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Economic Considerations for the Adoption of Transgenic Crops: The Case of Bt Corn[1]

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Abstract: Biotechnology is offering farmers new crop production opportunities and challenges. Prior to selecting a transgenic variety, farmers must consider the cost of the technology fee, possible yield drag, potential pest infestations, possible reductions in pesticide costs, refuge requirements to minimize the development of insect resistance, and adjustments in cultural practices. Moreover, crop segregation in the field, storage, and shipment may be necessary to capture potential price premiums for non-transgenic varieties. As farmers consider these various production and marketing factors, they find that Bt corn is a more profitable control method for European corn borer in the Western Corn Belt relative to the Eastern Corn Belt. This is primarily due to higher infestation probabilities in the Western Corn Belt, coupled with greater demand for manufacturing and export uses in the Eastern Corn Belt where several buyers do not accept transgenic corn.

Key words: Bt corn, genetic engineering, pest management, transgenic crop adoption.

Since the introduction of Bt cotton in 1995 and transgenic corn and soybeans in 1996, the total crop area planted to transgenic crops has reached 74 million acres in the United States and 109 million acres worldwide (International Service for the Acquisition of Agribiotech Applications, 2000). With the introduction of transgenic crops, farmers throughout the world face new production and marketing challenges as they determine whether or not to adopt transgenic crops.

When considering the adoption of a transgenic crop, the first issue that farmers must consider is the cost of the technology fee. For crops such as Roundup Ready soybeans (Monsanto Corporation, St. Louis, MO) and Bt corn, this fee is approximately $8 to $10 per acre (Wiatt, 2000). A second consideration is the probability of a pest infestation. Weeds, of course, grow every year and herbicides are used on nearly 100% of the corn and soybean acreage in North America. However, insect infestations vary by crop and by region. For example, infestations of the boll weevil (the insect targeted by Bt cotton) are quite likely to occur in most cotton-producing regions. On the other hand, European corn borer (ECB) (targeted by Bt corn) pressures are greater in the Western Corn Belt than in the Eastern Corn Belt. A third consideration is yield drag. Often, the transgenic trait is not initially introduced into the varieties producing the highest yield in every production region. Hence, farmers may find that some of the available transgenic varieties are not adequately adapted for their soils or micro-climatic conditions and, consequently, may yield less than other varieties. A yield drag of only 1 or 2% may offset the potential benefits of a transgenic trait, such as Bt corn (Hyde).

An additional consideration is the extent of any reduction in pesticide costs. For example, farmers planting Roundup Ready soybeans may find they can reduce by as much as 50% their herbicide cost as they switch from pre- and post-applied herbicides to a post-application of Roundup for weed control. Many cotton producers also report substantial reductions in insecticide costs.

Some transgenic crops such as Bt corn require a refuge. A refuge permits some ECB to survive and reduces the likelihood of the development of insect resistance to the Bt trait. In January 2000, the U.S. Environmental Protection Agency required all farmers growing Bt corn to plant at least 20% of their corn acreage as a refuge with a non-Bt variety. The impact the technology may have on beneficial insects also must be considered. For example, laboratory research at Cornell University (Losey et al. 1999) and a partial field study at Iowa State University (Jesse and Obrycki, 2001) suggest that the Bt trait in corn may harm the Monarch Butterfly. However, other research suggests that, under field conditions, the negative impact on the Monarch Butterfly is minimal (Agricultural Biotechnology Stewardship Technical Committe; 2001).

