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# Biotechnology and the European Corn Borer: Measuring Historical Farmer Perceptions and Adoption of Transgenic Bt Corn as a Pest Management Strategy

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**Abstract**

A 3-yr, multi-state survey of farmers who had planted transgenic Bacillus thuringiensis (Bt) corn was conducted to evaluate perceptions of Bt corn performance and its utility as a management option for European corn borer, Ostrinia nubilalis (Hu¨ bner). A questionnaire was sent to farmers in Illinois, Iowa, Kansas, Minnesota, Nebraska, and Pennsylvania who had grown Bt corn during the growing seasons of 1996, 1997, or 1998. There were 7,427 usable questionnaires returned with the following response percentages: 1996 (42.1%), 1997 (35.0%), and 1998 (22.6%). Adoption rates, based on percentage of acreage planted to Bt corn, increased dramatically from 1996 (10.5%) to 1998 (40.7%). The states growing the highest percentage of Bt corn were Minnesota, Iowa, and then Nebraska. However, Illinois, was adopting Bt corn at the fastest rate. Historical use of insecticides did not inßuence the adoption of Bt corn. In addition, of those farmers who used insecticides to control European corn borer, the percentage that decreased their use of insecticides nearly doubled from 13.2% (1996) to 26.0% (1998) over this 3-yr period. The primary reason farmers planted Bt corn was to eliminate the yield loss caused by European corn borer. Scouting for European corn borers decreased from 91% (scouting 2.2 times a year) in 1996 to 75% (scouting 1.8 times a year) in 1998. The percentage of farmers not scouting for European corn borers increased from 9.6% (1996) to 25% (1998). Most farmers believed yields of Bt hybrids were either similar to or greater than the yields of non-Bt hybrids. Minnesota farmers perceived the greatest yield advantages. Farmers are becoming more aware of insect resistance management guidelines; however, they also clearly show preferences for having the ßexibility to use different spatial plantings of Bt and non-Bt corn. Finally, after having planted Bt corn and obtained excellent control of European corn borer, most farmers believed that this insect had been causing more yield loss than they previously had suspected in their non-Bt corn. The data represented here provide an historical foundation for how transgenic Bt corn was used by farmers during the Þrst 3 yr of commercial availability, their initial perceptions on the performance of this technology, and their attitudes regarding management of the European corn borer.

**Keywords**

European corn borer, maize, transgenic corn, Bt corn, biotechnology, survey

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# Biotechnology and the European Corn Borer: Measuring Historical Farmer Perceptions and Adoption of Transgenic Bt Corn as a Pest Management Strategy

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**ABSTRACT** A 3-yr, multi-state survey of farmers who had planted transgenic *Bacillus thuringiensis* (Bt) corn was conducted to evaluate perceptions of Bt corn performance and its utility as a management option for European corn borer, *Ostrinia nubilalis* (Hübner). A questionnaire was sent to farmers in Illinois, Iowa, Kansas, Minnesota, Nebraska, and Pennsylvania who had grown Bt corn during the growing seasons of 1996, 1997, or 1998. There were 7,427 usable questionnaires returned with the following response percentages: 1996 (42.1%), 1997 (35.0%), and 1998 (22.6%). Adoption rates, based on percentage of acreage planted to Bt corn, increased dramatically from 1996 (10.5%) to 1998 (40.7%). The states growing the highest percentage of Bt corn were Minnesota, Iowa, and then Nebraska. However, Illinois, was adopting Bt corn at the fastest rate. Historical use of insecticides did not influence the adoption of Bt corn. In addition, of those farmers who used insecticides to control European corn borer, the percentage that decreased their use of insecticides nearly doubled from 13.2% (1996) to 26.0% (1998) over this 3-yr period. The primary reason farmers planted Bt corn was to eliminate the yield loss caused by European corn borer. Scouting for European corn borers decreased from 91% (scouting 2.2 times a year) in 1996 to 75% (scouting 1.8 times a year) in 1998. The percentage of farmers not scouting for European corn borers increased from 9.6% (1996) to 25% (1998). Most farmers believed yields of Bt hybrids were either similar to or greater than the yields of non-Bt hybrids. Minnesota farmers perceived the greatest yield advantages. Farmers are becoming more aware of insect resistance management guidelines; however, they also clearly show preferences for having the flexibility to use different spatial plantings of Bt and non-Bt corn. Finally, after having planted Bt corn and obtained excellent control of European corn borer, most farmers believed that this insect had been causing more yield loss than they previously had suspected in their non-Bt corn. The data represented here provide an historical foundation for how transgenic Bt corn was used by farmers during the first 3 yr of commercial availability, their initial perceptions on the performance of this technology, and their attitudes regarding management of the European corn borer.

**KEY WORDS** European corn borer, maize, transgenic corn, Bt corn, biotechnology, survey

THE EUROPEAN CORN borer, *Ostrinia nubilalis* Hübner, is a major pest of corn, *Zea mays* L., throughout the Corn Belt of the United States. Late-stage larvae tunnel into the stalks and ear shanks, and feed directly on the kernels. Physiological damage caused by a stalk-tunneling larva can reduce grain production by 2.4–6.6% per plant (Bode and Calvin 1990). Rice (1994) determined that in Iowa cornfields in which plants were infested with multiple larvae, yield losses were as great as 32.6 bushels per acre. Southwestern corn borer, *Diatraea grandiosella* Dyar, in Kansas caused yield losses as great as 57 bushels per acre (Buschman et al. 1999). Management practices to reduce injury caused by corn borers include planting dates, planting hybrids with natural plant resistance, application of insecticides, mowing of grassy areas where moths congregate, and stalk destruction after harvest (Mason et al. 1996, Rice and Ostlie 1997). Although each of these practices can reduce European corn borer popula-

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Table 1. Plantings of Bt and non-Bt corn in six states during the first 3 yr of commercial introduction

| State | 1996 | | 1997 | | 1998 | |
|---|---|---|---|---|---|---|
| | Total corn acres (*n*) | Bt corn acres (*n*) | Total corn acres (*n*) | Bt corn acres (*n*) | Total corn acres (*n*) | Bt corn acres (*n*) |
| Illinois | 716.0 ± 51.2 (326) | 56.0 ± 3.3 (314) | 570.2 ± 27.7 (522) | 70.9 ± 4.5 (524) | 476.3 ± 26.0 (305) | 166.5 ± 10.4 (302) |
| Iowa | 442.9 ± 12.8 (745) | 49.3 ± 1.9 (729) | 360.1 ± 8.2 (1535) | 73.0 ± 2.7 (1525) | 325.0 ± 9.8 (842) | 128.8 ± 5.2 (824) |
| Kansas | 710.8 ± 99.4 (25) | 81.1 ± 11 (24) | 476.9 ± 52.5 (68) | 139.1 ± 18.5 (68) | 349.1 ± 46.5 (63) | 115.3 ± 13.1 (63) |
| Minnesota | 456.4 ± 20.2 (476) | 57.6 ± 3.4 (471) | 370.8 ± 12.7 (592) | 99.3 ± 5.1 (597) | 371.3 ± 14.8 (488) | 182.7 ± 8.9 (483) |
| Nebraska | 671.5 ± 30.3 (307) | 68.4 ± 3.6 (302) | 609.9 ± 30.8 (418) | 111.5 ± 10.6 (422) | 489.5 ± 28.9 (201) | 190.6 ± 14.2 (195) |
| Pennsylvania | 265.4 ± 23.5 (182) | 25.8 ± 2.7 (183) | 190.7 ± 20.4 (188) | 50.4 ± 7.2 (188) | 176.2 ± 32.5 (34) | 62.6 ± 21.9 (34) |
| Mean | 510.5 ± 11.9 (2,057) | 53.4 ± 1.3 (2,023) | 419.3 ± 7.7 (3,323) | 82.4 ± 2.3 (3,321) | 376.1 ± 7.9 (1,931) | 153.1 ± 4.0 (1,901) |

Data are expressed as mean ± SE.

tions, densities of corn borers often exceed established economic thresholds (Mason et al. 1996). Application of insecticides can be economically justified to control damaging populations, but insecticides are applied infrequently in some major corn-producing states (Rice and Ostlie 1997).

Genetically engineered corn that produced an insecticidal protein derived from the bacterium *Bacillus thuringiensis* (Bt) (Koziel et al. 1993) was available commercially for the first time in 1996. Transgenic corn in 1996 contained genetic event 176 (Cry1Ab protein, NatureGard or Knock*Out*). This genetic event provided full protection against first-generation larvae but only partially controlled second-generation larvae. In 1997, corn hybrids that contained genetic event Bt11 or MON810 (Cry1Ab protein, YieldGard) were marketed. These two genetic events provided full-season protection against both first and second generations of European and southwestern corn borer larvae.

