Journal of Agribusiness 16,2(Fall 1998):151–168

Socioeconomic Profiles of Early Adopters of Precision Agriculture Technologies

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Corn producers are the largest users of cropland and agrichemicals in U.S. agriculture, and represent a major market for precision agriculture technologies. Based on a USDA survey of 950 corn-producing farms, approximately 9% utilized some aspect of precision agriculture for corn production in 1996. A logit analysis indicated that farmers were more likely to adopt precision technologies if they farmed a large number of corn acres, earned a sizable farm income, and had high expected corn yields. The probability of adoption was also higher for farm operators using a computerized farm record system, who were less than 50 years of age, and who relied on crop consultants for information on precision agriculture.

Key Words: corn farms, logit analysis, precision agriculture, precision farming, technology adoption

U.S. corn producers, by virtue of their significant use of the nation's cropland and extensive agrichemical, seed, and tillage applications, represent a potentially dominant market for precision agriculture technologies. According to the *1992 Census of Agriculture*, over one-half million farms, or more than one-third of all farms with harvested cropland, grew corn for grain or seed.

In 1996, the 79.5 million acres planted to corn accounted for nearly one-fourth of all cropland in the U.S. [U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS), 1997a]. Corn production utilized nearly 60% (224.4 million lbs. a.i.) of all agricultural herbicides and over 35% (20.8 million lbs. a.i.) of all insecticides applied to the major U.S. crops in 1992 (Lin et al.). Nearly 44% (4.9 million nutrient tons) of all commercial nitrogen fertilizer used in 1992 in the U.S., 45% (1.9 million nutrient tons) of phosphate fertilizer, and 46% (2.3 million nutrient tons) of potash fertilizer were applied to corn land (Lin et al.). Hybrid corn seed accounts for an estimated 30%, or over $1.5 billion, of the expenditures farmers made for seed in the U.S. in 1994 [USDA/Economic Research Service (USDA/ERS), 1995]. On a per acre basis, USDA's 1996 corn cost of production data indicate that fertilizer

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The opinions and conclusions expressed here are those of the authors and do not necessarily represent the views of the U.S. Department of Agriculture.

accounts for over 35% ($47/acre) of variable cash costs, pesticides 17% ($27/acre), and seeds 17% (USDA/ERS, 1998). These inputs collectively account for nearly 65% of cash costs per acre. Clearly, corn farmers have an economic incentive to manage these inputs efficiently to increase yields and/or reduce costs of production.

Much of the U.S. corn is grown on or near environmentally sensitive lands, requiring more intensive management. For example, in 1995, about 20% of the corn was grown on land designated as highly erodible land (HEL), and additional corn was produced near wetlands, shallow aquifers, rivers, streams, lakes, karst areas, etc. (USDA/ERS, 1997). Corn production accounts for nearly one-third of the cropland on which conservation tillage is practiced (USDA/ERS, 1997).

Precision agriculture offers a way to manage variability of soils, pests, landscape, and microclimates, which are present within most fields, by spatially adjusting input use to maximize profits and potentially reducing environmental risks. Recent advances in the computer, aerospace, and communications industries allow farmers to monitor and manage crop production on a sub-field basis. Such spatially oriented information technologies as yield monitors, the Global Positioning Systems (GPS), Geographic Information Systems (GIS), aerial and satellite remote sensors, and variable rate applicators are now commercially available for many crops to assist farmers in making sub-field agrichemical, seed, irrigation, and tillage decisions. Hence, both the level and rate of adoption of these precision agriculture technologies have implications for farm income as well as for the land and water resources associated with production agriculture. Furthermore, the characteristics of the farms and farm operators who have begun to adopt these spatial technologies offer insights to policy makers concerned with improving farm income and reducing environmental risk.

Study Objectives

The specific objectives of this study are to: (*a*) briefly review the literature on the factors influencing the adoption of agricultural technologies; (*b*) present survey-based data on the extent of adoption of precision agriculture technologies by U.S. corn producers; (*c*) offer a socioeconomic profile of corn farms and farmers who are early adopters of these technologies; (*d*) compare corn enterprise resource use, economic indicators, and management practices of precision agriculture adopters and nonadopters; and (*e*) use logit analysis to identify the key operator, farm, and financial characteristics associated with the decision to adopt a precision agriculture technology.

Agricultural Technology Adoption Literature

Economists and sociologists have made extensive contributions to the literature on the adoption and diffusion of technological innovations in agriculture (e.g., Feder, Just, and Zilberman; Rogers). Such research typically focuses on the long-term extent of adoption, rate of adoption (i.e., diffusion), and the factors that influence the adoption decision. While there is broad agreement that profitability (i.e., the extent of yield increases and/or input cost reduction from a new practice or innovation relative to the costs of adoption and the current management practices) plays a key role in extent and rate of technology adoption, most studies acknowledge that heterogeneity among farms and farm operators often can explain why not all farmers adopt an innovation in the short or long run (Khanna and Zilberman; Batte and Johnson; Lowenberg-DeBoer and Swinton). For example, Rogers hypothesized that technology innovators or early adopters have attributes different from the late adopter or those who never adopt the technology. In other cases the financial, locational, or physical attributes of the farm firm may influence technology profitability and, ultimately, the adoption decision.

