The Relevance of Information Sources on Adoption of Precision Farming Technologies by Cotton Producers

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Abstract

The effectiveness of sources of information (SI) on adoption of precision farming technologies (PFT) by US cotton producers is evaluated with data from the 2009 Southern Cotton Precision Farming Survey. The conceptual framework considers information flows as production inputs with a derived demand from the demand for PFT's and farm output. Coefficients of the chosen multivariate probit model are estimated with simulated maximum likelihood. The results indicate that information from the internet significantly affected the adoption of yield monitors with GPS and soil survey map technologies. Information from farm dealers impacted significantly the adoption of zone soil sampling technologies and soil survey maps. The use of university extension per se was not a statistically significant SI. Nevertheless, the use of university publications and attendance to events organized by universities had more consistent and significant positive effects on adoption of PFT's. Income, farmer's education and use of computer for management and field operations had positive effects as well. In conclusion, SI's have positive and asymmetric effects on adoption of PFT's. The paper ends providing recommendations for creation and delivery of outreach materials in the context of strategic communication plans executed by organizations serving this clientele.

Key Words: strategic communication, competitiveness, extension, economics of information, technology diffusion, technology supply, communication methods, knowledge management

JEL Classifications: D22, D80, D82, D83, Q12, Q16

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Introduction

Cotton producers have experienced gains in productivity due to technological developments. Particularly in the last five decades, unprecedented advances have occurred in communications, precision farming, plant breeding, managerial skills, input management, industrial processing and marketing. The improvements in communications infrastructure have facilitated the diffusion of technologies from an innovator region to one that is adopter. But, before the adoption of new technologies takes place, farmers acquire information from different sources such as farm dealers, crop consultants, university extension, fellow farmers, trade shows, internet, news media, university publications and events organized by universities.

New technologies are adopted if the revenues are greater than the costs, assuming that profits play the most fundamental decision criteria, thereby, it is assumed that there exists information gathering and learning that contributes to the assessment of cash flows and consequently to the diffusion of new technologies, see Griliches (1957) and Feder and O'Mara (1982). Other motives that may compel farmers to adopt PFT's are related to the preservation of the environment, e.g. soil conservation, optimal use of inputs, and water quality.

During the last 2 decades, the use of PFT's is increasingly becoming important because they generate greater productivity, profitability, and environmental benefits that will sustain yields in years to come. In the literature of technology adoption much is talk about the role played by farm and farmer characteristics, yet, the role of different sources of information on adoption of PFTs by cotton producers in the South has not received much attention. Consequently, this study aims to bridge that gap.

Using data from US Southern cotton farmers, Mooney et al. (2010) finds that 70% of surveyed farmers considered profits as a very important reason for adopting PFT's, while 7% indicated the contrary. In contrast, 23% of farmers stated that the search for environmental benefits was a very important factor for adopting PFT's, whereas 14% of farmers affirmed the opposite. Mooney et al. (2010) also find that 17% of farmers specified the need to be on the agricultural technology frontier as an important factor for adopting precision farming practices while 29% of respondents affirmed the contrary.

Once farmers have justified the use of PFT's, it is logical to consider that the adoption of PFT's will occur if and only if the valuation of the benefits and costs of new investments are able to produce enough returns to the farmer and/or the firm. For that reason, it is assumed that PFT's constitute another input in the production process, and that there exists an underlying demand for such input according to market conditions of the output; thus, the competitiveness of the enterprise is either maintained or enhanced.

Then, as the farmer demands more PFT's, the more information is consumed in the process of adoption. The adopted technologies at a particular time, not only will depend on how efficiently the information flows among farmers and SI's, but also on the quality and quantity of information being delivered. Nevertheless, questions remain about the effectiveness of SI's on contributing to the adoption of PFT's by US cotton producers. These arguments provide the theoretical base for the conceptual structure to be presented and the selection of econometric methods for data analysis.

The effects of SI's on adoption of PFT's by cotton producers are evaluated for the southern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and Texas). The analyzed SI's that farmers used for precision farming decisions included farm dealers, crop consultants, university extension, other farmers, trade shows, internet, and news media. Furthermore, the analysis controls for the use of computer, use of university publications and attendance to university events. The PFT's included in the analysis were yield monitor with GPS, soil sampling (zone & grid), aerial photos, and soil survey maps; they are the most commonly implemented technologies. Additional factors considered in the analysis were characteristics of the farmer, farm, and farm's location.

Three sets of results are presented in this research paper. The first set includes the results and analysis of the effects of SI's on adoption of precision farming practices without regard to a specific PFT. In contrast, the second set presents the results from multivariate probit regression for five PFT's. Finally, the third set of results comes from bivariate probit regressions that allow the calculation of nonnegligible marginal effects of SI's on adoption of PFT's.

Based on the empirical evidence compiled in this paper, it is concluded that SI's have positive effects on adoption of PFT's, yet, such effects are asymmetric for different PFT's. In general, the most relevant sources of information impacting adoption decisions of precision farming technologies are university publications, university events, dealers, news media, and crop consultants. These results illustrate the importance of information provided by universities and private entities.

The results of this research endeavor can be used to identify the most relevant sources of information that contributes significantly to the adoption of precision farming practices by US cotton producers in the southern region. In addition, the results can help on the elaboration of strategic communication plans by input suppliers and institutions serving this clientele. Nevertheless, the conclusions and recommendations may be applied to other technologies, commodities and circumstances.

Supply of Information

The role of agricultural extension in developing rural communities and agribusiness firms has become not only a task of creation, communication and distribution of information but also has become active promoter of interventions and/or transformation. Extension specialists have been involved in the promotion of changes from old practices to new practices, sponsoring replacement of older technologies by current technologies, and so forth. Just as university extension, private entities also deliver information in the process of reaching out to farming communities. In addition, suppliers of agricultural inputs target farmers for increasing sales and profits. For instance, suppliers may engage in interpersonal communications, setting of product trials and promotion of decision tools for managing the farms.

