THE IMPACT OF ADOPTION OF PRECISION FARMING TECHNOLOGIES ON COTTON YIELD IN TEXAS

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Abstract

Precision farming technologies have the potential to improve crop yield by matching the recourse application and agronomic practices to the within-field variability in soil conditions and crop requirements. The past work on the yield impact of precision farming technologies has been based on experimental data from a small number of fields; the results so obtained cannot be generalized to a regional scale. This study uses the 2009 Cotton Inc. Southern Precision Farming Survey to analyze the contribution of the adoption of precision farming technologies to cotton yield improvement in the state of Texas. The analysis examines yield improvements in both irrigated and dryland cotton. The county-wise hydrologic data from Texas Water Development Board is included in the model to account for the constraints of water availability on yield. A two-stage least square estimation is employed to overcome potential simultaneity bias. The results revealed that the adoption of PA in cotton on an average can result in 23.81 lbs. /acre yield increase in irrigated cotton and 10.59 lbs. / acre yield decrease in dryland cotton. However both these estimates were not statistically significant even at 10% alpha level.

Introduction

The Precision Agriculture (PA) can be considered as a management practice where resource application or agronomic practices are matched with the spatial and temporal variability in field conditions and crop requirements (Whelan and McBratney, 2000). However, in general, the identification and response to the spatial variability within the field is given more importance among the practitioners of PA. This spatial variability within the field can be inherent (for example because of differences in soil type) or induced (like differences in application of input or crop growth) and makes the uniform application of inputs to the entire field inappropriate for some portions of the field (Basso et al., 2003).

In PA, optimal decisions are made on inputs, crops, and soil management like what to apply, how much to apply, when to apply, and where to apply. The decision on when to apply relies on temporal variability in field conditions and crop requirements and the dosage may depend on the extent of the variability. This response to temporal variability is common in the fields of pest and disease management and irrigation scheduling. The decisions on where to apply depends on the spatial variability within the field and common application of this response are variable rate seeding and application of fertilizers, soil amendments, and plant growth regulators at variable rate.

US is a major producer of cotton in the world. With a harvested area of 10.4 million acres and a production of 18 million tons in 2010 (USDA, 2010), cotton is a prominent crop in the US. The cotton producers have to take an array of management decisions including choice of variety, seed rate, planting time, application of fertilizers and soil amendments, irrigation scheduling, plant protection, application of defoliants, and the time and method of harvest. Precision agriculture helps farmers make informed management decisions and can increase the input efficiency.

The adoption of PA is reported to have multiple advantages such as cost reduction, yield enhancement, increased input efficiency, and lesser impact on environment (Pierce and Nowark, 1990; Bongiovanni and Lowenberg-DeBoer, 2004). In this article we will concentrate on the influence of precision agriculture on yield of cotton. Based on the agronomic theory, PA can have a positive impact on the cotton yield. A brief account of a few PA practices and how they can increase yield is provided below.

Varietal selection based on soil fertility is one PA practice that can enhance yield. If varieties with higher yield potential are planted in more fertile areas of the filed, an overall improvement in yield can occur as the high yielding varieties can realize their yield potential in the fertile soil. Similarly, the variable rate seeding can improve yield as the better soils may be able to support a higher plant population. Managing the timing, quantity, and frequency of irrigation water according to the soil texture and cotton growth stages can increase yield by ensuring water availability to the crop during all critical stages. Application of fertilizers and soil amendments at variable rate can reduce the possibility of sub-optimal availability in portions of the field with lower nutrient concentration, and toxicity in areas with high nutrient concentration before the application. This can lead to optimal nutrient concentration all over the field leading to a higher yield. The optimal time and place of application of insecticides can help in managing the pest population below economic threshold without significant impact on the population of natural enemies and can reduce the yield loss due to pest infestation.

The impact of PA adoption on yield is generally estimated using field experiments. However these estimates vary widely from experiment to experiment. For example, from a three year agronomic study on the effect of variable rate input application for cotton in Lamesa, TX, Bronson et al. (2006) reported that variable rate irrigation or adjusting the speed of center pivot did not influence cotton yield whereas the variable rate nitrogen application resulted in increased cotton yield ranging from 25 to 125 kg/ha. However in another study conducted in Bolivar county MS, Thompson et al (1999) found no significant yield improvement due to variable rate nitrogen application. Since PA is a response to the within-field variability, its impact on the yield also depends on the within-field variability of the particular field. Hence the estimates from field experiments depend on the choice of the experimental field and can’t be generalized. Moreover size of the field can also influence the impact of PA on yield as the larger fields are generally considered to be agronomically and economically inefficient in a precision agriculture sense due to homogeneous management practices over a larger area.

Since the field experiments may not be able to provide a general estimate of the influence of PA on yield in a large geographical area like the state of Texas, this study make use of the 2009 Southern Precision Farming Survey to provide a general estimate. The objective of this study is to estimate the influence of adoption of PA on cotton yield in Texas using the 2009 Southern Cotton Precision Farming Survey.

