MANAGING THE CORN ROOTWORM VARIANT: EMPIRICAL RESULTS FROM AN INDIANA FARMER SURVEY

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ABSTRACT: The emergence of a corn rootworm "variant" has reduced the effectiveness of a corn-soybean rotation in some areas of Indiana. This research identifies potential control alternatives. Empirical results suggest that younger, more educated managers of larger farms would be the most likely to adopt transgenic corn for rootworm control.

Keywords: areawide pest management, corn rootworms, technology adoption, transgenic corn

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Introduction

Within the United States, pesticides used to control corn rootworms exceeds that used to control insects in other crops. Historic estimates suggest that crop losses and rootworm control measures cost corn producers approximately one billion dollars annually (Metcalf 1986). In areas with modest to severe corn rootworm pressure, soil insecticide costs can represent as much as 10 to 13 percent of total per acre variable costs.

In addition to the monetary costs associated pesticide applications, corn producers also incur losses from damage caused by corn rootworm larvae feeding on the root systems of corn plants. Apple (1971), Turpin et. al (1972), and Petty et. al (1969) established a relationship between larval root injury in corn and yield loss. The presence of adult rootworm beetles in a cornfield also can impact field performance. Because adult beetles feed on the silk and pollen of corn plants, rootworm beetle feeding can interfere with pollination, thereby reducing yields. The feeding cycle continues as adult beetles lay eggs in cornfields during the summer. The eggs remain dormant throughout the winter months. During the following growing season, rootworm larvae hatch and can inflict damage upon a subsequent corn crop.

Rootworm management generally involves the routine application of soil insecticides, the use of crop rotation, or both. Historically, adult rootworm beetles would feed, mate, and lay eggs *only* in cornfields during summer months. If eggs are laid in continuous cornfields, or fields in which corn is grown year after year, larvae hatch the following spring and damage the corn crop. To prevent this, farmers generally must apply soil insecticides in continuous cornfields. However, if eggs are laid in a field planted to corn one year, followed by soybeans the next year, rootworm larvae would hatch in a soybean field and have an inadequate food supply, and starve. Most rootworm larvae need to feed on corn roots to survive, and adult beetles do not lay eggs in soybean fields. Hence, rotating annually between corn and soybean crops disrupts the rootworm life cycle. Crop rotation can eliminate the need for soil insecticide use on corn grown after soybeans.

It appears, though, that the continued and aggressive use of crop rotation over the past half-century has selected for a western corn rootworm strain capable of laying eggs in soybean fields (Sammons et. al. 1997). The evolution of such a rootworm "variant" beetle has significantly reduced the effectiveness of a corn-soybean rotation in the Eastern Corn Belt. Crop rotation is no longer effective in eliminating the threat of corn rootworms in first-year corn (corn planted after a soybean crop). The occurrence of economic injury to corn planted after soybeans has become commonplace, particularly in east-central Illinois and northwestern Indiana.

Because crop rotation is no longer an effective biological control measure in certain areas, affected farmers have increased their reliance on soil insecticides even in rotated cornfields. The corn producer's problem is compounded further by the possibility that the Environmental Protection Agency (EPA) may limit the use of certain insecticides. The Food Quality Protection Act (FQPA) of 1996 requires the EPA to review the tolerances for pesticide residue in food. Organophosphates, the primary compound in several soil insecticides, are currently under review.

As soon as 2003, transgenic corn for rootworm control may become commercially available in the United States. One type of rootworm resistant corn will contain the Bt Cry3Bb gene, which produces a toxin in the corn root system that is lethal to rootworm larvae. Bt Cry3Bb comes from *Bacillus thuringiensis*, a soil microorganism (Horstmeier, 2000). This organism is also the source for the gene currently used to control the European corn borer. Another gene, Cry1F, may also be used to control secondary corn pests such as cutworms in addition to rootworms. Rootworm resistant corn is expected to have an efficacy level greater than that of soil insecticides. Bio-engineered corn will be easier to use, eliminate producer exposure to chemicals, and reduce worries about field re-infestations that can occur after insecticide applications.

Corn producers can obviously benefit from the introduction of rootworm resistant corn. The savings to producers on a national scale may be approximately $250 million, due primarily to controlling corn rootworm larval injury (Gray 2000). As long as per acre costs to use transgenic corn is comparable to that of applying soil insecticides, the use of transgenic corn may rival that of insecticides.

In addition to transgenic corn, experimental programs have been initiated to investigate the feasibility of an Areawide Pest Management (AWPM) approach to rootworm control. AWPM programs involve integrating control tactics over many adjacent fields with similar crops and target pests. The goal of AWPM programs is to suppress rootworm populations over time by incorporating the selective use of aerial sprays and soil insecticides based on intensive scouting activities. A sixteen square mile site was established in 1996 located in Benton and Newton Counties in Indiana, and Iroquois County in Illinois. This is a joint USDA-ARS/Land Grant University research project.

