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Bt Corn Farmer Compliance with Insect Resistance Management Requirements in Minnesota and Wisconsin

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The United States Environmental Protection Agency (EPA) re-registered Bt corn in 2001 with mandatory insect resistance management (IRM) requirements in order to promote sustainable use by farmers. Since then studies have reported IRM compliance rates ranging from 79% to 96%. Using survey data from Minnesota and Wisconsin, we show that previous compliance rate estimates are likely too high because they do not use a comprehensive measure for compliance. With a more comprehensive measure, we find compliance rates ranging between 72% and 76%. We also explore the relationship between IRM awareness, farm size, and IRM compliance.

Key words: Bt corn, compliance, insect resistance management, refuge.

Introduction

For more than 40 years, conventional and organic farmers have relied on foliar sprays with toxins derived from the soil bacterium *Bacillus thuringiensis* (Bt) to control lepidopteran (caterpillar) and other pests. These Bt sprays are considered safer to humans and other animals than synthetic insecticides (United States Environmental Protection Agency [EPA], 1998). In 1996, the biotech industry commercialized corn engineered with Bt genetic material. Bt corn produces proteins that are toxic when consumed by specific insects, such as the European corn borer (ECB). An important advantage of Bt corn is full-season control. Because the toxin is in the plant tissue, it is not subject to factors that degrade the activity of Bt sprays, so application timing is no longer crucial. Full-season control is also seen as a disadvantage, however. Because pests are exposed to Bt for longer periods of time, the evolution of resistance could render Bt ineffective.

The Environmental Protection Agency (EPA) re-registered Bt corn in 2001 with mandatory insect resistance management (IRM) rules aimed at slowing the evolution of Bt resistance (EPA, 2001). IRM practices include planting a non-Bt corn refuge that meets certain size, configuration, and insecticide use criteria. The EPA's IRM requirements were created to foster responsible stewardship and maintain the viability of Bt toxins.

We explore farmer compliance with the IRM requirements mandated by the EPA for ECB Bt corn.[1] Since 2001, compliance rates between 79% to 96% have been reported (Agricultural Biotechnology Stewardship Technical Committee [ABSTC], 2005; Jaffe, 2003a, 2003b). Using data from surveys of Bt corn farmers in Minnesota and Wisconsin, we show that previous studies overestimate IRM compliance because they do not use comprehensive measures. Using more comprehensive measures, we find IRM compliance rates of 75.7% and 71.8% in Minnesota and Wisconsin. We also revisit reports of a positive relationship between IRM compliance and farm size and explore the effect of IRM awareness on compliance.

Background

Bt corn has been rapidly adopted in the United States since commercialization in 1996 (see Figure 1). In 2005, Bt represented 35% of US corn acres (United States Department of Agriculture Economic Research Service [USDA ERS], 2005). The rapid adoption of Bt corn has raised concerns that such large-scale and unprecedented use of the Bt toxin will lead to insect resistance (Lewis & Portier, 2001; Mellon & Rissler, 1998). Insect resistance to Bt is a concern because Bt is considered a safer alternative to synthetic insecticides (EPA, 1998). If Bt becomes ineffective because of insect resistance, conventional farmers may switch to more harmful insecticides, and organic farmers may lose an effective pest-control tool (Center for Food Safety, 1999).

Scientists have proposed a high-dose refuge strategy to reduce the likelihood of Bt resistance (e.g., Alstad & Andow, 1995; Gould, 1988, 1998; Roush & Osmond, 1996). This strategy combines Bt plants producing high doses of toxin (i.e., enough to kill all but the most resistant insects) with the presence of a non-Bt corn refuge. The purpose of refuge is to provide susceptible insects that will mate with resistant insects emerging from Bt

1. *In 2003, the EPA approved corn rootworm Bt corn. Our paper does not consider corn rootworm Bt corn due to its limited availability at the time of the survey.*

