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Bt Corn Farmer Compliance With Insect Resistance Management Requirements: Results From The 2002 Minnesota And Wisconsin Farm Polls

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ABSTRACT: The U.S. Environmental Protection Agency (EPA) reregistered Bt corn in 2001 with mandatory Insect Resistance Management (IRM) requirements in order to promote sustainable use by farmers. Since then studies report IRM compliance rates ranging from 80 to 90 percent. 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 60 to 75 percent.

Key words: Bt corn, compliance, Insect Resistance Management, refuge

Bt corn is engineered with genetic material from the soil bacterium *Bacillus thuringiensis* (Bt). This material allows corn to produce proteins that are toxic when consumed by specific insect pests, such as the European corn borer. Bt corn is an important example of the success and controversy engulfing agricultural biotechnology.

Bt corn has been rapidly adopted in the U.S. since its introduction in 1996 (see Table 1). This rapid adoption stalled and even declined in 2000, but picked up again in 2002. Bt corn currently represents about 29 percent of U.S. and 10 percent of global corn acreage (Buttel and Hirata, 2003). The rapid adoption of Bt corn is remarkable because debate still surrounds the potential

Table 1. Bt corn adoption in the U.S.

Year	Percentage Of Bt Corn
1996	1.4
1997	7.6
1998	19.1
1999	25.9
2000	19.0
2001	19.0
2002	24.0
2003	29.0

Note: Source: U.S. Department of Agriculture, Economic Research Service.

for higher returns and reduced insecticide use (see Marra et al., 2002, and literature cited therein). Also, important U.S. trading partners, like the European Union, have imposed import restrictions.

The decline and stagnation in Bt corn adoption in 2000 and 2001 are likely attributable to two controversies that were widely covered by popular media. Losey (1999) reported that monarch butterfly larvae died after eating milkweed dusted with Bt corn pollen, which fueled concerns about the ecological impact of Bt corn (see Pew Initiative on Food and Biotechnology, 2002). In 2000, genetic material from StarLink™ Bt corn was found in food products, even though the EPA had not approved it for human consumption, which fueled concerns about the human health effects of Bt corn. Both events raised farmer concerns regarding consumer acceptance of Bt corn.

Controversy erupted again when Quist and Chapela (2001) reported finding genetic material from Bt corn in traditional landraces of Mexican corn (also Gewin, 2003). Despite the ecological concerns raised about the impact of gene flow from Bt to native cultivars, the percentage of Bt corn planted increased in 2002 and again in 2003.

While there are varied opinions about the ecological and human health consequences of Bt crops, there seems to be a broad consensus that Bt resistant insects are likely to emerge without the careful management of this new technology (Mellon and Rissler, 1998 and ILSI/HESI, 1999). Insect resistance to Bt is a concern because Bt is considered a safer alternative to synthetic insecticides (U.S. EPA, 1998). If Bt becomes ineffective due to insect resistance, farmers may switch to more harmful insect control options (CFS, 1999).

Entomologists and ecologists have proposed a high-dose refuge management strategy to reduce the likelihood of Bt resistance (e.g. Gould, 1988, 1998; Alstad and Andow, 1995; and Roush and Osmond, 1996). For a high-dose, the amount of toxin produced by plants must kill all but the most resistant insects. For refuge, farmers must plant some corn with non-Bt cultivars. Refuge allows insects that are susceptible to Bt to thrive and mate with resistant insects. With a high-dose, the majority of offspring will be Bt susceptible prolonging the efficacy of Bt corn and reducing the likelihood of farmers using to more harmful insecticides.

The EPA extended Bt corn registrations in 2001 with mandatory Insect Resistant Management (IRM) based on the high-dose refuge strategy (EPA, 2001). Bt crop registrants implement EPA requirements by having farmers sign legally binding agreements. In the primary corn growing regions of the U.S., these agreements obligate farmers to plant at least 20 percent refuge. Refuge can be planted externally in a separate field if it is within ½ mile of the farmer's Bt corn. Alternatively, refuge can be planted internally in the same field as Bt corn using borders, blocks, or multiple strips, but not a seed mix. Microbial Bt insecticides are not permitted for insect control on refuge, but other insecticides can be applied based on economic thresholds.