The availability of new technologies for corn rootworm control does not, however, necessarily imply adoption by all corn producers. The adoption of transgenic corn or participation in an AWPM program will likely be dependent on a grower's demographic characteristics as well as his or her own management situation. Previous findings suggest that the adoption of new products or technologies is influenced by demographic variables such as age and education. For example, a study conducted in the 1960's showed that farmers in Kansas who were younger, more educated, and who operated larger farms were more likely to adopt hybrid sorghum than those who were older, less educated, and who managed much smaller farms (Bradner and Kearl, 1964). More recently, Bhattacharyya, et. al. (1987) indicated that the likelihood of cattle producers in Nevada adopting the trichomoniasis vaccine was influenced by their educational levels, the size of herds, their use of computers, and cooperative extension programs.

This study evaluates the overall pest management situation faced by Indiana corn producers. Specifically, the paper's objectives are to: 1) document the extent of the rootworm "variant" problem in Indiana, 2) assess farmers' management response to the emergence of the variant, 3) determine alternative control measures acceptable to corn growers, and 4) identify information avenues for disseminating rootworm management recommendations.

The Survey

To assess the severity of and management responses to the emergence of the rootworm variant data were collected through a random survey of Indiana corn and soybean producers. The questionnaire was mailed to 6,000 farmers during February and March 2001. Information on demographic characteristics and producer attitudes was also collected. A total of 1,135 usable surveys were returned (19% response rate). Ninety-seven percent of the counties in Indiana were represented in the survey.

To measure the severity of the rootworm variant problem, respondents were asked the following questions: 1) Compared to the early 1990's, please indicate if rotating corn after soybeans for corn rootworm control was more effective, equally effective, or less effective in 2000, and 2) Please indicate if rootworms were a major problem, a minor problem, no problem, or you don't know if rootworms were a problem in 2000 on your corn acres that were rotated after soybeans.

The expected management response to a less effective crop rotation is increased soil insecticide use. Thus, the survey inquired about insecticide application practices over time as the presence of variant beetles has increased in number and location throughout the Eastern Corn Belt. Survey participants were asked to indicate the total number of crop acres planted to corn, the number of corn acres that were rotated after soybeans, and the number of first-year corn acres that were treated with a soil insecticide in 1999 and 2000. Respondents also were asked to indicate whether or not they used soil insecticides as management tactics during the early 1990's. Finally, respondents were asked: Will you apply a soil insecticide in 2001 on a) all, b) half, c) less than half, d) none, or e) an unknown number of corn acres that were in soybeans in 2000?

Growers were provided a list of alternative rootworm management options and were asked to indicate the alternative(s), other than soil insecticides, that they would consider feasible to manage corn rootworm larvae in the future. The list included collaborating with neighbors on an areawide basis, growing bio-engineered corn resistant to rootworms, rotating between corn and another crop, and rotating out of corn for at least two years. Finally, respondents were asked to report their primary information sources for rootworm management recommendations.

Methods

Entomological data suggest that the variant problem is not uniform throughout Indiana, but that variant pressure is greatest in the northern portion of the state. It is generally accepted that the variant originated in east-central Illinois, and then spread in a north-eastwardly direction into Indiana. Consequently, counties located on the Illinois/Indiana border north of Interstate 70 are being impacted the most by the variant, while corn producers in southern Indiana appear to be largely unaffected. Accordingly, the study stratified the state into four geographical regions based on variant infestation levels determined by county-level, multi-year (1998-2001) sweep net surveys reported by Purdue University entomologists. The Severe Rootworm Problem Area comprises ten counties located near the Indiana/Illinois border that have extremely high average rootworm beetle numbers in soybeans. The Emerging Problem Area in central Indiana does not have average counts as high as those in the Severe Rootworm Problem Area, but beetle counts in soybean fields are persistent. The Emerging Problem Area has beetle counts that are moderate to low and typically includes counties located in the northeastern section of the state. Finally, the Unaffected Area comprises the vast majority of the state located south of Interstate 70 and represents those counties that have virtually no adult rootworm beetles present in soybean fields.

First, statistical summaries of farmer responses in each of the four affected areas are presented. Logistic regression analyses are then used to clarify which characteristics are associated with acceptable rootworm management alternatives. Specifically, the logit analyses are used to understand which factors influence the likelihood of adopting transgenic corn, the likelihood of participating in an areawide approach, and the probability that alternate crop rotational practices are an acceptable alternatives to soil insecticides. The farmer and farm characteristics selected as explanatory variables are farm size, age, location, education, whether or not the grower experienced a loss in the effectiveness of crop rotation, whether or not the grower experienced a problem with rootworms in first-year corn, rootworm management information sources, and grower concern about the cost or EPA cancellation of soil insecticides.

With the exception of the farm size variable, all dependent and explanatory variables are binary. Given that the dependent variables are dichotomous, a binomial logistic regression model (BLM) was selected. All variables used in the study, their definitions, arithmetic means, and standard deviations are discussed following a description of the empirical model. The BLM can be written as follows.

(1.) $y^* = \beta' x + \varepsilon, \qquad \varepsilon \sim N[0, 1].$

The vector y* is unobserved. Instead, what is observed is y=1 or y=0. In the case of bio-engineered corn, y=1 corresponds to “willing to adopt bio-engineered corn for rootworm control” and y=0 corresponds to “not willing to adopt transgenic corn.” β is the vector of unknown parameters and reflects the impact of changes in x on the probability of adopting rootworm-resistant corn. x is the matrix of explanatory variables (reported farmer and farm characteristics). ε is the vector of random stochastic errors. The cumulative logistic distribution function for the BLM can be written as follows.

