IMPLICATIONS OF REMOTE SENSING IMAGERY AND CROP ROTATION FOR NITROGEN MANAGEMENT IN SUGAR BEET PRODUCTION

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Abstract

Adoption of new technologies, such as remote sensing, is slowed by such factors as high monetary and/or human capital costs and uncertainty about their value. This analysis explores the impact on nitrogen fertilizer use and efficiency and net returns among sugar beet producers in the Red River Valley from using remote sensing technologies and crop rotation for nitrogen management. The study found that cropping patterns had a significant impact on nitrogen use and net returns, but that most decision tools used for nitrogen management had little influence. The impact of using remotely sensed images for nitrogen management in sugar beets was not statistically significant.

Keywords: nitrogen use and efficiency, profitability, remote sensing, crop rotation, sugar beets

Introduction

Adoption of many new technologies is slowed by such factors as high monetary and/or human capital costs, and uncertainty about their value. Precision agriculture (PA) technologies, which have only become commercially available during the last few years, appear to possess these adoption-hindering attributs. Consequently, the adoption level for many of these technologies is

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[1] The opinions and conclusions expressed here are those of the authors and do not necessarily represent the views of the USDA.

modest for most commodities (Daberkow, et al., 2002). PA technologies, such as grid soil tests, yield monitors, remote sensors, and variable rate applicators, are tools to manage sub-field spatial and temporal variability to enhance economic and/or environmental benefits. However, few survey-based studies of PA adopters and non-adopters have explicitly examined the economic or environmental implications of adopting this technology.

Most studies of PA profitability and environmental impacts based on field trials, response functions, or simulations have reported positive benefits for a given PA technology although these benefits vary among different crops. For example, Lambert and Lowenberg-DeBoer (2000) reviewed over 100 studies of PA, the majority (over 85 percent) of which were from peer-reviewed scientific journals or proceedings. They found that slightly over 60 percent of the studies reported positive net returns associated with using PA technologies, while about 10 per cent reported losses and the remainder indicated mixed results. Swinton and Lowenberg-DeBoer (1998) suggested that PA was much less likely to increase profitability for low-value crops, such as wheat and barley, and more likely for high-value crops like sugar beets. Several studies which focused on the use of PA in sugar beet production have reported significant economic benefits to this technology (Smith and Rains, 1997; The Sugarbeet Grower, 1996). For example, a 1995 study in Minnesota reported an increase in net returns of over $74 per acre from using variable rate fertilizer applications compared to uniform application (The Sugarbeet Grower, 1996). Similarly, other studies of the use of PA on sugar beets have suggested that there are environmental benefits associated with the use of PA, especially variable rate nitrogen application, in sugar beet production (Kaffka, et al., 2001; Kasowski and Genereux, 1994).

One of the few survey-based studies of PA adopters and profitability was conducted in Minnesota in 2000 (Olsen and Elisabeth, 2002). That study found that PA adoption was not a significant explanatory variable in a model which attempted to account for variability in whole farm rate of return to assets (ROA). The final model attempted to account for simultaneity and self-selection which is critical to any analysis of the impact of technology adoption. Out of a sample of 212 farms, only 16 farms were predominantly crop farms that had adopted one or more PA technologies. A farmer’s self-described level of soil variability positively influenced adoption while off-farm income negatively influenced adoption. The lack of PA significance in explaining ROA was attributed to small sample size, large variability in ROA, differences in management ability, the newness and lack of full implementation of the technology, and availability of alternative farming practices that are as profitable as PA.

This study uses farm-level survey data from sugar beet producers to examine the impact of adopting one aspect of precision agriculture, remotely sensed imagery (RSI), on nitrogen fertilizer application rates, nitrogen fertilizer efficiency, and returns above fertilizer costs. The analysis specifically accounts for crop rotations in sugar beet production because of the importance of residual soil nitrogen for sugar beet quality. The impact of RSI is modeled by accounting for several key farm and operator characteristics that influence RSI adoption, as well as for the possibility of sample selection bias.

Nitrogen Management in Sugar Beet Production

Nitrogen fertilizer management is a key factor in the profitability of sugar beet production. Nitrogen is not only the most important yield-limiting nutrient but its management is also critical for producing high quality sugar beets. Production of high quality sugar beets is important in a quality-based payment system because growers are paid on the basis of extractable sucrose content of their sugar beets and the level of impurities in the root. Nitrogen sources for sugar beet production include soil organic matter and sugar beet foliage, both of which often vary spatially across fields, and commercial nitrogen fertilizer, which can be applied using variable rate applicators. Adequate nitrogen fertilizer use normally increases yield of both roots and sugar; however, excessive use of nitrogen fertilizer decreases the sucrose content in the root.