Operator Characteristics

Information-intensive technologies, such as precision agriculture, require a high level of human capital (National Research Council). The ability of the farmer to adapt new technologies for use on his/her farm clearly influences the adoption decision. Most adoption studies attempt to measure this trait through operator age, formal education, or years of farming experience (Fernandez-Cornejo, Beach, and Huang). Greater years of education and/or experience is often hypothesized to increase the probability of adoption, whereas increasing age reduces the probability because of factors inherent in the aging process or the lowered likelihood of payoff from a shortened planning horizon over which expected benefits can accrue (Barry et al.; Batte and Johnson). The extent of off-farm employment or an occupation other than farming has been found to reduce the chances of technology adoption because of the competition for the operator's management time, which is particularly critical for information technologies (McNamara, Wetzstein, and Douce).

Other studies have concluded that the information sources consulted about the technology affect adoption, as does familiarity with related technologies (Fernandez-Cornejo). For example, computer literacy likely would facilitate acceptance of precision farming as a desirable management tool. The USDA recently reported that in the North Central region of the U.S., about 22% of all farms use a computer for their farm business (USDA/NASS, 1997b). This figure rises to 45% for large farms (those with annual sales of $100,000 and over).

In considering agricultural technologies, several studies have concluded that operator risk preferences affect the adoption decision (Feder, Just, and Zilberman). Operators who perceive that production or financial risks increase with a new technology likely will be less willing to adopt. Bultena and Hoiberg report that new technology adopters are less risk averse than nonadopters. Attempts to quantify risk preferences have focused on such factors as use of crop insurance, debt/asset ratio, or diversity of farm enterprises. The presence of crop insurance and a diverse crop mix has been used to indicate risk aversion, whereas a large debt/asset ratio may be an indication of willingness to assume the risks that may be associated with technology adoption (Fernandez-Cornejo, Beach, and Huang).

Farm Physical Attributes

Within the major U.S. corn-growing areas, extensive heterogeneity exists with respect to climate and soils, which in turn may influence technology profitability and the adoption decision (National Research Council). On a smaller scale, the variability in soils, landscape, pests, and microclimates, which are present in most fields, is also important in the individual producer's decision to adopt precision farming technologies. Some studies have suggested that the economics of precision technologies favor high-value crops or highly productive soils (Daberkow). Sub-field variations in such factors as pH, organic matter, soil type and texture, topography, and drainage influence the spatial yield patterns. Precision farming offers a set of tools to manage such spatial variability for increased profitability.

In addition to the variability of physical resources and climate across the Corn Belt, which could affect the demand for precision farming resources by different producers, the infrastructure to provide such services may not be uniformly accessible. The availability of crop consultants, input suppliers, or equipment dealers with expertise in precision agriculture services is likely to strongly influence the rate of adoption (Wolf and Nowak). Hence, a variety of location-specific factors have been found or hypothesized to affect producer adoption decisions. In many adoption studies, a dummy variable is included to account for regional demand or supply factors (e.g., Fernandez-Cornejo, Beach, and Huang).

Farm Financial and Structural Characteristics

Farm size, farm ownership, and financial situation are additional factors often associated with the technology adoption decision. Numerous studies have found that large farms tend to adopt new technology earlier than smaller operations (e.g., Feder, Just, and Zilberman). Innovations with large fixed transaction or information costs may be prohibitively costly for small farms. Furthermore, large farms may have fewer credit constraints or more access to technical information sources, such as consultants, dealers, and equipment manufacturers, than small farms.

Technologies which are linked to the land are often assumed to be adopted by land owners. Precision farming generates extensive site-specific information about land parcels, and such information is primarily of value to operators/tenants who farm that parcel for a number of years. Consequently, land ownership is the best way to ensure that multi-year spatial information will be utilized. However, anecdotal evidence suggests that tenant farmers can use precision agriculture technology and site-specific data to ensure that they maintain a good relationship with landlords. Finally, a profitable farm or enterprise generates capital for experimenting or risk taking with new technologies. Hence, such measures as net cash farm income, per acre cash income, or cost of production per acre may affect the decision to adopt a new technology.

