ORGANIC PEST MANAGEMENT DECISIONS:
A SYSTEMS APPROACH

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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 the intensity of adoption across the linked pest management categories. The results
showed that weed management is of greatest concern to 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 intensity 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

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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 agroecology of insects, diseases, and weeds is highly interrelated. Altering any part of this ecology changes the environment in which the farmer operates. Whereas chemical agriculture is increasingly target pest-specific, 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.

Caswell et al. summarized findings from the USDA Area Studies Project noting that the use of new conventional technologies in the four key management categories (nutrients, pests, soil, and water) resulted in little reduction in chemical loadings, even as yields remained stable. Some recommended “sustainable” practices actually resulted in greater use of protective chemicals. The widely adopted practice of insect scouting increased chemical use in cotton and failed to reduce use in corn. Under the piecemeal approach to technology adoption used by conventional farmers, in which system effects are typically not considered, a practice may fail to perform as expected because it alters the farm environment in self-defeating ways, or because it is not complementary to the existing technology set in a way that improves outcomes.

Comer et al. (pp. 30-31) noted that “despite economic and non-economic disadvantages of conventional agriculture, farms have been slow to adopt [sustainable agricultural] practices, and adoption appears to vary widely by region and crops.” Magleby 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. It is not simply a matter of how many practices are adopted, but how well the practices are integrated into the overall farming system.

Organic farmers are more likely to look for system level solutions, rather than target a single problem with an isolated solution, and to innovate approaches based on farm agroecology (Rosmann). 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). 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.

Contrast this spirit of innovation with the cautiousness of conventional farmers. From a review of USDA input use and management surveys, Magleby concluded that techniques that rely primarily on knowledgeable producers and management expertise are less likely to be adopted than chemical methods, even if they reduce direct costs to the farmer. Caswell et al. (p. 107) echoed this point in analyzing adoption of nutrient, pest, soil, and water management practices, commenting that “information-intensive practices are less likely to be adopted by experienced farmers.” One reason suggested for this result is that the conventional farmers in the Area Studies Project felt they had enough information to farm successfully.

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 their report on the future of pesticides, the National Research
Council emphasized the need to develop a set of flexible tactics for managing crop protection and to research how farmers can diversify their pest-management “toolbox” in an era of rapid economic and ecological change. Caswell et al. commented on the need for technical support in the case of information-intensive technologies, which tend to be more complex than input-driven technologies. A holistic approach to management would improve farm efficiency and the increase the likelihood of qualifying for the highest payment level of the Conservation Security Program, the new conservation measure introduced in the 2002 Farm Bill.

We modeled the factors that influence organic farmers' adoption of management practices for three production constraints: crop diseases and nematodes, insects, and weeds. Unique to our model is the accounting of intensity of management, measured by the number, frequency, and combination of alternative practices selected. The data are from the only 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, we more closely approximated the holistic planning methods used by organic farmers. The system-level linkage was made through model structure in using a seemingly unrelated regression.

**Modeling Intensity of Adoption**

Management decision making research has virtually ignored the question of why specific combinations of practices are selected. Previous studies described the adoption decision as a dichotomous choice - either the technology or set of technologies was adopted or not. For the most part, individual management practices have been aggregated prior to analysis, so that the level of commitment to alternative practices could not be determined. Consequently, these models only explained whether a farmer adopted alternative practices, neglecting the intensity and diversity of practices employed. Ruttan challenged researchers to focus on additional dimensions
such as intensity 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. 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. 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 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', rather than farmers', assessments of management and human capital requirements. The most accurate measure of the commitment level is observation of the intensity of use of practices.

A researcher is less likely to find significant variation in factors influencing adoption if the intensity measure is ignored, particularly for organic farmers. As Magleby noted, in 1995 up to 75% of organic vegetable growers used at least one biological control practice, such as *Bacillus*
thuringiensis (Bt). A dichotomous variable describing adoption of any biological control would obscure the difference among farmers. Refining this variable to measure intensity of adoption permits the decomposition of the group of all organic farmers into sufficiently small subgroups to identify factors that explain why fewer or more practices are implemented.

After estimating separate adoption models for each of ten soil and nutrient management practices, Soule concluded that the number of adopted practices is the appropriate choice variable to assess how farmers choose a suite of complementary practices. We selected this approach as the best measure of intensity of adoption for a portfolio of management strategies. We embedded usage frequency in the intensity measure by counting only practices that were used routinely.