(2.) $\text{Prob}(y=1) = (e^{\beta' x}) / (1 + e^{\beta' x})$

A primary model statistic is the likelihood ratio chi-square statistic and its corresponding probability value. This statistic compares the log-likelihood for the estimated model with the log-likelihood for a model with no explanatory variables. Coefficients of the logistic model cannot be interpreted as easily as in a linear model, thus results will be interpreted in terms of probabilities using the following equation.

(3.) $\partial p_i / \partial x_i = \beta p_i (1-p_i).$

This equation says that the change in the probability for a 1-unit increase in x depends on the estimated model coefficient for x, and on the value of the probability itself (Allsion). These changes will be referred to hereafter as marginal effects. The SAS® statistical software package was used.

Variable Descriptive Statistics

Almost half (42%) of all survey respondents reported that they would be willing to grow bio-engineered corn for rootworm control (Table 1). Fifty-nine percent of growers expressed a willingness to rotate with a crop other than soybeans, while only 14 percent reported that they would be willing to rotate out of corn for at least two years. Managing corn rootworms on an areawide basis appealed to about 31 percent of the Indiana producers who participated in the survey.

The average farm size in the survey is 753 acres, ranging from 49 acres to 6,600 acres. Twenty percent of the growers perceived that in 2000, crop rotation was less effective than in the early 1990's. Across the state, almost half (42%) of the corn growers reported a major or minor problem with corn rootworm in first-year corn.

Purdue extension specialists provide rootworm management recommendations to approximately thirty percent of the survey respondents. A slightly lower percentage (27%) contact County Extension agents for rootworm management information. Concern about the cost or possible cancellation of soil insecticides was reported by about a quarter of the corn growers. Relatively few farmers between the ages of 20 and 29 (2%) participated in the survey and less than ten percent between the ages of 30 and 39 participated in the survey (Table 1). Twenty-seven percent, 29%, and 28% of respondents were aged 40 to 59, 50 to 59, and over 60, respectively.

Fourteen percent of respondents reported that they managed farms within the Severe Rootworm Problem Area. About a third indicated that they operated farms in the Emerging Problem Area. Thirty-two percent of respondents managed farms in the Potential Problem Area. Twenty-five percent operated farms in the Unaffected Area, where there is minimal rootworm variant pressure.

Most growers in the survey have at least a high school education (43%). Twelve percent have attended trade or technical school, 17% have a bachelor's degree, and less than 10% have a graduate degree.

Current Effectiveness of Crop Rotation

Survey responses reveal that crop rotation is becoming less effective in regions with greater corn rootworm variant pressure. From the Severe Rootworm Problem Area to the Unaffected Area, there is a definite downward trend in the percentage of respondents who report experiencing a loss in crop rotation's effectiveness over time (Table 2). Over one-third of producers operating in the Severe Corn Rootworm Problem Area (36%) indicated that crop rotation was less effective in 2000. Less than a fourth of respondents from the Emerging Rootworm Problem Area so indicated. Eighteen percent and 12% of respondents from the Potential Problem Area and the Unaffected Area, respectively, indicated that crop rotation was less effective.

Crop rotation remains a viable management option for the majority of growers operating in lower rootworm variant pressure areas. The Potential and Unaffected Areas have the highest percentage of farmers who reported that crop rotation was equally effective in controlling rootworms now as in the early 1990's (66%). Sixty percent from the Emerging Problem Area reported that crop rotation was just as effective in 2000 as it was during the early 1990's. Less than half (44%) of the respondents in the Severe Rootworm Problem Area indicated that crop rotation was currently equally effective.

As expected, the likelihood of having any problems with rootworm larvae in first-year corn is highest in areas with greater variant pressure (Table 3). Again, based on the survey responses, the region of the state that is most affected by rootworms is the Severe Rootworm Problem Area. Corn producers operating in this area have a fourteen percent probability of having a major problem with rootworms in first-year corn. The Emerging Rootworm Problem Area has the second highest probability, with eight percent of producers indicating they have a major problem. The Potential Corn Rootworm Problem Area has the third highest probability, while in the Unaffected Area only one percent of producers had major problem with rootworms in first-year corn in 2000.

About half (51%) the respondents from the Problem Area reported that rootworms were a minor problem in rotated corn acres. The percentages decrease across areas as the variant problem becomes less severe. Forty-one percent of farmers in the Emerging Problem Area had a problem with rootworms in first-year corn in 2000. The remaining two areas had 30% of producers who reported a minor problem with rootworms.

In all, nearly two-thirds of producers operating in the Severe Problem Area, reported a problem with rootworms in corn rotated after soybeans. Forty-nine percent of respondents from the Emerging Problem Area indicated that they had a problem in 2000 with rootworms. Thirty-five percent from the Potential Problem Area had a problem, while the lowest percentage of farmers who had a problem was located south of Interstate 70 (31%).