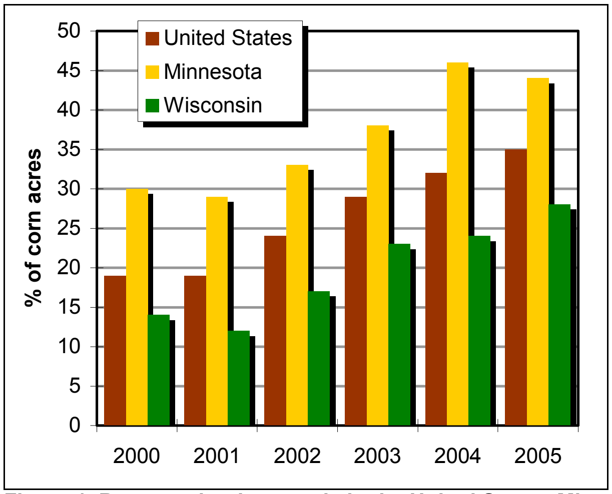

Figure 1. Bt corn adoption trends in the United States, Minnesota, and Wisconsin, 2000-2005.
Note. Data from USDA ERS (2005).

plants. With a high dose, the majority of offspring will be Bt susceptible.

The EPA adopted a mandatory high-dose refuge approach in its re-registration of ECB Bt corn in 2001 (EPA, 2001). Bt crop registrants (e.g., DOW, Monsanto, Pioneer, and Syngenta) implement EPA requirements by having farmers sign legally binding agreements that outline the terms and conditions of Bt corn use. In the primary corn-growing regions of the United States, these agreements obligate farmers to plant at least a 20% non-Bt refuge. The refuge can be planted externally in a separate field within 1/2 mile of the farmer's Bt corn. Alternatively, the refuge can be planted internally in the same field as Bt corn using borders, blocks, or strips of at least four rows wide. Microbial Bt insecticides are not permitted for insect control on refuge acres, but other insecticides can be applied based on economic thresholds.

Compliance with the EPA's IRM guidelines has been controversial. In June 2003, the Center for Science in the Public Interest (CSPI) published *Planting Trouble: Are Farmers Squandering Bt Corn Technology?* (Jaffe, 2003a). This report, along with an update issued in September 2003 (Jaffe, 2003b), presented National Agricultural Statistics Service (USDA NASS) data indicating that only 79% of farmers growing Bt corn in 10 Midwestern states complied with the 20% refuge size requirement in 2002. The report also noted that noncompliance was especially high among farms with less than 200 acres of corn.

Although the CSPI reports were the first to bring IRM compliance to public attention (see, e.g., Weise, 2003), compliance was not a new issue (EPA, 2001; Hurley, 1999). Indeed, the EPA requires Bt corn registrants to implement a Compliance Assurance Program (CAP), which includes a multifaceted IRM education program as well as an annual assessment of compliance among licensed growers. As part of the latter, the Agricultural Biotechnology Stewardship Technical Committee (ABSTC) has commissioned annual telephone surveys of Bt corn growers since 2000. Results show that compliance rates increased from 87% to 91% for the 20% size requirement and 82% to 96% for the 1/2-mile external refuge distance requirement (ABSTC, 2005). In 2003, Bt crop registrants began conducting on-farm IRM assessments, which revealed compliance rates of 95.4% in 2004 (ABSTC, 2005).

Jaffe (2003a) attributes disparities between the USDA NASS and ABSTC data to a difference in sampling protocols. Whereas the USDA NASS data included corn farms of all sizes, ABSTC's telephone survey only sampled farms with a minimum of 200 corn acres. Using farm-level survey data collected in Minnesota and Wisconsin, we replicate and extend Jaffe's and the ABSTC's analysis. We extend the analysis by using a more comprehensive measure of IRM compliance, which includes the refuge size requirement as well as external and internal refuge configuration requirements. We explore the relationship between grower awareness of IRM requirements and compliance (a topic covered in ABSTC, 2005). Finally, we extend Jaffe's analysis of the relationship between farm size and IRM compliance. By presenting data from Minnesota and Wisconsin, our study permits a comparison of two states that vary in terms of Bt corn adoption and prevalence of large-scale corn production.

Survey Data

Surveys were sent to Minnesota and Wisconsin corn producers in the winter and spring of 2004. In each state, 2,000 participants were randomly and confidentially selected from the Minnesota and Wisconsin Agricultural Statistics Services' farmer databases. Survey response rates were 39% in Minnesota and 49% in Wisconsin.[2]

The survey asked farmers about their use of genetically modified (GM) crops during the 2003 growing season. Farmers were also asked why they planted GM

2. *The lower response rate in Minnesota is attributable primarily to a larger proportion of surveys that were sent unintentionally to noncorn farmers.*

crops, how their GM crops performed, and whether they were aware of the EPA's IRM requirements for Bt corn. Information on the demographic and socioeconomic characteristics of the farmer and farm operation was also requested. Finally, the survey included objective measurements for more aspects of IRM compliance than previously explored. Therefore, unlike Jaffe (2003a, 2003b), we can assess grower compliance with refuge size requirements as well as external and internal refuge configuration requirements.