Crop rotation is a common practice associated with sugar beet production that can have implications for nitrogen management throughout the cropping cycle (Meyer et al., 2001). Most sugar beets are grown in 3-4 year rotations in the Red River Valley (RRV) with small grains commonly preceding and succeeding beets. Crop rotations are primarily used to control diseases and nematodes that affect beets. However, the preceding crop can also influence the level of nitrogen available for beets. For example, legume crops, such as soybean and alfalfa, can add to the residual soil nitrogen level, while intensive nitrogen-using crops, such as corn, may deplete soil nitrogen. In addition, nutrient management of nitrogen-responsive crops following beets has been shown to enhance the profitability of the entire rotation (Reitmeier et al., 1998). Beet foliage, or tops, contain large amounts of nitrogen and are typically incorporated into the soil following beet harvest, which clearly provides nutrients for the crop following beets. Nitrogen from decomposing tops which is not used by the subsequent crop may be leached below the crop's root zone. However, sugar beets are a very deep rooted crop that can extract this residual nitrogen. Hence, knowledge about the availability of this source of nitrogen is also critical for nitrogen crediting for the current beet crop. Furthermore, more efficient nitrogen use of deep soil nitrates implies that risks to the environmental from residual soil nitrates are reduced.

Most fields in the Red River Valley of North Dakota and Minnesota exhibit extensive spatial variability in soil types, organic matter, topography, water holding capacity, and other factors that affect yields and nitrogen availability. Because of the importance of nitrogen availability in sugar beet quality and returns, information about sub-field spatial variability has been shown to be useful in managing nitrogen applications throughout the entire sugar beet crop rotation cycle (Morahgan, 1998). RSI of either bare soils or sugar beet canopies provides producers with geo-referenced data on field-level spatial variability which can be used for within-season as well as multi-season management decisions regarding nitrogen application and other field operations such as harvesting.

The most common use of RSI in sugar beet production has been for identifying discrete management zones and identifying drainage problems within fields (Newcomb, et al., 1998; Corbley, 1999). RSI, by measuring the reflectance properties of the sugar beet canopy, has been successfully used to delineate such zones and locate poorly drained areas. Management zones (i.e., areas with homogeneous properties) are used to efficiently locate soil sample sites for assessing residual nitrate levels for sugar beets as well as for subsequent crops. Soil sample results by zone, when used with variable rate applicators, allows more efficient use of nitrogen by applying fertilizer to meet plant needs that vary spatially across the field. Similarly, areas with poor drainage can be rectified. This benefits the sugar beet crop and all crops in the rotation cycle.

Using RSI for decision making within the growing season is in the experimental stage (i.e., current year RSI used for current year decisions). For example, RSI canopy reflectance properties collected during the beet production growing season may be useful for scheduling harvest (Cattanach, 2003). As with nitrogen management, the timing of harvest can affect both sugar content and impurities in the beets. There is also anecdotal evidence that current RSI is being used by crop scouts to increase the efficiency of their scouting patterns and pest management recommendations.

Data

Data for the analysis comes from a detailed survey of U.S. sugar beet operations conducted in 2000 as part of USDA's annual Agricultural Resource Management Survey (ARMS, 2003). Each farm sampled in the ARMS represents a known number of farms with similar attributes so that proper weighting provides a basis for calculating estimates for the target population. The target population in the sugar beet survey was operations planting one or more acres of sugar beets in 2000. The survey collected information about sugar beet input use, production practices and yields, costs of production, and farm financial status. The survey also collected specific data on the extent to which various precision farming technologies were used in sugar beet production as well as information on socio-economic characteristics of the farm operator. Producers were asked about their use of RSI for the 2000 sugar beet crop, which could be imagery collected during the current crop year as well as from earlier years when beets were grown[2].

[2] The question was phrased at follows: Was this field remotely sensed (by airplane or satellite) and an image produced either before or during the 2000 growing season? According to researchers in the RRV, experimental use of RSI began in 1993 and has expanded commercially since that time. For example, ACSC has provided RSI to all of its contracted acreage since 1998 (Cattanach, 2003).