Lawson and Dail (1966) have pointed out that the effectiveness of information acquired by farmers from different sources may differ according to the stage of adoption of a technology and level of difficulty of the problems being experienced by farmers; in part, due to the perception of the reliability of the information being delivered. Lawson and Dail (1966) find that information from agricultural extension services is the most reliable source as perceived by farmers, yet, the authors point out that input suppliers could be seen as retailers of information while extension as wholesalers of information. As such, extension services must engage in establishing cooperative relationships with input suppliers for achieving common goals more efficiently. However, ethical considerations have to be weighed in as conflicts of interest may arise as the search and intensity of such collaboration progresses.

Holt (1989) identified that extension services have contributed greatly to the transformation of US agriculture, still, in the late 80's there was strong support for shrinking agricultural extension services. This circumstance has encouraged the reduction in the number of employees involved in extension. Same situation can be observed in the new millennium as the budgets of land grant universities are reduced for coping with the financial crisis that emerged in 2008. As Holt described the situation in the 80's, if public support for extension is reduced, then management of extension services must recognize the imperative need to deliver effectively the mission granted. This can be achieved by fostering greater cooperation with a broader clientele and competing suppliers of the same services. Thereby, managers can exploit the credibility that extension services providers have, refer to Lawson and Dail (1966).

Farmers may exhibit different preferences toward different channels by which different types of information are delivered; in part, because of the heterogeneity of farmers in terms of human capital that is accumulated either through formal education or experience (Just and Zilberman, 2002). Gloy et al. (2000) in a study of farms with sales above $100,000 categorized sources of information between media and personal. The media information category included information sources from crop/livestock-specific publications, general farm publications, direct mail, and radio. The personal information category included sources such as local dealer sales and technical people, manufacturer salespeople, manufacturer technical specialists, and other farmers.

Gloy et al. (2000) finds that farmers who have adopted PFT’s (computerized field mapping, satellite imagery, soil sampling with GPS, and yield monitoring with GPS) were more likely to find either often useful or always useful all the sources from the personal information category with the exception of information from other farmers. Conversely, the marginal effects of adopted PFT’s were not significant factors influencing the perceptions about the usefulness of information sources from the media category. The internet had a positive effect on farmer’s perception as useful in five of the eight sources of information in the analysis.

According to Khanna (2001), farmers with bigger operations may be more able to adopt new innovations due to learning costs and information gathering costs. In the case of PFT’s, their adoption requires greater information since their use needs to be learned given that precision agricultural practices are not only relatively new techniques in the business but also more complex.

Consequently, it’s expected that more difficult technologies would require greater amount of information for various decisions such as adoption, further maintenance and even disadoption of PFT’s. Moreover, the information demanded will be conditioned on the ability to process it. Therefore, differences in human capital are expected to influence the diverse demand for sources of information by farmers. McBride and Daberkow (2003) find that human capital is a significant factor on the adoption of PFT’s as described by farm’s operator age, experience, education and use of computers, after controlling for farm size. Furthermore, they find that interpersonal sources of information have greater effects than media outlets on adoption of precision farming practices.

Jenkins (2009) studied the use of SI’s by cotton producers without distinction between adopters and non-adopters of PFT’s, finding that extension was used in simultaneous combination with private sources such as news media, crop consultants, trade shows, and fellow farmers. Jenkins (2009) also established that heavy users of extension have lower age, more years of education and higher income in comparison to non-users. Farmers with greater land tenure tended to be non-users of extension (Jenkins, 2009; Velandia, 2010). In addition, Jenkins (2009) also finds that education, income, and farm size have positive effects on the use of private sources of information as well as information from extension, and media sources. Conversely, age was negatively related to the use of all SI’s.

Given the gaps in the literature and data available for empirical evaluation, the main objective of this research endeavor is to identify the sources of information that contribute to the adoption of precision farming technologies by US cotton farmers in 12 southern states. We achieve this by focus on finding answers to the following research questions: Are the effects of SI's symmetric? What SI's have significant effects on adoption? Does information from university publications and events play a role on adoption of PFT's?

Econometric Methods

The effects of different sources of information on the adoption of PFT's by cotton producers in the southern states is investigated using multivariate probit regression. Thus, the simultaneity of the choices is taken into account (Greene, 2003). For this reason, multivariate probit estimation has being used widely in the analysis of technology adoption and best management practices in the agricultural sector (Rahelizatovo, 2002). Given the binary nature of the dependent variables, the equations of interest have the following functional form

(1) $$Y_k = c + \beta_k' X + u_k \ \forall \ k = 1, 2, \cdots, 5$$

where Y_k corresponds to the adoption of technology k, it takes values of one if technology k is adopted, otherwise the value is zero. The errors u_k have an assumed multivariate normal distribution. The independent variables are denoted by vector X, they are divided in two sets. The first set corresponds to characteristics of the farmers and respective farms. The second set corresponds to dummy variables that represent SI's used in precision farming decisions. The vector β_k corresponds to the set of parameters for equation k. Refer to Greene (2003) and Stata reference manuals (2007) for technical details about the estimation of both parameters and marginal effects in probit regressions (univariate, bivariate, and multivariate).

In addition, the analysis controls for the use of computer to manage the farm and use of computer for field operations. Moreover, the analysis controls for the use of university publications and attendance to university events related to precision farming during the last 5 years prior to the survey. The main reason for inclusion of these variables lies in the fact that they clearly constitute additional sources of information. The information delivered in publications and events may contribute to the adoption and continuance of precision farming practices; moreover, the inclusion of these sources in the analysis would also further the understanding of the relevance of broader extension services provided by land grant institutions.

The vector of coefficients is obtained using simulated maximum likelihood, by employing the mvprobit procedure in Stata developed by Cappellari and Jenkins (2003, 2006). Since choices are represented by multidimensional integrals, then, random draws are needed to solve the problems of recursively estimating posterior probabilities, thereby, allowing the calculation of the contribution to the likelihood function for each observation (Bolduc, 1999). The mvprobit routine relies on the Geweke-Hajivassiliou-Keane choice probability simulator, where the square root of the number of observations approximates the number of draws (Cappellari and Jenkins, 2003). The coefficients for the initial iterations of the multivariate estimation were calculated from probit regressions. Different numbers of random draws and seed numbers were used for realizing the sensitivity of the estimates given the asymptotic properties of the estimator.

