McGuckin, Gollehon, and Ghosh, 1992) suggesting the inefficiency of these and other non-advanced methods. Underutilization of SST and other automated scheduling aides risks limiting the profitability and sustainability of irrigated agriculture by decreasing WUE through increased inefficiency in otherwise competent technical systems and therefore contributes to possible future environmental degradation and water unavailability.

The literature suggests a process of agricultural technology adoption related to operator characteristics including age (Bernard, Pesek, and Fan, 2004; Morrison, 2009), education level (Bijay et al., 2018; Mishra, B. et al., 2018), income and risk-preferences (Feder, 1980; Marra, Pannell, and Ghadim, 2003; Rodgers, Morgan, and Harri, 2017). While the estimation of economic costs and benefits by the farmer has been considered as critical in the adoption decision, few studies capture the complexity of personal motivations and characteristics which can encourage the adoption of new technology even though these may be significant (Gartrell and Gartrell, 1985). An understanding of how these characteristics influence or impede adoption can lead to more effectively directed extension programming, which in-turn can facilitate improvements in WUE for irrigated operations.

The focus of this research is to identify the main farm and operator characteristics motivating SST adoption among agricultural irrigators in the U.S. state of Georgia. Our results, obtained from a logistic regression model, suggest that producer age, farm income, and producer attitudes about agricultural use of water all are significantly related to use of SST. These findings are largely consistent with existing literature on technology diffusion in agriculture in which wealthier, less risk-averse producers are the first to adopt new technologies.

2. Background

As briefly noted in the introduction, a summary of the characteristics of 3,545 irrigated farms in Georgia has been previously reported by USDA (2013). These data, obtained from the 2013 Irrigation and Water Management Survey, is to supplement the basic irrigation data collected from all farm and ranch operators in the 2012 Census of Agriculture. The survey includes questions regarding technology utilization, including SST adoption, and agricultural water use for irrigation. The summarized information is presented in Table 1.

Table 1. Summary of Georgia irrigated operations (USDA, 2013)

From 2012 Census of Agriculture	
Total number of irrigated operations	5,230
Total acres irrigated	1,125,355
From 2013 Irrigation and Water Management Survey	
Irrigated operations surveyed	3,545
Total farm acres	3,157,131
Total farm acres, irrigated	1,196,947
Acres irrigated (% of total)	
Less than 100 acres	51
100 – 499 acres	29
500 – 999 acres	11
Greater than 1,000 acres	8
Irrigated acreage by enterprise (% of total)	
Cotton	18
Vegetable and melon	10
Fruit and tree nut	11
Greenhouse, nursery, and floriculture	2
Other crop farming (including peanut)	45
Methods of deciding when to irrigate (% of total)	
Crop condition	88
Feel of the soil	40
Soil sensor	9
Evapotranspiration	7
Calendar ("days-after-planting" method)	12
When neighbors begin to irrigate	2
Sources of irrigation information (% of total)	
Extension agents or specialists	73
Federal or state agencies	15
Consultants	22
Irrigation equipment dealers	32
Other farmers	15

The summarized information suggests that irrigated acres account for 38 percent of all farmland on operations using irrigation and that the majority (51 percent) of these operations have a total of less than 100 irrigated acres (USDA, 2013). In terms of enterprises, 18 percent of irrigated acres in 2013 were in cotton production. 45 percent of all irrigated acres in Georgia were in "sugarcane farming, hay farming, and all other crop farming". It is probable that a large majority of irrigated acres in this category are in peanut production, as Georgia-grown peanuts represented approximately 732,000 production acres in 2012 and are often grown in rotation with cotton (USDA, 2012) where roughly half of those acres are irrigated. Fruit and tree nuts were the third-most prevalent enterprise on irrigated acres in 2012; presumably, a significant portion of these acres were in pecan production (114,000 acres in 2012). Moreover, the USDA survey results indicated that an overwhelming majority of Georgia irrigators rely on non-advanced, non-technical methods when deciding when to irrigate. Relying on the condition of the crop or soil was utilized by 88 and 40 percent of irrigators, respectively. SST was utilized by only 9 percent of Georgia irrigators in 2012. Other non-technical methods, such as relying on a calendar-based "days-after-planting" method or irrigating when neighboring farmers irrigate, were not as heavily utilized. Georgia irrigators relied on multiple sources for irrigation-related agricultural information, but extension agents and specialists were identified by 73 percent of respondents as being a preferred source. Therefore, extension seems to be in an ideal position to affect producer attitudes and beliefs about irrigation technology and management. Other sources of information cited, from most common to least common, were irrigation equipment dealers, paid consultants, federal and state agencies, and other farmers. These statistics suggest that irrigation is a significant aspect of maintaining the sustainability and competiveness for some of Georgia's most valuable agricultural commodities.

