Factors Influencing Adoption of Integrated Pest Management in Northeast Greenhouse and Nursery Production

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We collected surveys from 94 greenhouse and nursery growers in three northeastern states to examine factors influencing integrated pest management (IPM) adoption. We constructed three alternative dependent variables describing the extent of IPM adoption and employed discrete choice models to identify factors that affect adoption. We find that operations with more full-time workers are more likely to adopt IPM. Additionally, greenhouse/nursery growers that rank pests as a serious problem are likely to use a wider array of IPM practices. The reliability of IPM practices is critical for adoption. Our analysis highlights differences between self-reported and objective IPM adoption measures.

Key Words: greenhouse and nursery production, integrated pest management, northeast United States, technology adoption

The income-generating potential of greenhouse and nursery products far exceeds that of most traditional crops in New England on a per-acre basis. The 2009 Census of Horticulture Specialties (Agricultural Research Service (ARS) 2009) counted 1,472 greenhouse and nursery operations in New England, a decrease of 218 operations since 1998, while the total retail value of horticultural crops in New England exceeded $431 million in 2009, an increase of 53.1 percent over the period (ARS 1998, 2009). Greenhouse horticultural production covered 55.9 million square feet. The largest 20 percent of operations in the region produced almost 50 percent of total revenue with the majority of producers managing comparatively small operations, which are endemic in the New England agricultural economy. The industry is thus critical to the health, expansion, and sustainability of the region's rural economy.

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Ornamentals are grown for their aesthetic value to consumers who have a minimal tolerance for pest and disease damage. Consequently, some growers use chemical pesticides repeatedly to control a number of persistent pests and diseases. However, greenhouse and nursery growers' heavy reliance on chemical pesticides may not be sustainable. A recent study (Sanderson 2006) reported that insecticide resistance among most of the important greenhouse insect and mite pests is a major concern. The Environmental Protection Agency (EPA) has pointed out that integrated pest management (IPM) is an effective and environmentally sensitive approach to pest control that can reduce growers' reliance on chemical insecticides (EPA 2011). IPM practices include setting action thresholds (a point at which pest populations or environmental conditions indicate that pest control action must be taken), monitoring and identifying pests, and using biological controls, bio-rational pesticides, and chemical pesticides judiciously.

Although greenhouse and nursery growers in New England have expressed interest in IPM, little is known about the extent of its adoption in the region or factors that facilitate or limit adoption. Recent studies have demonstrated that IPM can contribute to improved health for workers and consumers (Alston 2011) and reduced environmental risks and improved production efficiency through rational use of inputs (Fernandez-Cornejo 1996, Dasgupta, Meisner, and Wheeler 2007). Thus, a systematic analysis of the factors that affect IPM implementation by growers of greenhouse and nursery crops in New England is important to private and public decision-makers who are interested in expanding IPM adoption.

This study focuses on adoption of IPM by greenhouse and nursery growers in Maine, New Hampshire, and Vermont. We hypothesize that a variety of factors (e.g., size of the greenhouse/nursery operation, knowledge about and confidence in IPM, and types of crop production problems faced) influence decisions to adopt new practices. We test this hypothesis with survey data from 94 greenhouse/nursery growers and employ discrete-choice econometric models to assess factors that influence whether such growers adopt IPM.

Our results suggest that nursery and greenhouse growers are most likely to employ IPM practices to control arthropod pests. They are less likely to use IPM if they rank disease and production as more serious problems than pests. Our results also indicate that improving the reliability of IPM methods is critical to increased IPM adoption. In addition, large operations are more likely to adopt IPM than smaller ones and adoption is more frequent when the survey respondent is responsible for making pest management decisions.

Literature Review

IPM has received considerable attention in the literature on agricultural economics. The impacts studied are diverse and have included IPM's positive effect on the environment (Dasgupta, Meisner, and Wheeler 2007, Fernandez-Cornejo 1996, Williams et al. 2005, Mullen, Reaves, and Norton 1997, Trumble, Kund, and Carson 1997, Burkness and Hutchison 2008, Bentley 2009) and on business profitability (Trumble, Kund, and Carson 1997, Burkness and Hutchison 2008, Fernandez-Cornejo 1996, Dasgupta, Meisner, and Wheeler 2007). Earlier studies also found positive consumer attitudes toward products grown using IPM (Govindasamy and Italia 1998, Florax, Travisi, and Nijkamp 2005), increased government support and investment in IPM programs

(Templeton and Jamora 2010, Castle and Naranjo 2009), and efforts of Cooperative Extension systems to promote IPM adoption (White and Wetzstein 1995, Castle and Naranjo 2009, Mauceri et al. 2007, Ricker-Gilbert et al. 2008). Not surprisingly, previous work has centered mostly on food crops. We extend the literature by focusing on determinants of IPM adoption in a nonfood sector.