To determine whether Bt corn farmers were in compliance with the 20% refuge requirement, total corn and Bt corn acres were used to compute the percentage of refuge corn. If farmers had 20% or more of their corn acreage planted with non-Bt corn, they were considered compliant, otherwise they were noncompliant.[3]

In terms of the refuge configuration requirements, Bt corn adopters were asked if they had planted fields with both Bt and non-Bt corn, or fields entirely with Bt corn. The former—farmers with internal refuge—were asked if their non-Bt corn was planted as borders, blocks, multiple strips, or mixed with Bt corn. Farmers who reported fields planted with a mix of Bt and non-Bt corn seed were considered noncompliant, otherwise they were compliant. Farmers with fields planted entirely with Bt corn—those with external refuge—were asked about the distance between their Bt and non-Bt corn fields. If any of a farmer's Bt corn fields were more than 1/2 mile away from one of his non-Bt fields, the farmer was deemed noncompliant, otherwise he was compliant. If a farmer was noncompliant with at least one of the refuge configuration requirements, he was considered noncompliant in terms of overall refuge configuration, otherwise he was compliant.

The EPA's IRM regulations do not permit the use of microbial Bt on refuge acres, but do allow the use of other insecticides based on economic thresholds. To assess compliance with these insecticide rules, we asked Bt corn farmers if they had used chemical or microbial Bt insecticides on any of their non-Bt corn. However, because non-Bt corn acres can include refuge and non-refuge acres on farms with less than 80% Bt corn, our data do not precisely measure compliance with the EPA's refuge insecticide requirements.[4]

Due to our imprecise measurement of refuge insecticide compliance, we define *full compliance* with the EPA's IRM requirements based on refuge size and configuration compliance. If farmers complied with both of these requirements, they were fully compliant, otherwise they were noncomplaint. Compared to Jaffe and ABSTC, our notion of full compliance is more comprehensive.

The three indicators of farm size used in our analysis are based on direct survey questions about total corn acreage, total cropland acreage, and gross farm income. Rather than employing dichotomous measures of farm size (see Jaffe, 2003a, 2003b), we divide each of our farm size variables into five categories. Our IRM awareness variable is based on a survey question that presented respondents with a description of the EPA's IRM requirements for Bt corn and then asked: "Were you aware of these IRM requirements when you planted Bt corn in 2003?" Our CAP awareness variable is based on a similarly structured survey question.

Findings

We begin by comparing our 2003 Bt corn adoption and refuge size compliance results with Jaffe (2003a, 2003b; see also USDA NASS, 2003). Second, we present data on refuge configuration compliance and full compliance. Third, we explore the relationship between compliance and awareness of both the EPA's IRM requirements and the Compliance Assurance Program's on-farm assessments. Finally, we extend Jaffe's analysis of IRM compliance and farm size by using more comprehensive measures of farm size.

Table 1 presents the number and percentage of corn farms that planted Bt corn varieties in our Minnesota and Wisconsin samples. Bt corn adoption rates were 58.2% in Minnesota and 31.4% in Wisconsin. For both states, we found higher adoption rates for farms with

3. *Although small deviations from the EPA's IRM requirements may not be significant, we opted to use discrete categories (i.e., compliant vs. noncompliant) to evaluate IRM compliance as per previous studies of compliance (see ABSTC, 2005; Jaffe, 2003a, 2003b). Compliance is also assessed at the farm level, instead of field level, to be more consistent with other studies. With partial farm compliance, it is possible that compliance rates are higher at the field level.*

4. *It is worth noting that 99.7% and 100.0% of Bt corn farmers surveyed in Minnesota and Wisconsin did not use any microbial Bt insecticides in 2003. These figures suggest complete compliance with the IRM requirement regarding the use of Bt-based insecticides on refuge acres. In terms of conventional insecticide use, our data indicate that 10.0% and 6.5% of Bt corn adopters in Minnesota and Wisconsin used conventional insecticides to control corn borer and corn earworm on their non-Bt corn. Of these farmers, 27.3% in Minnesota and 7.7% in Wisconsin reported that they applied insecticides based on economic thresholds.*

Table 1. Number and percentage of Bt corn farms in Minnesota and Wisconsin, 2003.

