Farmers' Perceptions of Spatial Yield Variability as Influenced by Precision Farming Information Gathering Technologies

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Abstract

This study evaluated how farmers' perceptions of spatial yield variability in farm fields are influenced by precision farming information technologies. Farmer yield variability estimates from a mail survey were regressed on use of information technologies and farmer characteristics. Results indicate that farmers who adopted cotton yield monitors with GPS reported significantly higher spatial yield variability. Farmers who use information technologies to update their knowledge of yield variability may perceive greater benefits from the adoption of variable rate technology. Thus, the relationship between use of information technologies and yield-variability perceptions is important to understand.

Introduction

Learning and information gathering often play a major role in the adoption of technology by farmers (Leathers and Smale, 1991). This behavior by farmers is particularly prevalent when they are uncertain about the impact of a new technology on profitability and risk. Thus, it may be rational for farmers to sequentially adopt certain components of a technology system so they can learn more about the potential value of other components rather than adopt the complete package at one time (Byerlee and de Polanco, 1986; Leathers and Smale, 1991). This piecemeal adoption behavior by farmers may be particularly important with precision farming, which consists of a set of technologies with each component serving a specific purpose (Lowenberg-DeBoer 1998, Khanna, Epouhe, and Hornbaker 1999, Khanna 2001). With precision farming, technologies such as grid soil sampling, remote sensing, on-the-go sensing, and electronic yield monitoring help farmers gather very detailed information about the heterogeneous makeup of a farm field. Graphic information system (GIS) based computer applications enable analysis of the site-specific information and the making of management decisions to address crop needs for relatively homogeneous smaller-than-field-size areas within the field. The final step in the precision farming adoption sequence is to apply inputs based on the site-specific information using variable rate technology (VRT).

An important factor influencing the profitability of precision farming is the level of spatial variability that farmers find in their farm fields, where spatial variability is defined as the distribution across a field of areas with different crop yield responses to an input (Roberts, English, and Mahajanashetti, 2000). Within-field variability in soil physical and chemical characteristics is a necessary condition for the economic viability of using variable rate technology (English, Roberts, and Mahajanashetti, 1999; Forcella, 1993; Hayes, Overton, and Price, 1994; Roberts, English, and Mahajanashetti, 2000; Snyder, 1996). Relationships among crop yields, the level of input applied, and soil characteristics determine spatial variability within a field. These relationships also determine yield response variability, where yield response variability is defined as the differences in magnitudes of yield response among management zones (English, Roberts, and Mahajanashetti, 1999; Forcella, 1993; Roberts, English, and Mahajanashetti, 2000). Thus, spatial and yield response variability, along with the crop price, the input price, and the additional cost of using VRT versus uniform rate technology (URT), factor into the economic decision to adopt VRT.

The preceding discussion indicates that farmers observing fields with larger spatial variability may perceive greater potential benefits from the adoption of precision farming technologies. However, spatial variability in fields is not known with certainty and may be discovered over time by a farmer (Jaenicke and Cohen-Vogel 2000). For example, farmers may enroll a field in a grid soil sampling-VRT input application program sponsored by their local fertilizer dealer (Lowenberg-DeBoer 1999). This can be a low-cost method for a farmer to learn about spatial variability. Another example is farmers purchasing yield-monitoring equipment but not using VRT application of inputs until they have built up a yield history on the field (Swinton, Harsh, and Ahmad 1996).

Farmer perceptions of field spatial variability may be influenced by the use of precision farming technologies such as yield monitors designed to identify field spatial variability in crop yields. In turn, these updated perceptions may influence farmers' decisions to adopt VRT. Currently, there is no research documenting how farmer perceptions of field spatial variability are influenced by the use of yield monitors and other precision farming information technologies. The objectives of this study are: 1) to evaluate the personal characteristics and precision farming practices of adopters of site-specific information technologies, and 2) to analyze how farmers' perceptions of field spatial yield variability are influenced by the use of yield monitors and other precision farming information technologies. Data provided by cotton farmers from a six-state survey are used to achieve these objectives.