An additional consideration is a potential need for adjustments in the tillage system. For example, the use of Roundup Ready soybeans has further encouraged farmers to adopt a no-till system. With Roundup Ready soybeans, no tillage is necessary to incorporate pre-emergence herbicide into the soil. Hence, farmers can plant directly into the corn stalks from the previous year and return, after the soybeans have emerged, to apply the Roundup herbicide for weed control. Thus, the transgenic soybean technology system may contrib-

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[4] The data for this study were provided by entomologists at Purdue University, the University of Illinois, Iowa State University, and Kansas State University, who provided information on scouting and spraying costs. They also provided information on spraying efficacy (Hyde, 2000). Scouting programs are essential for optimal timing of spraying for ECB. Furthermore, rain events or other weather factors may reduce the efficacy of a given spraying treatment. The entomologists provided information on yield losses associated with different planting dates and the probability of ECB infestations. They also offered information on the physiological damage that might occur depending on planting date and the predicted generation of ECB infestations. With each infestation, it is important to account for the number of borers per plant that may occur.

ute to a reduction in soil erosion and may mitigate potential water-quality problems associated with soil-incorporated herbicides.

Some consumers, particularly in the European Union, have expressed concerns about the impacts of transgenic crops on the environment and food safety. Consequently, some consumers and processors are unwilling to purchase transgenic crops. Thus, a parallel market system has emerged. Premiums have been offered for small amounts of non-GMO (genetically modified organism) corn or soybeans. These premiums typically range from $0.05 to $0.20 per bushel depending on the market location. This parallel market system means that farmers may face additional crop segregation costs. To obtain a premium for non-GMO crops, farmers must purchase and plant non-transgenic seed. In the case of crops, such as corn, where pollen can drift, there must be segregation among the fields and all harvesting and handling must take into account careful segregation of GMO from non-GMO crops. Some markets require a less-than-1% ''contamination'' with GMO varieties. Such stringent market requirements mean that farmers must carefully clean their combines, trucks, grain legs, and storage bins and assure delivery of the uncontaminated product to the marketplace. Hence, farmers who wish to qualify for a non-GMO premium will incur additional costs.

The Case of BT Corn

To further understand the factors that farmers must consider when they decide whether or not to adopt a transgenic crop, the Bt corn case is illustrative. The United States experiences approximately $1 billion in damage due to the ECB annually. This cost accounts for insecticide application costs as well as yield losses. Yield losses may be due to both physiological and mechanical damage. Physiological damage is a result of the ECB entering the corn stalk and limiting the movement of water and nutrients in the xylem and phloem in the stalk to the ear. This can limit ear and kernel formation and, thus, reduce yields. Mechanical damage may be a result of stalks blowing over during a windstorm or ears dropping at the time of combining, as a result of stalks weakened by the ECB damage. This can further reduce per-acre corn yields.

ECB infestations (Fig. 1) in the United States are heaviest in the Western Corn Belt, especially parts of Nebraska, western Iowa, and southwestern Kansas. More modest infestation levels are common in eastern Iowa, Missouri, and Illinois. Eastern Corn Belt states such as Indiana tend to have minimal infestations in most years.

Bacillus thuringiensis (Bt) is a soil bacterium that contains in its spores a crystalline (''cry'') protein (Ostlie et al., 1997). Different cry proteins from different bacterial strains have been selected for the control of different insects. In the case of Bt corn, a particular cry protein has been introduced into the plant's genome that primarily kills ECB. The most widely used is YieldGard (Monsanto Corporation, St. Louis, MO, and various seed corn companies). The transgenic YieldGard plants, Bt11 and Mon810, provide a high dose or expression of the cry protein in all parts of the above-ground portion of the corn plant during the entire growing season. Thus, ECB larvae are likely to encounter the protein, regardless of timing of infestation. Once ingested, the cry protein is converted by the ECB larva into a toxin that disrupts the cell membrane in the digestive system, causing the insect to stop feeding within a matter of hours and to die within 24 hours.