Materials and Methods

The materials and methods used for this study are described below in three sections. The first section is on the data used for the study, the second section is on the econometric model, and the third section is on the empirical model.

The Data

The data adoption of precision agriculture practices, irrigation practices, and demographic data for this study was extracted from the 2009 Southern Precision Farming Survey (see Mooney et al., 2010). The survey received 1692 responses from cotton farmers of 12 southern US states with a response rate of 12.5% of which 883 were from Texas. The survey provided information on adoption of different variability data gathering technologies, adoption of different variability rate technologies, type of irrigation technology used, different farming practices adopted in the farm, acreage and production of cotton during 2007 and 2008, and characteristics of the farm and the farmer. Only the data for Texas was used in this study.

The study also utilized data on average pumping lift for wells in each county in Texas and county-wise productivity data of upland cotton in Texas (USDA NASS, 2011)

Econometric Model

The lint yield of cotton is related to several soil and climatic factors and management practices adopted by the farmer. The adoption of precision agriculture is such a management practice that can have an impact on the lint yield of cotton. The age of the farmer (Akridge and Whipker, 1999; Batte and Johnson, 1993; Fernandez-Cornejo, Beach, and Huang, 1994; Larson et al., 2008; Sevier and Lee, 2004), ownership of the farm (Daberkow and McBride, 2003), level of education of the farmer (Larson et al., 2008; McBride and Daberkow, 2003), farm size (Reichardt and Jurgens, 2009; Walton et al., 2010), and use of computers for farming operations (Daberkow and McBride, 2003) are reported to have significant impact on the adoption of different precision agricultural practices.

However, these factors can also influence the intensive management of the farm and thereby the cotton yield, resulting in the problem of endogeneity ($Cov(adopt, u) \neq 0$). To deal with this problem, instrumental variable estimators using the two-stage least squares were used (Cameron and Trivedi, 2005)

The following two equations represent the two stages of two-stage least squares estimation. Equation (1) represents the first stage regression where the endogenous variable is regressed on all the explanatory variables including the instrumental variables.

$$y = X_1\alpha_1 + X_2\alpha_2 + v = Z\alpha + v \qquad (1)$$

$$Y = \hat{y}\beta_1 + X_2\beta_2 + u = X\beta + u \qquad (2)$$

Here y is the endogenous variable, $X_1$is the matrix of excluded exogenous variables (instrumental variables), X_2 is the matrix of included exogenous variables, $\hat{y}$ is the predicted value of the endogenous variable from the first stage regression, and Y is the independent variable.

Empirical Model

The definition of all the variables used in the empirical model is provided below as Table 1. Since the consistency of the parameter estimates at the second stage in two-stage least squares estimation is not dependent on specifying the correct functional form in the first stage (see Kelegian, 1971), linear regression was used in both stages of the two-stage least squares estimation even though the endogenous variable (*adopt*) was dichotomous in nature.

Among the variables listed in Table 1, *yield* is the independent variable and *adopt* is the endogenous variable. The variables *vdt*, *seminar*, and *pub* are the instrumental variables (excluded exogenous variables), and the remaining variables are the explanatory variables (included exogenous variables).

Table 1. Definition of variables used in the empirical model.

Variable	Definition
yield	Average yield cotton lint (lbs/acre) reported by the farmer
adopt	Dummy variable for adoption of application of any input at variable rate
others	Dummy variable for counties not overlaying the Ogallala aquifer (excluded from model)
shallow	Dummy variable for counties with average well depth less than 100 feet
medium	Dummy variable for counties with average well depth between 100 and 200 feet
deep	Dummy variable for counties with average well depth more than 200 feet
percp	Percentage of the irrigated area with center pivot irrigation system
perssd	Percentage of the irrigated area with sub-surface drip irrigation system
countyprod	The average productivity of upland cotton in each county from 2006 to 2010 (lbs/acre)
manure	Dummy variable for application of manure in the field
farmsize	Average area planted to cotton in 2007 and 2008
peririg	Percentage of the farm size that is irrigated
perown	Percentage of the farm size that is owned by the farmer
age	Age of the farmer in years
exp	Farming experience of the farmer in years
edu	Number of years of formal education received by the farmer
comp	Dummy variable for use of computers for farming operations
laptop	Dummy variable for use of laptop in farming operations
vdt	Dummy variable for adoption of variability data gathering technologies
seminar	Dummy variables for attending university educational events related to PA
pub	Dummy variables for exposure to university publications related to PA

Results and Discussion

The results are furnished and discussed in two sections. The results of the first stage regression and its discussion are provided in the first section while the results of the second stage regression are provided in the second stage along with the discussion.

First Stage Regression

The results of the first stage regression for both irrigated and dryland models are provided in Table 2. The results for irrigated cotton show that, among the explanatory variables, pumping lift had a significant and positive relationship with the PA adoption. The use of manure for farming operations and the experience of the farmer also had significant and positive impact on PA adoption, while the age of the farmer had negative impact on PA adoption. Among the instrumental variables, adoption of variability data gathering technologies and attending university extension seminars have significant and positive relationship with the adoption of PA.