A few studies have examined how grower characteristics influence the decision to adopt IPM. Fernandez-Cornejo, Beach, and Huang (1994) pointed out that IPM adopters usually operated large, well-irrigated farms, used more family labor, were less risk-averse, and tended to spend more time on the operation's managerial activities. Similarly, Alston and Reding (1998) demonstrated that full-time growers who had large farms and who received most of their incomes from their farms were more likely to adopt IPM. Mahmoud and Shively (2004) argued that both access to IPM technology (IPM practices versus prevailing farm practices) and IPM availability (adequate access to labor and capital) increased the likelihood of adoption.

Measuring IPM adoption is not simple, and agricultural economists have employed several approaches. Some earlier studies employed self-reported measures of IPM adoption and used binary variables to distinguish between conventional and IPM growers. For example, Fernandez-Cornejo, Beach, and Huang (1994) defined IPM growers as ones who used one or more IPM techniques. Dasgupta, Meisner, and Wheeler (2007) characterized IPM growers as those who practiced at least one of a suite of methods: biological control, light traps, organic production, crop rotation, manual clearing, and natural parasites. Other studies employed more elaborate measures of adoption in which growers were assigned to categories based on their use of IPM tactics. Ricker-Gilbert et al. (2008), for instance, identified several levels of IPM adoption for rice growers in Bangladesh and defined IPM growers as (i) simple (e.g., using disease-resistant varieties), (ii) intermediate (e.g., using trap systems), or (iii) complex (e.g., using beneficial insects).

The U.S. Department of Agriculture's (USDA's) Economic Research Service (ERS) released a set of guidelines in the mid-1990s to establish a baseline estimate of IPM adoption to monitor expansion of sustainable production practices (Vandeman, Fernandez-Cornejo, and Lin 1994). The guidelines recognized that there was no universal definition of IPM. The report explained that IPM systems vary widely according to the crop produced. Practices ranged from chemical-based to biological-based along a continuum. The USDA approach divided growers into four categories: No IPM and three levels of adoption—low, medium, and high—according to how many practices identified by USDA as IPM methods were adopted by a grower.

In summary, the literature suggests that IPM can increase profitability for some growers and reduce dependence on agrichemicals. IPM requires important public investments in Cooperative Extension support and grower education but, in return, is valued by consumers and yields definable environmental benefits. In spite of strong public support to increase IPM adoption by ornamental producers in New England and growers' interest in use of IPM, little is known about the current extent of IPM adoption in the region or factors that facilitate or limit adoption. To begin to fill this gap, we develop an empirical model and a set of hypotheses by which to study the factors that influence IPM adoption by this group of growers in three northeast states. We extend earlier modeling work by employing a self-report measure and a set of alternative measures of IPM adoption.

The Survey Instrument

We developed a survey questionnaire to collect pertinent information regarding factors that facilitate (or hinder) adoption of IPM among greenhouse and nursery growers in Vermont, New Hampshire, and Maine. We requested that the survey instrument be completed by the person within the operation who was responsible for making pest management decisions. Respondents were asked to describe their greenhouse/nursery operations; rate the importance of various pest, disease, and production problems in their operations; identify management practices used; select the type of production system that best described their operations (conventional versus IPM); assess the performance of IPM methods used relative to conventional practices; and list challenges that have prohibited greater IPM adoption.

We used a single standard written survey that we mailed to all greenhouse/nursery growers (approximately 900) listed on the Tri-state Greenhouse and Nursery IPM mailing list maintained by the University of Vermont's Entomology Research Laboratory. That list includes most nursery/greenhouse operations in Maine, Vermont, and New Hampshire. We also handed out the survey to growers who attended IPM workshops held in the three target states in January 2009 (about 40 growers per state) and asked them to complete it only if they had not completed and sent it already. To boost the response rate, we provided growers with incentives for attending the workshop and completing the survey—a complimentary copy of the *Greenhouse/Nursery Managers' Guide to IPM in Northern New England* (Parker et al. 2008), credits toward pesticide applicator licenses, and a chance to win one of several door prizes donated by corporate sponsors.