Economic Decision Model of Adoption

The model of management practices recognizes the discrete and integer elements of the adoption decision following Sah. The grower chooses a portfolio of M management practices where the random variable m represents the number of practices that enhance farm goals, such as profitability or soil improvement, and meet grower performance expectations, and M ≥ m ≥ 0. The probability that a practice is goal-enhancing is an independent event with probability, p, which is bounded by zero and one. The probability that m out of M chosen practices will be goal-enhancing is represented by the binomial density

\[ B(m, M, p) = \binom{M}{m} p^m (1 - p)^{M-m}. \]  

The producer’s utility from the M goal-enhancing management practices, U(m), depends on the expected performance of the practices, where the utility function is increasing and concave in m. The grower’s expected utility in choosing the M practices with a given probability that the practice will be goal-enhancing is denoted by U(M, p) or
Based on the farmer’s assessment of available practices, the largest optimal number of management techniques to implement is represented as \( m(p) \) and the producer’s indirect utility for this decision is \( V(p) \) so that

\[
V(p) \equiv \max_m U[m, p] \equiv U[m(p), p].
\]  

The producer’s assessment of the probability that a management practice will improve the farm situation derives from information available to the farmer from external sources or through experience. For the conventional farmer, natural resource technology adoption is considered separately from production input adoption (Caswell et al.). Under the system-level perspective of organic farmers, a new practice may be considered utility-improving even if it performs a preventive role, such as soil organic matter improvement, or enables the farmer to more easily comply with federal organic regulations. Profitability for the organic farmer is intimately related to natural resource management.

The new practice must be goal-enhancing, in the judgement of the farmer. Forming the discrete equivalent of the first-derivative of equation 2, adoption of a technique occurs if the producer’s expected marginal utility \( U_M(M, p) \) from the \( t^{th} \) technique is positive, or

\[
U_M(M, p) \equiv U(M + 1, p) - U(M, p) > 0.
\]

The optimality condition in equation 4 can be solved to explain the producer’s decision to adopt the \( t^{th} \) management technique, \( M_t(p, Y) \). The set of adopted management practices given the producer’s expectations is defined as

\[
NumAdopt = \left\{ t \mid M_t(p, Y) > 0 \right\}
\]
where NumAdopt is the number of adopted management practices used regularly by the organic producer. Survey responses from producers provided the number of adopted management practices and a count data model may be specified for these practices. Both farm level factors and regional growing conditions affect a grower's perception of the suitability of a new practice.

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

$$\ln(\text{NumAdopt}_{ij}) = \alpha_j + \sum_{j=1}^{J} \beta_j F_{ij} + \sum_{j=1}^{J} \gamma_j R_j$$ (6)

where NumAdopt$_{ij}$ measures the number of regularly used techniques by farmer $i$ in management category $j$. $\alpha_j$ is the intercept associated with management category $j$, and $\beta_j$ and $\gamma_j$ 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.

The adoption decision in equation 6 was structured as a seemingly unrelated negative binomial model following Winkelmann. Let $z_i = (z_{i1}, \ldots, z_{iJ})$ be the vector of $J$ counts where $z_{ij}$ | $v_{ij}$ follows a Poisson distribution with parameter $\lambda_{ij} v_{ij}$ and $\lambda_{ij} = \exp(x_{ij}\theta)$. The $x_{ij}$ encompass the farm level and regional variables while the $\theta_j$ represent the parameters ($\beta, \gamma$) 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 $Var(z_{ij}) = \lambda_{ij} + \alpha^{-1} \lambda_{ij}^2$ 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 presents the log-likelihood function for the model along
with the variance-covariance matrix and establishes that the resulting estimates are asymptotically normal. The model in equation 6 was estimated using SUR negative binomial regression 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, to mimic the holistic approach used in organic producer decision making.

**Data and Variable Description**

*Data*

Analysis on a scale broad enough to be generalizable must draw from a national survey that is representative of all organic farmers. 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, 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 (Walz). 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 (Greene; Walz). 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.

Applicability to conventional farms is more difficult to document, but a comparison of our data with all U.S. farms revealed that the organic sample has income and management structure distributions remarkably similar to all U.S. farms. To the extent that these variables affect adoption decisions, the system-level adoption model can be generalized to all farms.

