Organic Pest Management Decisions: A Systems Approach

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

Acknowledgements: This paper was completed while the authors were visiting faculty at the University of Minnesota. Dr. Park received support from the Sloan Foundation and The Food Industry Center. Dr. Lohr received support from the School of Agriculture Endowed Chair in Agricultural Systems and the Minnesota Institute for Sustainable Agriculture. Research for this paper was also supported by Cooperative Agreement 43-3AEK-9-80002 with the USDA-ERS. The cooperation of the Organic Farming Research Foundation is gratefully acknowledged.

Abstract:

Organic farmers make system-level crop protection decisions that combine complementary insect, disease, nematode, and weed management strategies. Data from a national survey of U.S. organic farmers were used in a multivariate count data model to identify the farm and regional factors influencing adoption across the linked pest management categories. The results showed that weed management requires the greatest management effort by organic farmers. More intensive information-seeking and on-farm experimentation, higher educational attainment, and intensity of commitment to organic farming were positively related to the number of weed control strategies adopted. Predictions of adoption based on this model and customized to farm and region specifications will give information providers lead time to develop technical support for reduced chemical pest management systems.

Key words: organic farming, technology adoption, count data model, seemingly unrelated negative binomial model, farming systems

Organic Pest Management Decisions A Systems Approach

Introduction

System-level decision making for crop protection is a hallmark of organic farming. Organic certification requires soil improvement, whole farm planning, and adherence to approved input lists based on the premise that the agro ecology of insects, diseases, and weeds is highly interrelated. Altering any part of this ecology changes the environment in which the farmer operates. Organic farm management requires a holistic approach to crop protection, not least because economies may be realized from multi-pest management strategies. Organic farmers must consider the complementarity of practices when choosing among options.

Comer et al. (1999, pp. 30-31) noted that "farms have been slow to adopt [sustainable agricultural] practices, and adoption appears to vary widely by region and crops." Magleby (1998) reported that certain "green practices" such as integrated pest management (IPM) are widely accepted by farmers, but other proven techniques, including biological methods, crop rotations, and cultural practices, are not. Within the USDA increasing emphasis is placed on focusing research and development to deal with the management concerns of producers who are currently adopting sustainable technologies (Hrubovcak, et al., 1999). Our research explicitly addresses this issue for organic producers.

Rosmann's (1999) analysis of U.S. organic production noted that organic farmers tend to look for system level solutions, rather than target a single problem and to innovate approaches based on farm agroecology. In its 1997 national survey, the Organic Farming Research Foundation (OFRF) found that 87% of American organic farmers had conducted their own on-farm experiments (Walz, 1999). Collaborative experimental research with private companies, universities, or cooperative extension agencies was reported by 23% of organic farmers. Over 70% of respondents cited observation of and experimentation on their own farms and information gathered from books, other farmers, and researchers as important elements in shaping their personal knowledge base.

By understanding the system-level selection of pest management techniques demonstrated by organic farmers, we may better inform the research and education process to improve the sustainability of all farmers. In its report on the future of pesticides, the National Research Council (2000) emphasized the need to develop a set of flexible tactics for managing crop protection and to understand how farmers can diversify their pest-management “toolbox” in an era of rapid economic and ecological change. Building on this systems approach to management practices along with an assessment of the factors influencing the complete portfolio of practices that organic farmers use forms the basic framework for the model we develop.

The factors that influence organic farmers’ adoption of management practices for three production constraints including crop diseases and nematodes, insects, and weeds are evaluated. The data are from the only U.S. national survey of organic farmers and represent a cross-section of crops, production regions, management statuses, and farm scales. By treating the adoption decisions as interrelated in a seemingly unrelated regression (SUR) approach, we more closely approximated the planning methods used by organic farmers. The policy implications of the analysis in predicting adoption patterns of organic management practices are also discussed.

Modeling the Adoption Decision

Management decision making research has virtually ignored the question of why specific combinations of practices are selected, a primary issue explored here. Previous studies described the adoption decision as a dichotomous choice - either the technology or set of technologies was adopted or not. Individual management practices are typically aggregated prior to analysis, so that the level of commitment to alternative practices could not be determined. Consequently, these models explained whether a farmer adopted alternative practices, neglecting the level of use and the diversity of practices employed. Ruttan (1996) challenged researchers to focus on additional dimensions such as frequency of use and complementarity among closely related innovations in order to fully understand the adoption and diffusion of new technology and innovative management techniques.

In an extension of the dichotomous adoption variable, Fernandez-Cornejo et al. (2001) used the percentage of acreage on which genetically engineered crops and precision agriculture technologies were applied as a measure of intensity of adoption. This approach allowed the effect of independent variables on the adoption decision to be interpreted as increasing or decreasing the number of adopters and the proportion of acreage under adoption. However, the adoption variable was still predicated on a yes-no decision, constructed by multiplying one (yes) or zero (no) by the share of acreage, and did not capture the diversity of options inherent in multi-practice technologies such as IPM, soil conservation, and precision agriculture.

Researchers have grouped practices by category of technology, but this technique does not account for the degree of commitment required by farmers to adopt the technology. Caswell et al. (2001) modeled the adoption of any of a set of twelve soil conservation practices along with any of a subset of four practices oriented primarily towards protecting water quality. Fernandez-Cornejo and Ferraioli (1999) described the adoption of bundles of pest management techniques grouped into three broad categories: improved efficiency of chemical pesticide use, cultural and production techniques, and biological controls. Classifications such as these reveal the researchers' assessments of management and human capital requirements. Weaver (1996) developed a count measure of adopted soil conservation practices with values ranging from zero to eighteen. Binary indicators of adoption were combined into an aggregate measure of total environmental effort, an approach consistent with previous work that summed decisions on conservation practices by Ervin and Ervin (1982) and Lynne et al. (1988). Farm-level economic evaluations have focused on the adoption of a family of soil conservation practices such as conservation tillage techniques, reinforcing the validity of considering the number of adopted practices.