Empirical Model

We employed three strategies to measure IPM adoption, one subjective measure (grower self-reporting) and two objective measures (binary and three-tiered analyses). Using these measures, we identified factors that influence adoption, including the importance of various pest, disease, and production problems rated by growers, growers' confidence in the reliability of IPM to control pests and diseases, their knowledge of IPM, the availability of commercial IPM supplies and biological control agents, the diversity of crops produced and the size of the operations, and respondents' positions in the greenhouse operation. In general form, the empirical model can be expressed as

(1) IPM ADOPTION = F [Pest Problems, Disease Problems, Production Problems, Grower Confidence, Grower Knowledge, Availability of IPM Supplies, Revenue Source, Size of Operation, Position of Respondent].

Dependent Variables: Measures of IPM Adoption

Based on information collected in the survey, we constructed three dependent variables to measure IPM adoption. The first was a self-reported indicator (subjective measure). In the survey, we asked respondents whether IPM or "conventional control" best described their strategies for controlling pests and diseases in their operations. We denoted *Y_selfreport* as the subjective

Practices for scouting (monitoring and pest identification)	Practices for pesticide application methods associated with IPM	Practices indicative of an IPM approach in greenhouse/nursery operations
Use sticky cards	Rotate pesticide classes	Sanitize soil and pots or use new soil or pots
Use indicator plants	Use pesticides less toxic-to-beneficial	Biocontrol method: release predators/parasites or use fungi/bacteria
Conduct regular scouting	Use pesticides with short residual activity	Cover floor with weed cloth or remove weeds
Hire commercial scout	Make spot pesticide treatments	Test water or soil
Use degree days to track pests		Rotate crops or fix space
Foliar testing		Inspect new plant shipments
Identify pests/diseases yourself		Disinfect growing areas
Seek professional insect/disease identification		Use pest resistant varieties
Use disease test kits		Use drip irrigation
Send plants out for disease testing		

Figure 1. Practices Used to Measure IPM Adoption in Greenhouses and Nurseries

dependent variable, which was equal to 1 if the respondent stated that he/she was an IPM grower and 0 for those who described themselves as users of conventional control.

We developed objective measures of IPM adoption following USDA's guidelines for vegetables (Vandeman et al. 1994).[1] According to that classification, growers are placed into one of four broad categories—No IPM, Low IPM, Medium IPM, and High IPM. Low IPM growers use only scouting (a method to monitor pest populations and crop development) and applications of pesticides according to the threshold for the pest. A Medium IPM grower conducts the same core activities as a Low IPM grower plus one or two of nine additional IPM activities identified by USDA. A High IPM grower conducts the same activities as a Low IPM grower plus three or more of the nine additional practices that are indicative of an IPM approach.

Figure 1 shows the IPM practices listed in our survey and used to construct objective measures of IPM adoption. Ten practices are classified as scouting, four as pesticide application methods associated with IPM, and nine as indicative of an IPM approach in operations growing greenhouse ornamentals.

We classified the greenhouse and nursery operations in our sample as No IPM, Low IPM, and High IPM (no operation in our sample fit the criteria for Medium IPM). We defined the categories as follows.

- No IPM growers do not use scouting, which includes monitoring and identifying pests, and do not use pesticide application methods associated with IPM.

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[1] USDA has not established specific guidelines for greenhouses and nurseries. We employ the production practices for vegetables because they are comparable to the ones employed in greenhouses and nurseries.

- Low IPM growers implement practices from the scouting list and use the pesticide application methods associated with IPM. To be classified as an IPM grower, a respondent had to report using at least one practice from the scouting list and one pesticide application method associated with IPM.
- High IPM growers conduct the same activities as Low IPM growers plus three or more of the nine additional practices listed as indicative of an IPM approach in ornamental greenhouse/nursery operations. The High IPM class also includes growers who use no pesticides and rely on scouting practices and biocontrol methods.

The first objectively measured dependent variable, denoted as *Y_binary*, is a dichotomous variable that equals 1 for Low IPM and High IPM growers and 0 for No IPM. The second objective measure of IPM adoption, *Y_IPMlevel*, classifies respondents into three levels of IPM adoption: 0 for No IPM, 1 for Low IPM, and 2 for High IPM.