These IRM requirements have become the focal point of a new controversy. In June 2003, the Center for Science in the Public Interest (CSPI) released the provocatively titled, *Planting Trouble: Are Farmers Squandering Bt Corn Technology?* (Jaffe, 2003 a and b). Using U.S. Department of Agriculture National Agricultural Statistics Service (NASS) data, the reports showed that in 2002, 21 percent of farmers growing Bt corn in ten Midwestern states did not comply with the EPA's 20 percent refuge size requirement. The report also noted that the rate of noncompliance was higher for small farms (less than 200 corn acres).

While the CSPI reports were the first to bring IRM compliance to broader public attention (e.g. Weise, 2003 and Pollack, 2003), compliance was not a new issue for the EPA

(Hurley, 1999 and EPA, 2001). Indeed, the EPA requires Bt crop registrants to implement a Compliance Assurance Program (CAP). As part of these CAPs, the Agricultural Biotechnology Stewardship Technical Committee (ABSTC) commissioned independent surveys between 2000 and 2002, which showed at least 85 and 89 percent compliance with the 20 percent size and ½ mile distance requirements in the Midwest (ABSTC, 2002).[1] Jaffe (2003 a) attributes the disparity between the NASS and ABSTC data to a difference in sampling protocols. ABSTC only surveyed farms with 200 corn acres or more.

Using farm level survey data collected in Minnesota and Wisconsin, we replicate and extend Jaffe (2003 a and b) and ABSTC (2002). Specifically, we employ a more comprehensive set of measures of IRM compliance, which include the EPA's refuge size, and external and internal configuration requirements. We also use more comprehensive data to explore the relationship between farm size and IRM compliance. By presenting data from Minnesota and Wisconsin, our study permits the comparison of two states that vary in terms of Bt corn adoption rates and prevalence of large-scale corn production.

DATA AND METHOD

Surveys were sent to Minnesota and Wisconsin corn producers in the spring of 2002. In each state, 2,000 participants were randomly and confidentially drawn from the Minnesota and Wisconsin Agricultural Statistics Services' farmer databases. Survey response rates were 39 and 49 percent in Minnesota and Wisconsin.[2]

The survey asked farmers about their use of genetically modified (GM) crops in 2001: insect-resistant (Bt) corn, and herbicide-tolerant (HT) corn and soybeans. It asked why they planted GM 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. But most importantly for present purposes, the survey included objective measurements for all aspects of IRM. Therefore, unlike the NASS data drawn upon by Jaffe, our data can be used to assess grower compliance with external and internal refuge configuration requirements.

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

In terms of the 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 were non-compliant with the internal requirement, 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 fields were more than ½ mile away from one of his non-Bt fields, the farmer was non-compliant with the external requirement, otherwise he was compliant. If a farmer was non-compliant with either the internal or external requirement, he was considered non-compliant with the configuration requirement, otherwise he was compliant.

We also asked Bt corn farmers if they used chemical or microbial Bt insecticides on any non-Bt corn acres. Recall, the EPA does not permit the use of microbial Bt on refuge, but does allow the use of other insecticides based on economic thresholds. Since non-Bt corn acres can include refuge and non-refuge when the percentage of Bt corn is less than 80, in hindsight, our measurement does not precisely identify compliance with refuge insecticide use. Therefore, while for example 9.8 percent of the Wisconsin respondents reported using microbial Bt insecticides or other insecticides without economic thresholds, we cannot be sure that all of them were out of compliance.

Due to our imprecise measurement of compliance with refuge insecticide use requirements, we define “Full Compliance” with the EPA’s IRM requirements based on refuge size and configuration compliance. If farmers complied with both, they were defined as fully compliant, otherwise they were not.

FINDINGS

We begin by comparing our 2001 compliance results for refuge size with the 2002 results reported in Jaffe (2003 a and b) and USDA/NASS (2003). We then consider refuge configuration compliance with and without refuge size compliance. Finally, we explore the relationship between farm size and compliance using more comprehensive measures of farm size.

Table 2 presents the number and percentage of corn farms that planted Bt corn varieties in our Minnesota and Wisconsin samples. Bt corn adoption rates among the Minnesota and Wisconsin samples were 44.5 and 23.5 percent, respectively. For both states, we found a higher Bt corn adoption rate for farms with 200 or more corn acres. In Minnesota, 67.6 percent of these large farms grew Bt corn, compared to only 32.8 percent of small farms (those with less that 200 corn acres). The Wisconsin sample had lower adoption rates for these two size categories: 53.7 percent for large and 17.0 percent for small farms. These percentages are somewhat higher—except for large Bt corn farms in Minnesota—than those presented by Jaffe and USDA/NASS.