Economic Decision Model of Adoption

The model of agricultural management practices follows Weaver's (1996) analysis of adoption decisions where farmers choose production activities along with a level of environmental effort. Farmers are aware of environmentally beneficial agricultural practices which can be incorporated with marginal changes in production plans and technologies. The farmers choice problem is to maximize utility of production by choosing an optimal production plan along with the private provision of environmental goods. Beneficial environmental pest management practices available to organic farmers for dealing with disease and nematodes, insect pests, and weed control are denoted by E and the price of the practice is given by q. In the two-stage decision model, the optimal choice of inputs and outputs are initially determined, conditional on the level of environmental effort, E^0. The conditional profit function π^0 depends on the output price (p) and input prices (r) and environmental effort (E). In the second stage, the optimal choices of environmental effort and public environmental effects are derived from the producer's choice problem

$$\max U = U(\pi^0, Q^i) \quad where\; \pi^0 = \pi^0(p, r, Q^i, E^i) - qE. \tag{1}$$

The farmer's decisions on beneficial environmental practices are defined from the first-order condition leading to a reduced form specification of the decision to adopt the environmentally beneficial practice, E^*

$$U_\pi \left[\frac{\partial \pi^0}{\partial E} - q\right] = 0 \rightarrow E^* = E(p, r, q, Z) \tag{2}$$

The producer's level of environmental effort depends on the individual assessment of the private profitability of the practice, which is controlled for in the model. Also included are sociodemographic indicators, farm factors, and regional variables, denoted by the vector Z.

Econometric Model and Data Description

Model

The level of environmental effort by organic producers is measured by the portfolio of management practices to which the farmer has committed and has demonstrated expertise in effectively using. Management practices for controlling crop diseases and nematodes, insect pest techniques, and weed control methods must be used on a regular basis and fully incorporated into ongoing farm operations to meet this requirement. Organic farmers who used a given technique on an occasional or regular basis during a year were identified as "adopters" while farmers who rarely or never used a strategy were classified as “non-adopters.” Frequency of use is thus embedded within the count of strategies used in each management category. Only practices that are used regularly are counted as adopted.

Based on this framework and building on previous work, the management practices regularly used by an organic producer were enumerated and a count data model was specified for the adopted practices. Both farm level factors and regional growing conditions affect a growers' adoption decision. We constructed a model to describe the effects of farm level and regional variables on the interrelated strategies chosen in three management categories: crop disease and nematode control, insect pest control, and weed control. The resulting count data regression model was

$$\ln(\text{NumAdopt}_{ij}) = \alpha_j + \sum_{j=1}^{J} \beta_j F_{ij} + \sum_{j=1}^{J} \gamma_j R_{ij} \tag{3}$$

where NumAdopt_{ij} measures the number of regularly used techniques by farmer i in management category j, α_j is the intercept associated with management category j, and β_j and γ_j are parameters to be estimated. Farm level and demographic factors that influence adoption are denoted by the vector F_{ij} and R_j is a vector representing the regional agronomic and geographic effects.

Following Winkelmann (2000) , the model was estimated using a SUR negative binomial regression model recognizing that the number of adopted management strategies was recorded as count or integer data. Each of the J=3 management categories was an equation in the SUR, model. Let $z_i = (z_{i1}, \ldots, z_{iJ})$ be the vector of J counts where $z_{ij} \mid v_{ij}$ follows a Poisson distribution with parameter $\lambda_{ij} v_{ij}$ and $\lambda_{ij} = \exp(x_{ij}\theta_j)$. The x_{ij} encompass the farm level and regional variables while the θ_j represent the parameters (β, γ) which will be estimated. The v_{ij} term has a gamma distribution with mean $E(v_{ij}) = 1$ and $Var(v_{ij}) = \alpha^{-1}$. The marginal distribution of z_{ij} is negative binomial with mean $E(z_{ij}) = \lambda_{ij}$ and $Var(z_{ij}) = \lambda_{ij} + \alpha^{-1} \lambda^2_{ij}$ but with a convenient redefinition of $\alpha = \lambda_{ij} /\sigma$, the variance becomes a linear function of the mean, $Var(z_{ij}) = \lambda_{ij}(1 + \sigma)$. Winkelmann (2000) presented the log-likelihood function for the model along with the variance-covariance matrix and established that the resulting estimates are asymptotically normal. The negative binomial SUR structure allows for overdispersion when $\sigma > 0$. The validity of the Poisson model which imposes equality between the conditional mean and the conditional variance is assessed using a likelihood ratio test of the restriction that $\sigma = 0$.

Data

Since 1993, the private not-for-profit OFRF has conducted biennial surveys of organic farmers in the U.S., each year increasing its sample base until, in its 1997 survey, the entire U.S. certified organic farm population was surveyed. The 1997 OFRF survey was based on grower lists maintained by organic certification organizations and was designed by a committee of nationally recognized organic practitioners, extensionists, researchers, and government specialists. The stated purpose was to "...provide the most comprehensive picture currently available about the state of organic farming in the United States, from the organic farmer's perspective" (Walz, 1999, p. 1).

Comprehensive data on production and marketing practices of organic farmers were gathered, as well as details of production and marketing problems, information sources, and demographic information. The data represent all crops grown organically, and all regions in which organic production is conducted. Of the 1,192 surveys returned to the OFRF (26% response rate), sufficient detail was provided in 1,001 responses to test the model. The data were obtained by special agreement with the OFRF under a project to assess the U.S. organic sector. Of 49 states with organic producers in 1997, 44 states were represented in the OFRF survey. The five states missing from the survey response set represented only 0.18% of the total certified organic cropland in 1997. Thus, the data were deemed sufficiently representative of the U.S. organic farming sector to use for testing the adoption model.