Explanatory Variables

The survey included questions related to factors that influence IPM adoption as well as a number of relevant controls. We constructed three categories of explanatory variables that accounted for crop production problems, limitations or challenges associated with IPM adoption, and characteristics of the greenhouse/nursery operation.

Respondents were asked to rate the relevance of each problem on a scale of 0 to 3: 0 (not important), 1 (low importance), 2 (moderate importance), and 3 (high importance). Based on the responses, we created three variables to represent the relative importance of diseases, pests, and production problems. *DiseaseAvg* is the average rating on the 19 questions that related to disease (e.g., anthracnoses, botrytis blight, and crown gall). *PestAvg* equals the average rating on the 19 questions that related to insects and mites (e.g., aphids, black vine weevils, mealy bugs, and fungus gnats), and *ProdAvg* equals the average rating on the 11 questions that related to production (e.g., environment control, fertility, and irrigation problems). Since EPA indicated that IPM generally is used to manage pest damage (EPA 2011), we hypothesized that greenhouse and nursery operations that ranked pest problems as a serious concern would be more likely to adopt a wide array of IPM practices than operations in which pests were not the primary problem.

We constructed three variables to capture important constraints on IPM adoption based on survey responses to a discrete list of possible limitations/challenges. Respondents were asked to answer yes or no to each limitation in the list. The three variables are as follows.

- *Reliability* equals 1 if IPM methods were thought to be reliable and 0 otherwise. We assigned *Reliability* as 1 when respondents disagreed with any of the following statements: "biocontrols are unreliable," "hard to control disease and weeds with IPM," and "it is hard to control insects/mites with IPM."
- *Availability* equals 1 if IPM supplies are readily available and 0 otherwise. We assigned *Availability* as 1 if respondents disagreed with either of the following statements: "general IPM supplies are not available (e.g., sticky cards, indicator plants)" and "biocontrol agents are not readily available."

- *Knowledge* equals 1 if respondents believe they have sufficient knowledge about IPM and 0 otherwise. We assigned *Knowledge* as 1 if respondents disagreed with any of the following statements: "do not know how to reduce chemical pesticide use," "lack of knowledge about alternatives," and "lack of workers skilled in IPM."

We also control for a number of greenhouse/nursery characteristics that may influence IPM adoption. We control for the size of the operations with a variable for the number of full-time workers (*Fullworker*).[2] Area under cultivation is not a good measure of size because greenhouse/nursery operations often include growing areas that are under plastic or glass and areas in the open, which have very different cultivation densities. We control for the production crop mix within the operation using a variable that reflects the share of total operation revenue represented by vegetable crops (*PercentVeg*). Finally, we construct a dichotomous variable, *Responsible*, that equals 1 if the survey respondent was in charge of pest management decisions and 0 otherwise.

Data

We received 94 surveys and 72 were useable. To examine the representativeness of our sample, we compared the characteristics of our sample of growers with data about the operations covered by the 2009 Census of Horticultural Specialties (ARS 2009). In particular, we compared operation size and number of full-time workers. The average size of greenhouse operations in our sample was 22,500 square feet.[3] The 2009 census reported that the average greenhouse size in the three states (Maine, Vermont, and New Hampshire) was about 25,000 square feet. The average number of hired full-time workers in our sample was 3.7 (no family laborers), which is slightly less than the average of 4.9 workers (including family members) from the 2009 census. This comparison shows that our sample of growers is reasonably representative of greenhouse and nursery operations in the tri-state region.

Descriptive statistics for the three dependent variables and nine explanatory variables are presented in Table 1. The variable *Y_selfreport* has a mean of 0.63 as 41 of the 72 respondents classified themselves as IPM growers. The variable *Y_binary* has a mean of 0.78, which is slightly larger than the mean of *Y_selfreport*. According to the objective measure, 56 of the 72 respondents could be classified as IPM growers (includes both Low-IPM and High-IPM growers). Among those 56 growers, 57 percent were considered IPM growers based on both the self-reported measure and the objective measures. The variable for the second objective measure, *Y_IPMlevel*, had three categories and the highest level was assigned a value of 2. Under this measure, 22 percent of respondents were classified as No IPM and 61 percent were considered to be High IPM (Table 1).