Data

The data for the analysis comes from the 2009 Southern Cotton Precision Farming Survey described and obtained by Mooney et al. (2010) which is funded by Cotton Incorporated and six land grant institutions. Binary variables were constructed for the adoption of PFT's and the presence of use of different SI's for precision farming decisions. The analyzed PFT's were yield monitor with GPS, soil sampling (grid & zone), aerial photos, and soil survey maps. The final sample contains 1098 observations corresponding to individuals who reported have planted cotton in 2008, and, have also experienced a positive fraction of income from farming.

A classification between adopter and non adopters indicates that 71% percent of cotton farmers were non-adopters of PFT's. Moreover, 19% of farmers had 1 PFT, 6.5% of farmers had 2 PFT's, and finally, 3.5% of farmers had between 3 and 5 PFT's (Table 1). The correlation coefficients for adoption of PFT's ranged between 0.09 and 0.32, they are statistically significant different from zero at 0.01 probability level (Table 2). This structure is taken into account in multivariate probit regressions.

In the survey, farmers were asked about the origin of the source of information for precision farming decisions. The available responses included farm dealers, crop consultants, university extension, other farmers, trade shows, internet, and news media. Only 13.4% of surveyed farmers indicated having used one source of information for precision farming decisions, 56% between 2 and 4 SI's, and finally, 17% of farmers used between 5 and 7 SI's (Table 3).

Farmers also indicated having obtained information about precision farming from university publications and university educational events, in the sample 34.7% and 48.4% of cotton producers indicated having used those sources of information in the past five years, respectively. To account for these additional sources, a dummy variable was introduced for evaluating the incidence of university publications on adoption of PFT's. The influence of university educational events was evaluated by the number of attended events related to precision farming during the last 5 years (Table 4).

The use of computers was included in the analysis, 54.1% of cotton producers employed them for management purposes while only 12.7% of surveyed farmers stated having used them for field operations (Table 5). The average size of the farm was about 807 acres, one third of that land corresponded to the rented acreage.

The average age of the farmer was about 55 years, and on average 30.6 of those years match up to farming experience. On average, farmers had 14.3 years of education. Off farm income by cotton producers accounted for 25.1% of total income. Two thirds of farmers experienced an income below to $149,000 in 2007 (Table 5). Location of the farm was assessed by comparing farms in Alabama, Arkansas, Florida, Georgia, Louisiana, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, Virginia with those farms situated in Texas (Table 5).

Results and Discussion

The results are presented in three sets. By implementing univariate probit regression, the first set of results corresponds to the analysis of the effects of SI's on adopters versus non-adopters of precision farming practices. The second set corresponds to results from multivariate probit regression for the adoption of five PFT's. The third set of results comes from bivariate probit regressions for PFT's that provide greater accuracy of information.

For the first set of results, a dummy variable "adopter" was created for determining adoption of precision farming practices. The variable takes the value of one if the farmer adopted at least one out of the five technologies being considered in the analysis, otherwise the value of the variable is zero. Thus, the effects of sources of information on the overall adoption of precision farming technologies can be evaluated.

At different levels of significance (a=1%, b=5%, c=10%), it is found that information from dealers (a) and news media (c) have significant effects on the overall adoption of precision farming practices. Information from university publications (a) and attendance to educational events organized by universities (a) had positive and significant effects on adoption of PFT's (Table 6). These findings provide statistical evidence about the significance of diversified extension services that are delivered by universities.

The use of university extension per se was not a statistically significant source of information on adoption of PFT's. By contrast, Walton et al. (2010) find extension as a significant factor on adoption of portable computers at .05 probability level. Two reasons could be making the difference. First, they include extension as binary variable, taking the values of one if and only if farmers stated that extension was a useful resource for precision farming decisions. The second probable reason is related to the exclusion of other sources of information such as the internet, news media, trade shows, other farmers, university publications and university events. Although, the exclusion may have occurred because the evaluation of SI's on adoption was not the focus of their research.

By measuring the intensity of extension as the number of times the farmer meet with agents within a year, Rahelizatovo and Gillespie (2004) find extension as a significant factor on adoption of management practices in dairy production. As a result, there is the possibility that extension specialists may concentrate efforts on a few farmers. Daberkow and McBride (2003) have argued that extension personnel and suppliers of PFT's may provide information and promotion activities to producers with farm operations where precision farming practices are more likely to be profitable.

The intensity of the farming business expressed by the fraction of farming income (a) had a significant and positive effect on adoption of precision farming practices. In terms of education, each additional year of schooling (b) had a positive effect on adoption of PFT's (Table 6). Farms located in Arkansas, Florida, Georgia, Louisiana, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, Virginia were more likely to adopt precision farming technologies in comparison with farmers located in Texas.

In terms of the magnitude of probability changes, the greatest marginal effect on adoption of PFT's was university publications followed by information provided by dealers, and trailed by the effects of information from news media (Table 7). That is, use of university publications increased the probability of adoption by 12.29%, while dealers and news media by 8.01% and 6.01%, respectively. For each additional attended event by farmers, ceteris paribus, the probability of adopting PFT's increased by .65% (Table 7).

Each additional year of education increases the chances of adoption by 1.37% while the increase of 1% in the fraction of farm income increases the chances of adoption of PFT's by 0.23% (Table 7). Farmers located in Louisiana are 53.7% more likely to adopt PFT's in comparison with those in Texas, ceteris paribus (Table 7).

The first set of results describes the effects of SI's on adoption of PFT's without regard to a particular technology. For that reason, the second set of results increases the understanding of the effects of SI's on each PFT by obtaining the coefficients using a multivariate probit estimator given the correlation structure of the adopted technologies.