Data and Methods

Data collected in the 1996 Agricultural Resource Management Study (ARMS) were used to examine the application of precision agriculture technologies in corn production. The ARMS is a collaborative effort between the USDA's Economic Research Service (ERS) and National Agricultural Statistics Service (NASS) to annually collect and summarize information on farm resource use and finances. A special version of the 1996 ARMS collected detailed information about corn production practices and costs, farm finances, and the use of alternative precision agriculture technologies. Sampling and data collection for the corn version of the ARMS consisted of a three-phase process (Kott and Fetter). Phase 1 involved screening a sample of producers from NASS lists of U.S. farm operations to determine whether or not each farm produced corn for grain.[1] For Phase 2, production practice and cost information was collected on a randomly selected corn field on each of the farms in the sample of corn growers. All respondents to the Phase 2 interview subsequently were questioned about farm financial information in Phase 3.

Respondents in all phases of the 1996 ARMS for corn included 950 farms in 16 states.[2] The target population of this sample is farms planting any corn with the intention of harvesting grain. Each sampled farm represents a number of similar farms in the population, as indicated by its expansion factor. The expansion factor, or survey weight, is determined from the selection probability of each farm, and thereby expands the ARMS sample to represent the population of corn farms.[3]

When survey data are collected using a complex sample design, as in the ARMS, there is no easy analytical way to produce unbiased and design-consistent estimates of variance. The variance of survey statistics using standard statistical packages (such as SAS or SPSS) is inappropriate (Brick et al.). Therefore, the replication approach employing a delete-a-group jackknife method is used as the variance estimator (Kott). A major advantage of using the replication approach with the ARMS is that survey weight adjustments, such as for post-stratification and nonresponse, can be reflected in the variance estimates.

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[1] U.S. farm operations are defined as any operation with sales or production of $1,000 worth of agricultural products.

[2] The 16 states, by geographical area, include: North Central—Illinois, Iowa, Indiana, Ohio, Michigan, Minnesota, Missouri, and Wisconsin; Southeast—Kentucky, North Carolina, and South Carolina; Plains—Nebraska, Kansas, South Dakota, and Texas; and Northeast—Pennsylvania.

[3] A general farm version of the Phase 3 ARMS collected information about the use of precision agriculture technologies on a broader population of farms, but lacked the detailed information collected in the corn version. Because of the larger sample (1,673 farms), the general farm version was used to estimate population totals for corn farms and acreage in the 16 states. All other estimates presented in this study are based on the corn version (950 farms).

Measuring Technology Adoption

A farm operator is classified as an adopter of precision farming for corn production if: (*a*) any corn acres were soil-grid sampled and mapped, or (*b*) any corn acres were fertilized or limed with variable rate technology (VRT), or (*c*) any corn acres were harvested using a combine equipped with a yield monitor.[4] Because precision agriculture includes a relatively new set of technologies, this definition is intentionally broad to include the spectrum of farms experimenting with one or more components of precision agriculture.[5]

The estimated number of corn farms and the corn acreage on farms using precision agriculture technologies in 1996 are shown in table 1. Applying our broad definition of adoption, about 31,000 corn farms (approximately 9% of all corn farms) in the 16 states, with a range of 22,700 to 39,500 farms, used one or more precision agriculture technologies for corn production during the 1996 season. Among the specific technologies, 7% of farms used grid samples/maps, 4% applied fertilizer or lime with variable rate technology, and 6% used a yield monitor during corn harvest. Only 4% of farms used the yield monitor information to develop yield maps, which is an indication of the share of producers utilizing a GPS system to geo-reference yield data.[6]

The farm adoption estimate of about 9%, with no more than 7% for any individual technology (table 1), suggests that the diffusion of these technologies is very early in the typical adoption process (Rogers). However, these early adopters controlled a proportionally larger share of the corn acreage than nonadopters. The 9% of farms using any precision agriculture technology farmed 19% of corn acreage, indicating that adoption has occurred primarily on large farms.

Corn producers employed the different precision agriculture technologies on different shares of their corn acreage (table 2). Among the adopters of precision agriculture technologies, soil grid sampling/mapping was the most widely used technology, with approximately 70% of farms sampling/mapping 64% of their corn acres. About 60% of adopters reported sampling in 2.5-acre grids, with 43% indicating a sampling frequency of once every four years. Variable rate technology was used by the fewest adopters (36%) on nearly 55% of their acreage. Yield monitors were used by just over half the adopters (54%) on nearly all of their corn acres (94%). Yield monitors were used on an average of more than 500 acres per farm. However, not all farms reporting use of a yield monitor indicated that the data were (or will be) utilized for field mapping—only about 70% of the farms using yield monitors reported that they will

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[4] The survey did not specifically ask whether the grid soil sampling design was geo-referenced using GPS.

[5] Most adopters (52%) used only one of the three precision agriculture technologies, while 36% used two, and the remainder (12%) used all three.