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[2] A variable representing the number of continuous full-time workers was constructed using mid-point values for the corresponding categories included in the survey: less than one full-time worker, one or two full-time workers, three or four full-time workers, five or six full-time workers, and more than six full-time workers. The extreme values were assumed to be zero and seven.

[3] The survey included six levels related to the size of the operations: 1–10,000, 10,001–25,000, 25,001–50,000, 50,001–75,000, 75,001–100,000, and greater than 100,000 square feet. We used the mid-point value to calculate average greenhouse operation size. The extreme values were assumed to be 1 and 125,000 square feet.

We provide definitions of the explanatory variables and their descriptive statistics in Table 1. Pest, disease, and production problems are likely to influence adoption of IPM. Average scores were 0.82 for pests, 0.72 for diseases, and 0.53 for production-related problems. This suggests that growers rank pest-related problems as the most serious of the three issues in greenhouse/

Table 1. Descriptive Statistics

Variable	Description	Mean	Standard Deviation	Minimum	Maximum
Dependent Variables					
Y_selfreport	Self-reported as IPM grower (yes = 1, no = 0)	0.57	0.499	0	1
Y_binary	Objective measure of IPM grower (yes = 1, no = 0)	0.778	0.419	0	1
Y_IPMlevel	No IPM = 0; Low IPM = 1; High IPM = 2	1.389	0.832	0	2
Independent Variables					
PestAvg	Seriousness of pest problems in greenhouse crops	0.822	0.53	0.05	2.3
DiseaseAvg	Seriousness of disease problems in greenhouse crops	0.72	0.561	0	1.9
ProdAvg	Seriousness of crop production problems in greenhouse crops	0.534	0.372	0	1.5
Availability	Equals 1 if IPM supplies and biocontrol agents are readily available to growers, 0 if not available	0.819	0.387	0	1
Reliability	Equals 1 if IPM practices are deemed reliable, 0 if not reliable	0.792	0.409	0	1
Knowledge	Equals 1 if grower has knowledge to implement IPM practices, 0 otherwise	0.653	0.48	0	1
Responsible	Equals 1 if respondent in charge of pest management decisions, 0 otherwise	0.361	0.484	0	1
PercentVeg	Percentage of total revenue from growing vegetables	15.778	24.5	0	100
Fullworker	Number of employed full-time workers	3.7	2.143	0	7

nursery operations. The minimum score for pests is 0.05, showing that pest-related problems are important to greenhouse/nursery production to some degree. The sample means of *Availability*, *Reliability*, and *Knowledge* were 0.82, 0.80, and 0.65, respectively. These values are close to 1, suggesting that most greenhouse/nursery operations have access to IPM supplies and biocontrol agents, that IPM methods are generally considered reliable, and that growers believe that they are somewhat knowledgeable about implementing IPM practices. The greenhouse and nursery operators in our sample derived, on average, 15.7 percent of their income from vegetable crops and employed 3.7 workers on average. Just over a third of the respondents were in charge of decisions about IPM.

Results

In Tables 2 and 3, we present regression results for the models with *Y_binary, Y_selfreport*, and *Y_IPMlevel* as dependent variables and include the estimated coefficients and their marginal effects. We next discuss the parameter estimates of each model.

Regression 1: IPM Binary Measure—Logistic Model

Columns 1 and 2 in Table 2 present estimated coefficients and marginal effects of the explanatory variables for the model with *Y_binary* as the dependent variable. The Wald test indicates that the model is significant overall and the pseudo R-square suggests that the model has explanatory power. Regarding greenhouse/nursery problems, the coefficient of *PestAvg* is positive and significant, suggesting that greenhouses and nurseries that rank pests as a more serious problem are more likely to adopt IPM. The marginal effect indicates that a one-level increase in the importance of *PestAvg* increases the probability of IPM adoption by 67.6 percent. The coefficient of *DiseaseAvg* is negative and statistically significant, indicating that greenhouse/nursery growers are less likely to adopt IPM when they rank disease as a more serious problem for their operations. A one-level increase in the importance of *DiseaseAvg* decreases the probability of IPM adoption by 45 percent. Table 2 also shows that *ProdAvg* has a significant negative effect on IPM adoption. Growers are less likely to adopt IPM when ranking production problems as the most serious for their operations.