Dependent Variable

The dependent variable represents the number of adopted practices, derived from responses to three separate questions related to crop disease and nematode management, insect pest controls, and weed controls. The OFRF survey tabulated the frequencies of use for practices in each category. The specific practices listed in the survey are provided in Appendix A. Organic farmers who used a given technique on an occasional or regular basis were identified as "adopters" while farmers who rarely or never used that strategy were coded as "non-adopters."

Table 1 shows the variable descriptions and summary statistics for the dependent and independent variables estimated in the econometric model, as well as the question number from the OFRF survey results (Walz, 1999) that corresponds to each variable. The average number of crop disease and nematode management strategies applied by the 1,001 sample farmers (CropAdopt) was 3.01 from a set of 7. Organic farmers used an average of 3.29 of 11 insect pest control techniques (BugAdopt). Weed control methods (WeedAdopt) had the highest number of adoptions at 5.86 out of 12 surveyed methods. In enumerating the variety of practices adopted by farmers in the sample, we found no evidence that farmers view practices as conflicting with one another, confirming that organic producers consider a full portfolio of practices which are most appropriate for their farming operation.

Figure 1 shows the practices that were adopted by more than 50% of farmers. The weed control category has the largest number of regularly used practices including (in the same order as on the figure) mechanical tillage, weeding by hand, crop rotations, use of cover crops, mulches, and planting date adjustments. Three techniques in the crop disease and nematode control category were adopted by over half of surveyed organic farms: crop rotations, planting of disease resistant varieties, and use of compost applications. Of the 11 insect control techniques, only crop rotations were used by more than 50% of farmers. These results may reflect the relative complexity of management for each category or a lack of information about effective alternatives.

The percentages of farmers adopting by number of techniques adopted across the three management categories reflect the emphasis on weed research needs stressed by organic farmers in the OFRF survey (Rosmann, 1999). The proportion of farmers adopting three or fewer techniques was roughly the same for both crop disease/nematode and insect management problems at 58% and 55%. However, for addressing weed management problems only 16% of producers relied on three or fewer techniques. Conversely, 59% of the sample used 6 or more techniques for weed control while only 6% employed this many strategies for disease/nematode management. Weed control requires the most effort or creativity in the pest management portfolio.

Independent Variables

Constrained by legal requirements for organic certification, lack of research information on alternative practices, and the risk of yield loss if the agro-ecological balance is upset, organic farmers must be particularly concerned with system outcomes when selecting management techniques. The system-level adoption model reflects the farm organizational, financial, and demographic factors that affect information collection and technology experimentation, as well as the regional variation in adoption patterns.

Farm structure variables for sole proprietorship (SoleProp) and corporate organization (Corporat) on Table 1 reflect the potential flexibility accorded the farmer in making management decisions. Sole proprietorships offer the greatest management flexibility to the farmer because they involve the least number of other decision makers. Corporations offer the least flexibility and the most demanding financial requirements. In our sample of 1,001 farmers, 72% of farms were sole proprietorships and 6% were corporations. In the U.S. as a whole, proprietorships compose about 90% of all farms, and partnerships make up from 5% to 6% (Hoppe et al., 2001). Alternative farm structures representing a third, intermediate level of flexibility, including partnerships, cooperatives, and property management firms, were grouped and omitted from the regression.

Factors that might predispose a farmer to greater knowledge about the farm ecology and the ability to form reasonable expectations about the suitability of a new practice include time allocated to farming activities, experience with organic farming, and educational attainment. Schultz (1975) suggested that schooling is valuable in assessing information under disequilibrium such as when farmers are adopting and integrating new production and management techniques.

Caswell et al. (2001) theorized that greater complexity of information-intensive technologies, such as organic methods, explains the positive effect of education on their adoption.

About 36% of the producers in our sample were engaged in farming on a full time basis (FullTime), compared with 39% of all U.S. farmers (Hoppe et al., 2001). Experience in organic farming averaged 10 years (YrsOrg), although a few farmers reported no previous experience. With experience ranging up to 70 years, farmers' ability to match practices to the specific agro-ecosystem should exhibit significant variability in this sample. About 58% completed a college degree or attained a higher educational level (Educ), much higher than the national average of 19% for all U.S. farmers.

Under the U.S. regulation, farmers may certify as organic less acreage than they farm, leading to parallel organic and conventional systems being managed by the same operator. Farmers who manage both types of systems (Mixed) account for 24% of the sample. Managing very different systems such as this could reduce time and commitment to learning about the full complement of organic practices available and designing an optimal organic system.

A scale effect for farm size is likely to hold, in that larger farms are able to streamline their enterprises to minimize production costs and numbers of different practices required per unit of output (Caswell et al., 2001). In this sample, the smallest farm was 0.125 acre, the largest was 6,000 acres, and the mean farm size was 140 acres (OrgAcre). The average amount of land operated per farm unit nationally in 1998 was 453 acres for all types of farms, but the average of owned land operated was 262 acres (Hoppe et al., 2001).

High gross incomes might be expected to support more practices because revenues are sufficient to offset the financial risk of experimentation with multiple practices. The twelve response categories for total gross organic farming income provided by OFRF were combined into the five classes shown on Table 1 for more meaningful comparison with USDA definitions of farm structure and national certification requirements. Scale of farm operation and organic farm income measures account for the organic farmer's determinants of private profitability in adopting the management practices, following Weaver (1996) and Saha et al. (1994).