The growing demand for water in Georgia has generated considerable legal conflict over the past three decades. In 1989, the U.S. Army Corps of Engineers (USACE) proposed to increase withdrawals from the ACF to relocate storage to Lake Lanier and Allatoona Lake, two freshwater lakes supplying Metro Atlanta. The states of Alabama and Florida resultantly initiated litigation against the Corps, but the lawsuit was eventually stayed in 1992 when Alabama, Florida, Georgia, and the Corps signed a Memorandum of Agreement to delay any subsequent action until the Corps conducted a comprehensive water usage study for the region. The study was never completed, and in 1997 the three states initiated a Congressionally-approved interstate compact to negotiate future withdrawals from the ACT while permitting the Corps to provide reasonable quantities of water to meet the needs of Georgia. In 2003, Alabama terminated the ACT compact and resumed litigation, which is once-again joined by Florida. Georgia and the Corps secure a major victory in 2012, when the U.S. Supreme Court effectively upheld a lower court ruling that the Corps has the legal authority to withdraw from the ACT in order to meet Georgia's future water needs (Stockdale, 2012). The state of Florida initiated new litigation in 2013, alleging that increased withdrawals from the ACT had contributed to a poor Apalachicola Bay shellfish/oyster harvest in 2011 and 2012. A court appointed special master reviewed the matter, and ultimately chose to reject Florida's petition in 2017 citing no "clear and convincing evidence" that enforcing upstream withdrawal limits on Georgia would have mitigated the effects of the 2011-12 drought. On appeal to the U.S. Supreme Court, Florida secured a major victory when the Court ruled 5-4 that the special master's standard was too strict and ordered the case to be remanded (*Florida v. Georgia,* 2018). Motivating continued conflict and litigation in the matter are the competing needs of Florida, whose multi-million dollar seafood industry relies on ACF-fed freshwater to prevent saltwater intrusion in Apalachicola Bay shellfish and oystering beds, and Georgia's need as an upstream user to extract from the ACF to support continued population growth and agricultural usage in the southwestern portion of the state (Southern Environmental Law Center, 2016). This situation has heighted regulatory and legal risk for Georgia irrigators who rely on withdrawals from the ACF. However, improved WUE through better irrigation management and scheduling techniques, such as the adoption of SST, has the potential to mitigate these risks by promoting more sustainable utilization of the ACF watershed.

3. Data and Methodology

A survey was completed on a sample of Georgia farmers between December 2017 and January 2018 (n=219). The survey was administered at the 2017 Georgia Farm Bureau annual meeting on Jekyll Island, Georgia in December 2017 and at cotton/peanut production meetings in Tifton, Georgia in January 2018. Survey responses were logged on either laptop computers, iPads, or with paper survey instruments with the assistance of enumerators from the UGA Extension Agricultural Water Efficiency Team (AgWET) project. In order to incentivize participation, survey respondents at each event were given an opportunity to enter a raffle awarding a gift approximately valued at 250 USD. The survey focused on irrigation technology utilization, basic producer demographics, farm characteristics, and producer attitudes on agricultural water issues, farm technology, and perceptions of agricultural risk.

For questions relating to producer attitudes, respondents were asked to respond to a given statement by selecting one of a five-point agree/disagreement continuum in a method first described by Likert (1932). One feature of Likert's fixed-choice approach is that it imposes ordinality and continuity onto a respondent's preferences, thus making it useful for the construction of quantitative variables (Bowling, 1997). As with all survey methods, our approach suffers from potential social desirability bias as has been the case in other studies utilizing in-person surveys on environmental issues (Leggett et al., 2003; Yadav et al., 2012). Table 2 presents descriptive statistics for the survey responses, with the survey population split into full and irrigated samples.