Management Response

What has been the Indiana farm managers' response to the corn rootworm variant phenomenon? A comparison of production characteristics among the four areas indicates that farm managers in Indiana now rely heavily on soil insecticides (Tables 4 and 5). In 1999, the Severe Problem Area had the highest proportion of rotated corn acres to total corn acres (94%) as well as the highest percentage of treated first-year corn acres (73%). The percentage of treated rotated corn acres in the Severe Problem Area increased to 77% in 2000. In 1999 and 2000, the Emerging and Potential Problem Areas had similar proportions of first-year corn acres to total corn acres, 87% and 88%, respectively. However, the Emerging Problem Area appears to have applied soil insecticides to a greater proportion of rotated corn acres than in the Potential Problem Area in both years. In 1999, the difference is about 9-percentage points, with growers from the Emerging Problem Area treating 42% of first-year corn, and farmers from the Potential Problem Area treating 33%. In 2000, the gap narrowed to 5-percentage points.

The group of counties classified as the Unaffected Area had the smallest percent of first-year corn acres (82%) in both years. As expected, this area also has the lowest percentage of first-year corn acres treated with insecticides in 1999 and 2000 (28%).

In the more heavily affected areas, there has been a decrease in the number of farmers who use crop rotation as a management practice to control rootworms (Table 6). The number of Emerging Problem Area producers who chose to alternate between corn and soybeans as a management practice to control rootworms fell as well. There has been no change in the number of growers who alternate crops for rootworm management in the Potential Problem Area, while in the Unaffected Area the number has increased by eight percent since the early 1990's.

In contrast, as the viability of crop rotation to control rootworms has declined over time, the number of growers located in affected regions who apply soil insecticides for rootworm control has increased (Table 6). As expected, applying soil insecticides as a rootworm management tactic has gained significant popularity in the Severe Rootworm Problem Area. The number of producers using chemical controls in the region had more than doubled in 2000 compared to the early 1990's. Only twenty-one percent more operators from the Emerging Problem Area reported that they applied soil insecticides in 2000 when compared to the number of growers from that region that applied soil insecticides in previous years. Chemical usage has even increased in the Potential Problem Area, suggesting that there may be cause for concern in the future. The Unaffected Area reportedly is the least affected, and the number of producers south of Interstate 70 who rely on pesticides as a rootworm control tactic has actually decreased twenty percent since the early 1990's.

Will the trend towards a dependence on soil insecticides continue? According to the survey data, it will. The severity of the rootworm variant problem determines the intended level of soil insecticide application (Table 7). The Severe Rootworm Problem Area has the highest percentage of growers who intend to apply soil insecticides to all of their rotated corn acres in 2001 (66%). Percentages are noticeably lower in other areas. Only twenty-nine percent of farmers in the Emerging Problem Area reported that they intended to apply soil insecticides on all of their rotated corn acres. Twenty-three percent and twenty percent, respectively, of farmers in the Potential Problem and Unaffected Areas indicated that they would apply soil insecticides on all of their rotated corn acres during the current crop year.

Alternatives to Soil Insecticides

Collaborating with neighbors to scout and spray adult beetles prior to egg laying in the summer on a multi-field basis appears to be an acceptable option for about a third of the corn producers (Table 8). About 37 and 31 percent of Severe and Emerging Problem Area producers expressed a willingness to collaborate with neighbors in an AWPM program. Slightly less than a third of Potential Problem and Unaffected Area producers (29%) reported that working with fellow producers is a feasible alternative to applying soil insecticides. A higher percentage was expected in the Severe Problem Area, given the USDA-ARS research currently underway to determine the feasibility and effectiveness of AWPM is located in the region.

More interest in transgenics exists among corn farmers in those counties impacted by the variant (Table 8). Nearly half of the corn growers who operated in the three affected areas indicated that they would consider growing bio-engineered corn as a feasible option to soil insecticides. Although there is no apparent variant problem in the Unaffected Area of the state, farmers there also are interested in growing bio-engineered corn. Thirty-six percent of growers managing corn farms south of Interstate 70 expressed a willingness to use transgenics as an alternative to soil insecticides.

Many corn growers reported that they would be willing to rotate with another crop besides soybeans in an attempt to control rootworms (Table 8). Fifty-three percent of Severe Problem Area growers favor rotation with a non-soybean crop as a feasible alternative. Results further indicate that as the variant problem becomes less severe across Indiana, interest in rotating with another crop increases. Fifty-four percent, 61%, and 65% of the Emerging, Potential, and Unaffected Area growers, respectively, expressed an interest in alternative crops to rotate with corn. In Southern Indiana, double cropping with wheat is common, and thus a higher interest in alternative crops is expected. However, in Northern

Indiana, no other economically viable crop has been identified which can be rotated with corn on a large-scale basis. Hence, the challenge is to identify a profitable crop that can be rotated with corn and biologically disrupt the corn rootworm life cycle.

Farmers in areas of low rootworm variant pressure view rotating out of corn for at least two years as an acceptable option (Table 8). In the Unaffected Area, nearly one-fifth of respondents are willing to try this technique. On the other hand, only seven percent of respondents from the Severe Rootworm Problem Area considered rotating out of corn for two years a feasible alternative to soil insecticides.