Next, we consider important types of constraints on IPM adoption. The coefficient of *Reliability* is positive and statistically significant, indicating that growers are more likely to use IPM if they believe it is a reliable way to manage pests and diseases. The estimated marginal effect suggests that the probability of IPM adoption is 27.1 percent higher when growers consider IPM reliable. The coefficient of *Availability* is positive, as expected, but statistically insignificant. Contrary to expectations, the coefficient of *Knowledge* is negative and significant and suggests that increased knowledge about IPM is associated with a 16 percent reduction in the probability of adoption. The reason may be that growers with greater IPM knowledge are perhaps more aware of the risks associated with this method.

Our results indicate that size of operation, measured as the number of full-time workers (*Fullworker*), has a significant positive effect on IPM adoption: an additional full-time worker increases the probability of greater IPM adoption by 10.7 percent. Having a larger labor force may facilitate IPM adoption, which is more labor intensive than conventional production. The coefficients of *PercentVeg* and *Responsible* are positive but statistically insignificant.

Table 2. Regression Results for Objective and Self-Reported Measures of IPM

	Binary IPM Measure		**IPM Self-Report**	
	Logit Model		***Logit Model***	
Variable Name	**Coefficient**	**Marginal Effect**	**Coefficient**	**Marginal Effect**
Constant	–4.926**		–1.696*	
	(2.017)		(0.982)	
PestAvg	10.683***	0.676**	–1.031	–0.251
	(3.353)	(0.342)	(1.944)	(0.473)
DiseaseAvg	–7.106**	–0.450**	1.640	0.400
	(2.840)	(0.214)	(1.690)	(0.411)
ProdAvg	–2.783*	–0.176	–0.779	–0.190
	(1.629)	(0.149)	(1.195)	(0.292)
Reliability	2.321*	0.271	1.942**	0.445*
	(1.405)	(0.291)	(0.862)	(0.163)
Availability	0.935	0.076	1.272*	0.307*
	(1.399)	(0.133)	(0.727)	(0.162)
Knowledge	–2.986**	–0.160*	–0.690	–0.164
	(1.272)	(0.089)	(0.774)	(0.175)
Responsible	0.707	0.042	–0.226	–0.055
	(0.758)	(0.054)	(0.542)	(0.133)
PercentVeg	0.011	0.001	–0.003	–0.001
	(0.013)	(0.001)	(0.012)	(0.003)
Fullworker	1.695**	0.107***	0.035	0.008
	(0.736)	(0.034)	(0.187)	(0.046)
No. of observations	72		72	
Wald Chi^2 / F	22.89		10.39	
Prob > Chi^2 / F	0.0064		0.3201	
Pseudo R^2	0.4327		0.1057	

Notes: The number of observations in the models is 72 instead of 94 because some values were missing when we constructed the independent variables. We evaluated the difference of the probability of 1 and 0 for the discrete variables while holding all other variables at their means. For continuous variables, we obtained the marginal effects by taking the derivatives of the variable while fixing all variables at mean. We employed STATA for estimation. *, **, and *** denote coefficient estimates that are statistically significant at the 0.10, 0.05, and 0.01 level, respectively. Standard errors are presented in parentheses. Each variable is defined in Table 1.

Regression 2: IPM Self-Reported Measure—Logistic Model

Here we explore whether the results change when the dependent variable is a self-reported measure of IPM adoption. Because the dependent variable *Y_selfreport* is binary, we employ the logistic method for estimation (Table 2, columns 3 and 4). The overall model is not statistically significant.

Table 3. Ordered Logistic Regression Results and Marginal Effects

			Three IPM Levels		
			No IPM Grower	**Low IPM Grower**	**High IPM Grower**
Variable Name	**Coefficient**	**Odds Ratio**	**Marginal Effect**		
PestAvg	7.127*** (1.983)	1,244.909	–0.820*** (0.279)	–0.772** (0.307)	1.592*** (0.477)
DiseaseAvg	–4.357*** (1.702)	0.013	0.501** (0.214)	0.472** (0.219)	–0.973*** (0.379)
ProdAvg	–3.632** (1.842)	0.026	0.418* (0.226)	0.393* (0.246)	–0.811* (0.440)
Reliability	1.675** (0.844)	5.336	–0.268* (0.176)	–0.125*** (0.046)	0.393** (0.187)
Availability	0.349 (0.811)	0.705	–0.037 (0.078)	–0.038 (0.088)	0.075 (0.166)
Knowledge	–2.290*** (0.767)	0.101	0.220*** (0.076)	0.207** (0.081)	–0.427*** (0.132)
Responsibility	1.297* (0.740)	3.659	–0.134** (0.068)	–0.133* (0.082)	0.266* (0.140)
PercentVeg	0.004 (0.010)	1.004	–0.0005 (0.001)	–0.0005 (0.001)	0.0009 (0.002)
Fullworker	0.760*** (0.242)	2.138	–0.087*** (0.033)	–0.082*** (0.035)	0.170*** (0.057)
No. of observations	72				
Wald Chi^2 / F	22.81				
Prob > Chi^2 / F	0.0066				
Pseudo R^2	0.2534				