The largest percentage of farmers in our sample (48%) received less than $15,000 from organic farming, compared with 52% of all farmers in USDA's lowest sales class receiving less than $10,000. In our sample, 37% of respondents grossed between $15,000 and $99,999, comparable to the USDA's "low sales" small farms (sales from $10,000 to $99,999) making up 30% of all U.S. farms. "High sales" small farms making between $100,000 and $249,999 were 9% of the sample farms and of all U.S. farms. About 6% of our sample and 8% of all U.S. farms qualified as "large farms" grossing at least $250,000. The income variable (OrgInc) has a mean value of 2.50, which means that the average farm income is between $5,000 and $99,999. This places the average organic farmer in the sample into the USDA "low sales small farm" class, the same as for the majority of conventional U.S. farmers.

The strategies selected to manage crop diseases/nematodes, insect pests, and weeds depends on the crops grown. With the exception of crop rotation, alternative practices are used far more extensively in conventional agriculture by horticultural producers than by field crop producers (Anderson et al., 2000). For example, foliar applications of Bacillus thuringiensis were used on 1% of corn and 2% of cotton acreage in 1997, compared with 16% of apple and 11% of grape acreage in 1997, and 33% of head lettuce and 64% of fresh tomato acreage in 1996.

The variable PctHort was constructed to test this difference for organic farmers. Total acreage in vegetables, including herbs, flowers, and ornamentals, fruits, nuts, and tree crops was divided by the total organic acreage to obtain the share of acreage per farm in horticultural crops. The mean share of horticultural acreage (PctHort) was 51%, with both 0% (no horticultural crops) and 100% (all acreage in horticultural crops) represented in the sample.

Kalirajan and Shand (2001) suggested that a main constraint in achieving technical efficiency in agricultural production is the lack of information about the best practice techniques. With limited information farmers benefit from gradual "learning by doing" in adopting new production and management methods. Information accessibility and reliability are of particular importance in the adoption of management strategies for organic systems. As Padel and Lampkin (1994) pointed out, direct costs of information and experience gathering constitute major barriers to organic conversion. Information gathering, evaluation, and on-farm testing costs are incurred by individual organic farmers due to the lack of public sector research and technical advice.

Information about organic production methods is gathered from personnel or food and agricultural organizations. From a list of 12 personal information sources listed in the OFRF survey, respondents indicated the usefulness of each and the frequency of use. To evaluate the effort required to obtain information, we constructed variables that counted the number of personal sources contacted (InfoSrc). The average number of personal contacts in our sample (InfoSrc) was 5.4, with a low of 0 and a high of 12.

Conventional and organic farmers rely on different sources of technical information on pest management. Other producers are the primary personal source of information for the organic farmers (Walz, 1999; Anderson et al., 2000). Conventional growers look to farm supply and chemical dealers as their primary personal contact for pest management strategies. Organic farmers rated the extension service rated very low in terms of average frequency of use and moderately in terms of usefulness of information. Extension advisors and private sector crop consultants or scouting services were the second most important personal sources for conventional farmers.

There are several sources of variation in pest management strategies that are detectable at the regional level, including climate, insect regimes, crop production practices, regulatory environment, and support infrastructure. To assess institutional support and information availability for organic pest management practices, we used the four USDA Sustainable Agriculture Research and Education (SARE) regions. These regions reflect the federal government's demarcation for sustainable agriculture extension-research support, which we hoped to proxy in the model. A dichotomous variable was created for each region, equal to one if the respondent's farm was in that region, and zero otherwise. In our sample, 33% of farmers were in the SARE 1 region (West), 33% in the SARE 2 region (NorthCent), 8% in the SARE 3 region (South), and 26% in the SARE 4 region (Northeast).

Results

Coefficient estimates and asymptotic standard errors for the count data model of the three management categories (crop disease and nematode management, insect pest control, and weed control) are presented on Table 2. Estimates held constant across all equations are listed in the first column. The pseudo-R^2 value was 0.26, which is consistent with the range of values (0.30 to 0.44) for on-farm technology adoption decisions reported by Caswell et al. (2001). The overdispersion parameter has an asymptotic distribution which follows a 50/50 mixture of a χ^2_1 and the constant value zero. Testing the restriction implied by the seemingly unrelated Poisson model yields a calculated value of 15.93 which exceed the critical value of 1.92 for the 50/50 mixture at the 5% significance level.

Endogeneity tests for a set of key statistically significant variables in the count data model including the number of information sources used (InfoSrc) and the amount of organic acreage were developed following Wooldridge (2002). The test (full details of which are contained in an extended online working paper) revealed no evidence of endogeneity so estimation of the SUR negative binomial model is appropriate. A reasonable implication of these results is that the organic farmer develops and assesses the validity of key technical and market information sources that are subsequently relied on in guiding the decision to adopt management practices. Decisions on acreage and farm structure occur in the planning stage and the optimal management practices are chosen based on structure of the farm operation.

Joint estimation of the count data model allows us to examine the relationships among the three management categories in a systems context by permitting some of the coefficients to vary across the equations. The data model was specified to test whether the coefficients differ across the three categories for six variables (YrsOrg, Mixed, OrgAcre, PctHort, InfoSrc) thought to have the most influence on number of practices adopted. The hypothesis that the variable has a similar impact across the three management categories is rejected if the Wald test statistic exceeds the critical χ^2_2 of 3.84 at the 5% significance level. The Wald statistics are given on Table 2. The hypothesis was rejected for all tested variables.

Two overall results stand out. First, for coefficients permitted to vary across the three management categories, all but PctHort have the same (negative) sign for crop disease/nematode management and insect pest management, but a positive sign for weed management. Second, weed management was the only equation for which the information variable (InfoSrc) and experience (YrsOrg) were significant and positive. These results are consistent with organic farmers' assessment that weed control is the primary production constraint and the highest priority for institutional research (Walz, 1999). The OFRF survey reported that 20% of respondents had "serious difficulty managing" weeds, 3% diseases, and 6% insects. This suggests more intensive information-seeking and on-farm experimentation with weed control methods.