	Minnesota		Wisconsin	
	Farms	% of farms	Farms	% of farms
All corn farms				
No Bt corn	256 (20,310)	41.8 (61.1)	521 (27,960)	68.6 (82.7)
Bt corn	356 (12,920)	58.2 (38.9)	238 (5,850)	31.4 (17.3)
Total	612 (33,230)	100.0 (100.0)	759 (33,810)	100.0 (100.0)
Farms with < 200 corn acres				
No Bt corn	228 (17,270)	58.2 (75.9)	475 (25,960)	73.1 (86.1)
Bt corn	164 (5,470)	41.8 (24.1)	175 (4,180)	26.9 (13.9)
Total	392 (22,740)	100.0 (100.0)	650 (30,140)	100.0 (100.0)
Farms with ≥ 200 corn acres				
No Bt corn	28 (3,040)	12.8 (29.0)	44 (2,000)	41.5 (54.5)
Bt corn	190 (7,450)	87.2 (71.0)	62 (1,670)	58.5 (45.5)
Total	218 (10,490)	100.0 (100.0)	106 (3,670)	100.0 (100.0)

Note. For comparison, USDA NASS data for 2002 are provided in parentheses. See Table 6 in Jaffe (2003a) for Minnesota data and Tables 1–3 in USDA NASS (2003) for Wisconsin data.

200 or more corn acres.[5] In Minnesota, 87.2% of large farms (200 or more corn acres) grew Bt corn, compared to only 41.8% of small farms (less than 200 corn acres). The Wisconsin sample had lower adoption rates: 58.5% for large farms and 26.9% for small farms. Our Bt corn adoption rates are somewhat higher than the USDA NASS figures, which is most likely due to our use of data from the 2003, rather than 2002, growing season.

Table 2 presents the percentage of corn acreage planted with Bt corn for adopters. Of the Bt farms surveyed, 85.1% and 85.7% in Minnesota and Wisconsin planted 80% or less of their corn acreage with Bt corn during the 2003 growing season, indicating compliance with the EPA's refuge size requirement.[6] These figures are slightly higher than the USDA NASS data reported in Jaffe (2003b) and lower than the estimate (92%) reported by ABSTC (2005) for the 2003 growing season. The majority of Bt corn growers who did not comply with the refuge size requirement planted 100% of their corn acreage with Bt varieties.

Table 3 reports our survey results for refuge size, refuge configuration, and full compliance. If we consider only the size requirement, 85.1% and 85.7% of Minnesota and Wisconsin Bt corn farmers were compliant. However, the EPA requires that the non-Bt corn refuge also satisfy certain configuration criteria. An

Table 2. Percentage of corn acreage planted with Bt corn on farms in Minnesota and Wisconsin, 2003.

% of corn acreage planted with Bt corn	Minnesota		Wisconsin	
	Farms	% of farms	Farms	% of farms
0.1–80.0	279 (10,560)	85.1 (81.7)	192 (4,810)	85.7 (82.2)
80.1–99.9	21 (680)	6.4 (5.3)	7 (120)	3.1 (2.1)
100	28 (1,680)	8.5 (13.0)	25 (920)	11.2 (15.7)
Total	328 (12,920)	100.0 (100.0)	224 (5,850)	100.0 (100.0)

Note. For comparison, USDA NASS data for 2002 are provided in parentheses (see Table 1 in Jaffe, 2003b).

Table 3. IRM compliance rates for Bt corn farms in Minnesota and Wisconsin, 2003.

	Minnesota	Wisconsin
20% refuge size compliance	85.1	85.7
Internal refuge configuration compliance	93.0	83.4
External refuge configuration compliance	90.4	92.5
Overall refuge configuration compliance	89.9	83.7
Full compliance (i.e., refuge size and configuration compliance)	75.7	71.8

5. *It follows that the difference in Bt corn adoption rates (58.2% in Minnesota and 31.4% in Wisconsin) may be explained in part by the proportion of small and large corn operations in the two states. Minnesota corn production centers on larger cash grain enterprises, whereas Wisconsin farmers grow corn primarily as on-farm feed for dairies. Our Minnesota survey respondents grew 217 corn acres on average, with large corn operations (200 or more corn acres) comprising 36% of the sample. In contrast, Wisconsin respondents grew 117 corn acres on average, with large corn operations comprising only 14% of the sample.*

6. *A closer look at our data revealed that the majority of Bt corn farmers who complied with the 20% refuge size requirement did not plant as much Bt corn as they were allowed under the EPA's IRM rules. Refuge size compliant farmers planted on average 52% (in Minnesota) and 41% (in Wisconsin) of their corn acreage with Bt corn in the 2003 growing season.*

Table 4. IRM awareness and compliance in Minnesota (MN) and Wisconsin (WI), 2003.