[6] Grid soil sampling was reported to have been used on about twice as many acres as was the variable rate application (VRT) of fertilizer and lime. Several explanations for this result are possible. First, the survey asked for the number of acres using VRT in 1996, whereas the grid-sampling question did not specify a year of occurrence, and therefore the grid sampling could have occurred during a span of several years. Second, a reviewer pointed out that grid sampling may have revealed a lack of variation in the field, which would diminish the value of variable rate applications.

Table 1. Estimated Number of Corn Farms and Corn Acreage on Farms Using Precision Agriculture Technologies, 1996

	Percent		Number (000s)	
Technology	Mean	Interval [a]	Mean	Interval [a]
Farms:				
Soil grid samples/maps	7.1	5.1–9.2	24.1	17.1–31.1
Variable rate technology	3.7	2.7–4.6	12.4	9.2–15.5
Yield monitor	5.5	4.4–6.6	18.7	15.0–22.4
Yield maps	3.9	2.7–5.2	13.2	9.0–17.5
Total [b]	9.2	6.7–11.7	31.1	22.7–39.5
Acreage: [c]				
Soil grid samples/maps	15.8	12.5–19.0	9,513	7,526–11,501
Variable rate technology	8.4	6.2–10.7	5,092	3,733–6,451
Yield monitor	15.6	12.0–19.3	9,441	7,218–11,664
Yield maps	12.4	8.2–16.4	7,478	4,977–9,894
Total [b]	18.7	14.4–22.9	11,271	8,710–13,832

Note: Corn farms are those planting any corn for grain in 16 major corn-producing states: Illinois, Iowa, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, Nebraska, North Carolina, Pennsylvania, South Carolina, South Dakota, Texas, and Wisconsin.

[a] 95% confidence interval.

[b] The total is based on a sample of 1,673 farms, while the percentage distribution among the technologies is based on a sample of 950 farms (refer to text footnote 3). The estimated percentage distribution is used to distribute the estimated total among the technologies.

[c] Total corn acres harvested for grain.

Table 2. The Extent to Which Precision Agriculture Technologies Were Used in the Corn Enterprise on Adopting Farms, 1996

Technology	Adopting Farms Using Technology (%)	Acres on Which Technology Used (%)	Average No. Acres on Which Technology Used
Soil grid samples/maps [a]	69.9	63.8	267
Variable rate technology	35.8	55.3	242
Yield monitor	54.2	93.7	502
Yield maps	38.3	98.7	593

Notes: Adopting farms are defined as adopters of one or more precision agriculture technologies. Corn farms are defined in note to table 1, above.

[a] Initial grid soil sampling of fields used for 1996 corn production may have occurred prior to 1996.

make yield maps. Underutilization of the yield data may be indicative of the newness of these technologies, and suggests that some early adopters may still be learning how to fully utilize the technology.

Comparison of Precision Agriculture Adopters and Nonadopters

The comprehensive nature of the ARMS provided data on a variety of operator, farm structural and financial, and corn enterprise characteristics. Given the sufficiently large number of respondents indicating the use of one or more precision agriculture technologies, a number of traits of adopters and nonadopters could be compared using a modified *t*-test.

Operator Characteristics

The personal characteristics of farm operators who have adopted some form of precision agriculture technology differ in a variety of ways from those of nonadopters (table 3). While the average operator age for the two groups was nearly the same, a significantly larger share of adopters (69%) were less than 50 years of age, compared to less than half of the nonadopters (48%). A smaller share of adopters had only a high school or less education (37%) compared to the nonadopters (62%), whereas a larger share of adopters had completed college (27% compared to 14% for nonadopters). Over 90% of the adopters gave farming as their major occupation, as opposed to only 75% of nonadopters—indicating more management time available for crop production decision making. Likewise, adopters had gained more experience with computers in the farm business than nonadopters (30% versus 12%).

As seen in table 3, the sources of information about precision agriculture differed substantially between the two groups. Both groups relied heavily on farm suppliers and dealers, but adopters were more likely to seek out crop consultants and rely less on the Extension Service.[7] In general, adopters were younger, more educated, less likely to work off the farm, were likely to seek out crop consultants, and were extensive computer users relative to nonadopters.

Based on several measures of risk preference, adopters appeared to be less risk averse than nonadopters (table 3). Adopters had a significantly higher debt/asset ratio, had less crop and income diversity, and owned a smaller share of the land they farmed relative to nonadopters. While adopters reported a larger share of their gross cash income from crops, nonadopters relied more heavily on both crops and livestock. Nearly 85% of the acres harvested by adopters consisted of two crops (corn and

[7] One reviewer suggested that our survey should have made a distinction between university specialists and local extension staff as sources of information about precision agriculture. There is some evidence that producers view university specialists differently from the local extension staff, which has implications for where public resources might be expended.