Notes: Three levels of IPM growers: No IPM (value = 0), Low IPM (value = 1), High IPM (value = 2). We evaluated the difference of the probability of 1 and 0 for the discrete variables while holding all other variables at their means. For the continuous variables, we obtained the marginal effects by taking the derivatives of the variable while fixing all variables at mean. We employed STATA for estimation. *, **, and *** denote coefficient estimates that are statistically significant at the 0.10, 0.05, and 0.01 level, respectively. Standard errors are presented in parentheses. Each variable is defined in Table 1.

The three variables that control for greenhouse/nursery problems (*DiseaseAvg*, *PestAvg*, and *ProdAvg*) are statistically insignificant under this specification. For constraints on IPM adoption, the coefficient of *Reliability* is positive and statistically significant. As with the first regression, these results suggest that *Reliability* is associated with a 44.5 percent increase in the probability of IPM adoption. The coefficient of *Availability* is positive and significant, suggesting that increased availability of IPM supplies increases the probability of IPM adoption. However, the coefficient estimated for *Knowledge* is not statistically significant in this model. Unlike in the model that used objective measures of IPM adoption, the coefficients estimated for *Fullworker* are statistically insignificant.

Regression 3: Objective IPM Adoption in Levels

In this regression, the dependent variable *Y_IPMlevel* takes one of three values: No IPM, Low IPM, or High IPM. The Wald test indicates that the null hypothesis of all coefficients being equal to zero is rejected at the 1 percent level of significance. Table 3 presents the estimated coefficients, odds ratios, and corresponding marginal effects.

The coefficient for *PestAvg* suggests that the extent of pest problems is an important determinant of IPM adoption. With a one-level increase in the importance of average pest problems, a greenhouse/nursery is much more likely to have a higher degree of IPM adoption than a lower one. Conversely, the score of *DiseaseAvg* has a significant negative relationship to IPM adoption. The odds ratio is 0.013, indicating that a one-level increase in the average importance of disease problems decreases the odds of being in the High IPM category by 98.7 percent. The coefficient of *ProdAvg* in this case is negative and statistically significant. The odds ratio indicates that a one-level increase in the average importance of production problems decreases the odds of being in the high IPM category by 97.4 percent. These results are comparable to the ones from the first regression, which also involved an objective measure of IPM adoption.

The factors that constrain adoption of IPM also limit how extensively IPM is applied when it is adopted. The coefficient of *Reliability* is positive and statistically significant. These results suggest that the odds of being in the High IPM category are 5.34 times greater when IPM methods are perceived as reliable. The coefficient of *Availability* is positive but statistically insignificant, and, contrary to expectations, the coefficient of *Knowledge* is significant but negative.

The coefficient of *Fullworker* suggests a significant positive effect from operation size on the level of IPM adoption. The odds ratio indicates that increasing the size of the operation by one full-time worker more than doubles (2.14 times greater) the odds that the operation is in the High IPM category. The estimated coefficient of *Responsible* is positive and statistically significant; the odds ratio indicates that the greenhouse/nursery operation is 3.7 times more likely to be classified in the High IPM category when the respondent is responsible for pest management decisions.

In addition, the increase of an additional full-time worker decreases the probability of being in the No IPM level by 21.1 percent and increases the probability of being in the Low IPM and High IPM levels by 18.1 and 3.0 percent, respectively. The marginal effects shown in Table 3 also contribute to our analysis of factors that affect IPM adoption. For example, a one-level increase in the average importance of disease problems (*DiseaseAvg*) increases the probability of being in the No IPM and Low IPM categories by 50.1 and 47.2 percent respectively and decreases the probability of being in the High IPM category by 97.3 percent. As previously discussed, the effects of changes in the average importance of pest problems (*PestAvg*) are the opposite of those associated with changes in disease problems. A one-level increase in the average importance of pest problems decreases the probability of being in the No-IPM category by 82 percent, decreases the probability of being in the Low IPM category by 77.2 percent, and increases the probability of being in the High IPM category by 159 percent.