The business structure variable for corporations has a significant negative impact on the choice of how many practices to adopt for the pest management system. Full time organic farmers tend to adopt fewer practices, according to the significant negative coefficient for FullTime. These findings are in contrast to the hypothesis by Caswell et al. (2001) that off-farm employment motivates adoption of time-saving technologies while discouraging use of time-intensive technologies such as most organic practices are. Upon finding no relationship between off farm employment and adoption in most cases, Caswell et al. (2001) concluded that the technologies assessed were neutral in time-intensity. However, most of these same practices were analyzed in our model, suggesting that the greater attention given to farm ecology by full time organic farmers, not the time required to implement the practices, is critical to the selection of the minimum number of practices required for successful pest management.

The human capital variables (YrsOrg and Educ) are significant factors in adoption. College education has a greater influence by an order of magnitude on the number of strategies adopted than does organic farming experience. Greater human capital is typically associated with an expanded capacity to incorporate new practices into an existing operation, both through the ability to learn new technology and willingness to try new methods. Organic farmers are highly educated and tend to experiment with new methods, so the finding that college education (Educ) has a positive effect on number of practices is not surprising. Experience (YrsOrg) is significantly positively related only to weed control practices, and is significantly negatively related to insect pest management practices. This result indicates that greater efficiency in insect control is gained with more experience, while the longevity in farming does not improve weed management knowledge. No effect from experience is observed for nematode/disease management.

Farmers with some organic and some conventional acreage (Mixed) adopt fewer crop disease/nematode and insect pest control strategies but have a higher demand for weed control techniques relative to those farming only organic acreage. One explanation for this result is the conventional acreage is probably in the three-year window required for transition to organic agriculture. Normally, weed pressure is a greater challenge during this time than nematode/disease and insect pest control as weed seed banks germinate. In the OFRF survey, 28% of respondents listed weed control as the greatest barrier to organic transition (Walz, 1999). Insect and nematode/disease control were identified as the greatest barrier by only 9%.

Farm size (OrgAcre) was a significant negative factor in adoption of disease/nematode and insect pest control techniques, but not significant for number of weed control practices. Smaller farms adopt more organic practices than larger farms, a finding that is not typically observed in adoption models. Empirical studies often report that larger farmers are more likely to adopt and invest in new technology as increased farm size contributes to lower management costs for each unit of output (Just and Zilberman, 1983; Caswell et al., 2001).

Most of the organic management strategies to control diseases/nematodes and insect pests require intensive monitoring and management to be successful, which would be easier to do on smaller farms. Most of these practices do not require large fixed investments nor changes in land allocation, so costs are not disproportionately high for small farms. Since the same type of monitoring is required to judge the performance of and make adjustments to several of the alternatives, there are lower marginal costs for certain combinations of practices. Conversely, many of the weed control techniques require new equipment, changes in productive land allocation, or additional trips across the field, which entails higher labor and machinery costs.

The income variable (OrgInc) had no effect on the number of strategies applied, which is consistent with results for soil conservation practices by conventional farms and for genetically engineered crops and precision agriculture (Fernandez-Cornejo et al., 2001). Changes in farm income levels alter the number of pest management practices adopted.

The coefficient for PctHort was significant only for insect pest management. Horticultural farmers employ more insect pest control strategies than field crop producers, as the positive coefficient indicates. This result is not surprising since most organic horticultural crops are sold to fresh market. Cosmetic damage from insects is unacceptable for growers trying to match the visual quality of conventional produce. Weeds and diseases primarily reduce yield, a concern shared equally by field crop and horticultural producers.

The information variable (InfoSrc) was significant and positive for the weed management category. This reflects the importance of personal contacts to organic farmers under conditions when little published information is available and farmers turn to each other for strategies to test. The interest in integrated pest management (IPM) to reduce chemical use among conventional farmers has resulted in a number of scientific findings that benefit organic producers. The IPM research has been focused on insects, and to a lesser extent, disease/nematode complexes, and has made little progress with weed management. As a result, there are numerous crop- and region-specific IPM-related publications and demonstrations that are of use to organic farmers, but none dealing with weeds.

The regional effects were negative and significant for the three SARE region dummy variables included in the estimation. This indicates that farmers in these regions (West, North Central and Northeast) regions choose significantly fewer practices than farmers in the South, the region excluded from the regression. Caswell et al. (2001) showed that natural resource characteristics have little to do with adopting alternative practices, suggesting that climate and soil factors are not as relevant to the portfolio choice as other attributes, such as crop selection, farm size, and infrastructure.

Predicting System Level Information Needs

Nationally, 42% of organic farmers consider “uncooperative or uninformed extension agents” to be a serious problem, and 25% believe “unavailable or hard to find” information on organic systems is a serious barrier to transition (Walz, 1999, p. 91). This perception might be altered if information providers could predict and prepare for the technical questions organic farmers are likely to ask. With better understanding of the factors influencing the demand for pest management information, providers could determine the personnel and research requirements needed and develop programs accordingly. Such predictions are possible with the system level model and may be customized to farm and regional conditions that are expected to prevail.

Using the estimated regression model in equation 3 and specifying scenarios with appropriate farm and regional characteristics, the percentage of farmers adopting different numbers of management practices may be determined. In the examples that follow, three management portfolio sizes were predicted - zero practices, 1 to 4 practices, and 5 or more practices. For information providers, the last group is of the most interest because the four most popular practices in each of the three categories shown in Appendix A are the most researched and most widely practiced, so the marginal cost of providing technical support is lower than for the rarer practices. As the diversity of practices increases, the likelihood of farmers asking questions about experimental or unknown techniques increases.