**Dependent Variable**

In constructing the dependent variable, the number of practices regularly used, we relied on responses to three separate questions related to crop disease and nematode management, insect pest controls, and weed controls. The OFRF survey tabulated the frequency of use for provided lists of disease and nematode strategies, insect pest techniques, and weed control methods. This lists are given in Appendix A. Frequency of use could be checked as “never” use, use “rarely or as a last resort,” use “on occasion” or “frequently or regularly” use. 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.” Thus, the intensity of use was embedded in the number count of strategies used in each management category.

Table 1 shows the variable descriptions and summary statistics for the dependent and independent variables estimated for equation 6, as well as the question number from the OFRF survey results (Walz) that corresponds to each variable. To quantify the intensity of adoption, we recorded the number of management strategies adopted by each organic farmer. 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.

Figure 1 shows the practices that were adopted by more than 50% of farmers. Weed control had 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 actual percentages of farmers by number of techniques adopted across the three management categories echoes the emphasis on weed research needs stressed by organic farmers in the OFRF survey (Rosmann). 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.
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.). 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 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. 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 part time basis (PartTime), compared with 61% of all U.S. farmers (Hoppe et al.). 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 (Hoppe et al.).

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.). 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.).

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 (see Question 8.8, Walz) were combined into the five classes shown on Table 1 for more meaningful comparison with USDA definitions of farm structure (Hoppe et al.) and national certification requirements.
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 depend on the crops grown. With the exception of crop rotation, alternative practices are used more extensively in conventional agriculture by horticultural producers than by field crop producers (Anderson et al.). 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 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 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 may be classified along two dimensions: personnel or organizations and media sources or outlets. From a list of 12 personal information sources and 9 information outlets listed in the OFRF survey, respondents indicated the usefulness of each and the frequency of use (see Question 2.2, Walz, p. 38). To evaluate the effort required to obtain information, we constructed variables that counted the number of personal sources contacted (NumWho) and the number of information outlets used (NumWhat). The average number of personal contacts in our sample (NumWho) was 5.4, with a low of 0 and a high of 12. The mean number of outlets used (NumWhat) was 3.5, with a low of 0 and a high of 9.

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, but the least likely source for conventional farmers (Walz; Anderson et al.). Instead, conventional growers look to farm supply and chemical dealers as their primary personal contact for pest management strategies. Organic farmers rated the extension service 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.
Organic farmers rely on a range of print and electronic media and interactive activities for technical information, of which books and conferences are most intensively used (Walz). Conventional growers use print and electronic media very little for pest management information (Anderson et al.). Organic growers used media outlets nearly twice as frequently as personal contacts, and found outlets about equally useful as contacts. Caswell et al. showed that conventional farmers' pest management choices were significantly influenced by their use of farm advisement services.

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. The significant variance parameter, $\alpha$, is included on Table 2 to confirm the appropriateness of the negative binomial specification of the estimated models.

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 seemingly unrelated count data model was specified to test whether the coefficients differ across the three categories for six variables (YrsOrg, Mixed, OrgAcre, PctHort, NumWho, NumWhat) 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 $\chi^2_2$ 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 and NumWhat 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 both information variables (NumWho and NumWhat) 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). 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.

Neither of the business structure variables (SoleProp, Corporat) significantly affected the choice of how many practices to adopt for the pest management system. This suggests that
farmers choose the practices without undue outside influence from corporate partners. Part time organic farmers tend to adopt fewer practices, according to the significant negative coefficient for PartTime. These findings align with the hypothesis by Caswell et al. 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. 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) were significant factors in adoption. College education had a greater influence by an order of magnitude on the number of strategies adopted than did organic farming experience. Usually, greater human capital is associated with greater 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 both more highly educated and more likely to experiment with new methods than their conventional counterparts, so the finding that college education (Educ) had a positive effect on number of practices is not surprising. Experience (YrsOrg) was 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.
Intensity of organic commitment significantly affects number of practices adopted across all management categories. Farmers with some organic and some conventional acreage (Mixed) adopted fewer crop disease/nematode and insect pest control strategies but had 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). 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; Caswell et al.).

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 (Soule) and for genetically engineered crops and precision agriculture (Fernandez-Cornejo et al.). 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 variables (NumWho and NumWhat) were both significant and positive for the weed management category, but only NumWhat was significant for the disease/nematode and insect pest management categories. 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 two (West and NorthCent) of the three SARE region dummy variables included in the estimation. This indicates that farmers in the West and North Central regions choose significantly fewer practices than farmers in the South, the
region excluded from the regression. Caswell et al. 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. If the intensity of demand for pest management information could be predicted, 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 6 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 is 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 intensity 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 intensity of adoption 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.