The Red River Valley (RRV) of North Dakota and Minnesota was chosen as the study area for this analysis because of its importance to U.S. sugar beet production, and because of the significant adoption of precision farming technologies in this area. About half of the sugar beet acreage in the U.S. is located in the RRV. Over half of the sugar beet farms in the RRV had remotely sensed images (RSI) available for their sugar beet fields (Table 1). Given that a number of previous studies of PA use in sugar beets report positive benefits from using RSI, a survey-based analysis of sugar beet RSI adopters would appear to be an opportunity to determine if, in fact, RSI can offer economic and/or environmental benefits.

Methods

The impact on nitrogen use and net returns of basing nitrogen applications on RSI was assessed by statistically controlling for several other factors that may also affect these variables. That is, the effect of economic and environmental conditions, management practices, and operator characteristics were accounted for in order to isolate the effect of the innovative decision tool. To control for factors other than the RSI, multiple-regression was used in a two-stage econometric model of adoption and the adoption impact. The first stage of the model was an adoption equation that describes factors influencing the likelihood of using RSI. Predictions from the adoption model were then included as an explanatory variable in regressions relating farm and operator characteristics, and other decision tools, to measures of nitrogen use and net returns. This specification was used as a means of correcting for potential self-selection bias[3].

The adoption model was estimated by a probit analysis. The model was specified with several variables that have been shown to be related to technology choice (Feder, et al., 1985; Khanna et al, 1999; McBride and Daberkow, 2003; Daberkow and McBride, 2003). Adopters were those who reported that sugar beet acreage was remotely sensed (by airplane or satellite) and an image was produced either before or during the 2000 growing season. Just over half of the sugar beet growers could be classified as adopters (Table 1).

Farm operator variables regressed against the decision to adopt included age (*OPAGE*) and education (*OPEDUC*). Farm operation variables were size in acres (*APL*), size squared (*APLSQ*), specialization in sugar beet production (*SPECIAL*), business organization (*BUSORG*), and the percent of sugar beet acreage that was owned (*PEROWN*). Size was measured as the harvested acreage of sugar beets. Business organization was specified by an indicator that the operation was organized as a corporation. A variable indicating the use of computerized financial records (*COMPREC*) was added because it may indicate comfort with using new technologies like RSI. Whether the producer was likely to be associated with the American Crystal Sugar Company (ACSC) was also indicated (*COMPANY*) [4]. ACSC has been known for promoting the use of RSI for nitrogen management among its contract growers.

Impact models were then estimated for measures of nitrogen use, nitrogen use efficiency, and net returns to sugar beet production. Nitrogen use (*QN*) was measured as the pounds of N applied

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[3] Self-selection bias occurs because users of RSI are not a random sample of sugar beet growers, but rather are assigned based on their selection. Therefore, users of RSI may differ from other growers in ways that may also influence nitrogen use and net returns.

[4] The survey did not indicate to which company growers were affiliated. Instead, growers were assigned to a company based on their location in counties with factories operated by the company. ACSC operates 5 factories in the Red River Valley.

per acre to sugar beets. Nitrogen use efficiency (*NEFF*) was measured as pounds of gross sugar produced per pound of N applied to sugar beets. Net returns per acre were defined as the gross returns to sugar beet production less fertilizer cost (*NETFERT*). Thus, the returns are the amount available to pay for other input costs, including the costs associated with RSI.

Operator age and education, and specialization and acreage in sugar beets were specified in the impact models. A variable indicating the extent to which actual sugar beet yield fell short of expected yield (*YLDDEF*) was also included in the model (Table 1). This variable was included to account for the impact of uncontrollable factors, such as variations in weather and pest pressure. Variables indicating the crop grown on sugar beet fields during the previous year were also added (*PCSMGRAIN*, *PCCORN*, *PCOTHER*). Previous crops were classified as either small grains (including wheat and barley), corn, or other (including dry beans, dry peas, potatoes, soybeans, vegetables, or fallow). The previous crop affects the level of soil nutrients remaining from the previous year, and thus the amount of commercial nutrients that need to be purchased and applied for the current crop.