After controlling for farm and farmers characteristics, at different significant levels (a=1%, b=5%, c=10%), it is found that adoption of PFT's responded positively to different SI's used in precision farming decisions. In the case of yield monitor with GPS, only information from the internet (c) had a significant effect. Adoption of grid soil sampling technologies was influenced significantly by crop consultants (c) and dealers (c). In contrast, adoption of zone soil sampling technologies was influenced significantly by information from dealers (a) and news media (b) (Table 8).

Adoption of soil survey maps was more influenced by information originated from dealers (b) and the internet (a). Furthermore, the adoption of aerial photos was influenced only by the presence of information from news media. Then, it is concluded that SI's have positive and significant asymmetric affects on adoption of PFT's, possibly due to different degrees of complexity and investment requirements of each PFT (Table 8).

Organized events by universities in the past five years had a significant and positive effect on the adoption of yield monitors with GPS (b), zone soil sampling (c), aerial photos (c) and soil survey maps (c). Use in the past five years of outreach materials published by universities, was a significant factor on the adoption of grid and zone soil sampling technologies (c,b) (Table 8).

The use of computer in the field and management purposes also plays an important role in the adoption process of PFT's. Thus, computers can be seen as complementary technologies. Computer for farm management had positive effects on the adoption of yield monitor with GPS (b) and grid soil sampling technologies (a). While use of computer in the field had positive effects on adoption of yield monitor with GPS (a) and aerial photos (b) (Table 8).

The total number of acres planted with cotton had positive effects on the adoption of yield monitor with GPS (a) and aerial photos (c). However, the adoption of grid soil sampling technologies was negatively influenced by the proportion of rented acres (c) (Table 8). Statistically insignificant negative effects of farming experience were found on the adoption of both soil sampling technologies (grid and zone) and aerial photos.

Years of education had positive effects on the adoption of PFT's, but there was a significant effect only on zone soil sampling technologies. As the fraction of income from farming increases, there are positive and significant effects on the adoption of precision farming practices (Table 8), this result is very consistent for all PFT's. Kim et al. (2005) found the same pattern about farming income in the analysis of adoption of best management practices in beef cattle production.

These results suggest that the intensity/specialization of the farming business plays a very important role on the implementation of precision farming practices in the United States. Possibly, the intensity of the business at cotton production makes the adoption of PFT's economically feasible, i.e., the benefits achieved by using PFT's are greater than their costs and opportunity costs of alternative production practices.

The dummy variables assigned to the states where farms are located, had in general positive and significant effects. In comparison with farmers in Texas, this finding implies that farmers in other states are more likely to adopt PFT's, ceteris paribus (Table 8).

Marginal probabilities were predicted after the estimation. On average, it was found that the highest probability of adoption was for zone-soil sampling technologies (0.15) followed by grid-soil sampling technologies (0.13) (Table 9); implying that zone-soil sampling technologies are more likely to be adopted, ceteris paribus.

The average joint probabilities for adoption of all technologies were 0.0023 and they ranged from values approximately zero to 0.182. On the contrary, the average joint probability of not adopting all the considered technologies was 0.707, implying a good fit of the model considering that 71.13 % of farmers in the sample were not adopters of PFT's (Table 9). The estimates are quite robust to different seed numbers and number of random draws. As such, the results do not suggest misspecification in the model.

The results from the multivariate probit estimator improved in comparison with univariate probit regressions (Table 10). As expected, multivariate probit was able to discern additional SI's as significant factors. In the univariate analysis, however, the variable years of schooling had positive and significant effects on the adoption of three PFT's whereas in the multivariate analysis only zone soil sampling technologies were significantly affected by increasing levels of education (Table 10).

The completion of the analysis requires the calculation of marginal effects. Such calculation is cumbersome due to the heavy non-linearity of the multivariate probit estimator. In addition, the size of the sample, the number of variables in each equation and the number of equations increase the time for computations. For these reasons, the reduction in the number of equations is favored, so that the estimation can reflect non-negligible marginal effects on adoption of PFT's. Moreover, although, the correlation coefficients were statistically significant different from zero, they may be weak in practice, because concurrent adoption of precision farming technologies is low in the sample (Table 2).

Currently, aerial photos and soil survey maps are being replaced by more accurate technologies. So, it is likely that farmers would adopt recent complementary technologies that provide higher level of accuracy. For example, yield monitor with GPS and soil sampling technologies (either zone or grid). These cases are more likely from the point of view of the farmer, since makes economic sense to combine information gathering technologies with variable rate application technologies.

For these reasons, the analysis of the effects of SI's on adoption of PFT's is reduced to two equations. In particular, two cases are considered. The first case studies the adoption of yield monitor with GPS and grid soil sampling technologies. The second case focuses on adoption of yield monitor with GPS and zone soil sampling technologies. In both cases, the goal is to obtain the marginal effects of SI's, refer to Greene (2003) for the technical details. Parameter estimates are displayed in Table 11.

For the first case, marginal effects from estimation of a bivariate probit model indicate that the probability of adoption of yield monitor with GPS increases by 0.23% for every university event that the farmer attends, the effect was significant at 0.1 probability level. At 5% level of significance, it is found that the probability of adopting grid soil sampling technologies increase with information from consultants and university publications, the marginal effects were estimated at 11.02% and 13.99%, respectively (Table 12).

As for the second case, it is found that zone soil sampling technologies are more likely to be adopted when information from consultants and news media are present. Such marginal effects were significant at .05 probability level, and they were estimated at 9.14% and 10.22%, respectively. Information from university publications increases the probability of adoption by 7.49%, such marginal effect was significant at 0.1 probability level (Table 13).

In summary, from the empirical evidence compiled in this paper, it can be stated that information from university publications, university events, dealers, and news media are the most relevant sources of information impacting adoption decisions of precision farming technologies. In general, trade shows and other farmers appear to be non-significant sources of information. Other factors that contributed to the adoption of PFT's were education, use of computer, the proportion of farm income, and size of the farm.

These findings have implications for developing strategic communication plans executed by organizations that serve this clientele. Once they have chosen their message and target audience, they need to identify the sources of information for disseminating appropriate information. This research project has identified the most relevant SI's that contribute to the adoption of PFT's. Now, organizations can use these findings and choose the most relevant sources of information that contributes to the adoption of precision farming practices.