The insertion of the Bt protein gene into the corn plant (i.e., making the plant transgenic) potentially improves a farmer's abilities to manage a serious insect pest. If a farmer perceives the biotechnology negatively however, this new pest management tool may not be widely adopted (Rice and Pilcher 1998). Farmers' perceptions of insect pests or innovative approaches to managing crop pests have been evaluated in several studies (Turpin and Maxwell 1976, Sisco et al. 1983, Lambur et al. 1985, Grieshop et al. 1988, Pingel 1991, Merchant and Teetes 1994, Rice and Ostlie 1997, Pilcher and Rice 1998). Researchers in the social sciences have developed a framework for analyzing human perceptions and their relation to the adoption of new technology, such as Bt corn. The process through which a new innovation or idea is communicated to and then either rejected or adopted by members of a social group over time is termed diffusion (Rogers 1995). The innovation is defined as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers 1995). The perception of transgenic corn by farmers will determine its diffusion, or rate of adoption, within the agricultural community. Fliegel (1993) predicted that a new technology would diffuse along a predictable path of awareness, interest, evaluation, trial, and adoption.

Surveys can be useful tools for evaluating farmers' perceptions of new technology (Grieshop et al. 1988). The information gained from a survey could be beneficial to a wide array of educational, regulatory, and agribusiness representatives in their attempts to understand farmers' attitudes and practices.

In 1995, Pilcher and Rice (1998) surveyed farmers and found that 57.2% reported an average loss of 5.38 bushels per acre each year from European corn borer. The remaining farmers reported no loss from European corn borer. Previous experience with European corn borer increased the level of enthusiasm and awareness of Bt corn among farmers before the seed was available to plant in 1996 (Pilcher and Rice 1998). A year before Bt corn seed was commercially available, farmers were surveyed for their perceptions on the following aspects of European corn borer management: yield loss attributable to European corn borer, mechanisms of corn borer damage, management strategies, and causes of insect mortality (Rice and Ostlie 1997, Pilcher and Rice 1998). Following the registration of Bt corn we decided to ask questions about the performance of Bt corn for managing European corn borer.

The objective of this study was to survey farmers' perceptions and practices regarding performance of Bt corn for insect protection, agronomic characteristics of Bt corn, perceptions of European corn borers,

Table 2. Percentage of acres planted to Bt corn hybrids during 1996–1998 on three farm sizes

| Year | Small farms <160 acres | Medium farms 160–520 acres | Large farms >520 acres |
|---|---|---|---|
| 1996 | 31.3% | 14.9% | 9.0% |
| 1997 | 35.0% | 22.9% | 17.3% |
| 1998 | 51.7% | 40.8% | 40.7% |
| Farm mean | 39.7% | 25.4% | 19.5% |

Table 3. Percentage of total corn acres planted to Bt corn and Bt adoption ratio (1998 acres: 1996 acres)

| State | 1996 | 1998 | Adoption ratio |
|---|---|---|---|
| Illinois | 7.8% | 35.0% | 4.5:1 |
| Iowa | 11.1% | 39.6% | 3.6:1 |
| Kansas | 11.4% | 33.0% | 2.9:1 |
| Minnesota | 12.6% | 49.2% | 3.9:1 |
| Nebraska | 10.2% | 38.9% | 3.8:1 |
| Pennsylvania | 9.7% | 35.5% | 3.7:1 |
| Mean | 10.5% | 40.7% | 3.9:1 |

**Table 4. Farmers' management of European corn borers prior to Bt corn**

| Response | 1996 ($n$ = 2,096) | 1997 ($n$ = 3,314) | 1998 ($n$ = 1,967) |
|---|---|---|---|
| Insecticide - 1st generation | 28.4% | 30.6% | 23.5% |
| Insecticide - 2nd generation | 14.6% | 15.3% | 13.2% |
| Resistant hybrids | 23.5% | 24.8% | 27.9% |
| Planting dates | 6.1% | 5.3% | 4.1% |
| Harvest early | 37.1% | 37.7% | 36.7% |
| Nothing | 41.2% | 39.6% | 41.1% |
| Other | 3.5% | 3.3% | 3.8% |

and management strategies for controlling this insect in one Eastern and five midwestern states. Data from these surveys will establish an historical perspective on early adoption of transgenic technology for control of European corn borer.

## Materials and Methods

The survey was designed as a self-administered questionnaire. Farmers had to have grown Bt corn and planted a minimum of 50 acres (Bt or non-Bt corn) to be eligible to receive a survey. During the winter or spring following the 1996, 1997, and 1998 growing seasons, farmers from Illinois, Iowa, Kansas, Minnesota, Nebraska, and Pennsylvania were randomly selected from lists provided by cooperating seed companies, and a survey was mailed to them. Sample size was determined using a stratified proportional sampling scheme (Sproull 1995). Within a given year, 25% of the farmers whose names had been provided were selected to receive a survey. Because the names were randomly selected, farmers who planted Bt corn in multiple years may have received a survey in more than one year. At least 125 surveys were mailed to farmers in each state to receive a minimum of 50 responses (assuming a 40% response rate) from each state. Total surveys mailed out each year were as follows: 4,981 (1996), 9,605 (1997), and 8,708 (1998). Any farmer on the mailing lists provided by cooperating seed companies had an equal probability of being selected. A second mailing was sent 1 mo after the first mailing if a response had not been received. Survey mailings and tabulation of raw data were conducted by Iowa Agricultural Statistics Service, Des Moines, IA.

The survey consisted of a cover letter giving a description of the purpose of the survey and inviting participation. The letter explained that the responses would be used to enhance extension education. The survey instrument included 30–35 questions (some questions were added in the later surveys) about the following topics: percentage of corn acres planted to Bt hybrids, historical and current European corn borer management practices, Bt corn performance, economics, insect resistance management, insecticide use, future management considerations with Bt corn, and sources of information. Survey questions stated herein may have been modified slightly to reflect the collective responses from all 3 yr.

Each question was subjected to a descriptive statistical analysis to identify central tendencies and to better understand the variability of the responses. Results are reported with the mean ± SEM for questions with numerical responses. Categorical questions are reported in tables as percentages of the number of respondents. Survey results were analyzed using the JMP statistical software package (SAS Institute 1995) with statistical significance set at $P = 0.05$. Inferential statistical procedures were used to answer particular hypotheses based upon responses to specific questions. Statistical tests to conduct the analyses were chi-square and analysis of variance (ANOVA) (Sproull 1995).

## Results and Discussion

Percentage response to the surveys varied among years. Completed useable surveys received by year were as follows: 2,096 (1996), 3,364 (1997), and 1,967 (1998) for a total of 7,427. The percentage responses by year were as follows: 42.1% (1996), 35.0% (1997), and 22.6% (1998). Minimum sample size was predetermined to be 50 respondents for each response category. Krejcie and Morgan (1970) had reported that 380 farmers would be the minimum needed to represent 100,000 Iowa farmers. The response rates declined by almost 50% from 1996 to 1998. Possible explanations for the decline in the response rate could have been a decreasing fascination with the Bt corn technology or less awareness of Bt corn performance, which can be deduced from the responses to some survey questions. Farmers who were less fascinated with Bt corn or less aware of its performance may have been unwilling to complete the questionnaire.

**Table 5. Insecticide use by Bt corn farmers during the 5 yr before they planted Bt corn**

| State | 1996 | | 1997 | | 1998 | |
|---|---|---|---|---|---|---|
| | Mean ± SE years 1st gen. ($n$) | Mean ± SE years 2nd gen ($n$) | Mean ± SE years 1st gen ($n$) | Mean ± SE years 2nd gen ($n$) | Mean ± SE years 1st gen ($n$) | Mean ± SE years 2nd gen ($n$) |
| Illinois | 2.2 ± 0.1 (100) | 2.0 ± 0.1 (64) | 2.4 ± 0.1 (148) | 1.8 ± 0.1 (100) | 2.2 ± 0.2 (67) | 1.8 ± 0.1 (44) |
| Iowa | 2.5 ± 0.1 (192) | 1.8 ± 0.1 (60) | 2.3 ± 0.1 (332) | 1.6 ± 0.1 (117) | 2.2 ± 0.1 (126) | 1.5 ± 0.1 (57) |
| Kansas | 3.6 ± 0.9 (5) | 4.0 ± 0.3 (17) | 3.7 ± 0.3 (21) | 4.3 ± 0.2 (38) | 3.1 ± 0.5 (14) | 4.0 ± 0.3 (22) |
| Minnesota | 1.6 ± 0.1 (108) | 1.5 ± 0.2 (28) | 1.5 ± 0.1 (163) | 1.3 ± 0.1 (40) | 1.6 ± 0.1 (120) | 1.5 ± 0.1 (53) |
| Nebraska | 3.3 ± 0.1 (195) | 3.0 ± 0.1 (174) | 3.5 ± 0.1 (242) | 3.0 ± 0.1 (182) | 3.4 ± 0.1 (92) | 2.6 ± 0.1 (73) |
| Pennsylvania | 3.8 ± 0.2 (48) | 1.9 ± 0.3 (9) | 4.0 ± 0.2 (49) | 4.0 ± 0.4 (12) | 4.5 ± 0.3 (11) | 2.0 (1) |
| Mean | 2.7 ± 0.1 (648) | 2.5 ± 0.1 (352) | 2.6 ± 0.1 (955) | 2.4 ± 0.1 (489) | 2.4 ± 0.1 (430) | 2.1 ± 0.1 (250) |

**Table 6. Farmers' reasons for planting a Bt corn hybrid (multiple responses allowed)**

| Response | 1996 ($n$ = 2,042) | 1997 ($n$ = 3,320) | 1998 ($n$ = 1,967) |
|---|---|---|---|
| 1. prevent yield loss | 85.0% | 69.1% | 82.0% |
| 2. eliminate field scouting | 11.9% | 12.5% | 11.2% |
| 3. eliminate insecticide for corn borer | 30.7% | 29.5% | 27.1% |
| 4. experience with company hybrids | 28.0% | 17.9% | 17.3% |
| 5. university trial performance | — | 7.2% | 9.6% |
| 6. seed company trial performance | — | 19.0% | 21.6% |
| 7. neighbor's experience with Bt corn | — | 5.4% | 10.0% |
| 8. other | 9.4% | 5.3% | 7.4% |

Responses to the first two questions allowed us to make an assessment of the adoption of Bt corn over time.