Data and Methods

Survey Methods

A mail survey of cotton farmers located in Alabama, Florida, Georgia, Mississippi, North Carolina, and Tennessee was conducted in January and February of 2001 to query producers about their attitudes toward and use of precision farming technologies (Roberts et al., 2003). Following Dillman's (1978) general mail survey procedures, the questionnaire, a postage-paid return envelope, and a cover letter explaining the purpose of the survey were sent to each producer. The initial mailing of the questionnaire was on January 16, 2001, and a reminder post card was sent one week later on January 23, 2001. A follow-up mailing to producers not responding to previous inquiries was conducted three weeks later on February 15, 2001. The second mailing included a letter indicating the importance of the survey, the questionnaire, and a postage-paid return envelope. Recipients were instructed to return a blank questionnaire if they were not a cotton producer.

The list of potential cotton producers, which included a total of 8,411 individuals for the 1999-2000 season, was furnished by the Cotton Board in Memphis, Tennessee (Skorupa, 2000). Of the potential cotton producers, 1,158 were from Alabama, 212 from Florida, 2,990 from Georgia, 1,334 from Mississippi, 1,798 from North Carolina, and 919 from Tennessee. The total number of surveys mailed was reduced to 6,423 by randomly selecting 1,400 potential producers from the Georgia list and 1,400 from the North Carolina list. This reduction lowered the cost of the survey but did not perceptibly reduce the ability to draw inferences about cotton producers in Georgia, North Carolina, or the six-state region.

Of the 6,423 questionnaires mailed, 196 were returned undeliverable, and 251 indicated that they were not cotton farmers or they had retired, giving a total of 5,976 cotton producers who received the questionnaire in the six-state region. Estimated responses totaling 1,331, which gave a six-state aggregate response rate of 19%.

Besides questions about precision farming, other information describing socioeconomic and demographic characteristics were also collected from survey respondents. Farmers were given the following definition before being asked a series of question about their use of precision farming technologies. “Precision farming involves collecting information about within field variability in yields and crop needs to assist in determining appropriate input levels and applying that information to your farm fields. This may result in varying input levels in the field.” Farmers were then asked to identify from a list provided to them, which precision farming information gathering technologies they have used on cotton, corn, peanut, rice, soybean, tobacco, and wheat. The information technology choices were: yield monitoring with a global positioning system (GPS); yield monitoring without GPS; grid soil sampling; management zone soil sampling; remote sensing using aerial imagery; remote sensing using satellite photographs; soil survey maps; mapping field topography, slope, soil depth, etc., plant tissue testing for nutrients and pests, and on-the-go sensing. GPS is an integral part of many of information technologies. Spatial field data that have been referenced to specific locations in a farm field using GPS can then be converted from raw data into a field map using GIS-based precision farming computer applications.

Survey respondents also were asked to provide estimates of annual average yield variability of typical fields that they farm for cotton, corn, peanut, rice, soybean, tobacco, and wheat. For each crop that they grew, farmers were asked to provide yield estimates for the following proportions of their typical farm field: the least productive third, the most productive third, and the field average.

Analytical Framework

To achieve objective 1 of the study, data from the survey were used to evaluate farmer use of alternative precision farming technologies in conjunction with cotton yield monitors with GPS. Adoption rates for alternative information gathering technologies and crops were also analyzed using the survey data.

To accomplish objective 2 of the study, farmer yield estimates were used to calculate a field spatial yield variability (SYVAR) statistic for crop i using the following variance formula:

(1) $$SYVAR_i=0.33\times(Y_{low}-Y_{avg})^2+0.33\times(Y_{mid}-Y_{avg})^2+0.33\times(Y_{high}-Y_{avg})^2,$$

where Y_{low} is the estimated yield for the least productive third of the typical field, Y_{avg} is the estimated average yield for the typical field, Y_{high} is the estimated yield for the most productive third of the typical field, and $Y_{mid}=3\times Y_{avg}-Y_{low}-Y_{high}$ is the yield estimate for the middle productive third of the typical field. To make comparisons among crops, $SYVAR_i$ and Y_{avg} were used to create a coefficient of field spatial yield variability ($SYCV_i$) statistic using the following formula:

(2) $$SYCV_i = \frac{SYVAR_i^{0.5}}{Y_{avg}} \times 100.$$

Farmers' estimates of field spatial yield variability for crop i were evaluated using the following equations:

(3) $$SYVAR_i^{0.5} = \beta_0 + \beta_1 YMGPS_i + \beta_2 YM_i + \beta_3 SOIL_i + \beta_4 REMOTE_i + \beta_5 MAP_i + \beta_6 PLANT_i + \beta_7 GO_i + \beta_8 ACRE_i + \beta_9 OWNED_i + \beta_{10} INCOME_i + \beta_{11} COLLEGE_i + \beta_{12} AGE_i + \beta_{13} PINDEX_i + \beta_{14} AL_i + \beta_{15} FL_i + \beta_{16} GA_i + \beta_{17} NC_i + \beta_{18} MS_i$$

and

(4) $$SYCV_i = \beta_0 + \beta_1 YMGPS_i + \beta_2 YM_i + \beta_3 SOIL_i + \beta_4 REMOTE_i + \beta_5 MAP_i + \beta_6 PLANT_i + \beta_7 GO_i + \beta_8 ACRE_i + \beta_9 OWNED_i + \beta_{10} INCOME_i + \beta_{11} COLLEGE_i + \beta_{12} AGE_i + \beta_{13} PINDEX_i + \beta_{14} AL_i + \beta_{15} FL_i + \beta_{16} GA_i + \beta_{17} NC_i + \beta_{18} MS_i,$$

where $SYVAR^{0.5}$ is the standard deviation of spatial yield variability estimated using equation (1); SYCV is the coefficient of spatial yield variability estimated using equation (2); YMGPS is 1 if a farmer used a yield monitor with GPS, 0 otherwise; YM is 1 if a farmer used a yield monitor that was not equipped with a GPS receiver, 0 otherwise; SOIL is 1 if a farmer employed grid soil sampling or management soil sampling, 0 otherwise; REMOTE is 1 if a farmer utilized remote sensing, 0 otherwise; MAP is 1 if a farmer made use of soil maps, 0 otherwise; PLANT is 1 if a farmer used plant tissue testing, 0 otherwise; GO is 1 if a farmer employed on-the-go sensing, 0 otherwise; ACRE is total farm acreage; OWNED is owned acreage divided by total crop acreage; INCOME is 1 if farming was the primary source of household income, 0 otherwise; COLLEGE is 1 if the farmer attended college, 0 otherwise; AGE is age of the farmer in years; PINDEX is a soil productivity index using 10-year county yields as a proxy (U.S. Department of Agriculture, National Agricultural statistics Service, 2002); and AL, FL, GA, NC, and MS are 0-1 binary variables for Alabama, Florida, Georgia, North Carolina, and Mississippi.

Ordinary least squares regression was used to estimate coefficients for both equations (3) and (4). Equations were estimated for cotton, corn, peanut, soybean, and wheat. Not enough observations existed to estimate spatial yield variability equations for rice and tobacco.

The estimated coefficients from equation (3) [standard deviation of spatial yield variability] were used to evaluate whether perceptions of spatial yield variability by farmers who used alternative precision farming information technologies were different from the perceptions of farmers who did not use these technologies. In addition, coefficient estimates from equation (3) were used to evaluate whether perceptions of spatial yield variability were influenced by the type of information gathering technology used. Finally, coefficient estimates from equation (3) were used to evaluate whether demographic factors influenced farmer's perceptions of spatial yield variability. Little is known about the relationship between producer adoption of precision farming information gathering technology and their perceptions about spatial yield variability. Because of this lack of knowledge, a significance level of up to 20%, as suggested by Manderscheid (1965), was used to evaluate which factors were important in explaining perceptions.

The error sums of squares from the regressions estimated from equation (4) were used to evaluate the relative spatial yield variability rankings among the different crops. *F*-tests constructed using the error sums of squares for each crop were used to evaluate whether one crop had perceived spatial yield variability that was significantly different from another crop ($p \leq 0.10$). The null hypothesis was that the spatial yield variance estimates were identical for pair-wise comparisons of alternative crops.