These marginal effects are consistent with our odds ratio discussion but provide an additional level of detail regarding factors that influence IPM adoption.

Summary of Results

Our results suggest that pest, disease, and production problems influence IPM adoption. Greenhouse/nursery operations that rank disease or production problems as more serious than pests are less likely to adopt IPM whereas those for which pest problems are the most challenging are more likely to use IPM practices. Our results also suggest that growers believe that IPM practices are reliable for pest/disease control, which should encourage IPM adoption among New England's greenhouse/nursery growers. Furthermore, greenhouse and nursery operations that hire more full-time workers adopt IPM more extensively.

Results from the two models that use objective measures as dependent variables (*Y_binary* and *Y_IPMlevel*) provide similar results regarding factors that influence IPM adoption. However, we identify substantial differences between those two models and the model that uses a self-reported adoption measure (*Y_selfreport*). The coefficients of *Fullworker, PestAvg, DiseaseAvg*, and *ProdAvg* all show significant effects on IPM adoption in the models using objective measures as dependent variables but become statistically insignificant when the self-reported measure is the dependent variable. In addition, the coefficient of *Availability* is not statistically significant in the models using objective measures but is statistically significant under the self-reported IPM measure.

Conclusion

We examined factors that influence IPM adoption among growers of greenhouse/nursery products in Maine, New Hampshire, and Vermont. Given recent attention to IPM methods favored by growers and public interest in sustainability, the findings of this study contribute to ongoing efforts to promote IPM adoption in greenhouse and nursery operations.

The differences identified between self-reported and objective measures imply that greenhouse and nursery growers may require more education on IPM. The university extension system can play a critical role here, and specialists and educators within Cooperative Extension can use the classification proposed in this study to develop training programs that would aim to enhance growers' knowledge of IPM. Another important finding is that greenhouses and nurseries that have a greater number of full-time employees are more likely to adopt IPM. This does not mean that extension programs should solely target these better-staffed operations to encourage IPM adoption. Instead, we suggest that extension specialists should work with both smaller and larger operations to encourage IPM implementation. Smaller operations may require more help from extension specialists to make progress toward wider use of IPM. Larger operations can demonstrate the benefits of IPM adoption since they tend to be early IPM adopters. Smaller operations may not have adequate resources in terms of time and personnel to adopt some of the more time-consuming IPM practices. Extension specialists should figure out more cost-effective IPM methods. Extension specialists and educators should also expect that greenhouse and nursery growers who rank pests as a more serious problem are more likely to use a wide array of IPM practices. Thus, targeting those greenhouse and nursery operations may enhance the efficiency of extension efforts to boost IPM adoption.

We find that increasing the reliability of IPM methods to control pests and disease is an important facilitating factor to IPM adoption. Therefore, suppliers and extension specialists may need to refine the technologies to enhance their reliability. Cooperation between extension and research programs can be useful to suppliers of IPM technologies and methods. Extension specialists interact frequently with large numbers of growers and grower networks and can advise about where to get IPM supplies. In addition, increased cooperation with research universities could lead to studies that enhance the reliability of IPM methods (i.e., the appropriate IPM tactic may vary with the stage of the plant's growth cycle).

We find substantial differences in our models between objective and self-reported measures of adoption as dependent variables. This suggests that growers and IPM extension specialists may think of IPM standards differently. Self-reported IPM measures might lack objectivity. Growers may misreport that they use IPM when in reality they employ conventional methods. This may be due to financial incentive programs (Brewer et al. 2004) to promote IPM in some states and to consumers' willingness to pay higher prices for IPM-labeled products. Therefore, regulators should maintain strict surveillance of products labeled as IPM. Such surveillance should include setting standards, monitoring production processes, and establishing commodity traceability systems. At the same time, though, surveillance measures may be costly and may raise concerns about the efficiency of financial incentives for IPM.

While this study provides valuable insights into factors that influence IPM adoption, it has some limitations that require further investigation. For example, future research should conduct cost-benefit analyses to compare IPM and conventional methods in greenhouses and nurseries since cost is an important factor that limits growers' ability to make wide use of IPM.

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