Rootworm Management Information Sources

University and county extension educators provide many survey respondents with information on rootworm management (Table 9). At least a quarter of survey respondents from each area seek information from a county extension educator. Farm operators from the Emerging Problem Area are most likely to consult a county extension agent. Twenty-seven percent of Unaffected Area respondents reported getting rootworm management information from county educators. Twenty-six and twenty-five percent of Severe and Emerging Problem Area growers, respectively, get rootworm control suggestions from county extension educators.

Farmers located in the northern region of the state more often use Purdue University Extension Specialists rather than county educators as information sources on rootworm management (Table 9). In contrast, Unaffected Area respondents are more likely to rely upon management suggestions from county educators. The probability of an Severe Problem Area respondent utilizing University extension resources is 37%, and the likelihood for an Emerging Problem Area producer is 31%. Twenty-nine percent of Potential Problem Area producers get information from Purdue University Extension educators, while only twenty-four percent of Unaffected Area respondents do the same.

BLM Results

A combination of farm and farmer characteristics likely influences the probability of adopting alternative management techniques. The BLM was used to identify the characteristics of likely adopters of transgenic corn for rootworm control as well as likely adopters of an areawide approach or alternate rotational practices.

The log likelihood chi-square coefficient for the adoption of transgenic corn (ADOPTECH) is 152.41 and is significant at the 0.01 level (Table 10). Estimated coefficients for the BLM are not easily interpreted. Marginal effects indicate that a 1-acre increase in size increases the probability of adopting transgenic corn by 0.0076-percentage points. (Each 100-acre increase corresponds to a 0.76-percentage point increase.) Reporting that crop rotation was less effective in 2000 (EFFECT) or reporting a problem with rootworms in first-year corn (PROBLEM) corresponds to a 9- and 11-percentage point increase, respectively, in the probability of reporting interest in adopting transgenic corn.

Information sources appear to influence producer attitudes towards bio-engineered corn. The probability of adoption increases by 12-percentage points if the grower indicated that he or she gets rootworm management information from Purdue extension specialists (INFOPUR). Those who get information from county extension agents (INFOCO) are 8-percentage points more likely than those who do not refer to extension agents to adopt transgenic corn. Expressing concern about the loss of insecticides due to EPA actions (CONLOSS) or about the cost of insecticides (CONCOST) is associated with an increase in the likelihood of adopting transgenic corn by about 12- and 14-percentage points, respectively.

If a grower reports that he or she operates a farm in the Potential Rootworm Problem Area (POTENTIAL), the probability that the manager will adopt transgenic corn for rootworm control is 8-percentage points higher than if he operated a farm in the Unaffected Area (reference group). Variables representing the Severe Rootworm Problem Area (SEVERE) and the Emerging Rootworm Problem Area (EMERGING) do not have statistically significant coefficients. Finally, education influences grower attitudes towards transgenics. Producers who attended trade or technical school (TRADE), who have some college experience (SOMECOLL), or who have a bachelor's degree (BACHELOR) are about 11-, 9-, and 12-percentage points, respectively, more likely than producers who have only a high school education (reference group) to adopt bio-engineered corn for rootworm control. Age does not appear to influence the likelihood of adopting transgenic corn.

The EFFECT, INFOCO, CONLOSS, CONCOST, SEVERE, and EMERGING variables have a statistical influence on the likelihood of expressing interest in rotating corn with a non-soybean crop (ROTATE1) (Table 11). Experiencing a loss in effectiveness and operating in areas impacted the most by the variant decreases the likelihood of wanting to rotate with a non-soybean crop. However, those who get management information from county extension agents and those operators who expressed concern about soil insecticides have a higher propensity to accept rotating with a non-soybean crop than those who do not.

Marginal effects indicates that if crop rotation is no longer an effective rootworm management tool, the probability of wanting to rotate with a crop other than soybeans decreases by 16-percentage points. Respondents from the Severe and Emerging Problem Areas are about 10-percentage points less likely than respondents from the Unaffected Area to express an interest in planting a non-soybean crop. Operators who get management information from Purdue are 6-percentage points more likely to try planting an alternate crop in order to control rootworms. Expressing concern about soil insecticide loss and cost positively impacts the likelihood by seven to ten percentage points.

Operating a larger farm, observing a less effective rotation system, and operating in the Severe Rootworm Problem Area negatively impacts the likelihood of expressing an interest in rotating out of corn at least two years (ROTATE2) (Table 12). Marginal effects indicate that a 100 acre-increase in farm size decreases the probability of rotating out of corn for two years by 0.4-percentage points. Corn producers who reported that rotation was less effective in 2000 are about 7-percentage points less likely to be interested in rotating out of corn for at least two years.

Age is the only variable with a positive impact on the likelihood of expressing interest in rotating out of corn for at least two years. Respondents between the ages of 30 and 39 are about 11-percentage points more likely to express interest in rotating out of corn for two years. Farmers in their forties or fifties are about seven- and six- percentage points, respectively, more likely to be willing to try a different approach to crop rotation for rootworm management than those growers who are at least 60 years old.