**Implications of the Results**

The National Research Council 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 pest management intensity reflects the integrated decision framework used by organic farmers in choosing complementary techniques that benefit the whole farm's agroecology. System-level pest management is significantly different from the piecemeal technology adoption of conventional farmers. Efficiency gains could be realized by all
farmers switching to a holistic approach. As the method gains ground, information providers can expect to be confronting with demands for increasingly diverse strategies from which to choose.

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 is more likely to yield beneficial insights to research on conventional IPM than vice versa because the emphasis is on cultural practices that attack weeds as a generic problem. Conventional weed control research has taken a targeted approach, testing chemicals or chemical-biotechnology packages specific to individual weed species. The ecology of weed seed banks and the air-borne and land-borne mobility of weed seeds, not to mention herbicide resistance, makes this a difficult strategy to pursue successfully in the long term.

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 cost-effectiveness of information delivery, adoption intensity can be predicted for the relevant subgroups of organic farmers and effort level planned 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.
References


<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Survey Questiona</th>
</tr>
</thead>
<tbody>
<tr>
<td>CropAdopt</td>
<td>Number of adopted crop disease management strategies, sum of practices, from 0 to 7</td>
<td>3.01</td>
<td>1.62</td>
<td>5.4</td>
</tr>
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<td>BugAdopt</td>
<td>Number of adopted insect management strategies, sum of practices, from 0 to 11</td>
<td>3.29</td>
<td>2.32</td>
<td>5.3</td>
</tr>
<tr>
<td>WeedAdopt</td>
<td>Number of adopted weed control strategies, sum of practices, from 0 to 12</td>
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<td>2.29</td>
<td>5.5</td>
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<td>0.72</td>
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<td>Corporat</td>
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<td>0.24</td>
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<td>PartTime</td>
<td>Operator is part time farmer, 1 if yes</td>
<td>0.36</td>
<td>0.48</td>
<td>8.3</td>
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<tr>
<td>YrsOrg</td>
<td>Years as an organic farmer, from 0 to 70 years</td>
<td>10.22</td>
<td>8.18</td>
<td>8.10</td>
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<tr>
<td>Educ</td>
<td>Education, 1 if completed college or higher</td>
<td>0.58</td>
<td>0.49</td>
<td>8.14</td>
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<tr>
<td>Mixed</td>
<td>Production system, 1 if both organic and conventional</td>
<td>0.24</td>
<td>0.42</td>
<td>8.1</td>
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<tr>
<td>OrgAcre</td>
<td>Acreage farmed organically, from 0.125 to 6,000 acres</td>
<td>139.65</td>
<td>387.09</td>
<td>8.6a</td>
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<tr>
<td>OrgIncm</td>
<td>Total gross organic farming income, integer variables for 5 categories</td>
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<td>1.16</td>
<td>8.8</td>
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<td></td>
<td>Share of all farmers by income category</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 if less than $5,000</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 if $5,000 to $14,999</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>3 if $15,000 to $99,999</td>
<td>0.37</td>
<td></td>
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<td></td>
<td>4 if $100,000 to $249,999</td>
<td>0.09</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>5 if at least $250,000</td>
<td>0.06</td>
<td></td>
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</tr>
<tr>
<td>PctHort</td>
<td>Share of total organic acreage in horticultural crops, calculated</td>
<td>0.51</td>
<td>0.46</td>
<td>3.1, 3.2, 8.6a</td>
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<tr>
<td>Variable</td>
<td>Description</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
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<td>------------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
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<td>NumWho</td>
<td>Number of personal information sources contacted, sum of contacts, from 0 to 12</td>
<td>5.4</td>
<td>2.9</td>
<td>2.2a</td>
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<td>NumWhat</td>
<td>Number of media information outlets used, sum of outlets, from 0 to 9</td>
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<td>2.2</td>
<td>2.2b</td>
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<td>West</td>
<td>Farm is in SARE Region 1, 1 if yes</td>
<td>0.33</td>
<td>0.47</td>
<td>8.12</td>
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<td>NorthCent</td>
<td>Farm is in SARE Region 2, 1 if yes</td>
<td>0.33</td>
<td>0.47</td>
<td>8.12</td>
</tr>
<tr>
<td>South</td>
<td>Farm is in SARE Region 3, 1 if yes</td>
<td>0.08</td>
<td>0.27</td>
<td>8.12</td>
</tr>
<tr>
<td>Northeast</td>
<td>Farm is in SARE Region 4, 1 if yes</td>
<td>0.26</td>
<td>0.25</td>
<td>8.12</td>
</tr>
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</table>