		20% refuge size compliance		Refuge configuration compliance		Full compliance (i.e., refuge size and configuration compliance)	
		MN	WI	MN	WI	MN	WI
IRM awareness	**Yes**	87.1	92.0	91.0	87.2	79.2	80.2
	No	75.0	51.6	70.6	59.1	47.4	29.0
	χ^2	2.334	36.756	7.350	11.524	10.239	34.752
	significance	(0.127)	(0.000)	(0.007)	(0.001)	(0.001)	(0.000)
CAP awareness	**Yes**	89.5	88.4	91.8	90.1	80.9	80.9
	No	82.7	83.1	87.6	78.9	72.7	65.3
	χ^2	3.095	1.237	1.487	5.443	2.919	6.157
	significance	(0.079)	(0.266)	(0.223)	(0.020)	(0.088)	(0.013)

Note. The number of observations varied from 304 to 318 for Minnesota and 198 to 219 for Wisconsin.

internal refuge must be planted as borders, blocks, or multiple strips, while an external refuge must be located within 1/2 mile of Bt corn. Our findings indicate that 93.0% and 83.4% of Bt growers in Minnesota and Wisconsin complied with the EPA's internal refuge configuration requirement. In terms of the external refuge configuration requirement, 90.4% and 92.5% of Bt corn growers in Minnesota and Wisconsin were compliant. These external refuge configuration compliance rates are similar to the average estimate (93%) reported by ABSTC (2005) for the 2003 growing season. Turning to overall refuge configuration compliance, we find that 89.9% and 83.7% of Minnesota and Wisconsin Bt corn farmers were compliant.

Consideration of only size or configuration compliance is likely to overestimate compliance. Therefore, we calculated full compliance, which combines size and configuration compliance. Table 3 shows that 75.7% and 71.8% of Minnesota and Wisconsin Bt corn farmers were fully compliant during the 2003 growing season. These results imply that many noncompliant farmers violated either the size requirement or the configuration requirements, but not both. They also indicate that the widely cited CSPI report (Jaffe, 2003a, 2003b) and ABSTC's annual telephone survey results exaggerate IRM compliance rates because they consider the different IRM requirements individually, but not combined.

One explanation for noncompliance is lack of awareness. ABSTC (2005), for example, found that 8% of Bt corn growers surveyed by telephone in 2004 were unfamiliar with IRM requirements, 45% could not correctly provide the required refuge size, and 45% did not know that the refuge must be planted within 1/2 mile of Bt corn. Of the Minnesota and Wisconsin Bt corn farmers we surveyed, 7.5% and 15.3% reported that they were unaware of the EPA's IRM requirements when they planted Bt corn in 2003. Moreover, approximately half of the Bt corn growers in Minnesota (47.5%) and Wisconsin (57.4%) were unfamiliar with the new on-farm assessment component of CAP.

To explore the relationship between IRM awareness and compliance, we conducted Chi-square (χ^2) tests to measure the association between IRM and CAP awareness and our three compliance measures. The χ^2-test results are presented in Table 4. The results suggest that we can reject the null hypothesis that IRM awareness is unrelated to compliance: All but one χ^2 statistics are statistically significant (p-value < 0.05). In other words, IRM awareness may be a strong predictor of IRM compliance. The relationship between CAP awareness and IRM compliance is less clear: two χ^2 statistics are significant at the 0.05 level, two are significant at the 0.10 level, and two are not statistically significant.

Compliance also seems to be related to farm size. The inclusion of small farms in the USDA NASS sample was a primary reason Jaffe found lower compliance rates than ABSTC. Consequently, Jaffe argued that compliance was positively related to farm size. We now revisit the relationship between farm size and IRM compliance. In addition to employing a more comprehensive set of compliance measures, our data allow us to consider several farm size indicators: total corn acreage, total cropland acreage, and gross farm income. Each of these size measures was divided into five descriptive categories in order to obtain a clearer picture of any potential relationships.