Results and Discussion

Information Technology Adoption Rates

The percentages of cotton farmers using alternative site-specific information technologies on different crops are presented in Table 1. Results indicate that grid or management zone soil sampling was the information technology most often used by cotton farmers. The highest rates of usage of site-specific soil testing in crops were reported by farmers who grew cotton (19%), peanut (15%), corn (14%), soybean (11%), and tobacco (11%). The second most used site-specific information technology used by farmers was soil surveys and maps—ranging from a high of 9% of farmers using them for cotton to a low of 5% of farmers using them for rice. About 8% of farmers growing cotton used plant tissue testing. Less than 2% of farmers were using remote sensing for any crop. The least used information technology was on-the-go sensing with less than 1% of farmers reporting its use on cotton.

By contrast, the use of yield monitoring with GPS by cotton farmers was much lower than for site-specific soil testing. The largest percentages were reported by cotton farmers who grew rice (9%), corn (5%), and wheat (5%). Only 2% and 1% of farmers reported they using yield monitors with GPS on cotton and peanuts. The same adoption pattern among crops was observed for yield monitors without GPS. The largest percentages of farmers who reported that they used yield monitors without GPS were for rice (5%) and corn (4%). The earlier commercial availability of yield monitors for grains and oilseeds relative to cotton and peanuts was likely the primary factor behind the lower adoption rates for these crops. Results indicate that, with the exception of yield monitors, cotton was the crop on which cotton farmers used site-specific information technologies the most.

Characteristics of Cotton Precision Farming Technology Adopters

A comparison of early adopters and non-adopters of cotton yield monitors with GPS is presented in Table 2. The numbers under the adopter and non-adopter columns indicate the percentage of farmers falling under adopter and non-adopter categories for a particular question from the 2001 precision farming survey. The numbers in parentheses indicate the number of respondents who fell into the cotton yield monitor adopter and non-adopter categories. The important findings that can be derived from Table 2 are as follows.

First, adopters of cotton yield monitors with GPS were more likely to use other site-specific information technologies than non-adopters. One in four adopters (24%) used remote sensing compared with only 1% for non-adopters. One-third of adopters (33%) used soil maps for management decision making. By comparison, only 7% of non-adopters indicated they used soil maps. All cotton farmers who adopted cotton yield monitors with GPS (100%) combined management zone/grid soil sampling with yield monitoring information. Only 15% of non-adopters reported using management zone/grid soil sampling information. An equal percentage (5%) of adopters and non-adopters reported the use of on-the-go sensing. Results indicate that adopters of cotton yield monitors with GPS were more likely to use several sources of site-specific information in management decision making.

The second important finding is that adopters of cotton yield monitors with GPS were more likely to use VRT to apply crop inputs. Ten percent of adopters reported that they used VRT to seed their crop compared with only 2% of non-adopters. One-third (33%) of yield monitor adopters used VRT to apply lime. Only 8% of non-adopters used VRT to apply lime. More than four in ten adopters (43%) applied fertilizer using VRT compared with only 8% for non-adopters. Nearly four in ten adopters (38) applied chemicals using VRT. By comparison, only 8% of the non-adopters applied chemicals using VRT.

The third major finding is cotton farmers were computer literate and actively used computers in making management decisions. The majorities of adopters (95%) and non-adopters (75%) of cotton yield monitors with GPS owned a computer. Eighty-five percent of adopters used the computer for farm management, compared with 60% of non-adopters.

Survey results suggest that farmers who adopted yield monitors with GPS were also likely to have used other site-specific information technologies and computers to analyze that information. Farmers who used a more comprehensive set of precision farming technologies that included yield monitors with GPS may have had a better feel for how yields varied in farm fields than non-adopters. Thus, farmers who used yield monitors with GPS may have been able to more accurately discern spatial yield variability than farmers who had not adopted this technology.