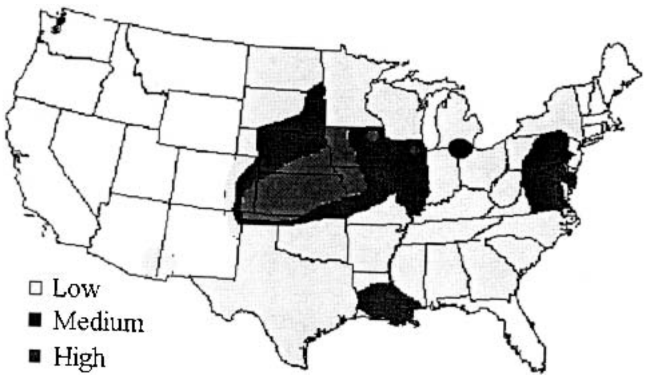

Fig. 1. European Corn Borer Infestation

A multi-state study was conducted to explore the adoption decision for ECB (Hyde). States selected (Fig. 2) include Indiana, Illinois, Iowa, and Kansas. In 2000, these four states represented 41% of total corn production in the United States. Furthermore, they represent a range from low to moderate to high ECB infestation levels. And, at the time of the study, the technology fee for YieldGard ranged from $8 to $10 per acre, depending on the seeding rate (Wiatt, pers. comm.).

The analysis was conducted using a decision analysis model (Raiffa, 1970). This model involves a decision tree. At each node or branch in the tree, the farmer faces a decision. For example, the first key decision a

Fig. 2. Multi-State Study

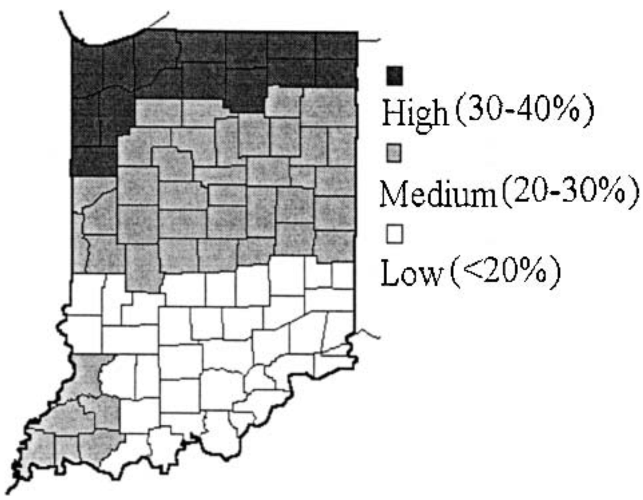

FIG. 3. European Corn Borer Infestation—Indiana

farmer must make is whether to select a Bt or a non-Bt seed corn. If a non-Bt seed corn is selected, the farmer then faces the possibility of a first, second, and (or) third-generation infestation of ECB. With each infestation level, the farmer must decide whether it is economically viable to spray with an insecticide.

The planting date in th model is random, ranging from mid-April through early June. The decision analysis model calculates for each decision node or branch the economic payoff that reflects the income minus any associated costs for spraying. The model is solved using a Microsoft Excel 2000 spreadsheet working from the leaves, or payoffs, back through the branches and ultimately to the root of the tree. The model maximizes expected utility and calculates ''certainty equivalents.'' The certainty equivalent is a monetary measure of expected utility, which is a mathematical estimate of the satisfaction of an individual with the probabilistic outcome of a given event. These calculations provide a monetary estimate of an economically optimal decision for a given set of economic and agronomic conditions.