**1. How many acres of field corn did you plant in (the respective year)?**

**2. How many of those acres were planted to Bt corn?** The amount of Bt corn acreage among the farmers surveyed increased substantially during the first 3 yr of commercial availability from 10.5% of their acres in 1996 to 19.7% in 1997 and 40.7% in 1998 (Table 1). We divided farms into three categories (small, <160 acres; medium, 160–520 acres; large >520 acres) based on a distribution of farm sizes. Significant differences were detected for farm size ($F$ = 250.2; df = 2, 8; $P$ < 0.0001) and across years ($F$ = 614.3; df = 2, 8; $P$ < 0.0001) in the amount of Bt corn acres planted (Table 2). Small farms had more acres, as a percentage, planted to Bt corn than medium or large farms, and there was a significant farm size-by-year interaction ($F$ = 7.7; df = 4, 8; $P$ < 0.0001). More Bt corn was planted on small farms earlier than on large farms, but the percentage increase of Bt corn acreage on small farms reflected was slower during 1996–1998 than the percentage increase in Bt corn acreage on large farms (Table 2). These differences probably reflect the increasing availability of Bt seed over time. Rate of adoption in the six states after 3 yr was highest among Illinois farmers, primarily because their initial acreage in 1996 was the lowest among the states surveyed (Table 3). Kansas farmers had the lowest adoption ratio of Bt corn.

The states with the highest percentages of acres to Bt corn were Minnesota, Iowa, and Nebraska (Table 3). Recent communications with industry personnel suggest that the rates of increase of Bt corn acreage leveled off during 1999 and 2000.

**3. During the 5-yr period of 1991–1995 (before Bt corn was introduced), what steps did you take to minimize yield losses from European corn borers? (multiple answers allowed).** Approximately 4 of 10 Bt corn farmers did nothing to minimize yield losses from European corn borers before Bt corn became available, although several pest management options were available (Table 4). We suspect that a primary reason for farmers adopting Bt corn was that Bt corn afforded excellent control of European corn borer, a pest they had rarely managed, for various reasons, in the past.

Before the availability of Bt corn, ≈37% of the farmers had harvested their fields early in an attempt to prevent yield losses from dropped ears or broken stalks in heavily infested fields. A similar response (44%) was observed by Pilcher and Rice (1998). Unfortunately, this cultural method of control does not prevent physiological damage from European corn borers feeding in stalks or shanks, resulting in reduced number of kernels or reduced kernel size. Early harvest only prevents the loss of ears that otherwise would fall to the ground.

Insecticides to control first-generation European corn borers were used by ≈27% of the farmers. Insecticides for control of second-generation larvae were used less frequently (≈14% of the farmers). These responses were similar to responses to a 1995 survey; 26.3% of the growers reported using synthetic insecticides to manage European corn borer (Pilcher and Rice 1998). In the 1995 survey, ≈32% of the growers reported doing nothing to control European corn borer. Of the farmers that had not used insecticides previously to control European corn borer, only 26.8% said they would spray if treatment were warranted (Pilcher and Rice 1998). For many farmers, ignoring the pest is easier than controlling the pest because of the difficulties associated with scouting, calculating economic thresholds, and determining the proper time to apply an insecticide (Mason et al. 1996).

Before Bt corn was available, ≈25% of the farmers attempted to control European corn borers with hybrids with traditional forms of resistance. Many commercial corn hybrids contain high concentrations of 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA) (Mason et al. 1996), which offers some protection against leaf feeding and stalk tunneling from first generation larvae but no protection against second-generation larvae.

Planting corn as early as possible in the spring has been recommended to diminish the effects of second-generation European corn borers (Mason et al. 1996).

**Table 7. Number of times farmers scouted their Bt corn fields for European corn borers**

| Response | 1996 ($n$ = 2,045) | 1997 ($n$ = 3,318) | 1998 ($n$ = 1,962) |
|---|---|---|---|
| Never did | 9.6% | 17.1% | 25.0% |
| 1 time | 11.2% | 15.9% | 20.6% |
| 2 times | 29.4% | 29.6% | 27.8% |
| 3 times | 20.6% | 16.9% | 12.8% |
| 4 or more | 29.0% | 20.5% | 13.6% |

**Table 8. Percentage of farmers finding European corn borer in Bt corn**

| Response | 1996 ($n$ = 2,034) | 1997 ($n$ = 3,283) | 1998 ($n$ = 1,962) |
|---|---|---|---|
| No | 64.5% | 66.1% | 61.2% |
| Yes | 26.6% | 19.6% | 16.2% |
| I don't know | 8.9% | 14.3% | 22.4% |

**Table 9. Farmer perceptions of first- and second-generation European corn borer control**

| Category | 1996 | | 1997 | | 1998 | |
|---|---|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd | 1st | 2nd |
| Poor | 0.3% | 1.9% | 0.9% | 1.7% | 0.7% | 0.9% |
| Fair | 2.6% | 11.5% | 2.1% | 4.7% | 2.4% | 4.3% |
| Good | 35.9% | 50.8% | 27.2% | 32.0% | 30.6% | 33.6% |
| Outstanding | 55.5% | 26.7% | 62.1% | 53.1% | 50.5% | 42.2% |
| Don't know | 5.5% | 9.2% | 7.7% | 8.4% | 15.0% | 17.2% |

Under ideal planting conditions, 91% of the farmers can complete their spring planting in less than 10 d. During the early and mid-1990s however, only ≈50% of the planting in Iowa has been completed by the 15 May recommended cutoff date for spring planting (National Agricultural Statistics Service 1998).

**4a. Out of those 5 yr, how many years did you use an insecticide against first-generation larvae?**

**4b. Out of those 5 yr, how many years did you use an insecticide against second-generation larvae?** During the 5 yr before the introduction of Bt corn, farmers who used insecticides to manage first-generation European corn borers did so about half the time, but this practice varied widely among states (Table 5). Pennsylvania farmers had the highest incidence of insecticide use for control of first-generation European corn borers, applying insecticides an average of 3.8–4.5 yr out of 5. In contrast, Minnesota farmers rarely sprayed for European corn borer early in the season; they used insecticides to control first-generation larvae an average of 1.5–1.6 yr out of 5.

Insecticide use for control of second-generation European corn borers during the same 5-yr period occurred slightly less frequently in five of the six states. In Kansas, insecticide use for second-generation borers occurred more often than the use of insecticides to control first-generation borers. Farmers in this western Corn Belt state applied insecticides to control second-generation corn borers at least four out of 5 yr. This higher level of insecticide use for second-generation European corn borers, relative to the other five states, may reflect the compounded damage potential of both the European and southwestern corn borers during late summer. In general, insecticide use against European corn borer is much higher in the western Corn Belt and therefore, Bt corn would provide the greatest environmental benefit in this region.

Past insecticide use did not significantly ($F = 1.64$; df = 1, 7,199; $P = 0.20$) influence the percentage of Bt corn that was planted on a farm where insecticides had been used (26.6%) or where no insecticides had been used (27.1%).

**Table 10. Yield performance of Bt corn hybrids compared with non-Bt corn hybrids**

| Response | 1996 ($n$ = 2,036) | 1997 ($n$ = 2,848) | 1998 ($n$ = 1,956) |
|---|---|---|---|
| Lower | 21.6% | 7.6% | 7.0% |
| Similar | 32.2% | 28.7% | 41.2% |
| Higher | 42.2% | 57.4% | 44.9% |
| I don't know | 4.0% | 6.4% | 7.0% |

Of the farmers who had used insecticides, 46.6% believed that insecticide use would decrease. However, 13.7% believed that insecticide use would increase after the commercialization of Bt corn. These percentages are similar to the predictions of farmers surveyed in 1995 (Pilcher and Rice 1998). Without segregating insecticide users, ≈53% of the farmers believed that the use of Bt corn would decrease the need to use insecticides, whereas 14.2% believed that scenario would be unlikely (Pilcher and Rice 1998). Although history of insecticide use has not affected the rate of adoption of Bt corn, it is likely that the eventual adoption of Bt corn will greatly affect the future use of insecticides in regions where insecticides traditionally have been used to manage European corn borer (question 21). To examine this expectation, the states were divided between those representing the western Corn Belt (Kansas and Nebraska) and the rest of the Corn Belt. In the western region, the percentage of farmers who believed insecticide use would decrease after Bt corn was introduced increased from 30.5% in 1996 to 46.6% in 1998. For the rest of the Corn Belt, the response increased from 9.9% in 1996 to 22.8% in 1998.