In addition, survey results indicate that adopters of yield monitors with GPS were more likely to have had a larger farm size, were somewhat younger, and were more likely to have attended college than non-adopters. Yield monitor adopters were more likely to believe that precision farming would be profitable for them in the future. Thus, socioeconomic differences between adopters and non-adopters of yield monitors may also play an important role in farmers' perceptions of spatial yield variability.

Farmer Perceptions of Spatial Yield Variability

Error sums of squares from the OLS regressions of the coefficient of spatial yield variation are reported in Table 3. The error sums of squares indicate the relative spatial yield variance rankings for each crop, all other factors being equal. Cotton had the largest spatial yield variance followed in descending order by soybean, corn, peanut, and wheat. F-tests constructed using the error sums of squares for each crop to evaluate whether one crop produced perceived spatial yield variability that was significantly different from another crop are presented in Table

3. Spatial yield variability for cotton was significantly different from the spatial yield variability for corn, peanut, and wheat at p=0.01. The difference in spatial yield variability between cotton and soybeans was not significant at p=0.10. The differences in spatial yield variability for the corn versus peanut (p=0.10), soybean (p=0.01), and wheat (p=0.01) comparisons also were statistically significant as were the peanut versus soybean (p=0.01) and wheat (p=0.01) comparisons.

The estimated coefficients for the standard deviation of spatial yield variability equations for each crop estimated using OLS are presented in Table 4. Standard errors for the estimated coefficients are in parentheses. All five crop equations were statistically significant at $p \leq 0.20$. Multicollinearity diagnostics found that the standard errors of the coefficients were not seriously degraded. The important findings that can be derived from Table 4 are as follows.

First, farmers using yield monitors with GPS may perceive larger spatial yield variability than non-adopters in certain crops. The coefficients for the yield-monitor-with-GPS variables were significantly different from zero in the cotton, peanut, and wheat equations but were not significantly different from zero in the corn and soybean equations. For cotton, farmers using yield monitors with GPS perceived 20% (69.45 lb/acre) more spatial yield variability than non-adopters. Results indicate that farmers who used yield monitors with GPS on cotton, peanut, and wheat may have been able to discern larger spatial yield variability than farmers who have not adopted this technology. Crops with larger spatial yield variability have been associated with more profitable use of precision farming technology such as variable rate application of inputs (English, Roberts, and Mahajanashetti, 1999; Forcella, 1993; Roberts, English, and Mahajanashetti, 2000).

Second, farmers who used other site-specific information gathering technologies on alternative crops, in general, did not perceive spatial yield variability that was significantly different from non-adopters. The exceptions were for farmers who reported using yield monitoring without GPS on corn and wheat and remote sensing on peanuts. Farmers who used yield monitors without GPS on corn perceived higher spatial yield variability than non-adopters. By contrast, farmers who used yield monitors without GPS on wheat and farmers who used remote sensing on peanuts perceived lower spatial yield variability than non-adopters. With the exception of yield monitors with GPS, the explanatory variables for the other information technologies did not exhibit consistent relationships in terms of direction of impact on farmer perceptions of spatial yield variability.

Third, socioeconomic factors did influence the spatial yield variability perceptions of cotton farmers. However, no one demographic factor had a consistent influence on farmers' perceptions of spatial yield variability across all five crop equations. Total crop acreage—a proxy for farm size—had a positive and significant influence on farmers' perceptions of spatial yield variability in soybean and wheat. The significant relationship for these crops suggests that a farmer with a larger farm size may have more opportunities to observe spatial yield variability in more farm fields. The coefficients on the owned-to-rented acres variable were significant in the corn and wheat equations but did not exhibit the same sign. A farmer whose primary source of household income was from farming and grew cotton, corn, or soybean perceived significantly higher spatial yield variability. Whether farmers attend some college did not impact farmers' perceptions of spatial yield variability. The estimated coefficient for operator age had a negative sign and was statistically significant in the cotton, corn, and wheat equations. Older producers of these crops perceived less spatial yield variability than younger producers.