Figure 2 illustrates this phenomenon by comparing adoption of weed control strategies by all farmers (those choosing zero to 12 practices) and those choosing five or more. For all organic farmers and the five-plus subset, the top four practices are mechanical tillage, crop rotations, cover cropping, and hand weeding. Most extension agents are well prepared to offer advice on these strategies because they are components of well documented IPM and reduced chemical systems. The fifth (72% of the five-plus subset) and sixth (68%) most popular choices, mulches and planting date adjustment, are probably less familiar to conventional extensionists, but the next four, adopted by 30% to 51% of the five-plus subset, are probably unheard of by most agents- smother cropping, row width adjustment, flaming or burning, and grazing. If the percentage of farmers likely to demand information beyond the basics is large, information providers should be aware of these needs.

To make predictions, a base case must be selected by substituting into the estimated regression model a zero or one for the dichotomous variables and the means of the continuous variables. Table 3 shows some examples resulting from the prediction method. The base case is for a college educated part time organic farmer with 10 years' experience operating as a sole proprietor in a Western state. The farm has 140 mixed organic and conventional acres of which 51% is in horticultural crops, generating gross organic farming income between $5,000 and $99,999 per year. The farmer consults 5 personal sources and 3 media outlets for information about production practices.

For all producers who conform to the base case, 19% will choose five or more crop disease/nematode management practices, 24% will select at least five insect pest management strategies, and 71% will choose that many weed control techniques. Scenario 1 describes the situation if these producers transitioned to 100% organic production, all other factors held constant. In this case, 25% would choose five or more crop disease/nematode management practices and 31% would choose that many insect pest management practices. However, the percentage demanding five or more weed control strategies would drop to 64%. Scenario 2 illustrates what would happen if the fully transitioned organic farmers increased their acreage by 10%. The percentages demanding five or more crop disease/nematode control practices and weed management strategies would not change. The percentage adopting five or more insect pest control practices would decline to 24% as a result of the increased per farm acreage.

The effect on probability of adoption due to changes in any variable can be computed. Since organic production is evolving differently across regions and farm conditions, the most likely scenarios may be constructed and adoption levels predicted to the advantage of information providers The model predictions would be useful in targeting research and training for extensionists, as well as developing cost-effective information programs for farmers. Finally, the model can easily be adapted to predict adoption patterns for specific pest management practices. Extension agents and agricultural consultants can build on the identified variables which influence the portfolio of agricultural management decisions and analyze any individual practice, assessing the probability of adoption and identifying specific farm groups that show may be targeted for adoption. Ongoing work is assessing the applications of this technique.

Implications of the Results

The National Research Council (2000) report on the future of pesticides in U.S. agriculture highlighted the organic food market as the most rapidly expanding food segment while delineating emerging constraints on growth, consolidation trends, and limitations on management and research facing organic farmers. Our results confirm that the need for research-based recommendations and technical information will become more acute.

The multivariate count data model of adopted pest management strategies reflects the integrated decision framework used by organic farmers in choosing complementary techniques that benefit the whole farm's agro ecology. Organic farm management requires a holistic approach to crop protection, not least because economies may be realized from multi-pest management strategies. As organic production methods gain ground, information providers will need familiarity and expertise with increasingly diverse management strategies.

There is a critical need for public sector research in organic weed control. Farmer-to-farmer exchanges and increased experience in organic farming can solve most insect management and disease/nematode problems. If weed control is the primary barrier to organic agriculture expansion, it should be a main research priority. Organic weed control research with its emphasis on cultural practices that attack weeds as a generic problem., has the potential to yield beneficial insights to research on conventional IPM.

Extension agents, crop consultants, insect scouts and other information providers need better information to increase their credibility with organic farmers. Public information delivery systems have proven to be cost-effective in technology diffusion, but are little used by the organic community, possibly slowing development of the sector. Given the leadership role played by organic farmers in innovating new management methods and the continued pressure to reduce chemical use on all farms, a fully integrated extension service could serve as a conduit to transfer information in the other direction, to conventional farmers and university researchers interested in ecology-based methods. To maximize effectiveness of information delivery, adoption levels can be predicted for the relevant subgroups of organic farmers and extension resources allocated accordingly. The systems level pest management approach used by organic farmers places greater demands on the information research and delivery network, but in the end will benefit all farmers.

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Table 1. Variable descriptions and summary statistics

Variable	Description	Mean	Standard Deviation	Survey Question[a]
CropAdopt	Number of adopted crop disease management strategies, sum of practices, from 0 to 7	3.01	1.62	5.4
BugAdopt	Number of adopted insect management strategies, sum of practices, from 0 to 11	3.29	2.32	5.3
WeedAdopt	Number of adopted weed control strategies, sum of practices, from 0 to 12	5.86	2.29	5.5
SoleProp	Farm is a sole proprietorship, 1 if yes	0.72	0.45	8.2
Corporat	Farm is a corporation, 1 if yes	0.06	0.24	8.2
FullTime	Operator is full time farmer, 1 if yes	0.36	0.48	8.3
YrsOrg	Years as an organic farmer, from 0 to 70 years	10.22	8.18	8.10
Educ	Education, 1 if completed college or higher	0.58	0.49	8.14
Mixed	Production system, 1 if both organic and conventional	0.24	0.42	8.1
OrgAcre	Acreage farmed organically, from 0.125 to 6,000 acres	139.65	387.09	8.6a
OrgIncm	Total gross organic farming income, integer variables for 5 categories	2.50	1.16	8.8
	Share of all farmers by income category			
	1 if less than $5,000	0.25		
	2 if $5,000 to $14,999	0.23		
	3 if $15,000 to $99,999	0.37		
	4 if $100,000 to $249,999	0.09		
	5 if at least $250,000	0.06		
PctHort	Share of total organic acreage in horticultural crops, calculated	0.51	0.46	3.1, 3.2,8.6a

InfoSrc	Number of personal information sources contacted, sum of contacts, from 0 to 12	5.4	2.9	2.2a
West	Farm is in SARE Region 1, 1 if yes	0.33	0.47	8.12
NorthCent	Farm is in SARE Region 2, 1 if yes	0.33	0.47	8.12
South	Farm is in SARE Region 3, 1 if yes	0.08	0.27	8.12
Northeast	Farm is in SARE Region 4, 1 if yes	0.26	0.25	8.12

[a] The question number in Walz corresponding to each variable.