Table 3 presents the percentage of corn acreage planted with Bt corn for Bt corn adopters in Minnesota and Wisconsin. Of the Bt corn farms in our survey, 16.3 percent in Minnesota and 9.3 percent in Wisconsin did not comply with the EPA's 20 percent refuge size requirement. In Minnesota, refuge size noncompliance was greater among small farms (19.7 percent) when compared to large farms (13.1 percent). In contrast, Wisconsin noncompliance rates were nearly

Table 2. 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	274 (20,310)	43.5 (61.1)	531 (27,960)	69.1 (82.7)
Bt Corn	356 (12,920)	56.5 (38.9)	238 (5,850)	30.9 (17.3)
TOTAL	630 (27,960)	100.0 (100.0)	769 (33,810)	100.0 (100.0)
	Farms With < 200 Corn Acres			
No Bt Corn	244 (17,270)	59.8 (75.9)	484 (25,960)	73.4 (86.1)
Bt Corn	164 (5,470)	40.2 (24.1)	175 (4,180)	26.6 (13.9)
TOTAL	408 (22,740)	100.0 (100.0)	659 (30,140)	100.0 (100.0)
	Farms With ≥ 200 Corn Acres			
No Bt Corn	30 (3,040)	13.6 (29.0)	46 (2,000)	42.6 (54.5)
Bt Corn	190 (7,450)	86.4 (71.0)	62 (1,670)	57.4 (45.5)
TOTAL	220 (10,490)	100.0 (100.0)	108 (3,670)	100.0 (100.0)

Note: For comparison, results for 2002 reported in Jaffe (2003a and b) and USDA/NASS (2003) are provided in parentheses.

identical for small and large farms (9.3 percent and 9.2 percent, respectively). Compared to Jaffe and USDA/NASS, we find nearly identical rates of noncompliance among large farms in both states. However, USDA/NASS suggests a higher degree of noncompliance among small farms, especially in Wisconsin.

Table 4 reports results for our survey when refuge configuration compliance is considered in addition to refuge size compliance. If we only consider the refuge size requirement, 83.8 and 90.7 percent, respectively, of Minnesota and Wisconsin Bt corn farmers were compliant. Both estimates suggest more compliance than Jaffe and USDA/NASS. While the Minnesota estimate is a little lower than the average estimate reported by ABSTC (2002), the Wisconsin estimate is a little higher.

Table 3. Percentage of corn planted with European corn borer Bt corn on farms in Minnesota and Wisconsin, 2003.

% Of Corn Acreage Planted With Bt Corn	Minnesota		Wisconsin	
	Farms	% Of Farms	Farms	% Of Farms
	All Corn Farms			
0.1 - 80.0	277 (10,560)	83.7 (81.7)	182 (4,810)	84.7 (82.2)
80.1 - 99.9	27 (680)	8.2 (5.3)	11 (120)	5.1 (2.1)
80.1 - 85	12	3.6	2	0.9
85.1 - 90	8	2.4	5	2.3
90.1 - 95	4	1.2	1	0.5
95.1 – 99.9	3	0.9	3	1.4
100	27 (1,680)	8.2 (13.0)	22 (920)	10.2 (15.7)
TOTAL	331 (12,920)	100.0 (100.0)	215 (5,850)	100.0 (100.0)
	Farms With < 200 Corn Acres			
0.1 - 80.0	113 (4,120)	75.8 (75.3)	124 (3,290)	80.0 (78.7)
80.1 - 99.9	16 (230)	10.7 (4.2)	10 (80)	6.5 (1.9)
100	20 (1,120)	13.4 (20.5)	21 (810)	13.5 (19.4)
TOTAL	149 (5,470)	100.0 (100.0)	155 (4,180)	100.0 (100.0)
	Farms With ³ 200 Corn Acres			
0.1 - 80.0	164 (6,440)	90.1 (86.5)	58 (1,520)	96.7 (91.0)
80.1 - 99.9	11 (450)	6.0 (6.0)	1 (40)	1.7 (2.4)
100	7 (560)	3.8 (7.5)	1 (110)	1.7 (6.6)
TOTAL	182 (7,450)	100.0 (100.0)	60 (1,670)	100.0 (100.0)

Note: For comparison, results for 2002 reported in Jaffe (2003a and b) and USDA/NASS (2003) are provided in parentheses.

Table 4. IRM compliance rates (incomplete response rates) for European corn borer Bt corn farms in Minnesota and Wisconsin, 2003.