Conclusions

This study evaluated how farmers' perceptions of spatial yield variability in farm fields are influenced by precision farming information technologies. Farmer yield variability estimates from a mail survey were regressed on use of site-specific information gathering technologies and farmer characteristics. Results indicate that no one information technology had a consistent influence on farmers' perceptions of spatial yield variability across all five crops evaluated in this analysis. However, farmers who adopted yield monitors with GPS perceived significantly higher field spatial yield variability in cotton, peanut, and wheat. In general, farmers who used other site-specific information technologies did not perceive spatial yield variability that was different from non-adopters. Because yield monitors with GPS directly measure yields and can be used to develop yield maps, farmers who use this technology may be able to more accurately assess spatial yield variability than farmers who do not use this technology. Farmers who use yield monitors with GPS to update their knowledge of yield variability may perceive greater benefits from the adoption of variable rate technology. Future research should include a formal investigation to confirm the direction of causality between information technology adoption by farmers and farmers' perceptions of spatial yield variability.

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Table 1. Percentage of Respondents Using Alternative Electronic Information Gathering Technologies from a Six State Survey of Cotton Farms

Information Gathering Technology/Number	Crop						
	Cotton	Corn	Peanut	Rice	Soybean	Tobacco	Wheat
	---------------------------Percent---------------------------						
Yield Monitor w/ GPS	2.10	5.04	1.36	9.09	3.87	0.74	4.89
Yield Monitor w/o GPS	0.99	3.84	2.72	4.55	1.94	0.74	2.67
Grid/Management Zone Soil Sampling	18.78	13.91	14.97	4.55	10.97	11.76	1.22
Aerial/Satellite Remote Sensing	1.66	1.68	1.02	0.00	0.86	0.74	0.89
Soil Survey/Soil Maps	8.73	6.47	7.48	4.55	7.96	6.62	6.22
Plant Tissue Testing	8.29	3.12	3.06	0.00	1.08	1.47	1.78
On-The-Go Sensing	0.44	0.00	0.00	0.00	0.00	0.00	0.00
Number of Farmers	905	417	294	22	465	136	225

Table 2. A Comparison of Early Adopters and Non-Adopters of Cotton Yield Monitor with a Global Positioning System Technology From A Survey of Cotton Farmers in Six Southern States

Item	Adopters		Non-adopters	
Farmer Use of Other Information Technologies:				
Remote Sensing (%)	24	(21)[a]	1	(1109)
Soil Maps (%)	33	(21)	7	(1109)
Management Zone/Grid Soil Sampling (%)	100	(21)	15	(1109)
On-the-Go Sensing (%)	5	(21)	5	(1109)
Farmer Use of Variable Rate Application for:				
Seed (%)	10	(21)	2	(1109)
Lime (%)	33	(21)	8	(1109)
N, P, and K Fertilizer (%)	43	(21)	8	(1109)
Chemicals (%)	38	(21)	6	(1109)
Farmer Use of Computers:				
Own a Computer (%)	95	(21)	77	(994)
Use Computer for Farm Management (%)	85	(21)	60	(994)
Farmer Perceptions of Precision Farming:				
Believe It will be Profitable in Future (%)	85	(20)	68	(925)
Importance in Cotton (Scale 1-5)	4.1	(20)	3.6	(924)
Farmer Characteristics:				
2000 Crop Year Cotton Acreage	1,240	(21)	607	(1109)
2000 Crop Year Total Acreage	1,772	(21)	1,062	(1109)
Age (Years)	47	(20)	51	(1003)
Experience Farming (Years)	26	(19)	28	(965)
Attended College (%)	81	(21)	56	(1109)
Household Income from Farming (%)	82	(19)	69	(959)

[a] The number in parenthesis is the number of respondents in the 2001 precision farming survey reporting for each question.