Table 2. Multivariate count data model of the determinants of adopted management practices[a]

Coefficient	Same for All Equations	Crop Disease/Nematode Management	Insect Pest Management	Weed Management	Wald Statistic[b]
SoleProp	-0.018 (-0.776)				
Corporat	-0.097 (-2.212)				
FullTime	-0.067* (-2.932)				
YrsOrg		-0.002 (-0.701)	-0.004* (-2.027)	0.016* (10.191)	576.20
Educ	0.061* (2.956)				
Mixed		-0.114* (-2.235)	-0.120* (-3.158)	0.076* (2.134)	106.27
OrgAcre		-0.0001* (-2.121)	-0.0003* (-8.570)	0.00002 (0.627)	526.18
OrgInc	-0.0008 (-0.074)				

PctHort		-0.022 (-0.494)	0.169* (4.973)	-0.001 (-0.033)	189.64
InfoSrc		-0.0002 (-0.071)	0.003 (1.464)	0.022* (12.297)	638.13
West	-0.138* (-3.551)				
NorthCent	-0.207* (-5.158)				
Northeast	-0.082* (-2.051)				
Constant	1.356* (24.133)				
Variance parameter, σ	0.029* (3.553)				
Number of observations	1,001				

[a] Dependent variable is the count of regularly or occasionally used practices in each pest management category. Asymptotic t-values are in parentheses. A single asterisk (*) represents significance at the 0.05 level.

[b] Critical χ^2 value at the 5% significance level is 3.84.

Table 3. Predicted percentage of organic producers adopting farm management practices

Scenario	Crop Disease/Nematode Management	Insect Pest Management	Weed Management
Mixed Operation[a]			
No Adoptions	5.3%	4.1%	0.3%
1 - 4 Practices	75.3%	71.8%	29.0%
5+ Practices	19.4%	24.1%	70.7%
All Organic Operation			
No Adoptions	3.9%	2.9%	0.5%
1 - 4 Practices	70.9%	66.1%	35.4%
5+ Practices	25.2%	31.0%	64.1%
Mixed Operation with 10% Expansion in Organic Acreage			
No Adoptions	5.4%	4.2%	0.3%
1 - 4 Practices	75.3%	72.0%	29.0%
5+ Practices	19.3%	23.8%	70.7%
All Organic Operation with 10% Expansion in Organic Acreage			
No Adoptions	3.9%	4.2%	0.5%
1 - 4 Practices	71.0%	72.1%	35.4%
5+ Practices	25.1%	23.7%	64.1%

[a] Base case for all scenarios is for a farmer who is a college-educated sole proprietor engaged in farming parttime located in a Western state. Mixed operation is a farmer with both organic and conventional acreage while all organic indicates all production acreage is organic.

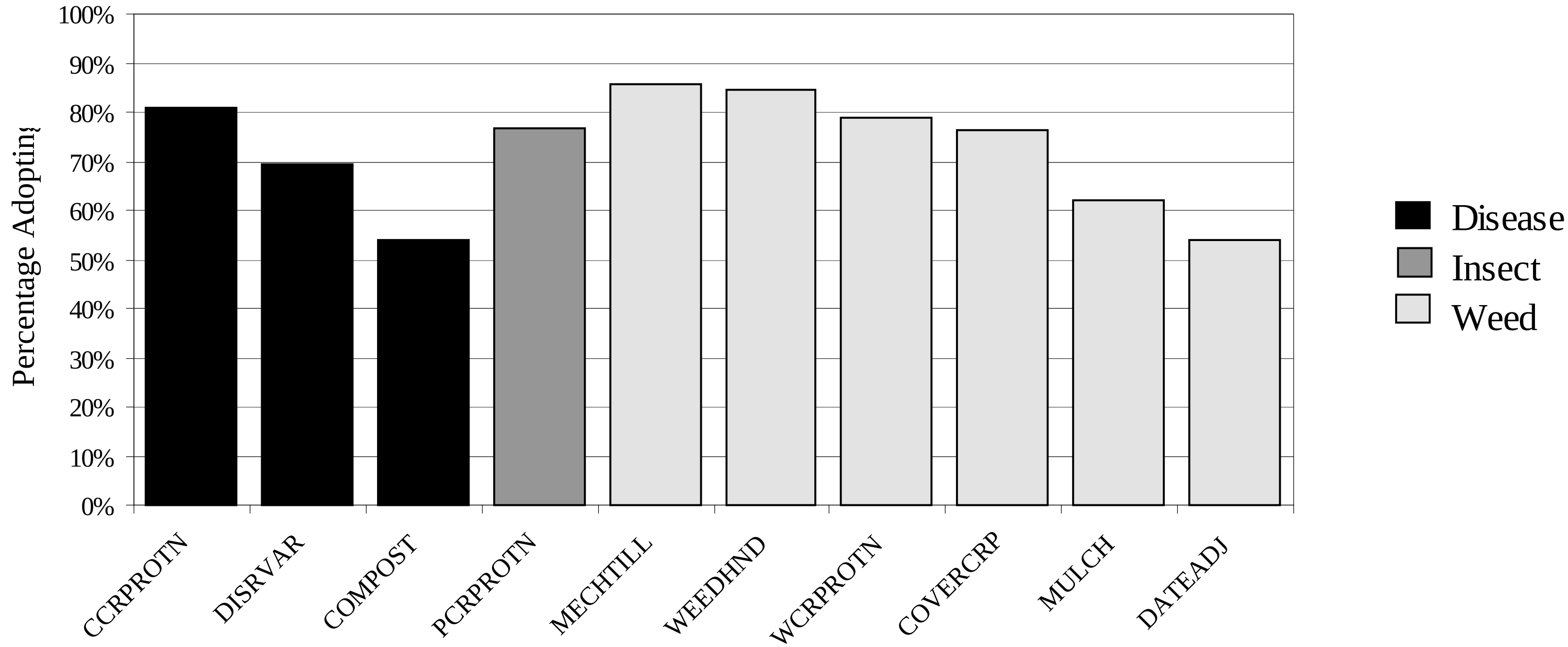

Figure 1. Practices Adopted by More than 50% of Organic Farmers, by Percentage Adopting, 1997