Information sources, concern about loss of soil insecticides, location in the state, and education all have a positive, significant effect on the probability of reporting a willingness to collaborate with neighbors (AREAWIDE) (Table 13). Growers who reported getting information from a county extension agent are 7-percentage points more likely to consider collaborating with neighbors on an areawide approach for rootworm management. Indicating a concern about cost increases the probability by 8-percentage points. Respondents located in the Severe Rootworm Problem Area are nearly eight-percentage points more likely to want to collaborate with neighbors. Respondents who hold a bachelor's degree are about 7-percentage points more likely than those respondents with at most a high school diploma to consider collaboration. Advanced degree holders are about 17 percentage points more likely to be willing to participate in an areawide program.

Concluding Remarks

Since the early 1990's, the occurrence of adult rootworm beetles laying eggs in soybeans fields has increased, especially in the Severe Rootworm Problem Area located in northwest Indiana near the Illinois/Indiana border. Farm managers operating in affected areas in northern Indiana have substantially increased soil insecticide use on rotated corn acres with the emergence of the corn rootworm variant. Growers in southern Indiana appear to remain largely unaffected by the rootworm variant.

There are alternatives to soil insecticides that Indiana corn producers might adopt. Those growers more likely to adopt transgenic corn for rootworm control are generally managers of larger farms, more educated, concerned about the cost or loss of soil insecticides, and are more likely to have experienced problems with rootworms on rotated corn acres. Producers in Indiana who are interested in AWPM programs are likely to manage farms in the Severe Rootworm Problem Area, have advanced university degrees, receive management information from the Purdue extension service, and be concerned about the loss of chemical controls due to EPA actions.

Extension programs remain important avenues for disseminating rootworm management information. In general, getting management recommendations from Purdue University specialists or from county extension educators positively influences the likelihood of adopting transgenic corn or an areawide approach for rootworm control.

TABLE 1: Variables, Definitions, and Descriptive Statistics

Variable Names	Mean	Standard Deviation
Dependent Variables		
Willing to adopt transgenic corn for rootworm control (ADOPTECH)	0.4225	0.49
Willing to collaborate with neighbors (AREAWIDE)	0.3048	0.46
Willing to rotate with another crop (ROTATE1)	0.5885	0.49
Willing to rotate out of corn at least two years (ROTATE2)	0.1383	0.34
Explanatory Variables		
Farm size in by acres (SIZE)	753.27	724.61
Perceived a loss in crop rotation's effectiveness (EFFECT)	0.2052	0.40
Reported a major/minor problem with rootworms (PROBLEM)	0.4211	0.49
Farmer gets information from Purdue Extension (INFOPUR)	0.2934	0.45
Farmer gets information from County Extension (INFOCO)	0.2661	0.44
Moderately/very concerned about loss of insecticides (CONLOSS)	0.7127	0.46
Moderately/very concerned about cost of insecticides (CONCOST)	0.7859	0.41
Grower age 20 to 29 (AGE29)	0.0229	0.14

TABLE 1: Variables, Definitions, and Descriptive Statistics cont.

Variable Names	Mean	Standard Deviation
Grower age 30 to 39 (AGE39)	0.0942	0.29
Grower age 40 to 49 (AGE49)	0.2749	0.44
Grower age 50 to 59 (AGE59)	0.2863	0.45
grower is at least 60 (AGE60) (reference)	0.2766	0.44
Located in Severe Problem Area (SEVERE)	0.1427	0.34
Located in Emerging Problem Area (EMERGING)	0.2793	0.44
Located in Potential Problem Area (POTENTIAL)	0.3242	0.47
Located in Unaffected Problem Area (NOPROB) (reference)	0.2520	0.43
Earned at most a high school diploma (HISCHOOL) (reference)	0.4299	0.49
Attended trade/technical School (TRADE)	0.1207	0.325
Completed some college (SOMECOLL)	0.1682	0.37
Earned a bachelor’s degree (BACHELOR)	0.1762	0.38
Earned a graduate degree (GRADUATE)	0.0678	0.25

TABLE 2: Reported Effectiveness of Crop Rotation for Rootworm Control in 2000 Compared to the Early 1990's [a]

	Severe	Emerging	Potential	Unaffected
More Effective	17 (10)	31 (10)	24 (7)	37 (13)
Equally Effective	72 (44)	189 (60)	244 (66)	189 (66)
Less Effective	59 (36)	72 (23)	68 (18)	34 (12)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.

TABLE 3: Severity of Pest Problem with Rootworms in First-Year Corn During 2000[a]

	Severe	Emerging	Potential	Unaffected
Major Problem	22 (14)	26 (8)	17 (5)	4 (1)
Minor Problem	82 (51)	130 (41)	109 (30)	87 (30)
Not A Problem	39 (24)	118 (37)	176 (48)	140 (49)
Don't Know	7 (4)	20 (6)	39 (11)	27 (9)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.

TABLE 4: 1999 Production Characteristics Among the Four Areas

	Severe	Emerging	Potential	Unaffected
Total Acres	136,990	240,144	268,452	188,880
Corn Acres	67,709	120,506	132,537	93,326
First-year	63,977	104,970	116,906	76,710
	(94%)[a]	(87%)	(88%)	(82%)
Treated	46,994	43,641	38,876	21,414
	(73%)[b]	(42%)	(33%)	(28%)

[a]As a percentage of total corn acres. [b]As a percentage of first-year corn acres.