	Minnesota	Wisconsin
20 Percent Refuge Size Compliance	83.7	84.7
	(7.0)	(9.7)
Refuge Configuration Compliance	90.6	86.0
	(7.0)	(3.8)
Refuge Insecticide Treatment Compliance	96.3	99.1
	(1.1)	(1.7)
Full Compliance (i.e. Refuge Size, Configuration, & Insecticide Treatment Compliance)	74.6	74.3
	(13.8)	(13.4)

If we only consider the refuge configuration requirement, 71.2 and 77.4 percent of Minnesota and Wisconsin Bt corn farmers were compliant. Refuge configuration compliance was lower than refuge size compliance. It is also worth noting that our estimates for configuration compliance are lower than those reported by ABSTC for the ½ mile distance requirement. A more disaggregated look at our data revealed that much of this discrepancy can be explained by our consideration of the internal configuration requirement in addition to the ½ mile external configuration requirement.

Considering the refuge size and configuration requirements together (i.e. “Full Compliance”), only 62.2 and 72.3 percent, respectively, of Minnesota and Wisconsin Bt corn farmers were compliant. This result implies that most noncompliant farmers violated either the size requirement or configuration requirement, but not both. The result also indicates that the widely cited CSPI report exaggerates IRM compliance rates because the USDA/NASS data only allows the consideration of refuge size violations. ABSTC results also seem to exaggerate compliance rates because they consider different facets of compliance individually, but not combined.

Table 5. IRM compliance and farm size in Minnesota (MN) and Wisconsin (WI), 2001.

	20 Percent Size		Configuration		Insecticide Treatments		Full	
	MN	**WI**	**MN**	**WI**	**MN**	**WI**	**MN**	**WI**
CORN ACRES								
0 - 100	75.0	75.2	90.1	82.7	98.7	100.0	72.6	64.3
101 - 200	77.0	89.8	89.5	90.5	97.8	98.4	71.6	82.1
201 - 400	93.6	100.0	93.3	83.9	99.0	100.0	86.9	86.7
401 - 1,000	86.1	90.0	88.9	88.9	89.2	94.7	65.7	76.5
1,001 or more	90.0	100.0	90.0	100.0	90.0	100.0	70.0	100.0
c^2**(4)**								
CROP ACRES								
0 - 100	66.7	59.1	87.5	80.0	100.0	100.0	64.3	47.6
101 - 200	82.9	81.1	95.5	83.3	100.0	100.0	84.6	68.6
201 - 400	81.8	87.7	88.9	85.2	96.4	98.8	72.6	77.1
401 - 1,000	88.5	95.7	90.4	89.4	97.7	100.0	80.6	88.6
1,001 or more	84.4	88.9	89.1	94.7	90.8	94.7	65.1	76.5
c^2**(4)**								
FARM RECEIPTS								
< $50,000	73.5	63.8	90.0	89.8	100.0	100.0	67.4	57.8
$50,000 – 99,000	80.8	87.0	85.7	80.0	98.2	96.0	72.3	66.7
$100,000 - 199,999	83.5	89.4	91.3	85.9	96.6	98.6	78.9	79.7
$200,000 - 499,999	88.5	92.7	92.4	85.7	93.8	100.0	75.8	81.1
$500,000 or more	92.3	88.9	89.3	90.0	89.3	100.0	69.2	82.4
c^2**(4)**								

Note: The number of observations varied from 286 to 351 for Minnesota and 200 to 233 for Wisconsin.

The inclusion of small farms was a primary reason why Jaffe (2003 a and b) found lower compliance rates than ABSTC (2002). Based on this result Jaffe argued that compliance was positively related to farm size. We now revisit the relationship between farm size and IRM compliance. In addition to looking at a more comprehensive set of IRM compliance measures, our data allow us to consider a more comprehensive set of farm size measures: corn acreage, cropland acreage, and gross farm income. Furthermore, each of these measures was divided into five categories (see Table 5) instead of two in order to obtain a clearer picture of any potential relationship.

Table 5 presents data for refuge size, 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) and Kendall's tau-*c* (*t-c*). The χ^2 is a test for independence. A significant χ^2 indicates correlation, but does not measure the strength or direction of correlation. The *t-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 (Kendall, 1962).