Table 2. Descriptive Statistics from Survey Instrument

	Full sample (n=219)	*Irrigated sample (n=94)*	*P-value of difference*
Panel A. Farm characteristics			
Farm has soil sensor	-	0.30	-
Farm is row crop operation	0.53	0.77	< 0.01
Farm is in South Georgia	0.58	0.79	< 0.01
Total value of gross farm sales	$646,565	$1,192,500	0.02
Total value of gross farm sales:			
Low (less than $100,000)	0.54	0.30	< 0.01
Medium ($100,000 to $999,999)	0.33	0.46	0.04
High ($1 million or greater)	0.12	0.22	0.02
Panel B. Operator characteristics			
Male operator	0.78	0.86	0.25
Age	53.2	48.5	0.02
Experience (years)	28.8	25.2	0.11
Panel C. Operator attitudes (10 point Likert scales)			
The following poses a "great deal" of risk to future agriculture…			
Government regulation	8.47	8.48	0.99
Climate change	5.59	5.29	0.49
Changing weather patterns	6.81	6.56	0.48
Drought	8.04	7.92	0.65
Future water availability	8.05	8.20	0.62
Urban population growth	7.64	7.47	0.64
Environmental group opposition	8.04	7.99	0.84
Agricultural water use concerns me a "great deal" for each of the following…			
My farm	6.24	6.52	0.47
Georgia	7.67	7.29	0.16
The United States	7.94	7.40	0.09
The current methods available to schedule irrigation are "easy to use"	-	6.98	-

Note: Values in columns 1 and 2 are means. *p*-values in column 3 are based on *t*-tests of equality of means, assuming equal sample variances.

There are observable differences between irrigated operations and the full sample in the survey, with irrigated operations being significantly more likely to report higher gross sales, produce row crops, or be in southern Georgia than the full sample. This is largely attributable to predictable variation in the suitability of different regions of the state for row crop production. Irrigated operations are more comparable to the complete sample based on operator characteristics, although producer age is unequal between the two samples at a 5% significance level. Operators are comparable based on gender and experience (measured as the number of years the operator has been farming since age 18). Panel C describes operator attitudes towards agricultural risks, water use, and perceived ease-of-use (PEOU) of existing irrigation scheduling technology. There are no significant differences between irrigators and the full sample in Panel C, suggesting that diffusion and adoption dynamics between the two groups may be broadly similar if these dynamics are primarily a function of personal motivations and beliefs.

SST is utilized on 30 percent of irrigated operations in our sample. This is significantly higher than the 9 percent utilization rate reported by USDA in 2012 for Georgia irrigators (p=0.04). Ostensibly, this is because SST has continued to diffuse and be adopted in the six years since the USDA data was collected; however, we cannot statistically demonstrate that survey sampling bias isn't responsible for this significance. Given sufficient variation in the use of SST among irrigators in our sample and a number of potential covariates, we are able to model logit the probability that SST was being used as:

$$\text{Logit } P(\text{Using SST} = 1|X) = \alpha + \beta X,$$

where X is a vector of explanatory variables and α is a constant term. Univariate analysis was initially undertaken in STATA/IC 14.2. As a result, a multivariate model was estimated through a process of backwards elimination, a method similar to that described by McDonald et al., 2016. A review of the literature suggests that farm income, operator age, and PEOU are significant predictors of technology adoption; the influence of personal motivations and beliefs (such as those relating to agricultural water usage) are less clear. Regressions will be estimated both with and without a location-fixed effect.

4. Resutlts

Table 3 presents the results of the multivariate logistic regressions:

Table 3. Multivariate Logistic Regression Results

	Model 1		Model 2	
	Coefficient	*p*-value	Coefficient	*p*-value
Age	-0.2119 (0.114)	0.063**	-0.2390 (0.119)	0.044**
Age-squared	0.0021 (0.001)	0.083**	0.0024 (0.001)	0.077**
Gross sales: medium	0.5481 (0.893)	0.539	0.1322 (0.887)	0.882
Gross sales: high	2.5015 (0.971)	0.010**	2.5533 (0.967)	0.008***
Environmental group opposition: high risk	-2.6699 (1.142)	0.019**	-2.6473 (1.013)	0.009***
Government regulations: high risk	1.0114 (0.891)	0.256	1.7011 (1.018)	0.095*
On-farm water usage: high concern	1.1817 (0.627)	0.059**	1.2619 (0.690)	0.067**
Perceived-ease-of-use: high	-0.3762 (0.708)	0.595	-0.3391 (0.837)	0.686
Constant	3.7549 (2.468)	0.128	3.4623 (2.760)	0.210
Location fixed effect?	No		Yes	
Observations	69		66	
Log pseudolikelihood	-32.6129		-29.2703	
Wald chi^2	17.86		26.40	
Prob > chi^2	0.0223		0.0057	
Pseudo R^2	0.2450		0.2770	

Notes: Robust standard-errors reported in parentheses. $p < 0.01$ (***), $p < 0.05$ (**), $p < 0.1$ (*).