TABLE 5: 2000 Production Characteristics Among the Four Areas

	Severe	Emerging	Potential	Unaffected
Total Acres	140,825	243,169	272,770	193,800
Corn Acres	70,628	120,811	134,526	95,665
First-year	65,868	104,609	117,693	78,558
	(93%)[a]	(87%)	(87%)	(82%)
Treated	50,448	44,647	44,292	24,144
	(77%)[b]	(43%)	(38%)	(28%)

[a]As a percentage of total corn acres. [b]As a percentage of first-year corn acres.

TABLE 6: Management Tactics used for Rootworm Control Over Time[a]

	Severe	Emerging	Potential	Unaffected
Crop Rotation				
Early 1990's	145	257	308	208
1999	125	252	305	221
2000	124	254	308	224
% Change	(-14)	(-1)	(0)	(8)
Soil Insecticide				
Early 1990's	50	112	127	128
1999	110	136	140	97
2000	115	136	146	102
% Change	(130)	(21)	(15)	(-20)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.

TABLE 7: Intended Level of Soil Insecticide Use for Rootworm Control on Corn Acres Rotated After Soybeans[a]

	Severe	Emerging	Potential	Unaffected
On All Rotated Corn	107 (66)	92 (29)	84 (23)	56 (20)
On 50% or More	10 (6)	15 (5)	23 (6)	18 (6)
On Less than 50%	3 (2)	26 (8)	23 (6)	13 (5)
Will Not Apply	32 (20)	152 (48)	208 (57)	158 (55)
Don't Know	5 (3)	16 (5)	17 (5)	22 (8)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.

TABLE 8: Reported Alternatives Corn Producers Are Willing To Use[a, b]

	Area 1	Area 2	Area 3	Area 4
Collaborate with Neighbors	60 (37)	97 (31)	105 (29)	83 (29)
Grow Bio-Engineered Corn	73 (45)	145 (46)	161 (44)	103 (36)
Rotate with Another Crop	86 (53)	172 (54)	225 (61)	185 (65)
Rotate out of Corn at Least Two Years	11 (7)	40 (13)	57 (15)	49 (17)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.
[b]Respondents could check more than one category.

TABLE 9: Primary Source of Information on Corn Rootworm Management Recommendations[a, b]

	Area 1	Area 2	Area 3	Area 4
County Extension Educator	42 (26)	91 (29)	92 (25)	76 (27)
Purdue University Extension Specialist	60 (37)	98 (31)	105 (29)	69 (24)

[a]By number of area survey respondents. Percentage of area survey respondents in parentheses.
[b]Respondents could check more than one category.

TABLE 10: Binomial Model's Results for Adoption of Transgenic Corn (ADOPTECH)

	Estimated Coefficient	Z-statistic	Marginal Effects
INTERCEPT	-2.2900***	9.68	
SIZE	0.0003***	3.17	0.000076
EFFECT	0.3737**	2.19	0.0914
PROBLEM	0.4337***	3.07	0.1060
INFOPUR	0.5044***	3.44	0.1233
INFOCO	0.3111**	2.07	0.0761
CONLOSS	0.4968***	3.10	0.1214
CONCOST	0.5834***	3.19	0.1426
AGE29	0.1874	0.42	0.0458
AGE39	-0.1272	0.52	-0.0311
AGE49	0.2025	1.17	0.0495
AGE59	0.0683	0.40	0.0167
SEVERE	-0.0265	0.10	-0.0065
EMERGING	0.2403	1.34	0.0587
POTENTIAL	0.3314*	1.92	0.0810
TRADE	0.4334**	2.09	0.1059
SOMECOLL	0.3569**	1.94	0.0872
BACHELOR	0.4783***	2.58	0.1169
GRADUATE	0.2395	0.89	0.0585
Log Likelihood χ^2 (18)	152.41***		

Note: (*), (**), (***) imply statistical significance at the 0.10, 0.05, and 0.01 level of Probability, respectively

TABLE 11: Binomial Model's Results for Expressed Interest in Rotating with a Non-Soybean Crop (ROTATE1)

	Estimated Coefficient	Z-statistic	Marginal Effects
INTERCEPT	-0.0823	0.41	
SIZE	0.0000	0.00	0.000000
EFFECT	-0.6792***	3.95	-0.1645
PROBLEM	0.1732	1.25	0.0419
INFOPUR	0.0938	0.65	0.0227
INFOCO	0.2546*	1.72	0.0617
CONLOSS	0.2906**	1.95	0.0704
CONCOST	0.3939**	2.40	0.0954
AGE29	-0.0309	0.10	-0.0075
AGE39	0.1253	0.54	0.0303
AGE49	0.1613	0.96	0.0391
AGE59	0.0855	0.52	0.0207
SEVERE	-0.4186**	1.99	-0.1014
EMERGING	-0.4049**	2.35	-0.0981
POTENTIAL	-0.0781	0.47	-0.0189
TRADE	0.0079	0.00	0.0019
SOMECOLL	0.1269	0.71	0.0307
BACHELOR	-0.0750	0.42	-0.0182
GRADUATE	0.2738	1.02	0.0663
Log Likelihood χ^2 (18)	49.36***		