**5. What was your primary reason for planting a Bt corn hybrid?**

(1) Prevent yield loss from European corn borer.
(2) Eliminate field scouting for European corn borer.
(3) Eliminate need of insecticide for European corn borer control.
(4) Previous experience with the company's hybrids.
(5) Performance in university field trials.
(6) Performance in seed company field trials.
(7) Neighbor's experience with Bt corn.
(8) Other, please list.

The principal reason farmers planted Bt corn in any year was to prevent yield loss caused by European corn borers. The percentage of Bt corn farmers who indicated this reason was substantially larger than the responses to any reasons. There were no significant differences in responses from any state across all 3 yr ($F = 2.27$; df = 5, 18; $P = 0.13$). The secondary reason for using Bt hybrids was to eliminate the need for insecticides for European corn borer control, but there were significant differences among states. The desire to eliminate the need for insecticides by using Bt corn was significantly greater ($F = 51.1$; df = 5, 18; $P < 0.0001$) for Bt corn farmers in Kansas (50.0%) and Nebraska (48.5%) than in Minnesota (28.1%), Illinois, (26.9%), Iowa, (24.1%), and Pennsylvania (16.4%). This response among all Bt corn farmers did not

**Table 11. Yield performance of Bt corn hybrids compared with non-Bt corn hybrids**

| Response | Illinois ($n$ = 1,064) | Iowa ($n$ = 2,896) | Kansas ($n$ = 146) | Minnesota ($n$ = 1,486) | Nebraska ($n$ = 858) | Pennsylvania ($n$ = 390) |
|---|---|---|---|---|---|---|
| Lower | 11.1% | 11.5% | 15.8% | 10.0% | 15.4% | 9.5% |
| Similar | 35.0% | 34.5% | 33.6% | 26.7% | 36.1% | 38.7% |
| Higher | 51.5% | 50.6% | 48.0% | 60.2% | 45.8% | 47.4% |
| I don't know | 2.4% | 3.5% | 2.7% | 3.2% | 2.7% | 4.4% |

change significantly over time ($F = 3.13$; df = 3, 18; $P = 0.09$). In 1995, 71.3% of Iowa farmers thought that less insecticide exposure to farm workers was a "very important" advantage to using Bt corn, and less insecticide exposure was viewed to be slightly more important than "better yields" (Pilcher and Rice 1998). The primary reasons for planting Bt corn reversed after the commercial release of Bt corn, with prevention of yield loss dominating any concern over eliminating insecticide use (Table 6). The third most common reason for planting Bt corn was to eliminate field scouting for European corn borers. Nebraska farmers offered the greatest response (17.8%) to this category, which was significantly greater ($F = 15.2$; df = 5, 18; $P = 0.0002$) than for farmers in Minnesota (12.6%), Illinois, (11.0%), Iowa, (10.8%), and Kansas (10.0%). Pennsylvania Bt corn farmers (2.7%) had indicated very little interest in using Bt corn for reducing field scouting for the European corn borer. There were no significant differences among states or across years for the following reasons to plant Bt corn: previous experience with a company's hybrids, performance in university or seed company trials, or a neighbor's experience with Bt corn (Table 6).

**6. How many times did you scout your Bt corn for European corn borers or their damage?** During the first year of commercial planting, nearly 91% of the farmers scouted their Bt corn for European corn borer larvae (or evidence that Bt corn was actually controlling this pest). By 1998, only 75% of the farmers scouted Bt corn for European corn borer larvae (Table 7). The average number of times Bt corn fields were scouted decreased significantly from 2.6 times per season in 1996 to 2.2 times in 1997 and 1.8 times in 1998 ($F = 144.1$; df = 2, 18; $P < 0.0001$). This trend was predicted by Iowa farmers in 1995 when 52.3% said that it was likely that farmers growing Bt corn would spend less time scouting for corn pests (Pilcher and Rice 1998). Kansas and Nebraska farmers scouted their fields the most number of times per season, 2.7 and 2.5 times, respectively, significantly more than in Iowa and Pennsylvania, which were scouted 1.9 and 1.8 times, respectively ($F = 54.5$; df = 5, 18; $P < 0.0001$). Survey responses suggested that by the third year that Bt corn was planted, a greater number of farmers were scouting their fields one time for European corn borers, but more farmers were not scouting at all. The percentage of farmers scouting their Bt corn multiple times also decreased from 1996 to 1998. They probably assumed that Bt corn was providing an acceptable level of insect control, and it was not necessary to validate this through field scouting.

**7. Did you find European corn borer larvae in your Bt corn?** Responses to this question reflected three possible situations. First, the percentage of farmers who found what they thought were European corn borers in their Bt corn declined from 1996 to 1998 (Table 8). In 1996, only Knock*Out*/NatureGard hybrids (event 176) were planted. Plants expressing event 176 did not completely control second-generation larvae. In 1998, Knock*Out*/NatureGard comprised only 13.3% of the total Bt acreage among survey respondents. The rest of the acres were planted with YieldGard hybrids (event Bt11 and MON810), which provide season-long control of European corn borers. Second, the high percentages of Bt corn farmers who indicated they found European corn borers or their damage in Bt corn may have been incorrect identifications. Several other lepidopterous larvae, such as southwestern corn borer, corn earworm [*Helicoverpa zea* (Boddie)], the bean cutworm *Loxagrotis albicosta*, armyworm [*Pseudaletia unipuncta* (Hawthorn], and stalk borer [*Papaipema nebris* (Guenée)] may attack and damage Bt corn ears or stalks. These larvae may have been misidentified as European corn borers. Third, the number of farmers who did not know whether they had an European corn borer infestation in their Bt corn nearly tripled over the 3-yr period. As farmers became more comfortable or familiar with the

**Table 12. Yield performance differences (bushels/acre) quantified between Bt and non-Bt corn**

| State | 1996 | | 1997 | | 1998 | |
|---|---|---|---|---|---|---|
| | Mean ± SE lower yields ($n$) | Mean ± SE higher yields ($n$) | Mean ± SE lower yields ($n$) | Mean ± SE higher yields ($n$) | Mean ± SE lower yields ($n$) | Mean ± SE higher yields ($n$) |
| Illinois | 14.3 ± 1.3 (56) | 11.7 ± 0.6 (141) | 13.5 ± 1.7 (47) | 16.1 ± 0.5 (328) | 14.9 ± 2.4 (24) | 9.2 ± 0.5 (114) |
| Iowa | 16.5 ± 0.9 (178) | 11.1 ± 0.4 (294) | 13.5 ± 1.0 (117) | 14.2 ± 0.2 (900) | 14.0 ± 1.5 (60) | 9.8 ± 0.4 (331) |
| Kansas | 18.1 ± 1.5 (9) | 12.4 ± 3.6 (5) | 18.3 ± 3.4 (8) | 16.2 ± 1.8 (32) | 12.0 ± 2.1 (6) | 8.4 ± 0.9 (30) |
| Minnesota | 12.3 ± 0.8 (98) | 10.9 ± 0.4 (234) | 11.4 ± 0.8 (38) | 19.4 ± 0.5 (421) | 15.1 ± 3.5 (22) | 11.7 ± 0.4 (264) |
| Nebraska | 18.0 ± 1.4 (89) | 10.0 ± 0.7 (100) | 18.1 ± 2.0 (29) | 17.2 ± 0.7 (232) | 17. ± 3.7 (20) | 10.5 ± 0.9 (66) |
| Pennsylvania | 21.0 ± 5.2 (17) | 16.0 ± 1.2 (76) | 18.4 ± 3.7 (23) | 15.0 ± 1.6 (46) | 1 (1) | 9.1 ± 0.0 (12) |
| Mean (bushels/acre) | 15.8 ± 0.6 (447) | 11.5 ± 0.3 (850) | 14.3 ± 0.7 (262) | 16.0 ± 0.2 (1959) | 14.7 ± 1.1 (133) | 10.3 ± 0.2 (817) |

**Table 13. Standability of Bt corn compared to non-Bt corn**

| Response | 1996 ($n$ = 2,045) | 1997 ($n$ = 3,054) | 1998 ($n$ = 1,930) |
|---|---|---|---|
| Worse | 6.6% | 16.9% | 9.3% |
| Similar | 21.9% | 13.9% | 24.7% |
| Better | 70.3% | 63.9% | 54.3% |
| I don't know | 1.3% | 5.3% | 11.8% |

technology, they scouted their Bt fields for European corn borers less frequently.

**8. How would you rate the level of control for European corn borer in the Bt corn? (circle the corresponding answer) (first = first generation; second = second generation).** For all Bt events for all 3 yr, farmers judged control of second-generation European corn borers to be slightly worse (smaller percentage selecting outstanding control) than control of first-generation borers (Table 9). However, judgments of effectiveness of YieldGard and Knock*Out*/NatureGard hybrids were different. The 2-yr (1997 and 1998) average response within the outstanding category for YieldGard was 60% for first generation and 55% for second generation. For Knock*Out*/NatureGard (3-yr average), 55% of farmers rated control of first-generation larvae as outstanding. In stark contrast, only 29% of the farmers rated Knock*Out*/NatureGard hybrids as outstanding for control of second-generation larvae. The differences in responses observed in 1996 compared with responses from 1997 and 1998 are due primarily to the differences in Bt hybrid performance, but also reflect yearly differences in European corn borer pressure. Significant differences in European corn borer control among the different transgenic events have been documented (Ostlie et al. 1997), and farmers have confirmed these findings. In addition, densities of European corn borers in 1997 were very large; therefore, "good" or "outstanding" control was easier to measure.