Table 3. Operator Characteristics of Precision Agriculture Adopters and Nonadopters: Corn Producers, 1996

Item	Unit	Adopters	Nonadopters	All
Characteristics:				
Operator Age	years	49	52	52
Age Distribution:				
▸ Less than 50 years	% of farms	69*	48	50
▸ 50 years or more	% of farms	31*	52	50
Operator Education:				
▸ High school or less	% of farms	37*	62	59
▸ Attended college	% of farms	35	24	26
▸ Completed college	% of farms	27*	14	15
Major Occupation:				
▸ Farming	% of farms	91*	75	77
▸ Other	% of farms	9*	25	23
Computer Record Use	% of farms	30*	12	14
Information About Precision Agriculture:				
Sources of Information:				
▸ Extension Service	% of farms	10*	23	22
▸ Crop consultant	% of farms	35*	14	16
▸ Farm supplier/dealer	% of farms	71	56	57
▸ Event or demo	% of farms	12*	6	6
▸ Newsletter/trade magazine	% of farms	40	37	37
Risk Preferences:				
Debt-to-Assets	ratio	0.23*	0.14	0.15
Income Sources:				
▸ Livestock	% of income	22*	38	34
▸ Crops	% of income	65*	50	53
▸ Government payments	% of income	4	4	4
▸ Other	% of income	9	8	9
Acres Harvested by Crop:				
▸ Corn	% of acres	48*	39	40
▸ Soybeans	% of acres	37*	28	30
▸ Wheat	% of acres	6	9	8
▸ Other	% of acres	9*	24	21
Land Tenure of Corn Acres:				
▸ Owned	% of acreage	33**	44	41
▸ Cash-rented	% of acreage	29	31	31
▸ Share-rented	% of acreage	38**	24	28

Note: Single and double asterisks (*) denote significantly different from nonadopters at the 10% and 5% levels, respectively.

soybeans), whereas nonadopters were much more diversified. Even though adopters owned a smaller share of their corn acres (thus risking the loss of cropland in future years), they reduced their production and/or financial risk by share-renting significantly more of their cropland than did nonadopters.

Farm Structural and Financial Characteristics

By nearly any standard farm size or financial measure, those farms which have begun to utilize one or more precision technologies are bigger and more profitable than other corn farms (table 4). Acres operated, acres harvested, asset values, return on equity, and net income measures were from 1.5 to over three times larger for adopting farms relative to nonadopters. The distribution of farms by sales class confirms the correlation of size with adoption of precision agriculture technologies. While over half of the adopting farms had sales of $250,000 or more, only 15% of nonadopting farms were of that size. Nevertheless, about 18% of the adopting farms had less than $100,000 in gross sales in 1996. With net cash and farm income over $90,000 in 1996, adopting farms had the financial ability to experiment with this new technology. Surprisingly, even though adopting farms are much larger than nonadopters, the average net worth per farm is not statistically different between the two groups. This may reflect the more risk-averse nature of nonadopters as indicated by their relatively modest use of debt.

The location and type of precision technology-adopting farms (table 4) may reflect the availability of vendors and related support services as well as demand for such goods and services. The vast majority (70%) of the corn farms (both adopting and nonadopting) are located in the North Central states, with over one-third of all corn farms located in Illinois, Indiana, and Iowa. However, over half of the adopting farms are in the three central Corn Belt states, and over two-thirds of the nonadopters are located in the other states. Relative to nonadopters, the adopting farms are overwhelmingly specialized in cash grain production rather than in livestock production.

Corn Enterprise Production and Economic Characteristics

Despite several notable exceptions, resource and input use for corn production was fairly similar between the precision technology adopters and nonadopters (table 5). Use of irrigation, pesticides, phosphate, potash, manure, and highly erodible land (HEL) was not significantly different between the two groups.

Based on the earlier discussion on farm size, it was not unexpected that the number of corn acres planted per farm was over 2.5 times greater for the technology-adopting farms than for nonadopters. Adopting farms reported much higher normal (i.e., expected) and actual yields, which likely reflects higher inherent soil productivity on these farms. Adopting farms also used higher seeding rates and nitrogen application rates, possibly in response to the higher soil productivity.

Table 4. Farm Size, Finances, and the Type and Location of Precision Agriculture Adopters and Nonadopters: Corn Producers, 1996