Table 3. Results of Pair-Wise Comparisons Among Crops of Spatial Yield Variability

Crop	Error Sums of Squares
Cotton	131,863
Corn	71,589
Peanut	58,944
Soybean	119,496
Wheat	27,795

Crop Comparison	*F*-statistic
Cotton versus Corn	1.84***
Cotton versus Peanut	2.24***
Cotton versus Soybean	1.10
Cotton versus Wheat	4.74***
Corn versus Peanut	1.21*
Corn versus Soybean	1.67***
Corn versus Wheat	2.58***
Peanut versus Soybean	2.03***
Peanut versus Wheat	2.12***
Soybean versus Wheat	4.30***

***, **, *, Significantly different from zero at the 1-, 5-, or 10-percent probability level, respectively.

Table 4. Factors Influencing Cotton Farmers' Perceptions of Yield Spatial Variability

Item	Cotton (lb/acre)	Corn (bu/acre)	Peanuts (lb/acre)	Soybeans (bu/acre)	Wheat (bu/acre)
Intercept	163.18****	13.77*	813.30***	3.35	16.32***
	(41.83)	(8.79)	(327.42)	(3.80)	(8.33)
Yield monitor w/ GPS	69.45***	2.52	1023.35****	0.66	6.34***
	(31.01)	(5.00)	(402.55)	(1.76)	(3.44)
Yield monitor w/o GPS	-39.21	7.29*	-118.72	-2.03	-5.60*
	(60.04)	(4.49)	(184.46)	(2.24)	(3.61)
Grid/zone soil sample	-12.32	0.55	-55.95	0.85	-1.80
	(13.38)	(3.16)	(96.66)	(1.14)	(2.34)
Remote sensing	17.67	6.63	-653.94***	3.03	0.36
	(33.20)	(6.85)	(316.42)	(2.51)	(5.26)
Soil surveys/mapping	11.16	-1.33	146.88	0.52	0.19
	(16.55)	(4.06)	(129.89)	(1.34)	(2.60)
Plant tissue testing	16.21	3.48	154.23	-2.45	6.90*
	(17.81)	(5.91)	(198.83)	(3.11)	(5.15)
On-the-go sensing	0.32	----	----	----	----
	(102.51)				
Crop acreage	1.31×10^{-3}	1.15×10^{-4}	$-1.40-\times10^{-2}$	1.61×10^{-4}*	2.91×10^{-4}*
	(2.14×10^{-3})	(3.22×10^{-4})	(2.40×10^{-2})	(1.01×10^{-4})	(2.27×10^{-4})
Owned-to-rented acres	−1.13	5.412**	−15.81	0.48	−4.44***
	(13.54)	(3.13)	(112.49)	(1.00)	(2.16)
Farm primary income	24.06***	7.29***	34.16	1.35*	−2.63
	(11.09)	(2.86)	(86.57)	(0.85)	(1.84)
Attended college	4.32	0.87	−18.07	0.21	−1.45
	(9.24)	(2.06)	(69.04)	(0.66)	(1.35)
Operator age	−0.89***	−0.21***	9.95×10^{-2}	-3.12×10^{-2}	−0.14***
	(0.41)	(9.36×10^{-2})	(3.23)	(2.96×10^{-2})	(6.03×10^{-2})
Productivity index	0.27	0.14***	−0.55	6.28×10^{-2}**	8.56×10^{-2}
	(0.37)	(6.05×10^{-2})	(2.24)	(3.07×10^{-2})	(7.46×10^{-2})
Alabama	27.71**	11.07****	173.37*	3.33***	2.19
	(15.15)	(3.54)	(114.92)	(1.32)	(1.95)
Florida	47.15***	10.37**	−94.36	4.17***	0.041
	(20.94)	(5.67)	(97.89)	(2.21)	(2.94)
Georgia	29.76**	8.27***	−14.63	2.41**	1.37
	(17.19)	(3.51)	(81.6)	(1.54)	(2.06)
North Carolina	54.99***	6.69***	----	1.46*	-0.53
	(13.75)	(2.93)		(0.82)	(1.62)
Mississippi	25.76*	-0.94	----	1.36*	1.85
	(16.82)	(2.96)		(0.89)	(2.12)
Model F-statistic	2.52***	3.03****	1.39*	1.42*	1.74***
Adjusted-R^2	0.04	0.10	0.03	0.02	0.07
Observations	635	308	177	320	160

Standard errors are in parenthesis with statistical levels as noted: *=0.15, **=0.1, and ***=0.05, and ****=0.01.