For the dryland cotton, only the use of laptops for farming operations had significant relationship with adoption of PA among the included explanatory variables whereas among the instrumental variables, adoption of variability data gathering technologies and exposure to university extension publications had significant impact on the yield.

This results show that some of the explanatory variables included in the model to predict yield has significant impact on the adoption of PA and indicate that *adopt* may be an endogenous variable. The detailed discussion on the effect of different variables on adopt is not provided here as our objective was to estimate the impact of adoption of PA on the yield, which is obtained from the second stage regression.

Table 2. The coefficient estimates and p values of the first stage regression.

Variable	Irrigated Cotton		Dryland Cotton	
	Coefficient estimate	p>|z|	Coefficient estimate	p>|z|
shallow	1.611	0.108	-	-
medium	1.329	0.157	-	-
deep	2.055	0.036	-	-
percp	-0.006	0.374	-	-
perssd	0.009	0.280	-	-
countyprod	-0.003	0.253	0.002	0.871
manure	0.799	0.099	0.260	0.609
farmsize	1.81E-4	0.412	4.26E-5	0.770
peririg	0.008	0.344	-0.006	0.360
perown	0.007	0.282	0.005	0.472
age	-0.150	<0.001	-0.057	0.121
exp	0.092	0.002	0.024	0.452
edu	-0.145	0.112	-0.151	0.177
comp	-0.369	0.427	0.323	0.462
laptop	0.886	0.167	1.090	0.014
vdt	2.470	<0.001	1.506	<0.001
seminar	1.001	0.033	0.529	0.154
pub	0.763	0.138	0.969	0.011

Second Stage Regression

The results of the second stage regression for both irrigated and dryland models are provided in Table 3.

The results of the second stage regression show that the adoption of PA practices in general by Texas cotton farmers can result in an increase of cotton yield by 23.81 lbs. / acre for irrigated cotton and a decrease in cotton yield by 10.59 lbs. /acre for dryland cotton. However both these estimates were not statistically significant even at 10% alpha level. This shows that the influence of PA on vary greatly from field to field in Texas and as shown by researchers with agronomic experiments (Bronson et al. 2006; Thompson et al., 1999) the within field variability and the level of input usage are the major driving forces for yield increase with PA

Among the explanatory variable used in the model, the pumping lift showed a significant influence on cotton yield for irrigated cotton. The counties with less than 100 ft. pumping lift and those with greater than 200 ft. pumping lift showed 151.20 and 117.02 lbs. / acre higher yield respectively compared to the counties not overlying the Ogallala aquifer. However, medium pumping lift did not significantly influence the lint yield of cotton. The effect of application of manure in the field on the lint yield of cotton was also significant at 10% alpha level.

All variables related to irrigation had significant impact on the yield. The percentage of the field irrigated, the percentage of the irrigated field under subsurface drip, and the percentage of irrigated field with center pivot had positive impact on the lint yield of cotton. Farm size, the average productivity in the county and the percentage of the land owned by the farmer also had positive impact on cotton yield. In the case of dryland cotton only the average productivity of the county had significant impact on the lint yield of cotton.

These results show the importance of effect irrigation on the yield of cotton in Texas. Most of variables related to irrigation significantly influence cotton yield and with that some farm and farmer characteristics are also significant, but when the irrigation is not there, only the difference in soil and climatic conditions represented by the average productivity of the counties is important.

Table 3. The coefficient estimates and p values of the second stage regression.

Variable	Irrigated Cotton		Dryland Cotton	
	Coefficient estimate	p>|z|	Coefficient estimate	p>|z|
adopt	23.81	0.194	-10.59	0.413
shallow	151.20	0.001	-	-
medium	61.06	0.176	-	-
deep	117.02	0.012	-	-
percp	1.60	<0.001	-	-
perssd	4.61	<0.001	-	-
countyprod	0.58	<0.001	0.44	0.094
manure	11.36	0.733	76.36	0.004
farmsize	0.03	0.061	-0.004	0.663
peririg	0.99	0.036	-0.11	0.718
perown	0.91	0.014	-0.43	0.124
age	-1.83	0.371	0.28	0.810
exp	-0.06	0.971	0.95	0.343
edu	4.72	0.388	2.21	0.543
comp	7.94	0.768	18.48	0.277
laptop	26.75	0.676	41.04	0.166

Summary

This study attempted to estimate the influence of adoption of precision farming practices, where variable rate application of inputs is conducted, on the lint yield of cotton in Texas. The study used the 2009 Southern Precision Farming Survey along with the county wise hydrologic data yield data. The two-stage least squares approach using instrumental variables was used for the estimation. The results revealed that even though the adoption of PA is estimated to result in 23.81 lbs. / acre yield increase in irrigated cotton and 10.59 lbs. /acre yield decrease in dryland cotton, both these estimates were not statistically significant.

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