The addition of a location-fixed effect (LFE) substantially improves the model's goodness-of-fit – as measured by its log-pseudolikelihood, pseudo-R^2, and chi^2-related statistics – while yielding more significant parameter estimates. The LFE is imposed based on a respondent's assigned University of Georgia Extension service district. Given the improved results, remaining discussion will center on Model 2. The presentation of Model 1 in Table 3 is done for reason of comparison.

Consistent with established literature on technology adoption, age is identified as a significant factor influencing SST utilization (Bernard, Pesek, and Fan, 2004; Morrison, 2009). The liner term is significant at the 5% level, while an associated quadratic term is significant at the 10% level. The signs of the coefficients suggest operators are less likely to utilize SST as they age, but that this age effect reaches a minimum likelihood of use before then increasing in likelihood. The estimated minimum likelihood of adoption contingent on operator age is around age 50, after which age has a positive marginal effect on SST utilization. This calculation should be interpreted with a high-degree of caution due to imprecision in the exact parameter estimates. A possible explanation for this pattern of adoption is the influence of second- and third-generation farmers on technology decisions on family-operated farms. As a primary operator ages, his younger family members (i.e., farm successors) typically assume more responsibility and agency in production and investment decisions (Potter and Lobley, 1992 and James, 1999). The influence of these younger, household decision-makers may be positively affecting SST utilization. The effect of highly reported gross farm incomes, the other explanatory variable suggested as highly influential by the literature, is positive, large in magnitude, and significant at the 1% level.

Producer attitudes concerning risks to future agricultural production appear to have mixed effects on SST utilization and adoption decisions. The influence on SST utilization of perceiving a "high level" of agricultural risk associated with government regulation is positive, but only significant at marginal levels (p=0.095). It is not significant in the model without LFE. As such, the indicated significance may not be worth discussing, especially considering that the relative lack of variation in the indicator variable (mean = 0.842; std. dev. = 0.366). However, parameter estimates for the variable representing a perceived high risk from environmental group opposition is highly significant ($p < 0.01$) and negative. It is not immediately clear, either from intuition or established literature, why such a perception would negatively influence SST utilization. It is possible, assuming a potentially reversed causal relationship (i.e, SST adoption influences producer risk perceptions, rather than the opposite), that utilization of SST makes it *less likely* for a producer to cite environmental group opposition as a major concern. This could be because his operation now has increased WUE and would thus be less likely to be affected by efforts supported by environmental groups, such as increased regulation of withdrawals from the ACF basin. This potential mechanism cannot be discounted because the observational nature of our survey instrument does not allow us to easily establish causality.

Producers indicating a high level of concern with agricultural water use on their individual farm positively influences SST adoption at a 10 percent significance level (p=0.067). Optimistically, farmers with an increased concern about their personal water use may be willing to install technology that will allow them to more efficiently use water, such as SST. However, if reverse causality is once again a culprit, SST adoption may influence a producer's attitudes towards his water utilization, perhaps by SST-associated monitoring and management practices improving his perception of the farm's WUE and possible areas for improvement. The suggested PEOU measure is not statistically significant, indicating that a farmer's perception of how easy it is to use SST will not affect his adoption decision. However, it is possible that producers' PEOU may not have been adequately assessed through our survey instrument, as we did not utilize the method as initially suggested by Davis (1989).

While Model 2 does indicate sufficient goodness-of-fit to possess valuable explanatory power, issues surrounding causality make interpretation of many parameter estimates challenging. It is not clear which mechanisms allow for SST to be related to producer risk perceptions or beliefs about water usage, for example. This is not an issue of model specification, but rather a consequence of being limited to observational survey data. Future research is needed to assess the causal mechanisms underlying significance in these estimated results. Of particular interest may be the development of a survey to collect panel data comparing producer attitudes and beliefs before and after SST adoption in an attempt to establish causal direction.

5. Conclusions

The research reported suggests that, in addition to economic considerations of costs and benefits, personal characteristics like producer age and income can also significantly affect the adoption of new farm technology, including SST. This is a valuable insight for extension professionals in Georgia, who are challenged with encouraging SST adoption as a means to achieve increased WUE on irrigated farms. The results of this research suggests producer beliefs and attitudes, such as the perception of governmental or regulatory risk, need to be researched further as to establish a possible casual mechanism for their impact on technology adoption and utilization.

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