Also specified in the impact models were variables indicating producer responses about what influenced their decision about nitrogen applications, including routine practice (*ROUTINE)*, results of a soil or plant test (*TEST*), crop consultant recommendation (*CONSULT*), fertilizer dealer recommendation (*DEALER*), extension service recommendation (*EXTEN*), and the company or factory recommendation (*FACTORY*). These variables were added to contrast their impact on nitrogen use and net returns with that of using RSI as a basis for nitrogen use decisions. Each of the impact models was estimated by weighted ordinary least-squares regression using the survey weights for each observation[5].

Results

Factors influencing the adoption of RSI were similar to those found in other studies of agricultural technology adoption. The decision to utilize RSI was positively associated with farm size, although the impact of farm size decreased as farm size increased (Table 2). Other factors that enhanced the probability of RSI use were owned acreage, familiarity with computers for the farm business, and contract association with an ACSC sugar processing plant. However, counter to prior studies, operator age was positively associated with RSI adoption. The average age of sugar beet growers is more than 5 years younger than the U.S. average among all farmers. Thus, age may be indicative of more experience among sugar beet growers that would have a positive impact on RSI adoption.

The regression models used to examine the impact of RSI use varied widely in their ability to explain variation in nitrogen use, nitrogen efficiency, and returns above fertilizer cost (Table 3). The R^2 in the equations for nitrogen use and efficiency were modest at less than 0.20. However, variables used in the net return equation explained more than 60 percent of the variation in returns above fertilizer costs.

Among factors controlled by the farm manager, the largest impact on nitrogen use, nitrogen efficiency, and net returns was from the previous crop grown on sugar beets fields. The models

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[5] Levels of fertilizer use and returns above fertilizer costs would also be affected by fertilizer prices. However, a measure of fertilizer prices was not available for each farm from the survey data.

were specified with the variable indicating that a small grain was the previous crop as the basis for comparison. Thus, the coefficients indicate the impact that producing corn and other crops had relative to producing a small grain crop. For example, if corn was the previous crop, nitrogen use on the sugar beet crop was about 15 pounds per acre higher than if sugar beets follow a small grain crop. Nitrogen use efficiency and net returns for sugar beets were significantly lower if sugar beets followed corn in the crop pattern. In contrast, nitrogen use was lower and nitrogen efficiency was higher when sugar beets were planted after other crops.

Few of the nitrogen use decision variables had a statistically significant impact on the dependent variables. Nitrogen use was about 10 pounds per acre higher for farmers who based nitrogen application rates on a routine practice, while nitrogen use efficiency was significantly lower for these producers. Routine applications fail to account for residual levels of soil nitrogen, such as that from previous crop residues, and can be expected to result in less efficient nitrogen use. Also, basing nitrogen decisions on dealer recommendations resulted in less nitrogen use, but lower net returns. Higher returns above fertilizer costs were statistically significant only when factory recommendations were the basis for nitrogen applications, an increase of about $35 per acre. The impact of RSI on nitrogen use, nitrogen efficiency, and net returns was not statistically significant.

Conclusion

The greatest impact on sugar beet nitrogen use and efficiency, and on net returns was found to be from planting sugar beets after corn. The nitrogen uptake of corn is much higher than that of small grain and other crops, meaning that more nitrogen was applied to sugar beets in order to replace what was taken by the corn crop. Other crops utilize less nitrogen and legume crops fix nitrogen in the soil. This is probably why the sugar beets following these crops required less nitrogen and had a greater efficiency of nitrogen use.

The fact that this study did not find a statistically significant relationship between the use of RSI and nitrogen use, efficiency, and net returns may be attributed to several reasons. For one, the impact of basing decisions on RSI may not be apparent for the current sugar beet crop. Rather the impact of RSI may be more pronounced for other crops in the rotation, like wheat or corn. Much of the organic nitrogen returned to the soil results from the residue from sugar beet production (i.e., beet tops). The ability to accurately credit this nitrogen source, through technologies like RSI, could reduce the amount of commercial nitrogen purchased and applied to following crops. Another reason may be that the effect of using RSI was confounded with that of using factory recommendations for nitrogen decisions. Factory recommendations were found to improve net returns by $35 per acre. Because the factory has been the primary provider of RSI technologies, some of this return may result from the use of RSI as the basis for their recommendations.