Item	Unit	Adopters	Nonadopters	All
Farm Size:				
Acres Operated	no. of acres	988*	569	612
Acres Harvested	no. of acres	894*	399	449
Sales Class:				
▸ $0–$99,999	% of farms	18*	53	50
▸ $100,000–$249,999	% of farms	29	31	31
▸ $250,000–$499,999	% of farms	36*	10	13
▸ $500,000 or more	% of farms	17*	5	6
Farm Finances:				
Income Statement:				
▸ Gross cash income	$000s per farm	341*	142	162
▸ Variable cash expenses	$000s per farm	176*	80	120
▸ Fixed cash expenses	$000s per farm	65*	26	30
▸ Net cash income	$000s per farm	100*	36	43
▸ Net farm income	$000s per farm	91*	37	42
Balance Sheet:				
▸ Assets	$000s per farm	972*	652	686
▸ Liabilities	$000s per farm	221*	90	104
▸ Equity	$000s per farm	751	563	582
Return on Equity	%	12.1*	6.6	7.3
Farm Type and Location:				
Type:				
▸ Cash grain	% of farms	79*	51	54
▸ Other crop	% of farms	1*	9	8
▸ Livestock	% of farms	20*	40	38
Location:				
▸ North Central	% of farms	77	69	70
IL, IN, and IA	% of farms	55	32	34
▸ Plains	% of farms	19	17	17
▸ Southeast	% of farms	3*	8	7
▸ Northeast	% of farms	—*	6	6

Note: Single asterisk (*) denotes significantly different from nonadopters at the 10% level.

Differences between adopters and nonadopters were also evident with respect to certain management practices (table 5). Nonadopters had a larger share of acreage under conventional tillage and a higher share of land in continuous corn. Precision technology adopters had a higher share of acres: (*a*) in a corn-soybean rotation, (*b*) scouted for weeds and insects, (*c*) soil-tested, and (*d*) on which a nitrogen inhibitor was applied. In general, precision technology adopters tended to exhibit a more management-intensive approach to corn production than their nonadopter counterparts.

Table 5. Resource Use, Management Practices, and Costs and Returns of Corn Production by Precision Agriculture Adopters and Nonadopters: Corn Producers, 1996

Item	Unit	Adopters	Nonadopters	All
Corn Acreage and Yields:				
Acres Planted	no. of acres	434*	162	189
Irrigation	% of acres	16	14	14
Highly Erodible Land (HEL)	% of acres	23	22	22
Corn Yield (actual)	bushels/acre	147*	122	128
Corn Yield (normal)	bushels/acre	148*	130	134
Input Use:				
Seed	000s seeds/acre	29.2*	27.6	27.9
Fertilizer:				
▸ Nitrogen	lbs./acre treated	148**	130	134
▸ Phosphorus	lbs./acre treated	90	86	54
▸ Potassium	lbs./acre treated	77	73	74
Pesticides (active ingredients):				
▸ Herbicides	lbs./acre treated	2.64	2.64	2.64
▸ Insecticides	lbs./acre treated	0.59	0.72	0.69
Management Practices:				
Nutrient Management:				
▸ Nitrogen inhibitor	% of acres receiving	19*	6	9
▸ Soil test	% of acres receiving	54*	40	43
Pest Management:				
▸ Weed scouting	% of acres scouted	94*	78	82
▸ Insect scouting	% of acres scouted	86*	63	68
Tillage System:				
▸ Conventional	% of acres covered	20*	33	30
▸ Reduced	% of acres covered	37	30	32
▸ Mulch	% of acres covered	13	19	18
▸ No-till	% of acres covered	30	17	20
Crop Rotation:				
▸ Continuous corn	% of acres with	13**	21	19
▸ Corn-soybeans	% of acres with	54*	40	43
Costs and Returns:				
Gross Value of Production	$/planted acre	418*	346	363
Variable Cash Expenses	$/planted acre	170	155	158
Seed	$/planted acre	28*	26	26
Fertilizer	$/planted acre	53**	46	48
Chemicals	$/planted acre	30	28	28
Total Cash Expenses	$/planted acre	223	206	210
Land Cost	$/planted acre	107*	79	86
Gross VOP less:				
▸ Variable cash expenses	$/planted acre	248*	191	204
▸ Total cash expenses	$/planted acre	195*	139	152
Costs per Bushel:				
▸ Variable cash expenses	$/bushel	1.15*	1.27	1.24
▸ Total cash expenses	$/bushel	1.51*	1.70	1.65

Note: Single and double asterisks (*) denote significantly different from nonadopters at the 90% and 95% levels, respectively.

Translating the physical yield and input use into economic costs and returns indicators revealed a similar story—higher yields and greater use of seed and nitrogen led to significantly greater returns per acre and lower costs of production per bushel of corn on farms adopting precision technology (table 5). Gross value of production per acre was larger on the adopting farms, but neither variable cash expenses nor total cash expenses were significantly different. The only exception to the similarities on cost of production per acre occurred with the increased costs of fertilizer and seed per acre for adopters. Hence, while the overall costs per acre were not different between the two groups, the revenue generated from larger yields resulted in greater returns per acre and lower costs per bushel for adopters.

Modeling the Technology Adoption Decision

The above analysis of traits of adopters and nonadopters was essentially a univariate approach where differences between the means of selected characteristics for adopters and nonadopters were compared using a pairwise statistical test. A binary choice model, using the logit specification, was also used to examine the adoption decision in a multivariate framework.