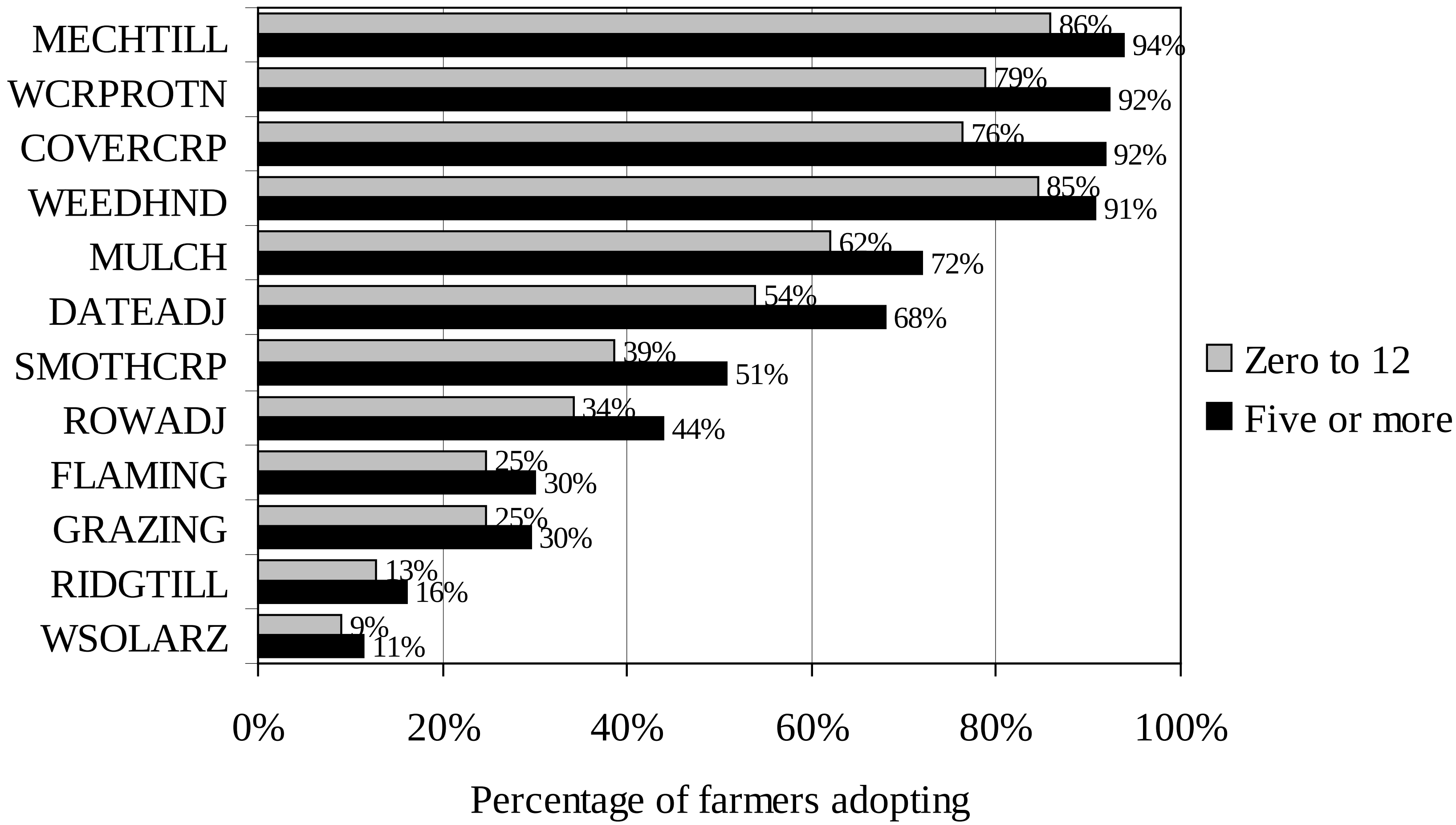

Figure 2. Percentage of Organic Farmers Adopting Weed Control Practices, 1997

Appendix A. Pest Management Strategies in the OFRF Survey

Disease and Nematode Management Strategies (Question 5.4, p. 80, Walz)

Crop rotations
Disease resistant varieties
Compost or compost tea applications
Companion planting
Sulfur or sulfur-based materials
Copper-based materials
Solarization

Insect Pest Management Strategies (Question 5.3, p. 80, Walz)

Crop rotations
Beneficial insect habitat
Beneficial vertebrate habitat
Bacillus thuringiensis (Bt)
Beneficial insect, mite or nematode releases
Dormant or summer oils
Insecticidal soaps
Botanical insecticides (e.g., pyrethrum, rotenone, ryania, sabadilla, quassia, neem...)
Trap crops
Pheromones or mating disruptors
Viral pathogens (e.g., granulosis virus)

Weed Control Methods (Question 5.5, p. 81, Walz)

Mechanical tillage
Weeding by hand or with hand implements
Crop rotations
Cover crops
Mulches
Planting date adjustment
Smother crops
Row width adjustment
Flaming or burning
Grazing
Ridge tillage
Solarization