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Table 1. Variables used to model the impact of using remote sensed images for nitrogen management by sugar beet producers in the Red River Valley, 2000

Item	Farms not using remote sensed images for N management	Farms using remote sensed images for N management
Sample size	107	124
Percent of farms	48	52
Dependent variables:		
NETFERT (dollars per harvested beet acre)	575	615
QN (pounds of N per harvested beet acre)	79	78
NEFF (lbs. gross sugar per lb. of N applied)	108	118
Operator and farm characteristics:		
OPAGE (years)	44	46
OPEDUC (years of school)	14.0	12.9
SPECIAL (percent of farm value from beets)	51	52
BUSORG (percent of farms)	15	20
APL (100s of harvested beet acres)	2.87	3.64
PEROWN (percent of beet acres)	46	52
COMPREC (percent of farms)	35	49
COMPANY (percent of farms) [1]	48	66
PCSMGRAIN (percent of beet acres) [2]	69	74
PCCORN (percent of beet acres)	23	14
PCOTHER (percent of beet acres)	8	12
YLDDEF (tons per acre)[3]	-0.52	-1.07
Basis for N decisions[4]:		
ROUTINE (percent of farms)	31	34
TEST (percent of farms)	80	80
CONSULT (percent of farms)	28	45
DEALER (percent of farms)	22	16
EXTEN (percent of farms)	4	16
FACTORY (percent of farms)	14	42

[1]American Crystal Sugar Company.
[2]*PCSMGRAIN*, *PCCORN*, and *PCOTHER* indicate whether the previous crop grown on the sugar beet acres was a small grain (included wheat or barley), corn, or other (included dry beans, dry peas, potatoes, soybeans, vegetables, or fallow), respectively.
[3]The sugar beet yield on farms not using remote sensed images was 21.4 tons per acre and was 22.0 tons per acre on farms using remote sensed images.
[4]Totals will not equal 100 because producers use more than one source as the basis for their N decisions.

Table 2. Probit estimates of the decision to use remote sensed images for nitrogen management by sugar beet producers in the Red River Valley, 2000

Variable	Coefficient	Std. error
INTERCEPT	-1.3450**	0.3025
OPAGE	0.0057**	0.0028
OPEDUC	0.0254	0.0172
SPECIAL	-0.0008	0.0014
BUSORG	0.0954	0.0742
APL[1]	0.1804**	0.0364
APLSQ	-0.0123**	0.0038
PEROWN	0.0023**	0.0006
COMPREC	0.1762**	0.0576
COMPANY	0.4205**	0.0570
Log-liklihood	-1,707	
McFadden's R^2	0.05	
Percent correct prediction	73	
Sample size	231	

Notes: Single and double asterisks (*) denote significance at the 10% and 5% levels.
[1]Measured as 100's of acres.

Table 3. Regression estimates of the impact of using remote sensed images for nitrogen management by sugar beet producers in the Red River Valley, 2000

Variable	*QN* (lbs. of N per acre)		*NEFF* (lbs. sugar per lb. N)		*NETFERT* (dollars per acre)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
INTERCEPT	52.04**	25.16	96.66	61.85	720.95**	83.34
OPAGE	0.08	0.22	0.32	0.54	-0.30	0.75
OPEDUC	1.51	1.37	-0.41	3.34	-6.92	4.60
SPECIAL	0.01	0.11	-0.23	0.26	-0.26	0.36
APL[1]	-4.68	3.09	9.92	7.57	3.39	10.22
APLSQ	0.42	0.30	-0.93	0.73	-0.17	1.00
YLDDEF	-	-	-4.50**	1.70	-26.29**	2.26
PCCORN	15.39**	6.46	-34.30**	16.04	-195.72**	22.00
PCOTHER	-22.43**	7.91	74.57**	19.20	-16.95	25.16
ROUTINE	12.64**	4.83	-21.42*	11.80	25.84	16.27
TEST	9.39	5.78	-4.97	14.55	4.25	18.14
CONSULT	1.35	4.59	-8.44	11.27	-0.61	15.30
DEALER	-10.19*	5.96	18.25	14.43	-36.22*	19.89
EXTEN	-10.80	7.42	15.06	18.03	23.35	25.30
FACTORY	2.17	5.28	3.17	13.03	34.73*	17.81
PrRSI[2]	-2.68	5.74	-8.71	14.05	-17.39	18.96
R^2	0.16		0.19		0.61	
Sample size	214		211		231	

Notes: Single and double asterisks (*) denote significance at the 10% and 5% levels.
[1]Measured as 100's of acres.
[2]Predicted probability of using remote sensed images for N management.