In modeling technology adoption in this study, producers are assumed to make adoption decisions based on an objective of utility maximization. A new technology likely will be adopted if its perceived utility is higher than that of the old technology. Let a utility function that ranks the preference for these technologies by the ith producer be denoted as $U(R_{ti}, A_{ti})$, where $t = 0$ for the old technology, and $t = 1$ for the new technology. Utility depends on a vector R_t, the distribution of net returns for technology t, and a vector A_t, including other attributes associated with technology. The variables in R_{ti} and A_{ti} are unobserved, but assumed to be related to a vector of observed firm-specific characteristics X_i, and a random disturbance term e_t. Thus, $U_{ti} = X_i\beta + e_{ti}$ $(t = 0, 1)$, and the probability of adoption is $P_{i1} = P(X_i\beta > e_{i0} - e_{i1})$. Assuming that the stochastic components e_{i0} and e_{i1} are independently and identically distributed with a Weibull distribution, then their difference follows a logistic distribution (Maddala). Thus, the adoption decision may be analyzed using a logit model.

Specification of the Logit Model

The dependent variable of the logit model is a binary variable equal to 1 if one or more precision agriculture technology was used in corn production, and equal to 0 otherwise. Based on the results from the univariate analysis and literature review, we selected the following operator and farm regressors for the logit model: *Size* (planted corn acres); *Income* (net cash farm income); *Land Productivity* (corn yield normally expected); *Operator Age* (1 if the operator is less than 50 years of age, 0 otherwise); *Operator Education* (1 if the operator graduated from college, 0 otherwise); *Related Technology Use* (1 if computer records were used for farm income and expense accounting, 0 otherwise); *Livestock* (percentage of gross farm income from livestock sales); *Debt-to-Asset Ratio* (1 if greater than 0.15, 0 otherwise); *Land Tenure* (1 if more than 40% of corn acreage was owned, 0 otherwise); *Location* (1 if the farm was in either Illinois, Indiana, or Iowa, and 0 otherwise); and four *Information Sources* (1 if the specific source of information about precision agriculture technologies was reported by the farmer, 0 otherwise). The four sources include the Extension Service, crop consultants or advisors, farm supply or chemical dealers, and special events or demonstration projects. These are the sources that farmers are more likely to actively seek out for themselves.[8]

Parameters of the logit model are estimated using the survey weights in a weighted least squares version of the maximum-likelihood method. Standard errors are estimated using the jackknife replication approach. The change in probability is the derivative of the probability function evaluated at the means of the regressors, and indicates the change in the precision agriculture adoption probability given a change in the corresponding regressor. Derivatives of the probability function with respect to the binary variables are computed as the difference in the adoption probability evaluated at 1 and 0 (Putler and Zilberman).[9]

Results of the Logit Analysis

Half of the hypothesized operator characteristics included in the logit analysis significantly influenced the technology adoption decision (table 6). Precision technologies were most likely adopted by operators who were less than 50 years of age, used computers for record keeping, and used crop consultants for information about precision farming. Education level, although not statistically significant, had a positive sign. Other sources of information about precision farming, such as input suppliers and farm shows/events, were not significant.

None of the variables used to assess risk preferences were statistically significant even though the univariate measures presented above indicated that adopters may be less risk averse. The share of corn acreage owned by the operator was not related to the adoption decision. Apparently, even though field-level data for precision technology are site specific, farm ownership is not a major consideration in the adoption decision.

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[8] The authors recognize the potential for problems resulting from sample selection bias and the endogeneity of independent variables specified in the logit model. Variables such as corn acreage, net farm income, and information sources may have been simultaneously determined with the adoption decision, or result from the adoption decision, rather than determining adoption. However, the authors feel that because of the relatively recent introduction of precision technologies into production agriculture, the effects on most farm structural characteristics, yields, and incomes were minimal in 1996. In this early stage of adoption, most producers are experimenting with precision agriculture and evaluating the economic potential of these technologies.

[9] For example, the change in probability associated with the size variable indicates that, holding other variables at their mean, a 100-acre increase in planted corn acreage raises the likelihood of precision agriculture adoption by 1.2%. Thus, the probability of adoption by a 1,100-acre corn farm is 12% higher than for a 100-acre corn farm, ceteris paribus. Similarly, the likelihood of adoption by growers contacting crop consultants is 7.5% higher than for other growers.