Conclusions and Recommendations

The need to communicate information has been with us from a long time ago. As technological developments have accelerated in the last five decades, the channels for communication have improved as well. They have shorted the distances and the time required for the exchange. The barriers for effective communication have vanished by enhancing the transmission of information, evolving from simple delivery to more interactive and participatory.

These developments are signaling organizations to develop comprehensive communication strategies for serving their audiences more effectively. But, the achievement of effective communication requires from organizations the definition of clear objectives, target audiences, credible sources of information, effective channels of communication, stronger cooperation with partner institutions and input suppliers, and, last but not least enough financial resources supported by all stakeholders.

The research findings presented in this paper are of particular interest to US cotton farmers, manufacturers of PFT's, extension personnel, and media outlets. Nevertheless, the conclusions and recommendations may be applied to other commodities, technologies & circumstances. The findings indicate that SI's have positive and asymmetric effects on adoption of PFT's. Therefore, it is imperative to discern the most important channels of communication for achieving the organizations' mission.

In the 3 sets of results, we find consistently that information from university publications and university events have positive and significant effects on adoption of PFT's. Providing statistical evident about the important role of universities in serving the information demands of farmers though publications and events. Perhaps, a possible reason for these results is the sustained farmers' credibility about university extension services. This credibility has not been achieved suddenly, it is the product of long term relationships that have been based on trust, constant support and effectiveness as perceived by the reliability and relevance of information provided over decades of continuous service.

Moreover, previously discussed results indicate that private sources of information are also significant factors on adoption of PFT's; for instance, information from dealers, news media, and crop consultants were the most relevant private sources. These results are in accordance with the findings of Lawson and Dail (1966) and McBride and Daberkow (2003) who have pointed out the increasing importance of input suppliers as SI's for farmers.

Given that broader extension services provided by universities and private sources of information were significant factors that contribute to the adoption of PFTs, this situation, calls for stronger and more active cooperation between the public and private sector. For achieving more effective cooperation between parties, ethical issues and possible conflicts of interest that may arise needs to be considered as such collaboration progress. In the end, the ultimate purpose is to strength US agriculture so that increasing global fiber demand can be supplied sustainably in the years to come.

We must understand that the involved parties obtain benefits from this joint effort. However, farmers, input suppliers, and manufacturers of PFT's can benefit even more from extension specialists as a result of their greater proficiency and experience at understanding the function of information in a knowledge-driven economy. The described results can be used to elaborate better communication strategies executed by organizations that aim to deliver information to farmers with the goal of promoting precision farming technologies.

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Table 1. Number and Frequency of Adopted Precision Farming Technologies[a]

	Number of PFT's	Frequency	Percentage	Cumulative Percentage[b]
	0	781	71.13	
	1	205	18.67	18.67
	2	71	6.47	25.14
	3	31	2.82	27.96
	4	9	0.82	28.78
	5	1	0.09	28.87
Total		1,098	100	

[a] Included PFT's: yield monitor with GPS, soil sampling (zone & grid), aerial photos, and soil survey maps.
[b]Cumulative percentage for positive use of five PFT's by cotton farmers.

Table 2. Correlation Structure of the Adopted Precision Farming Technologies[a]

	Yield monitor with GPS	Soil sampling grid	Soil sampling zone	Aerial photos	Soil survey maps
Yield monitor with GPS	1				
Soil sampling - grid	0.273	1			
Soil sampling - zone	0.159	0.141	1		
Aerial photos	0.129	0.093	0.259	1	
Soil survey maps	0.137	0.145	0.223	0.323	1

[a]Correlation coefficients were significant at 0.01 level of significance.

Table 3. Sources of Information Used for Precision Farming Decisions

Number of Sources[a]	Frequency	Percentage	Cumulative Percentage[b]
0	149	13.57	
1	147	13.39	13.39
2	202	18.4	31.79
3	237	21.58	53.37
4	177	16.12	69.49
5	90	8.2	77.69
6	33	3.01	80.7
7	63	5.74	86.44

[a]Included sources of information : farm dealers, crop consultants, university extension, other farmers, trade shows, internet, and news media.
[b]Cumulative percentage for positive use of seven sources of information.

Table 4. Number and Frequency of University Educational Events Attended in the Last 5 Years

Number of Events	Frequency	Percentage	Cumulative Percentage[a]
0	566	51.55	
1	68	6.19	6.19
2	138	12.57	18.76
3	78	7.1	25.86
4	40	3.64	29.51
5	75	6.83	36.34
6	14	1.28	37.61
7	6	0.55	38.16
8	9	0.82	38.98
10	51	4.64	43.62
11	1	0.09	43.71
12	5	0.46	44.17
13	1	0.09	44.26
15	19	1.73	45.99
18	3	0.27	46.26
20	11	1	47.27
23	1	0.09	47.36
25	7	0.64	47.99
30	3	0.27	48.27
50	1	0.09	48.36
100	1	0.09	48.45
Total	1,098	100	

[a]Cumulative percentage for attended university events.