Table 5 presents data for refuge size, refuge configuration, and full compliance rates disaggregated by our three measures of farm size. Significance levels are provided for two measures of association: Chi-square (χ^2)

Table 5. IRM compliance and farm size in Minnesota (MN) and Wisconsin (WI), 2003.

		20% refuge size compliance		Refuge configuration compliance		Full compliance (i.e., refuge size and configuration compliance)	
		MN	WI	MN	WI	MN	WI
Corn acres	**0–100**	73.2	74.1	88.7	79.1	65.2	58.4
	101–200	80.7	95.1	88.3	89.5	70.9	84.2
	201–400	93.7	100.0	93.0	83.3	86.4	83.3
	401–1,000	89.9	95.0	88.4	87.5	77.6	82.4
	1,001 or more	90.0	100.0	90.0	85.7	80.0	83.3
	χ^2 significance	0.003	0.000	0.846	0.564	0.029	0.002
	Kendall's τ-*c*	0.152	0.231	0.011	0.069	0.131	0.248
	significance	(0.001)	(0.000)	(0.792)	(0.229)	(0.020)	(0.000)
Cropland acres	**0–100**	68.8	51.9	83.3	73.7	56.3	38.5
	101–200	83.3	81.1	94.9	80.0	79.5	65.3
	201–400	82.7	93.5	87.8	83.6	71.2	77.5
	401–1,000	89.3	95.7	90.1	88.6	80.0	84.4
	1,001 or more	88.5	94.4	88.5	89.5	78.0	82.4
	χ^2 significance	0.182	0.000	0.733	0.547	0.219	0.000
	Kendall's τ-*c*	0.084	0.254	-0.010	0.099	0.070	0.282
	significance	(0.067)	(0.000)	(0.792)	(0.089)	(0.206)	(0.000)
Gross farm income	**< $50,000**	74.0	60.8	88.1	86.1	64.6	53.2
	$50,000–99,000	80.4	88.0	84.6	78.3	68.0	69.6
	$100,000–199,999	86.7	92.6	90.8	83.9	77.9	77.4
	$200,000–499,999	90.4	94.5	92.0	84.9	82.4	79.6
	$500,000 or more	96.0	94.4	89.3	89.5	84.0	82.4
	χ^2 significance	0.032	0.000	0.718	0.888	0.083	0.020
	Kendall's τ-*c*	0.144	0.255	0.039	0.026	0.156	0.216
	significance	(0.002)	(0.000)	(0.353)	(0.644)	(0.006)	(0.002)

Note. The number of observations varied from 285 to 328 for Minnesota and 193 to 224 for Wisconsin.

and Kendall's tau-*c* (τ-*c*). The χ^2-test is a test of independence for nominal data. A significant χ^2 indicates correlation but does not measure the strength or direction of correlation. The τ-*c* ranges from -1 to 1 and provides a measure of the strength and direction of correlation for ordinal variables when the number of columns and rows are unequal (Liebetrau, 1983).[7]

Three conclusions are apparent from Table 5. First, there is a significant positive relationship between all three farm size measures and refuge size compliance for both states. All but one of the χ^2 and τ-*c* statistics are significant (*p*-value < 0.10). Second, there is a significant positive relationship between the three farm size indicators and full compliance. All but two of the χ^2 and τ-*c* statistics are significant (*p*-value < 0.10). Third, there does not appear to be a statistically significant relationship between farm size and configuration compliance. For refuge configuration compliance, none of the χ^2 and τ-*c* statistics are significant (*p*-value < 0.10). Therefore, although farm size may be a predictor of refuge size compliance and full compliance, it does not appear to be related to refuge configuration compliance.

One might hypothesize that farms of different sizes have differential access to IRM/CAP information, which influences IRM awareness and compliance. In Table 6 we explore the relationship between farm size and IRM/CAP awareness. There is a significant positive relationship between all three farm size indicators and IRM awareness. The χ^2 and τ-*c* statistics indicate a sig-

7. *Although the τ-c statistic is more descriptive than the χ^2, it assumes a monotonic relationship which makes the appropriate scope of its application more restrictive. We report both statistics to show that more restrictive assumptions are not necessary to establish a significant relationship between compliance and farm size.*

Table 6. IRM awareness and farm size in Minnesota (MN) and Wisconsin (WI), 2003.