Two conclusions are apparent. First, there is essentially no relationship between farm size and full IRM compliance for both states. Second, there is an inconsistent relationship between farm size and refuge size, and farm size and configuration compliance. Only one-half of the χ^2 and one-third of the *t-c* statistics are significant (*p*-value < 0.05). Those that are significant pertain only to Minnesota. For Minnesota, all of the χ^2 and *t-c* statistics are significant when refuge size and configuration compliance are considered individually. For refuge size compliance, the *t-c* statistic are consistently less than 0.2 and greater than 0.1, which indicates a weak positive relationship. For refuge configuration compliance, the *t-c* statistics are all about -0.2, which indicates a moderate negative relationship. Combined these results imply smaller Minnesota Bt corn farms were slightly less likely to comply with refuge size requirements, but moderately more likely to comply with refuge configuration requirements.

DISCUSSION AND CONCLUSIONS

Our findings confirm, or are consistent with, several but not all of those reported by Jaffe (2003 a and b) and USDA/NASS (2003). While we found higher Bt corn adoption rates among corn producers in Minnesota and Wisconsin, the two sets of estimates are similar. For large farms, our compliance estimates for the 20 refuge size requirement are remarkably similar to Jaffe and USDA/NASS. However, we found higher rates of size compliance for small farms, especially those in Wisconsin. Like Jaffe, small Minnesota farmers were less likely to comply with refuge size requirements. Unlike Jaffe, there was no relationship between farm size and refuge size compliance in Wisconsin.

However, our primary purpose was to go beyond Jaffe and USDA/NASS by using more comprehensive measures of IRM compliance. Specifically, we include refuge configuration compliance along with refuge size compliance because an appropriate refuge configuration is crucial for IRM success (Milewski, 1998). When refuge size and configuration compliance are considered together, IRM compliance rate estimates drop by approximately 20 percentage points, which suggests the widely cited estimates of IRM compliance reported by Jaffe and USDA/NASS are exaggerated.

We also included a more comprehensive set of measures for farm size and a more variegated analysis of the role of farm size in predicting IRM compliance. Our analysis suggests that full IRM compliance (i.e., refuge size *and* configuration compliance) is not associated with farm size—whether measured in terms of corn acreage, cropland acreage, or gross farm sales—in Minnesota or Wisconsin. However, in Minnesota at least, the reason for noncompliance differs between small and large farms. Small farms are more likely to plant too little refuge, while large farms are more likely to plant refuge in the wrong place. Noncompliant farmers are noncompliant for different reasons; reasons that, at least in Minnesota, appear to have some association with farm size.

It may be tempting to dismiss the relevance of these and previous findings because two-thirds of the corn acreage in the U.S. is not planted with Bt corn, which presumably provides a de facto refuge for the remaining third. There are a variety of reasons why this interpretation may not be prudent.

The adoption of European corn borer (ECB) Bt corn in some U.S. counties is well in excess of a third of corn acreage. Furthermore, adoption rates are again rising. Therefore, the amount of de facto refuge is on the decline, increasing the importance of IRM compliance.

Monsanto released corn rootworm (CRW) active Bt corn in 2003 and will release CRW and ECB active Bt corn in 2004. Dubbed the "billion-dollar pest," CRW is considered the primary pest in many corn growing regions. It accounts for two-thirds or more of annual insecticide applications on corn, which is more than three times the corn acreage treated for ECB before the introduction of ECB active Bt corn (Miller, 2002; and UCS, 2002). CRW are highly adaptive, overcoming management efforts based on crop rotation as well as insecticides, which has increased the demand for a new CRW control technology (Alston et al., 2003). CRW active Bt corn does not appear to produce a high-dose (Milewski, 1998), which could reduce any margin of error built into existing IRM requirements. All of these factors increase 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 ones 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 role of farm size, our study begins to shed light on compliance behavior in two very different corn-producing states. Still, additional data is needed for the third major component of the EPA's IRM program — refuge insecticide use. Follow-up surveys are also needed to evaluate the impact of the more comprehensive compliance monitoring and enforcement program implemented during the 2003 growing season by Bt crop registrants. This new program calls for individual farm assessments of IRM compliance. If these assessments show a farmer has failed to meet the EPA's requirements in two consecutive years, the farmer will not be allowed to purchase Bt corn the following year. Finally, additional research is 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 important question (*Are Farmers Squandering Bt Corn Technology?*) will remain elusive.

Endnotes

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[1] ABSTC is a consortium of the agricultural biotechnology firms (Dow AgroSciences, Pioneer Hi-Bred/DuPont, Monsanto, and Syngenta) that market Bt corn.

[2] The lower response rate in Minnesota is primarily attributable to a larger proportion of surveys that were unintentionally sent to non-corn farmers.

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