Table 6. Logit Regression Results for Precision Agriculture Adoption in Corn Production, 1996

Variable	Variable Description	Parameter Estimate[a]	Standard Error	Change in Probability
Intercept	—	-5.8160**	1.2086	—
Size	Planted corn acres	0.0017**	0.0004	0.00012
Income	Net cash farm income ($000s)	0.0018**	0.0007	0.00013
Land Productivity	Normal corn yield	0.1112*	0.0060	0.00082
Operator Age	Less than 50 years	0.6435**	0.2947	0.04566
Operator Education	Completed college	0.4998	0.4555	0.04006
Related Technology Use	Computer record use	0.5530*	0.3032	0.04460
Livestock	Income % from livestock	-0.0076	0.0060	-0.00055
Debt-to-Asset Ratio	Greater than 0.15	0.3880	0.3177	0.02838
Land Tenure	Greater than 40% owned	-0.1463	0.3443	-0.01068
Location	IL, IN, or IA	0.5994**	0.2744	0.04440
Information Sources:	Extension Service	-0.1117	0.4892	-0.00796
	Crop consultant	0.8878**	0.3329	0.07514
	Input supplier	0.8627	0.5146	0.05908
	Event or demo	0.7412	0.4459	0.06410
Overall Measures:				
No. of observations	950			
-2 log likelihood function	56,616 with 14 df ($p = 0.0001$)			
McFadden R^2	0.24			
Concordant percent[b]	80.6			
Correct percent	91.0			

Note: Single and double asterisks (*) denote significance at the 10% and 5% levels, respectively.

[a] Using the jackknife variance estimator with 15 replicates means that the critical t-values are 2.145 at the 95% level, and 1.761 at the 90% level.

[b] Percent of pairs of observations with different responses in which the larger response has a higher probability than the smaller response.

Farm size, profitability, productivity, and location were statistically significant (table 6) and positively influenced the precision technology adoption decision. The probability of adoption increases as the number of corn acres increases—a result consistent with the findings of most other studies of technology adoption. The ability to pay for new technology, as measured by net cash income, raises the probability of adoption. Increased inherent land productivity also led to enhanced adoption levels—which may be an indication that such technology is more profitable on high-yielding fields, or perhaps high-yielding fields have more variability with respect to yield-limiting factors. Finally, location of the farm in the central Corn Belt states (Illinois, Indiana, or Iowa) also increased the probability of adoption. Most likely the location variable reflects the availability of precision technology vendors and/or support services, since much of the early precision farming equipment (i.e., yield monitors) was first introduced in these states.[10]

Summary and Conclusion

Corn production represents a potentially large market for precision agriculture technology because of significant natural and man-made resources used by corn farmers. By 1996, about 9% of all corn farms reported use of some type of precision agriculture—grid soil sampling, VRT for lime or fertilizer application, or yield monitors. Based on a comparison of means, early adopters of precision agriculture technologies tended to be less than 50 years of age, to have completed college, and to be a full-time farmer relative to nonadopters. Compared to nonadopters, early adopters: had farms which were significantly larger in size (i.e., assets, acres farmed, corn acres, and gross sales); were more leveraged; rented a large share of their acreage; were more specialized in cash grain production; produced corn at lower costs; and were more profitable. Further, precision-farming adopters were more likely than their nonadopter counterparts to soil-test and scout their corn fields, to use seed and nitrogen fertilizer more intensively per acre (which led to higher expenditures per acre for these inputs), and to have higher expected and actual corn yields.

A logit analysis indicated that precision agriculture adopters were more likely to farm more corn acres, earn greater cash farm income, be located in the central Corn Belt (i.e., Illinois, Indiana, or Iowa), and have higher expected corn yields. The probability of adoption was also higher for farm operators who used a computerized farm record system, who were less than 50 years of age, and who relied on crop consultants for information on precision farming. Our measures of risk preference were not significant in the logit analysis, nor was our measure of educational attainment.

From a policy perspective, several implications can be drawn from this analysis of early adopters of precision farming technologies. Large and profitable farms and younger operators, especially in the central Corn Belt, are adopting precision agriculture with little public assistance. If government policy makers decide to encourage more widespread adoption, such public policies could be targeted toward small farms with older operators—especially those operators having little experience with computer-related technologies.

Yet, a question arises as to whether scarce public resources should be devoted to training farmers who may soon retire, or to small farms which control few resources and produce a small share of the agricultural output. Educational programs to improve

[10] An examination of the independent variables indicated the presence of some multicollinearity. The size, net income, and productivity variables were positively correlated, as were size and location. However, each of these variables was statistically significant in the final model. One potential problem was related to the high (negative) correlation (based on the Pearson correlation coefficient of −0.86) between age and tenure, and may explain why tenure is not significant in our model.

producers' computer literacy, such as for farm record keeping, may be a strategy to expand adoption. Furthermore, investing in precision agriculture technologies through cost-sharing would encourage adoption. However, given the limited information available about the economic and environmental potential for precision agriculture technologies, another role for the public sector could be to increase research funding in these areas. Such research would enable policy makers to target the most appropriate producers, and identify those environmentally vulnerable resources, where the adoption of precision agriculture may provide the greatest public benefits.

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