* The question number in Walz corresponding to each variable.
Table 2. Multivariate count data model of the determinants of adopted management practices\(^a\)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Same for All Equations</th>
<th>Crop Disease/Nematode Management</th>
<th>Insect Pest Management</th>
<th>Weed Management</th>
<th>Wald Statistic(^b)</th>
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</thead>
<tbody>
<tr>
<td>SoleProp</td>
<td>-0.012</td>
<td></td>
<td></td>
<td></td>
<td>576.20</td>
</tr>
<tr>
<td>Corporat</td>
<td>-0.084</td>
<td></td>
<td></td>
<td></td>
<td>(-1.911)</td>
</tr>
<tr>
<td>PartTime</td>
<td>-0.060*</td>
<td></td>
<td></td>
<td></td>
<td>(-2.621)</td>
</tr>
<tr>
<td>YrsOrg</td>
<td>-0.001</td>
<td>-0.004*</td>
<td>0.015*</td>
<td></td>
<td>576.20</td>
</tr>
<tr>
<td>Educ</td>
<td>0.053*</td>
<td></td>
<td></td>
<td></td>
<td>(2.610)</td>
</tr>
<tr>
<td>Mixed</td>
<td>-0.104*</td>
<td>-0.109*</td>
<td>0.083*</td>
<td></td>
<td>106.27</td>
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<tr>
<td>OrgAcre</td>
<td>-0.0001*</td>
<td>-0.0003*</td>
<td>0.00005</td>
<td></td>
<td>526.18</td>
</tr>
<tr>
<td>OrgInc</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
<td>(0.288)</td>
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<tr>
<td>PctHort</td>
<td>-0.018</td>
<td>0.170*</td>
<td>-0.014</td>
<td></td>
<td>189.64</td>
</tr>
</tbody>
</table>
(-0.417)  (5.053)  (0.413)

NumWho  
-0.013  -0.008  0.028*  638.13  
(-1.607)  (-1.242)  (4.446)

NumWhat  
0.031*  0.034*  0.060*  591.54  
(2.613)  (3.953)  (7.031)

West  
-0.118*  (-3.063)

NorthCent  
-0.199*  (-5.009)

Northeast  
-0.070  (-1.772)

Constant  
1.282*  (23.052)

Variance parameter, $\alpha$  
0.021*  (2.788)

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 $\chi^2$ value at the 5% significance level is 3.84.
Table 3. Predicted demand for pest management practices, by percentage of farmers adopting

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crop Disease/Nematode Management</th>
<th>Insect Pest Management</th>
<th>Weed Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case - Mixed Organic-Conventional a</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>No Adoptions</td>
<td>5.3%</td>
<td>4.1%</td>
<td>0.3%</td>
</tr>
<tr>
<td>1 - 4 Practices</td>
<td>75.3%</td>
<td>71.8%</td>
<td>29.0%</td>
</tr>
<tr>
<td>5+ Practices</td>
<td>19.4%</td>
<td>24.1%</td>
<td>70.7%</td>
</tr>
<tr>
<td>Scenario 1 - All Organic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Adoptions</td>
<td>3.9%</td>
<td>2.9%</td>
<td>0.5%</td>
</tr>
<tr>
<td>1 - 4 Practices</td>
<td>70.9%</td>
<td>66.1%</td>
<td>35.4%</td>
</tr>
<tr>
<td>5+ Practices</td>
<td>25.2%</td>
<td>31.0%</td>
<td>64.1%</td>
</tr>
<tr>
<td>Scenario 2 - All Organic with 10% Expansion in Organic Acreage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Adoptions</td>
<td>3.9%</td>
<td>4.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>1 - 4 Practices</td>
<td>71.0%</td>
<td>72.1%</td>
<td>35.4%</td>
</tr>
<tr>
<td>5+ Practices</td>
<td>25.1%</td>
<td>23.7%</td>
<td>64.1%</td>
</tr>
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</table>

a See text for description of base case.
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