**9. How would you rate the grain yields of Bt corn compared with similar maturity non-Bt hybrids you planted on about the same date?** Farmers' perception about Bt corn yields changed significantly from 1996 to 1998 ($\chi^2 = 405.9$; df = 4, 6,616; $P < 0.0001$). During 1996, one out of five farmers thought that the Bt hybrids produced lower yields than their non-Bt hybrids (Table 10). This perception may have reflected the inability of the Knock*Out*/NatureGard hybrids to completely control second-generation European corn borers, thereby resulting in some yield losses. During the second and third years of Bt corn availability, farmers planted a wider range of new hybrids with events Bt11 and MON810, which expressed full-season European corn borer control. Farmers' responses during 1997 and 1998 indicated a better level of yield performance from the transgenic hybrids.

Obtaining better yields was listed as one of the most important advantages of Bt corn (Pilcher and Rice 1998, table 5). These farmer responses suggest that Bt corn hybrids performed well, especially in years when infestations of European corn borers were substantially large.

Approximately half the farmers during the 3-yr study thought that their Bt hybrids produced higher yields than non-Bt hybrids planted at the same time. Bt corn farmers in Minnesota reported significantly greater yields than farmers from all other states. More than 60% of them said their Bt corn yields were higher than their non-Bt yields (Table 11). More farmers in Nebraska and Kansas reported lower Bt corn yields. Responses from Iowa, Illinois, and Pennsylvania were similar. The greatest influence on whether a Bt corn hybrid will have a yield advantage over a non-Bt hybrid, besides the presence or absence of European corn borer, is hybrid genetics. The Bt trait is of greater value in a hybrid with superior genetics. It is possible that seed companies have chosen better Bt trait recipients among the earlier maturing hybrids that are typically grown in the northern Corn Belt.

**10. If the yields were lower, how much lower were they? If the yields were higher, how much higher were they?** In 1996, the ratio of farmers who reported higher yields to those who reported lower yields was almost 2–1; in 1997, the ratio was more than 7–1; in 1998, the ratio was ≈6 to 1 (Table 12). The average responses for lower grain yields from Bt hybrids across all six states were remarkably similar during the 3 yr and varied by only 1.5 bushels per acre (Table 12). In contrast, there was more variability in the response for higher yields with an average of 16 bushels per acre in 1997 and 10.3 bushels per acre in 1998, a difference of 5.7 bushels per acre. In 1996, farmers in Pennsylvania reported that Bt corn yielded an average of 21 bushels per acre less than non-Bt corn. The following year, farmers in Minnesota reported that Bt corn yielded an average of 19.4 bushels per acre more than non-Bt

**Table 15. Harvest grain moisture of Bt corn compared to non-Bt corn across years**

| Response | 1996 ($n$ = 2,041) | 1997 ($n$ = 2,908) | 1998 ($n$ = 1,899) |
|---|---|---|---|
| Worse | 3.3% | 34.9% | 23.2% |
| Similar | 19.7% | 40.4% | 44.1% |
| Better | 72.8% | 17.2% | 16.4% |
| I don't know | 4.2% | 7.5% | 16.3% |

**Table 14. Grain quality of Bt corn compared with non-Bt corn**

| Response | 1996 ($n$ = 2,042) | 1997 ($n$ = 2,925) | 1998 ($n$ = 1,914) |
|---|---|---|---|
| Worse | 4.2% | 3.4% | 2.8% |
| Similar | 49.0% | 47.7% | 52.6% |
| Better | 36.9% | 39.8% | 28.6% |
| I don't know | 9.8% | 9.1% | 16.0% |

**Table 16. Farmers' perceptions on the economic return of Bt corn compared with non-Bt corn**

| Response | 1996 ($n$ = 2,049) | 1997 ($n$ = 3,271) | 1998 ($n$ = 1,960) |
|---|---|---|---|
| Worse | 27.1% | 11.5% | 16.4% |
| Similar | 22.9% | 17.3% | 25.5% |
| Better | 44.3% | 64.1% | 48.5% |
| I don't know | 5.8% | 7.0% | 9.6% |

**Table 17. Farmers' perceptions about the economic returns of Bt corn compared with non-Bt corn across states**

| Response | Illinois ($n$ = 1,135) | Iowa ($n$ = 3,106) | Kansas ($n$ = 155) | Minnesota ($n$ = 1,578) | Nebraska ($n$ = 905) | Pennsylvania ($n$ = 401) |
|---|---|---|---|---|---|---|
| Lower | 16.2% | 18.6% | 18.1% | 15.3% | 18.6% | 13.2% |
| Similar | 23.7% | 20.6% | 27.7% | 18.6% | 21.7% | 23.4% |
| Higher | 53.7% | 52.8% | 47.7% | 59.5% | 53.8% | 50.9% |
| I don't know | 6.3% | 7.9% | 6.5% | 6.6% | 5.9% | 12.5% |

corn. Again this difference may be attributed to the background genetics of the hybrids available to specific growing regions. Certain hybrids may have a greater yield response from the protection provided by the Bt trait compared with other hybrids. Environmental conditions also contribute to yield variations. Quantifying the environmental effects on yield and the responses based on presence or absence of European corn borer damage is difficult and can only be speculated upon during any given year.

**11. How would you rate the following performance characteristics of the Bt corn hybrid compared with a similar maturity non-Bt hybrid that you planted on about the same date?** Perception of standability changed over the 3-yr period. In 1998, 11.8% of the farmers reported that they did not know whether Bt corn stood better in the field than non-Bt corn, compared with 1.3% in 1996 (Table 13). Significant differences were reported in Bt corn standability across years ($\chi^2 = 240.3$; df = 4, 6,608; $P < 0.0001$). Significant lodging of Bt corn was reported in 1997, with 16.9% of the farmers indicating standability of Bt corn was worse than standability of non-Bt corn. Reasons for excessive lodging in 1997 were blamed on drought stress followed by a weakening of the corn stalk. During dry weather, carbohydrates stored in the roots and stalks are moved to the developing ear causing a loss of resistance to soil-borne pathogens such as stalk rot (Spangler 1997). High temperatures at this time increase the rate at which these pathogens enter and infect the stalk. YieldGard Bt hybrids will not lodge as a result of tunneling from European corn borer, and they often yield more bushels per acre than similar non-Bt hybrids. Higher yields (i.e., larger ears, more kernels per ear) place greater physical and physiological demand on stalks weakened by environmental stresses and pathogens. Therefore, high-yielding corn often is more susceptible to lodging from high winds late in the season (Spangler 1997).

Significant differences in farmers' perceptions of grain quality were observed across the 3 yr ($\chi^2 = 47.8$; df = 4, 6,102; $P < 0.0001$) (Table 14). A small percentage of farmers reported that grain quality was worse in their Bt hybrids than in their non-Bt hybrids. However, most farmers reported either no difference or improved grain quality in their Bt hybrids. Improved grain quality may indicate that fewer or no European corn borers had damaged the ears, which could translate into a reduction in ear rot fungi, such as Fusarium (Munkvold et al. 1997, Munkvold et al. 1999).

Moisture levels in Bt grain at harvest in 1996 were rated substantially better (i.e., drier) than in non-Bt grain (Table 15). This perception changed dramatically during 1997 and 1998, when 7–10 times more farmers thought moisture levels were considerably worse (i.e., wetter) in Bt corn ($\chi^2 = 2{,}095.8$; df = 4, 6,229; $P < 0.0001$). One plausible reason for the differences in grain moisture is that in years where high populations of European corn borer occurred, non-Bt corn would be more susceptible to early plant death as a result of stalk tunneling, which translates into lower grain moisture levels during harvest. In 1997 and 1998, YieldGard hybrids did not have stalk tunneling by late-season larvae, resulting in greener stalks with higher moisture levels at harvest. The percentage of farmers who did not know about grain differences in grain moisture levels between Bt and non-Bt hybrids increased nearly four-fold during the 3 yr. This suggests that Bt corn farmers may have accepted the fact that Bt corn contains more moisture at harvest and they are less inclined to make hybrid comparisons.

**12. Considering the additional price premium for Bt corn seed, how does the economic return of Bt corn compare with similar non-Bt hybrids?** Responses to this question were significantly different across years ($\chi^2 = 320.3$; df = 4, 6,739; $P < 0.0001$). In 1997, when European corn borer pressure was high, farmers reported better returns (64.1%) from Bt corn than in 1996 (44.3%) and 1998 (48.5%) (Table 16). Hyde et al. (2001) developed a model that suggests the value of protection offered by Bt corn is generally lower than the current seed premium paid for the Bt technology in Indiana. In addition, they state that the economic value of Bt corn may exceed the current premiums for farmers with higher-than-average yields or who have a 40% or greater probability of an European corn borer infestation. Farmers will not recover the cost of their investment (premium paid for Bt seed) in Bt corn if densities of European corn borers do not reach or exceed economic levels, assuming all other factors are equal. Therefore, they lose money if they invest in Bt corn and European corn borer populations are small, i.e., noneconomic.