Table 5. Definition of Variables and Corresponding Descriptive Statistics

Variables	Definition	Mean	Std.
Dependent			
Yield monitor-GPS	=1 for adoption of yield monitor – with GPS	0.055	0.227
Soil sampling-grid	=1 for adoption of soil sampling – grid	0.132	0.339
Soil sampling-zone	=1 for adoption of soil sampling – zone	0.148	0.355
Aerial photos	=1 for adoption of aerial photos	0.042	0.200
Soil survey maps	=1 for adoption of soil survey maps	0.062	0.241
Independent			
Dealers	=1if information from dealers is present	0.617	0.486
Consultants	=1if information from crop consultants is present	0.302	0.459
Extension	=1if information from extension is present	0.381	0.486
Farmers	=1if information from fellow farmers is present	0.589	0.492
Trade shows	=1if information from trade shows is present	0.309	0.462
Internet	=1if information from internet is present	0.250	0.433
News media	=1if information from news media is present	0.338	0.473
Univ. events	Attended number of events about PFT's	2.643	5.518
Univ. publications	=1 if there is use of university publications	0.347	0.476
Computer for management	=1 if there is computer for farm management	0.541	0.499
Computer on field	=1 if there is computer usage in the field	0.128	0.334
Total acreage	Total number of acres planted with cotton	807.01	885.711
Percent of rented acreage	Rented acres planted with cotton (percentage)	65.099	36.757
Age	Years of age of the farmer	54.870	11.999
Farming experience	Years of farming experience	30.631	12.839
Years of schooling	Years of schooling	14.298	2.419
Income category	=1 if total income is above $149,999	0.347	0.476
Farming income	Income fraction from farming (percentage)	74.872	26.646
AL	=1 if farm is located in Alabama	0.051	0.220
AR	=1 if farm is located in Arkansas	0.033	0.178
FL	=1 if farm is located in Florida	0.017	0.130
GA	=1 if farm is located in Georgia	0.087	0.281
LA	=1 if farm is located in Louisiana	0.042	0.200
MO	=1 if farm is located in Missouri	0.021	0.143
MS	=1 if farm is located in Mississippi	0.060	0.238
NC	=1 if farm is located in North Carolina	0.114	0.318
SC	=1 if farm is located in South Carolina	0.032	0.176
TN	=1 if farm is located in Tennessee	0.051	0.220
VA	=1 if farm is located in Virginia	0.017	0.130
TX	=1 if farm is located in Texas	0.475	0.500

Source: 2009 Southern Cotton Precision Farming Survey. Sample Size: 1,098 observations.

Table 6. Estimates for Adopters of PFT's from Probit Regression[a,b]

Independent Variables	Coef.	Std. Err.	P-Value
Dealers	0.2618	0.1042	0.012
Consultants	0.0178	0.1025	0.862
Extension	0.0071	0.1038	0.945
Farmers	0.0397	0.1013	0.695
Trade shows	0.0514	0.1079	0.634
Internet	0.1557	0.1194	0.192
News media	0.1881	0.1021	0.065
Univ. events	0.0208	0.0077	0.007
Univ. publications	0.3789	0.0998	0.000
Computer/management	0.1480	0.1057	0.161
Computer/field	0.0780	0.1358	0.566
Total acreage	0.0001	0.0001	0.170
Percent of own acreage	0.0003	0.0013	0.832
Age	-0.0058	0.0074	0.433
Farming experience	-0.0100	0.0070	0.153
Years of schooling	0.0439	0.0206	0.033
Income category	-0.1067	0.0972	0.272
Farming income	0.0072	0.0019	0.000
AL	0.3814	0.2199	0.083
AR	0.7139	0.2464	0.004
FL	0.6471	0.3291	0.049
GA	0.7898	0.1628	0.000
LA	1.4683	0.2237	0.000
MO	0.5827	0.2874	0.043
MS	0.9998	0.1863	0.000
NC	0.7654	0.1504	0.000
SC	1.0286	0.2389	0.000
TN	0.7646	0.2015	0.000
VA	0.6389	0.3380	0.059
Constant	-2.2927	0.4861	0.000

N = 1098
Overall model significance: LR Chi2 (29) = 269.27 ***
Pseudo R2= 0.2040
[a]Adopters of at least one PFT equal to 28.87% of the sample.
[b]Dependent variable took the value of one if the farmer have adopted at least one of the five PFT's considered, otherwise the value was zero.

Table 7. Marginal Effects for Adopters of PFT's from Probit Regression Estimates[a,b]

Independent Variables	Marginal Effects[c]	Std. Err.	P-Value
Dealers	0.0801	0.0310	0.0100
Consultants	0.0056	0.0323	0.8630
Extension	0.0022	0.0326	0.9450
Farmers	0.0124	0.0316	0.6940
Trade shows	0.0162	0.0342	0.6360
Internet	0.0500	0.0393	0.2030
News media	0.0601	0.0332	0.0700
Univ. events	0.0065	0.0024	0.0070
Univ. publications	0.1229	0.0333	0.0000
Computer/management	0.0462	0.0328	0.1590
Computer/field	0.0249	0.0443	0.5730
Total acreage	0.0000	0.0000	0.1700
Percent of own acreage	0.0001	0.0004	0.8320
Age	-0.0018	0.0023	0.4320
Farming experience	-0.0031	0.0022	0.1530
Years of schooling	0.0137	0.0065	0.0330
Income category	-0.0330	0.0297	0.2670
Farming income	0.0023	0.0006	0.0000
AL	0.1321	0.0821	0.1080
AR	0.2619	0.0974	0.0070
FL	0.2363	0.1304	0.0700
GA	0.2879	0.0631	0.0000
LA	0.5370	0.0692	0.0000
MO	0.2107	0.1131	0.0620
MS	0.3715	0.0708	0.0000
NC	0.2762	0.0578	0.0000
SC	0.3848	0.0903	0.0000
TN	0.2807	0.0791	0.0000
VA	0.2331	0.1339	0.0820

[a]Parameter estimates are presented in the previous table.
[b]Adopters of PFT's equal to 28.87% of the sample.
[c]Estimated at the means of the independent variables.