		IRM awareness (% aware)		CAP awareness (% aware)	
		MN	WI	MN	WI
Corn acres	**0–100**	77.9	77.2	38.0	39.5
	101–200	96.7	93.8	55.3	38.1
	201–400	97.8	86.7	53.6	51.6
	401–1,000	94.6	95.0	59.7	63.2
	1,001 or more	100.0	85.7	70.0	42.9
	χ^2 significance	0.000	0.030	0.045	0.259
	Kendall's τ-*c*	0.124	0.137	0.159	0.108
	significance	(0.001)	(0.006)	(0.007)	(0.122)
Cropland acres	**0–100**	76.5	63.0	27.8	34.5
	101–200	84.4	76.4	41.3	41.5
	201–400	95.3	92.9	58.0	33.7
	401–1,000	95.9	89.4	48.8	58.7
	1,001 or more	96.9	90.5	69.8	55.0
	χ^2 significance	0.002	0.001	0.003	0.047
	Kendall's τ-*c*	0.093	0.180	0.165	0.152
	significance	(0.008)	(0.002)	(0.005)	(0.037)
Gross farm incomes	**< $50,000**	81.8	68.6	50.0	38.5
	$50,000–99,000	91.4	88.9	45.6	36.0
	$100,000–199,999	90.4	88.9	56.2	51.4
	$200,000–499,999	99.0	91.1	53.2	35.7
	$500,000 or more	100.0	95.2	60.7	57.1
	χ^2 significance	0.001	0.004	0.647	0.206
	Kendall's τ-*c*	0.130	0.175	0.066	0.052
	significance	(0.000)	(0.002)	(0.283)	(0.478)

Note. The number of observations varied from 320 to 352 for Minnesota and 226 to 235 for Wisconsin.

nificant positive relationship between CAP awareness and cropland acreage (in both states) and corn acreage (in Minnesota only). There does not appear to be a significant relationship between CAP awareness and gross farm income in either state.

To supplement these findings, we present data on the reasons for IRM noncompliance according to our samples of Bt corn growers in Minnesota and Wisconsin (Table 7). Specifically, we asked Bt corn adopters: "What do you think are the main reasons why some farmers do not follow insect resistance management requirements?" Respondents were presented with a list of 10 reasons and asked to check all that apply. The primary reasons for IRM noncompliance according to both Bt corn grower samples are the use of neighbors' fields as refuges, the hassle associated with changing planters, and the belief that IRM compliance is not important. Lack of enforcement of the IRM requirements, lack of IRM awareness, and farm layout were perceived as slightly less important reasons for noncompliance.

Discussion

IRM regulations are seen as important for the sustainability of Bt corn. However, the effectiveness of IRM depends on compliance (Hurley, 2005). Widely cited estimates for IRM compliance range from 79% to 96%. Considering individual components of IRM separately, we find similar rates of compliance, 85.1% to 93.0%. However, consideration of refuge size and configuration requirements together reduces compliance rates by about 10 to 20 points to 75.7% in Minnesota and 71.8% in Wisconsin. These findings suggest that many noncompliant Bt corn growers failed to comply with either the refuge size or configuration requirement, but not both.

Over the past few years, Bt corn registrants, the National Corn Growers Association (NCGA), the EPA, and other key stakeholders have spearheaded an ongoing IRM awareness campaign. This campaign appears successful, with almost nine in ten Bt corn growers

Table 7. Minnesota and Wisconsin Bt corn growers' perceptions of the reasons why farmers do not follow IRM requirements, 2004.

Reasons why farmers do not follow IRM requirements	% of Bt corn growers who selected item as reason why farmers do not follow IRM requirements: Minnesota	Wisconsin
They use their neighbor's fields as refuges	44.0	37.9
It is too much hassle to change planters	42.7	38.9
They don't think that following the requirements is important enough	38.7	37.9
There is no enforcement of the requirements, so they don't bother	24.8	28.6
They are not aware of the IRM requirements	18.2	27.1
Their farm layout does not allow them to plant refuges close enough to their Bt cornfields	16.6	23.6
It is too risky to wait until the economic threshold is reached to apply insecticides	16.6	7.4
Corn borer is too difficult to control without insecticides	16.2	12.8
They don't have enough labor available to follow all the requirements	8.6	8.9
Other reasons	5.0	9.9

Note. Based on 302 responses for Minnesota and 203 responses for Wisconsin.

reporting they are aware of the EPA's IRM requirements. Our results suggest that this campaign has had a positive affect on IRM compliance and that continued improvements to the campaign could further increase IRM awareness and compliance.