**Table 18. Percentage of farmers indicating they would plant 100 percent of their acres to Bt corn if given the option (subdivided by year)**

| Response | 1996 ($n$ = 2,080) | 1997 ($n$ = 3,327) | 1998 ($n$ = 1,956) |
|---|---|---|---|
| No | 70.5% | 73.4% | 78.0% |
| Yes | 15.0% | 14.8% | 12.3% |
| Undecided | 14.6% | 11.8% | 9.7% |

**Table 19. Percentage of farmers indicating they would plant 100% of their acres to Bt corn in 1996 and 1998 if given the option (subdivided by state)**

| Response | Illinois | | Iowa | | Kansas | |
|---|---|---|---|---|---|---|
| | 1996 ($n$ = 320) | 1998 ($n$ = 308) | 1996 ($n$ = 751) | 1998 ($n$ = 851) | 1996 ($n$ = 27) | 1998 ($n$ = 63) |
| No | 70.5% | 85.4% | 73.4% | 77.7% | 78.0% | 73.0% |
| Yes | 15.0% | 6.8% | 14.8% | 12.8% | 12.3% | 17.5% |
| Undecided | 14.6% | 7.8% | 11.8% | 9.5% | 9.7% | 9.5% |

Data from 1997 not included because composite data (Table 18) for this year were inside the range of 1996–1998 data.

The difficulty associated with developing an economic model is that many assumptions have to be made with regards to the biology of an insect. While models may be good tools to understand all the variables involved, no model has yet been developed that will make a recommendation on whether a farmer should or should not grow Bt corn. In any given year, unpredicted outbreaks of European corn borer can occur (Rice and Ostlie 1997), which underscores the difficulty of forecasting insect damage.

There was not much variability among responses to question 12 across states, but significant differences were observed ($\chi^2$ = 35.2; df = 10, 6,733; $P < 0.0001$) (Table 17). A greater percentage of Minnesota respondents reported higher economic returns from Bt corn (59.5%) than in the other five states. The lowest economic returns were reported from Kansas; 45.8% of the farmers reported economic returns from Bt corn that were similar to or lower than economic returns from non-Bt corn. Responses from the rest of the states were similar. These responses in Table 17 are similar to the responses in Table 11; perceived economic return is related directly to yield.

**13. Would you plant 100% of your acres to Bt corn if seed were available?** There were significant differences among the responses to this question across years ($\chi^2$ = 25.0; df = 2,7; $P < 0.0001$) (Table 18) and across states ($\chi^2$ = 58.9; df = 5, 7; $P < 0.0001$) (Tables 19 and 20). The overall percentage of farmers who indicated a desire to plant all of their acres to Bt corn declined from 15.0% in 1996 to 12.3% in 1998. In addition, the percentage of farmers who were undecided decreased from 14.6% in 1996–9.7% in 1998. Exceptions to this trend occurred in Minnesota and Kansas. There was only a slight increase from 1996 to 1998 in the percentage of farmers in Minnesota who indicated they would plant 100% of their acres to Bt corn. However, the percentage of farmers in Kansas who indicated they would plant 100% of their acres to Bt corn increased by 5.2% from 1996 to 1998. Farmers in Kansas probably want to use Bt corn as a tool for managing southwestern corn borers to prevent the stalk girdling that can result in losses of 57 bushels per acre (Buschman et al. 1999).

**14. Are European corn borers a consistent pest problem on your farm?**

(1) No, corn borers have never been a consistent problem anywhere on my farm.
(2) No, corn borers are not a consistent problem, but certain fields on my farm are more likely to have problems than other fields.
(3) Yes, corn borers are a consistent problem, but usually only in a few fields.
(4) Yes, corn borers are a consistent problem in most of my fields.
(5) I don't know.

European corn borer infestations were large in several midwestern states in 1997 and then declined to lower levels in 1998, which was reflected in the different responses to this question in 1997 and 1998. It is evident that farmers' answers to this question were dependent upon observations from the previous year. In 1997, 66.9% of the farmers said European corn borer was a consistent problem, compared with 50.7% in 1998 ($\chi^2$ = 164.7; df = 4, 5,268; $P < 0.0001$) (Table 21). Farmers in Nebraska and Kansas indicated during both years that European corn borers were a consistent problem: 1997 = 84% and 78%, respectively; 1998 = 57 and 57%, respectively.

**15. Did you intentionally plant Bt corn at a specific time during your spring planting to improve the effectiveness of Bt corn?** There were no differences between the first year and the third year for whether Bt corn was planted intentionally at a specific time to improve its effectiveness in controlling European corn borers ($\chi^2$ = 0.40; df = 1, 6; $P < 0.53$). The average responses were as follows: no (79.8%); yes, early

**Table 20. Percentage of farmers indicating they would plant 100% of their acres to Bt corn in 1996 and 1998 if given the option (subdivided by state)**

| Response | Minnesota | | Nebraska | | Pennsylvania | |
|---|---|---|---|---|---|---|
| | 1996 ($n$ = 486) | 1998 ($n$ = 498) | 1996 ($n$ = 307) | 1998 ($n$ = 201) | 1996 ($n$ = 188) | 1998 ($n$ = 35) |
| No | 74.7% | 76.1% | 68.7% | 74.6% | 56.4% | 74.3% |
| Yes | 14.4% | 14.7% | 13.3% | 11.4% | 23.9% | 11.4% |
| Undecided | 10.9% | 9.2% | 17.9% | 13.9% | 19.7% | 14.3% |

Data from 1997 not included because composite data (Table 18) for this year were inside the range of 1996–1998 data.

Table 21. Farmers' perceptions about the consistency of European corn borer as a pest on their farms

| Response[a] | 1997 ($n$ = 3,322) | 1998 ($n$ = 1,966) |
|---|---|---|
| No, never a problem | 11.7% | 18.6% |
| No, not a consistent problem | 18.5% | 26.1% |
| Yes, problem in few fields | 26.4% | 25.4% |
| Yes, problem in most fields | 40.5% | 25.3% |
| I don't know | 3.1% | 4.6% |

[a] This question was not asked in the 1996 survey.

(16.4%); yes, middle (1.9%) and yes, late (1.9%) (Tables 22 and 23). However, there were differences among states ($\chi^2 = 27.6$; df = 5, 6; $P < 0.0001$) across all years. In some states there were trends for an increase in early plantings of Bt corn from 1996 to 1998. This trend might reflect the adoption of recommendations regarding the best management practices for Bt corn (Ostlie et al. 1997). Benefits may not always be achieved with Bt corn by planting either early or late to control the first and second generation, respectively (Pilcher and Rice 2001). Results from a 3-yr study (1996–1998) in which planting dates were evaluated revealed that European corn borer egg-laying can be manipulated with different planting dates, but egg densities were not highly correlated with subsequent damage and yield losses (Pilcher and Rice 2001).

**16. What planting pattern did you use with your Bt corn hybrid?**

(1) It was planted as a block in one field.
(2) It was planted as several blocks in several fields.
(3) It was planted as single or several rows alternated with single or several rows of a non-Bt corn hybrid.
(4) It was planted as large strips alternated with large strips of a non-Bt corn hybrid.
(5) It was planted as a mixture with Bt and non-Bt seed together in the seed box.
(6) It was planted as a border around a field of non-Bt corn.
(7) Other.

Groups of scientists and practitioners have met to discuss options available to delay insect resistance to Bt corn (Ostlie et al. 1997, Caprio et al. 1998). A general consensus among many entomologists is that growers should plant a refuge. In the context of European corn borer management, a refuge is defined as adjacent non-Bt corn where susceptible European corn borers will survive and hopefully mate with any moths that survive in Bt corn (Ostlie et al. 1997). In 1995, farmers were asked, "Who should be responsible for developing a management plan for delaying European corn borer resistance to Bt corn?" (Pilcher and Rice 1998). Responses were as follows: seed industry (75%), university scientists (66%), and farmers (31%). When farmers were asked what information they needed to make informed decisions on Bt corn, the second most frequent response (after yield) was a desire for more information about how to plant Bt corn in conjunction with a refuge.

Currently there are differences of opinions on what constitutes an effective refuge, how large the refuge should be, and the refuge's proximity to Bt corn. Furthermore, there is limited knowledge about the best way to incorporate a refuge plan into a farming system. McGaughey et al. (1998) and Caprio et al. (1998) addressed the need for research regarding practical aspects of implementing and managing refuges. We report here how farmers incorporated the refuge concept in 1996–1998 (Table 24).

Planting patterns of Bt corn changed among years ($\chi^2 = 228.6$; df = 12, 7,249; $P < 0.0001$) (Table 24). Slightly >6 out of 10 farmers planted a large majority of Bt corn as single blocks in single fields during 1996. The availability of Bt seed for planting during this first year was limited. However, the number of Bt corn hybrids available for planting increased during 1997 and 1998. As more Bt corn seed became available, farmers planted more Bt corn in several fields, in large strips, and as a border around a field of non-Bt corn.