Table 8. Parameter Estimates for Adoption of PFT's from Multivariate Probit

Independent Variables	Yield monitor with GPS	Soil sampling grid	Soil sampling zone	Aerial photos	Soil survey maps
Dealers	0.1497	0.2149*	0.2928***	0.0012	0.2928*
Consultants	-0.2099	0.2051*	0.0780	-0.2675	0.1130
Extension	0.2061	0.0624	-0.0417	-0.0557	-0.0644
Farmers	0.1464	-0.0442	0.0897	0.0987	0.0381
Trade shows	0.1301	0.1361	0.0728	0.1574	0.0587
Internet	0.3493*	0.0776	0.0202	0.1169	0.5054***
News media	-0.2538	-0.1277	0.2228**	0.4074***	0.1061
Univ. events	0.0248**	0.0080	0.0139*	0.0189*	0.0179*
Univ. publications	0.0660	0.3873***	0.2294**	0.2142	0.1882
Computer/management	0.5380**	0.4929***	-0.1079	0.1988	-0.0323
Computer/field	0.5794***	-0.1982	0.1879	0.3795**	0.1501
Total acreage	0.0002***	0.0000	0.0000	0.00014*	0.0000
Percent of rented acreage	0.0001	-0.0030*	0.0018	0.0028	0.0016
Age	-0.0095	0.0390	-0.0025	-0.0030	-0.0153
Farming experience	0.0030	-0.0145	-0.0042	-0.0113	0.0071
Years of schooling	0.0103	0.0390	0.0629***	0.0034	0.0464
Income category	-0.1147	-0.1616	-0.0101	0.0126	0.1268
Farming income	0.0123***	0.0073***	0.0047**	0.0066*	0.0059*
AL	0.7993**	0.3322	0.4694**	0.3977	0.8234***
AR	1.4720***	1.1714***	0.3052	0.2291	-3.8071
FL	0.5309	1.2824***	0.1543	-4.7619	-3.8214
GA	0.1245	0.8136***	0.7887***	-0.2564	0.3075
LA	1.6691***	1.2819***	0.7069***	0.7971***	1.0052***
MO	0.5274	1.0362***	0.2409	0.5860	-0.0575
MS	1.4542***	1.4109***	0.1538	0.6799**	0.7572***
NC	0.7174***	0.7829***	0.5052***	0.5514**	0.9283***
SC	0.3828	0.8752***	0.6162**	1.0096***	1.1649***
TN	0.9592***	1.2599***	0.2448	0.0061	0.2704
VA	1.1813***	0.4330	0.6144*	-0.1036	1.3076***
Constant	-4.1964***	-2.9019***	-2.9848***	-3.0440***	-3.3880***

Number of draws=30
N=1098
Overall model significance - Wald Chi2 (145) = 407.47***
Significance of the correlation structure - LR Chi2 (10) = 88.5223***
*, **, *** indicate that the estimates are statistically different from zero at 0.10, 0.05, and 0.01 probability levels.

Table 9. Descriptive Statistics of Marginal and Joint Probabilities for Adoption of PFT's

Probabilities[a]	Obs	Mean	Std. Dev.	Min	Max
Marginal					
Yield monitor with GPS	1098	0.0541	0.1064	0.0000	0.8341
Soil sampling - grid	1098	0.1320	0.1544	0.0000	0.7770
Soil sampling - zone	1098	0.1477	0.1143	0.0012	0.6755
Aerial photos	1098	0.0431	0.0667	0.0000	0.5257
Soil survey maps	1098	0.0627	0.0906	0.0000	0.7127
Joint					
All PFT's Adopted	1098	0.0023	0.0107	0.0000	0.1817
All PFT's NOT Adopted	1098	0.7069	0.2216	0.0411	0.9987

[a]Parameter estimates were originated from results depicted in table 8, multivariate probit.

Table 10. Parameter Estimates for Adoption of PFT's from Univariate Probit Regressions[a]

Independent Variables[b]	Yield monitor with GPS	Soil sampling grid	Soil sampling zone	Aerial photos	Soil survey maps
Dealers	0.1289	0.2018	0.2938**	0.0898	0.3198*
Consultants	-0.1538	0.2205*	0.0846	-0.1706	0.1302
Extension	0.1786	0.0539	-0.0500	-0.0967	-0.0470
Farmers	0.1531	-0.0325	0.0870	0.1288	0.0074
Trade shows	0.2252	0.1437	0.0816	0.1980	0.1228
Internet	0.3221*	0.0643	0.0155	0.1188	0.5104***
News media	-0.3148*	-0.1189	0.2144*	0.3259*	0.0811
Univ. events	0.0243**	0.0075	0.0137*	0.0175	0.0182*
Univ. publications	0.0511	0.3721***	0.2184*	0.1428	0.1215
Computer/management	0.6238***	0.5065***	-0.1111	0.2911	-0.0255
Computer/field	0.5799***	-0.1844	0.2057	0.3446*	0.1974
Total acreage	0.0002***	0.0000	0.0000	0.0001*	0.0000
Percent of own acreage	0.0010	-0.0030*	0.0017	0.0037	0.0012
Age	-0.0084	-0.0003	-0.0025	0.0015	-0.0135
Farming experience	0.0043	-0.0147	-0.0036	-0.0127	0.0073
Years of schooling	0.0100	0.0431	0.0698***	-0.0002	0.0579*
Income category	-0.1039	-0.1558	-0.0129	-0.0291	0.0653
Farming income	0.0120***	0.0071***	0.0046**	0.0044	0.0055*
AL	0.9193**	0.4106	0.5157**	0.5475	0.8484***
AR	1.5277***	1.1766***	0.3175	0.3534	
FL	0.7499	1.3242***	0.2015		
GA	0.2093	0.8190***	0.7982***	-0.1805	0.2479
LA	1.7078***	1.2800***	0.6793***	0.7929**	0.9203***
MO	0.5143	1.0412***	0.2618	0.5402	-0.0523
MS	1.5108***	1.4357***	0.1685	0.7278**	0.7632***
NC	0.8065***	0.8132***	0.5199***	0.5792**	0.9093***
SC	0.2851	0.9183***	0.6409**	1.0421***	1.2143***
TN	1.0082***	1.3147***	0.2763	0.1657	0.3088
VA	1.3462***	0.5487	0.6687*	0.3248	1.3087***
Constant	-4.4425***	-3.0256***	-3.0944***	-3.2080***	-3.5942***

N=1098

[a]Number of adopters for each PFT: yield monitor with GPS (60), grid soil sampling (145), zone soil sampling (162), aerial photos (46) and soil survey maps (68).

[b]Marginal effects for adoption of each PFT are available upon request from the author.

*, **, *** indicate that the estimates are statistically different from zero at 0.10, 0.05, and 0.01 probability levels.