Note: (*), (**), (***) imply statistical significance at the 0.10, 0.05, and 0.01 level of Probability, respectively

TABLE 12: Binomial Model Results for Expressed Interest in Rotating Out of Corn For At Least Two Years (ROTATE 2)

	Estimated Coefficient	Z-Statistic	Marginal Effects
INTERCEPT	-1.6301***	5.75	
SIZE	-0.0003**	2.12	0.000040
EFFECT	-0.5455**	1.96	-0.0650
PROBLEM	0.0565	0.28	0.0067
INFOPUR	0.0304	0.14	0.0036
INFOCO	0.1700	0.84	0.0203
CONLOSS	-0.0274	0.14	-0.0033
CONCOST	-0.3366	1.51	-0.0401
AGE29	0.4900	0.84	0.0584
AGE39	0.9015**	2.85	0.1075
AGE49	0.6276**	2.55	0.0748
AGE59	0.5009**	2.08	0.0597
SEVERE	-0.8948**	2.48	-0.1067
EMERGING	-0.2804	1.19	-0.0334
POTENTIAL	-0.0664	0.30	-0.0079
TRADE	0.2545	0.94	0.0303
SOMECOLL	0.0252	0.10	0.0030
BACHELOR	0.1388	0.55	0.0165
GRADUATE	0.2732	0.79	0.0326
Log Likelihood χ^2 (18)	36.98***		

Note: (*), (**), (***) imply statistical significance at the 0.10, 0.05, and 0.01 level of Probability, respectively

TABLE 13: Binomial Model Results for Expressed Interest in an Areawide Approach to Rootworm Management (AREAWIDE)

	Estimated Coefficient	Z-Statistic	Marginal Effects
INTERCEPT	-1.5539***	6.76	
SIZE	0.0000	0.22	0.0000
EFFECT	-0.1485	0.82	-0.0315
PROBLEM	-0.0549	0.37	-0.0116
INFOPUR	0.1121	0.74	0.0238
INFOCO	0.3449**	2.28	0.0731
CONLOSS	0.3850**	2.32	0.0816
CONCOST	0.2684	1.44	0.0569
AGE29	-0.4730	0.95	-0.1002
AGE39	0.1381	0.57	0.0293
AGE49	-0.2915	1.61	-0.0618
AGE59	-0.1168	0.67	-0.0248
SEVERE	0.3658*	1.66	0.0775
EMERGING	0.0855	0.47	0.0181
POTENTIAL	-0.0069	0	-0.0015
TRADE	0.2734	1.28	0.0579
SOMECOLL	0.0954	0.50	0.0202
BACHELOR	0.3215*	1.71	0.0681
GRADUATE	0.8012***	3.09	0.1698
Log Likelihood χ^2 (18)	42.87***		

Note: (*), (**), (***) imply statistical significance at the 0.10, 0.05, and 0.01 level of Probability, respectively

References

Apple, J.W. "Gains From the Use of Carbofuran form northern corn rootworm control." Precedings of the North Central Branch, Entomological Society of America. 26 (1971): 26-28.

Allison, Pual D. *Logistic Regression Using the SAS® System: Theory and Application.* Cary, NC: SAS Institue., 1999; pp. 13-28.

Bradner L., and B. Kearl. "Evaluation for Congruence as a Factor in Adoption Rate of Innovations." *Rural Socialogy*. 29, 3(September 1964):288-303.

Bhattacharyya, A., T.R. Harris, W.G. Kvasnicka, and G.M. Vesarat. "Factors Influencing Rates of Adoption of Trichomoniasis Vaccine by Nevada Range Cattle Producers." *Journal of Agricultural Resource Economics*. 22, 1(July 1997); 174-190.

Gray, Michael E. "Prescriptive Use of Transgenic Hybrids for Corn Rootworms: An Ominous Cloud on the Horizon?" (2000) www.biotech-info.net/mgray.pdf

Horstmeier, Greg. Close in on rootworms. Farm Journal, February 2000.

Metcalf, R.L. Foreword. P. vii-xv, *In*: J. L. Krysan and T.A. Miller [eds.], Methods for the study of pest *Diabrotica*. Springer, New York. 1986

Petty, H.B., D.E. Kuhlman and R.E. Sechriest. "Corn Yield Losses Correlated with Rootworm Larval Populations, 1968." Proceedings of the North Central Branch, Entomological Society of America 24 (1969): 141-142.

Sammons, Amy E., C. Richard Edwards, Larry W. Bledsoe, Philip J. Boeve, and Jeffrey J. Stuart. "Behavioral and Feeding Assays Reveal a Western Corn Rootworm Variant that is Attracted to Soybean." *Environmental Entomology.* 26(6): 1336-1342.

Turpin, F.T., L.C. Dumenil, and D.C. Peters. "Edaphic and agronomic characteristics that affect potential for rootworm damage to corn in Iowa. *Journal of Economic Entomology*. 65 (1972): 1615-1619.