Planting patterns with Bt corn were significantly different ($\chi^2 = 135.0$; df = 30, 7,231; $P < 0.0001$) among states. Kansas farmers (66.9%) planted more Bt corn as blocks in individual fields than farmers in other states (Illinois 51.7%, Iowa, 53.9%, Minnesota, 54.4%, and Nebraska 58.7%). Pennsylvania farmers planted the least amount of Bt corn acres in single blocks. There were no significant differences among states in the percentages of Bt corn planted as several blocks in several fields, alternating single or several rows of Bt corn with non-Bt corn, large strips, mixed seed, or border plantings.

**17. If a seed company, seed dealer, or Extension specialist recommended a resistance management strategy, would you follow it?.**

(1) No, I have no interest in delaying European corn borer resistance to Bt corn.

Table 22. Farmers' decisions to intentionally plant Bt corn at a specific time to improve the effectiveness of Bt corn

| Response | Illinois 1996 ($n$ = 308) | Illinois 1998 ($n$ = 307) | Iowa 1996 ($n$ = 720) | Iowa 1998 ($n$ = 852) | Kansas 1996 ($n$ = 25) | Kansas 1998 ($n$ = 63) |
|---|---|---|---|---|---|---|
| No | 81.8% | 74.9% | 82.6% | 80.5% | 88.0% | 88.9% |
| Yes, early | 12.0% | 19.5% | 15.1% | 16.3% | 4.0% | 7.9% |
| Yes, middle | 1.9% | 1.3% | 1.3% | 2.2% | 0.0% | 0.0% |
| Yes, late | 4.2% | 4.2% | 1.0% | 0.9% | 8.0% | 3.2% |

Data from 1997 were similar to 1996 and 1998 and are not included here for purposes of conciseness.

**Table 23. Farmers' decisions to intentionally plant Bt corn at a specific time to improve the effectiveness of Bt corn**

| Response | Minnesota | | Nebraska | | Pennsylvania | |
|---|---|---|---|---|---|---|
| | 1996 ($n$ = 466) | 1998 ($n$ = 497) | 1996 ($n$ = 294) | 1998 ($n$ = 200) | 1996 ($n$ = 175) | 1998 ($n$ = 35) |
| No | 74.2% | 76.7% | 87.4% | 78.5% | 81.7% | 62.9% |
| Yes, early | 22.5% | 21.5% | 8.8% | 19.5% | 8.0% | 14.3% |
| Yes, middle | 1.3% | 1.6% | 2.0% | 1.5% | 4.0% | 8.6% |
| Yes, late | 1.9% | 0.2% | 1.7% | 0.5% | 6.3% | 14.3% |

Data from 1997 were similar to 1996 and 1998 and are not included here for purposes of conciseness.

(2) No, I don't think European corn borers will develop resistance to Bt corn.
(3) Yes, if the strategy can be easily worked into my farming operation.
(4) Yes, whatever the best strategy would be to delay resistance.
(5) I don't know.

There were significant changes in responses across years to the question about implementing resistance management strategies ($\chi^2$ = 108.7; df = 8, 7,348; $P <$ 0.0001) (Table 25). The biggest change was nearly a five-fold reduction in the percentage of farmers who thought that European corn borers would not develop resistance to Bt corn. Targeted educational efforts focused on resistance management may have been responsible for this dramatic change. Additionally, two important and critical points are apparent in these responses. First, at least four out of five Bt corn farmers indicated a willingness to adopt a resistance management plan "if it could be easily worked into their farming operation" or "whatever the best strategy might be to delay resistance." Second, by 1998 an extremely small proportion (2.6%) of Bt corn farmers were unwilling to follow a resistance management plan. Although this small number is encouraging, it also indicates a need for further educational efforts. Discussions with industry representatives who have conducted internal quality control have revealed that Bt corn refuge compliance is fairly high, but needs to be improved. Scientists need to continue to disseminate information about implementation of resistance management strategies so that continued improvement may be achieved.

Farmers want to be stewards of Bt corn technology. They are genuinely concerned about the longevity of Bt corn and its proper management. One message that farmers continually relay to industry and university scientists is the need for a clear, consistent message regarding resistance management recommendations. Improvement in responses to question 17 probably would occur as more educational efforts emphasize an established message about planting a refuge for Bt corn.

There were significant differences in responses among states ($\chi^2$ = 86.6; df = 20, 7,336; $P <$ 0.0001) (Table 26). Bt corn farmers in Pennsylvania were less willing to follow a resistance management plan than farmers in the other five states. This response may be related to the special management options that are used in Pennsylvania where very small and often widely separated fields of corn are planted. Illinois farmers indicated more willingness to follow a resistance management plan, and fewer of them were uncertain about the decisions they would consider.

**18. Seed companies are trying to determine the best resistance management strategies to use with Bt corn. Assuming there will be enough Bt corn seed available, what planting pattern would you most likely consider using to avoid European corn borers developing resistance? (circle answer)**

(1) I would prefer planting Bt corn as one block in one field.
(2) I would prefer planting Bt corn as a block in every field.
(3) I would prefer splitting the seed boxes on the planter and alternating every row or several rows with Bt and non-Bt corn in every field.
(4) I would prefer planting Bt corn as large strips alternated with large strips of a non-Bt corn hybrid.
(5) I would prefer to mix Bt and non-Bt seed together in the seed box.
(6) I would prefer planting Bt corn in an entire field and planting the border around the field to non-Bt corn.
(7) Other.

**Table 24. Farmer planting patterns with Bt corn**

| Option | 1996 ($n$ = 2,039) | 1997 ($n$ = 3,275) | 1998 ($n$ = 1,953) |
|---|---|---|---|
| 1 - block | 63.4% | 52.6% | 45.6% |
| 2 - several blocks | 14.1% | 18.4% | 26.9% |
| 3 - alternating rows | 6.4% | 10.5% | 6.0% |
| 4 - large strips | 10.8% | 11.1% | 14.6% |
| 5 - mixed seed | 0.2% | 0.6% | 0.7% |
| 6 - border | 2.1% | 3.6% | 4.3% |
| 7 - other | 2.9% | 3.2% | 1.9% |

**Table 25. Farmers' responses to the concept of implementing resistance management strategies for European corn borer**

| Response | 1996 ($n$ = 2,073) | 1997 ($n$ = 3,321) | 1998 ($n$ = 1,966) |
|---|---|---|---|
| 1 - no interest | 1.3% | 1.8% | 1.4% |
| 2 - no | 5.9% | 1.4% | 1.2% |
| 3 - yes, easy | 57.1% | 59.4% | 58.9% |
| 4 - yes, best | 23.5% | 24.5% | 25.5% |
| 5 - I don't know | 12.2% | 12.8% | 12.9% |

Table 26. Farmers' responses (by state) to the concept of implementing resistance management strategies for European corn borer

| Response | Illinois ($n$ = 1,153) | Iowa ($n$ = 3,133) | Kansas ($n$ = 157) | Minnesota ($n$ = 1,584) | Nebraska ($n$ = 925) | Pennsylvania ($n$ = 408) | Total ($n$ = 7,360) |
|---|---|---|---|---|---|---|---|
| 1 - no interest | 1.0% | 2.1% | 1.3% | 1.5% | 1.1% | 0.7% | 1.6% |
| 2 - no | 2.4% | 2.3% | 1.3% | 2.3% | 3.2% | 5.6% | 2.6% |
| 3 - yes, easy | 55.4% | 60.0% | 51.0% | 59.3% | 57.6% | 61.0% | 58.7% |
| 4 - yes, best | 31.5% | 22.5% | 33.8% | 24.0% | 25.2% | 16.9% | 24.5% |
| 5 - I don't know | 9.7% | 13.2% | 12.7% | 12.9% | 12.9% | 15.7% | 12.7% |

There were large differences in the types of planting patterns of Bt corn that farmers were willing to consider ($\chi^2 = 23.6$; df = 6, 5,187; $P = 0.0006$) (Table 27), but their responses did not change appreciably from 1997 to 1998. Planting Bt corn in blocks was the primary choice, followed by large strips, border plantings, or alternating rows. Few farmers selected a mix of Bt and non-Bt seed. The variability among the responses suggests that farmers from different growing regions and who employ different farming practices are going to have different needs related to refuge management. Current university and industry recommendations indicate a 20% non-Bt corn refuge planted within one-half mile of Bt corn if the field is not going to be sprayed for control of European corn borers (National Corn Growers Association 2001)

**19. If scientists determine that farmers should grow a certain amount of non-Bt corn on their farm to delay resistance, what percentage of your acres would you be willing to plant to non-Bt corn?** There was an extremely wide range of responses to the amount of non-Bt corn that farmers would be willing to plant to delay the development of resistance of European corn borers to Bt corn ($\chi^2 = 44.6$; df = 6, 5,273; $P < 0.0001$) (Table 28). These results may reflect either an unwillingness to accept a recommended ratio of Bt to non-Bt corn acres or an uncertainty about the implications of such a requirement. When the first Bt corn registration (event 176) was issued in 1995, there was no scientific consensus about the size of a non-Bt corn refuge for European corn borer. Recommendations for a non-Bt corn refuge ranged from a minimum of 10–20% (Caprio et al. 1998) to 20–30% of total corn acres, or even 40% of total corn acres if the non-Bt corn acres were going to be sprayed with an insecticide (Ostlie et al. 1997). Some industry representatives recommended a 5% non-Bt corn refuge at one time. The EPA (1999) eventually established a policy of a 20% non-Bt corn refuge for field corn in the Corn Belt.