Table 11. Parameter Estimates for Bivariate Probit Regressions

	Yield Monitor with GPS		Soil Sampling Grid		Yield Monitor with GPS		Soil Sampling Zone	
Independent Variables	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Dealers	0.1225	0.543	0.2151	0.109	0.1458	0.473	0.2949	0.014
Consultants	-0.1692	0.346	0.2157	0.078	-0.1797	0.322	0.0836	0.463
Extension	0.1993	0.286	0.0523	0.687	0.1877	0.318	-0.0519	0.655
Farmers	0.1581	0.391	-0.0376	0.766	0.1404	0.454	0.0848	0.456
Trade shows	0.1580	0.384	0.1401	0.287	0.1966	0.286	0.0804	0.501
Internet	0.3206	0.088	0.0816	0.569	0.3431	0.071	0.0202	0.879
News media	-0.2491	0.181	-0.1219	0.353	-0.3046	0.106	0.2135	0.059
Univ. events	0.0227	0.035	0.0075	0.414	0.0256	0.015	0.0140	0.083
Univ. publications	0.0494	0.780	0.3700	0.003	0.0487	0.784	0.2185	0.051
Computer/management	0.5561	0.014	0.5070	0.000	0.6121	0.009	-0.1088	0.370
Computer/field	0.6088	0.001	-0.1778	0.264	0.5639	0.002	0.2074	0.160
Total acreage	0.0002	0.002	0.0000	0.753	0.0002	0.003	0.0000	0.538
Percent of own acreage	0.0008	0.761	-0.0028	0.105	0.0005	0.856	0.0018	0.253
Age	-0.0059	0.717	-0.0003	0.974	-0.0102	0.550	-0.0025	0.767
Farming experience	0.0009	0.957	-0.0145	0.112	0.0050	0.770	-0.0035	0.653
Years of schooling	0.0090	0.806	0.0392	0.138	0.0075	0.840	0.0678	0.004
Income category	-0.1322	0.443	-0.1622	0.187	-0.0892	0.605	-0.0135	0.900
Farming income	0.0116	0.005	0.0072	0.003	0.0127	0.003	0.0046	0.034
AL	0.8552	0.020	0.3851	0.187	0.8935	0.016	0.5048	0.029
AR	1.4958	0.000	1.1778	0.000	1.5229	0.000	0.3043	0.280
FL	0.6101	0.372	1.2985	0.000	0.6726	0.313	0.1832	0.656
GA	0.1673	0.682	0.8147	0.000	0.1789	0.666	0.7915	0.000
LA	1.6576	0.000	1.2658	0.000	1.6980	0.000	0.6707	0.003
MO	0.5219	0.350	1.0197	0.002	0.4898	0.387	0.2461	0.456
MS	1.4482	0.000	1.4265	0.000	1.5098	0.000	0.1753	0.446
NC	0.7391	0.007	0.7939	0.000	0.7784	0.004	0.5114	0.002
SC	0.3363	0.532	0.9100	0.001	0.3198	0.560	0.6377	0.014
TN	0.9879	0.003	1.2941	0.000	1.0028	0.003	0.2730	0.245
VA	1.2908	0.004	0.4664	0.345	1.2982	0.004	0.6609	0.059
Constant	-4.3074	0.000	-2.9697	0.000	-4.3354	0.000	-3.0610	0.000

Table 12. Marginal Effects for Adoption of PFT's Calculated from Bi-probit Regression

PFT / Source of Information	Marginal Effects[c]	Std. Err.	P-Value
Yield Monitor with GPS[a]			
Dealers	0.0060	0.0227	0.7920
Consultants	-0.0257	0.0210	0.2210
Extension	0.0220	0.0244	0.3670
Farmers	0.0193	0.0214	0.3670
Trade shows	0.0136	0.0224	0.5460
Internet	0.0389	0.0296	0.1890
News media	-0.0230	0.0195	0.2370
Univ. events	0.0023	0.0014	0.0920
Univ. publications	-0.0081	0.0206	0.6950
Grid Soil Sampling[b]			
Dealers	0.0659	0.0549	0.2300
Consultants	0.1102	0.0570	0.0530
Extension	-0.0075	0.0540	0.8890
Farmers	-0.0369	0.0538	0.4920
Trade shows	0.0327	0.0543	0.5470
Internet	-0.0129	0.0582	0.8250
News media	-0.0125	0.0536	0.8160
Univ. events	-0.0003	0.0037	0.9430
Univ. publications	0.1399	0.0554	0.0120

a. Probability of adoption of yield monitor with GPS conditional on adoption of grid soil sampling technologies was estimated at 5.32%.
b. Probability of adoption of grid soil sampling technologies conditional on adoption of yield monitor with GPS was estimated at 32.58%.
[c]Estimated at the means of the independent variables.

Table 13. Marginal Effects for Adoption of PFT's Calculated from Bi-probit Regression

PFT / Source of Information	Marginal Effects[c]	Std. Err.	P-Value
Yield Monitor with GPS[a]			
Dealers	0.0053	0.0120	0.6580
Consultants	-0.0113	0.0111	0.3080
Extension	0.0129	0.0139	0.3540
Farmers	0.0075	0.0113	0.5080
Trade shows	0.0120	0.0134	0.3710
Internet	0.0250	0.0188	0.1820
News media	-0.0194	0.0123	0.1130
Univ. events	0.0014	0.0008	0.0790
Univ. publications	0.0004	0.0110	0.9730
Zone Soil Sampling[b]			
Dealers	0.0914	0.0440	0.0380
Consultants	0.0445	0.0453	0.3260
Extension	-0.0330	0.0441	0.4540
Farmers	0.0190	0.0418	0.6500
Trade shows	0.0131	0.0441	0.7670
Internet	-0.0197	0.0498	0.6920
News media	0.1022	0.0513	0.0460
Univ. events	0.0030	0.0029	0.3120
Univ. publications	0.0749	0.0437	0.0860

a. Probability of adoption of yield monitor with GPS conditional on adoption of zone soil sampling technologies was estimated at 2.6%.

b. Probability of adoption of zone soil sampling technologies conditional on adoption of yield monitor with GPS was estimated at 29.52%.

[c]Estimated at the means of the independent variables.