Similar to Jaffe, we found that smaller Bt corn farms exhibit lower compliance rates compared to larger farms. Specifically, our analysis suggests that refuge size compliance and full IRM compliance (i.e., refuge size and configuration compliance) are positively correlated with farm size—whether measured in terms of corn acreage, cropland acreage, or gross farm income. In contrast, there does not appear to be a significant relationship between farm size and configuration compliance.

There are several explanations for why large farms may have better compliance records than small farms. For example, the cost of losing access to Bt corn, the proposed sanction for noncompliant farms, is higher for farms that plant more Bt corn. Unfortunately, our survey results do not afford us the opportunity to test this hypothesis. Different levels of IRM awareness may also help explain differences in IRM compliance among small and large farms. Our findings indicated a positive relationship between IRM awareness (and CAP awareness, to a lesser degree) and farm size. These findings suggest that there may be deficiencies in IRM education programs, especially with respect to small Bt corn farms. For example, one component of the current IRM awareness campaign is the web-based Insect Resistance Management Learning Center (see http://www.ncga.com/biotechnology/IRMCenter) launched by the NCGA and ABSTC. Although web-based education like this may be suitable for large farms, it may not be as effective with small farms that are less likely to use computers and the Internet.[8]

Conclusion

It may be tempting to dismiss the relevance of our examination of IRM compliance because almost two thirds of the corn acreage in the United States is not planted with Bt corn, which presumably provides a de facto refuge for the remaining third. However, the adoption of European corn borer resistant Bt corn in some US counties is well in excess of one third. Furthermore, Bt corn adoption rates are once again on the rise after a period of stagnation during 2000–2001. Therefore, the amount of de facto refuge acres is on the decline, increasing the importance of IRM compliance.

It may also be tempting to dismiss the recent preoccupation with IRM compliance because after a decade of Bt corn, there have been no reported findings of Bt resistance among field populations of insects. However, as Tabashnik et al. (2003) point out, the lack of docu-

8. *In 2002 surveys of corn producers in Minnesota and Wisconsin, we asked respondents about their computer ownership and use. In both states, growers with less than 200 acres of corn were significantly (p-value < 0.05) less likely to own a computer and access the Internet, compared to growers with 200 or more corn acres.*

mented Bt resistance does not preclude resistance problems in the future.

Recent Bt corn developments also raise new questions about insect resistance management. Monsanto released corn rootworm resistant Bt corn in 2003 and a "stacked" variety containing Bt toxins targeting both European corn borer and corn rootworm in 2004. Dubbed the "billion-dollar pest," corn rootworm is considered the primary pest in many corn-growing regions. This pest accounts for over two thirds of annual insecticide applications on corn, which is more than three times the corn acreage treated for European corn borer before the introduction of corn borer-resistant Bt corn (Miller, 2002; Union of Concerned Scientists and Environmental Defense, 2002). Corn rootworm is highly adaptive and thus able to overcome management efforts based on crop rotation as well as insecticides, which has increased the demand for a new corn rootworm control technology (Alston, Hyde, Marra, & Mitchell, 2002). All of these factors signal higher adoption rates for Bt corn and an increase in the importance of IRM compliance.

As we enter a new generation of Bt corn transgenics, we must understand how farmers will respond to IRM requirements before we can design management strategies that have the best chance of promoting the sustainable use of Bt corn. By employing a more comprehensive set of measures of IRM compliance and conducting an in-depth analysis of the roles of farm size and IRM awareness, our study begins to shed light on compliance behavior in two corn-producing states. However, additional research is needed to validate the voluntary compliance reports of our mail surveys and the ABSTC's telephone surveys. New on-farm IRM assessment data may provide an important opportunity. Additional research is also needed to better understand the interaction between the economic, sociological, and social-psychological facets of farmer compliance behavior and the biology of insect resistance. Without a better understanding of this interaction, a comprehensive answer to Jaffe's provocative question ("Are farmers squandering Bt corn technology?"; Jaffe, 2003a) will remain elusive.

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