**20. Has Bt corn changed your perspective on the amount of loss caused by the European corn borer?**

(1) Yes, European corn borers cause less yield loss than I previously thought.
(2) No, the yield loss is what I expected.
(3) Yes, European corn borers cause more yield loss than I previously thought.
(4) I don't know.

Perceptions about yield losses caused by European corn borers were highly variable ($\chi^2 = 315.3$; df = 6, 7,320; $P < 0.0001$) (Table 29). In Iowa and Minnesota, Rice and Ostlie (1997) found that approximately one-third of farmers did not believe or were uncertain that either the first or second generation European corn borers caused economic loss. Responses to our survey revealed that between 10 and 14% of farmers believed that the European corn borer caused less yield loss than they had expected. One-fourth to one-third of the respondents indicated that yield losses were what they had expected. The largest shift in a response from one year to the next was for greater yield losses than expected. The percentage nearly doubled from 1996 to 1997, a year when large populations of European corn borer occurred in several midwestern states. Most western Corn Belt farmers (Kansas and Nebraska) felt that the yield loss caused by the European corn borer was more than they had expected (36.5%) or was exactly what they had expected (36.4%). Farmers in the rest of the Corn Belt indicated that yield losses were more than expected (43.2%) or as expected (27.2%). Most farmers are beginning to understand that European corn borers have been causing significant yield losses in the past, although the farmers did little to control the corn borers. Historically, most farmers have not managed European corn borer (Mason et al. 1996, Rice and Ostlie 1997). The advent of Bt corn has focused attention on managing this perennial pest.

Table 27. Farmers' preferences for planting patterns with Bt corn

| Option | 1997 ($n$ = 3,250) | 1998 ($n$ = 1,949) |
|---|---|---|
| 1 - block | 27.6% | 26.7% |
| 2 - several blocks | 18.8% | 21.5% |
| 3 - alternating rows | 11.5% | 13.2% |
| 4 - large strips | 18.0% | 18.7% |
| 5 - mixed seed | 4.1% | 4.4% |
| 6 - border | 15.4% | 12.4% |
| 7 - other | 4.5% | 3.0% |

Table 28. Farmers' indications of minimum percentages of acres planted to Bt corn

| Option | 1997 ($n$ = 3,319) | 1998 ($n$ = 1,966) |
|---|---|---|
| 5% or less | 7.1% | 4.8% |
| 10% or less | 14.6% | 11.8% |
| 20% or less | 16.9% | 20.9% |
| 30% or less | 13.6% | 13.6% |
| 40% or less | 6.6% | 5.8% |
| 50% or less | 21.8% | 26.3% |
| I don't know | 19.5% | 16.8% |

**Table 29. Farmers' perceptions about yield losses caused by European corn borers**

| Option | 1996 ($n$ = 2,041) | 1997 ($n$ = 3,323) | 1998 ($n$ = 1,967) |
|---|---|---|---|
| Yes, less | 14.0% | 10.0% | 12.3% |
| No, as expected | 33.5% | 25.2% | 28.9% |
| Yes, more | 28.1% | 51.7% | 40.7% |
| Don't know | 24.4% | 13.1% | 18.0% |

**21. In the current year, did insecticide use for European corn borers on your farm increase, stay the same, or decrease when compared with insecticide use trends during the past 5 yr?** Approximately half of the farmers did not use insecticides to manage European corn borers on their farms (Table 30) Of those farmers who used insecticides for European corn borer control during the previous 5 yr, the percentage who decreased their use of insecticides nearly doubled from 1996 to 1998. Farmers who decreased insecticide use on their farms increased the percentage of Bt corn acres they planted significantly ($P < 0.0001$) from 19.7% (1996) to 47.1% (1998) of total corn acres. In 1995, farmers noted that higher yields, less insecticide in the environment, and less insecticide exposure to farm workers were the most important advantages of Bt corn (Pilcher and Rice 1998). Our data suggest that these advantages are being achieved. Farmers have decreased their use of insecticides for control of European corn borer and, therefore, experienced less exposure to potentially harmful insecticides.

**22. During the next several years, do you expect your insecticide use against European corn borers in non-Bt hybrids to decrease, stay the same, increase, or don't know?** There were significantly different responses by farmers about whether their insecticide use would decrease, stay the same, or increase in future years ($\chi^2 = 63.7$, df = 4, 5,253, $P = < 0.0001$). A significant percentage of Bt corn farmers (45.4–47.2%, $n$ = 7,302) expected their insecticide use to remain constant. However, 16–17.4% of Bt corn farmers anticipated a decrease in future insecticide use, whereas a much smaller group, 5.1–11.6%, thought that insecticide use for European corn borers would increase. The remaining group (25.7–31.0%) was uncertain about future insecticide use. We also were interested in the potential differences in responses between farmers in the western Corn Belt (Kansas and Nebraska) where the majority of insecticide use occurs compared with farmers in the rest of the Corn Belt. Their responses to future increase or decrease of insecticide use were similar (≈17% decrease, ≈9% increase); however, a greater percentage of farmers (53.2%) from the western Corn Belt believed insecticide use for European corn borer control would stay the same, compared with farmers from the rest of the Corn Belt (45.3%).

**Table 30. Changes in insecticide use among Bt corn farmers**

| Option | 1996 ($n$ = 2,058) | 1997 ($n$ = 3,334) | 1998 ($n$ = 1,873) |
|---|---|---|---|
| Decreased | 13.2% | 19.3% | 26.0% |
| Stay the same | 23.8% | 24.6% | 17.9% |
| Increased | 14.3% | 5.0% | 2.4% |
| Don't use | 48.7% | 51.1% | 53.7% |

**Table 31. Sources of information used by Bt corn farmers**

| Option | 1996 ($n$ = 1,950) | 1997 ($n$ = 3,017) | 1998 ($n$ = 1,895) |
|---|---|---|---|
| Seed company | 85.2% | 80.1% | 78.4% |
| Extension service | 1.9% | 2.5% | 3.4% |
| Crop consultant | 3.9% | 4.2% | 5.1% |
| Farm press | 7.2% | 10.8% | 7.9% |
| Radio/TV/data network | 0.6% | 0.3% | 0.2% |
| Neighbors (not a seed dealer) | - | 1.2% | - |
| Other | 1.1% | 0.9% | 5.1% |

**23. From what source did you receive most of your information on Bt corn?**

(1) Seed companies/seed dealers.
(2) Cooperative Extension Service.
(3) Crop consultants.
(4) Farm press (magazines and newspapers).
(5) Radio/TV/farm data networks.
(6) Neighbors (not a seed dealer) 1997 question only.
(7) Other.

Seed companies or seed dealers were the primary sources of Bt corn information for farmers (Table 31). The "farm press" was the second most-used resource, followed by crop consultants. The Cooperative Extension Service and radio/television/farm data network ranked low in the delivery of Bt corn information. These results are similar to what was observed in 1995 (Pilcher and Rice 1998) before the release of Bt corn. Most farmers (76.3%) preferred to search for more information from seed companies or seed dealers followed by newspapers or magazines (59.2%) (Pilcher and Rice 1998). Because seed companies, seed dealers, and agricultural reports obtain some of their information from the Cooperative Extension Service, it is important for extension entomologists to work closely with others to disseminate information about Bt corn.

In conclusion, transgenic Bt corn has been widely adopted by farmers in the central Corn Belt and Pennsylvania as a method of managing the European corn borer. After the first year of Bt corn seed availability, the number of acres planted to Bt corn nearly quadrupled 2 yr later, with the highest percentage of Bt corn acres planted in Minnesota, followed by Iowa and Nebraska. Although there are several pest management options for the European corn borer, four out of 10 farmers stated that before Bt corn became available they did nothing to reduce economic damage.

The predominant historical reason farmers planted Bt corn was to reduce yield losses caused by European corn borer. Most farmers were satisfied with the level of protection afforded by Bt corn against both first- and second-generation larvae. Yields of Bt corn hybrids were viewed as mostly similar to or higher than yields of conventional non-Bt hybrids, especially in 1997 and 1998 when hybrids that provided protection against both generations of larvae became available.

Historically, farmers also planted Bt corn to eliminate the need for insecticides for control of European corn borer. One of the most significant changes documented by these surveys was the reported reduction in insecticide use. The percentage of Bt corn farmers who decreased their insecticide use doubled from 13 to 26% from 1996 to 1998. This reduction in insecticide use represents a substantial environmental benefit. In contrast, only slightly more than 2% of Bt corn farmers increased their insecticide use, probably as a result of realizing the consequences of European corn borer damage and managing these insects on non-Bt corn acres.

Management of European corn borer resistance to Bt corn has been a dominant issue among scientists, seed companies, governmental agencies, and other interested parties. Resistance management protocols currently are being used to delay development of resistance and extend the life of the technology. Most Bt corn farmers indicated that they used a variety of planting times and planting patterns acceptable for resistance management, and they stated a willingness to consider or follow resistance management recommendations. Although these are positive responses, continued education and involvement of farmers in the proper use of Bt corn will be necessary if we expect Bt corn to manage the European corn borer in years to come.

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