Indiana results: The same basic decision analysis model was used for both Indiana and Illinois because their agronomic and economic conditions are very similar. The first calculation was to determine whether or not it was economically viable to spray for ECB under various infestation levels. The extreme northern part of Indiana (Fig. 3) can experience relatively high infestation levels (30–40%). The central part of the state has a medium infestation level (20–30%), and the lower third of the state has low infestation levels (less than 20%). Because the return to spraying is less than $3 per acre in Indiana, and the typical scouting cost is $3 per acre, it does not pay to have a spray program for ECB in Indiana. Thus, the comparison for Indiana adoption of Bt corn is with unsprayed non-Bt corn. Under risk-neutral conditions (Table 1), at a 30% expected infestation level, the return to Bt corn is less than the typical $8-per-acre technology fee. Hence, the decision would be to not adopt Bt corn at this technology fee. However, at a $400 revenue ($2 per bushel and 200 bushels per acre) and a 40% infestation level, the value of the Bt corn would be $8.33 per acre. In this situation, it would be economically profitable for a farmer to adopt Bt corn if the technology fee is $8 per acre. The more risk-averse farmers would find that, at a slightly lower revenue level and a 40% probability of infestation, it is economically advantageous to adopt Bt corn. This is because there is some insurance value for more risk-averse farmers to adopt the Bt technology to protect yield. Risk aversion is a statistical coefficient that reflects the farmer's willingness to avoid risk. The coefficient is zero for a risk-neutral farmer. Larger, positive coefficients indicate the farmer is less willing or able to handle risk and might try to reduce risk by purchasing crop insurance and (or) by increasing willingness to plant Bt corn.

Illinois results: The north-central part of Illinois (Fig. 4) has high infestation levels (50–80%). The south-central part of the state has medium-level infestation (20–49%), and the extreme southern part of the state has a low infestation level (less than 20%). Using the same basic decision model as for Indiana, the results for Illinois suggest that with a $400-per-acre or higher revenue at both the 40% and 60% probability of infestation, Illinois farmers would find it economically profitable to adopt Bt corn. If the farmer is risk-averse, it would be economically profitable to adopt Bt corn when the infestation level is 40% or higher assuming a technology fee of $8 per acre.

TABLE 1. Estimated per-acre Bt corn values, given probability of infestation.

	Indiana				Illinois				Iowa			
	Risk neutral		Risk averse		Risk neutral		Risk averse		Risk neutral		Risk averse	
	Infestation probability											
	30%	40%	30%	40%	40%	60%	40%	60%	40%	60%	40%	60%
Revenue	Dollar value per acre											
$300	$4.53	$6.24	$5.12	$6.99	$6.99	$10.18	$6.99	$11.13	$6.55	$10.32	$7.30	$11.26
$350	$5.28	$7.29	$6.09	$8.31	$7.29	$11.88	$8.31	$13.17	$7.64	$12.04	$8.68	$13.33
$400	$6.04	$8.33	$7.11	$9.67	$8.33	$13.58	$9.67	$15.27	$8.74	$13.76	$10.10	$15.45
$450	$6.79	$9.37	$8.17	$11.09	$9.37	$15.27	$11.09	$17.43	$9.83	$15.48	$11.57	$17.64

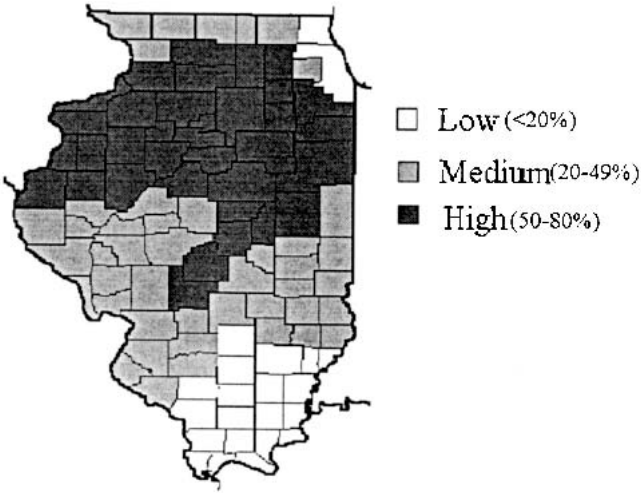

FIG. 4. European Corn Borer Infestation—Illinois

Iowa results: The conditions for Iowa are somewhat similar to those for Illinois and Indiana. While the scouting cost is about $2 per acre in Iowa, the returns for spraying are less than $2 per acre. Hence, the comparison should be Bt corn to unsprayed non-Bt corn. The infestation levels tend to be the highest in the north-northwest part of Iowa (40–60%) (Fig. 5), at medium infestation levels in the central part of the state (20–39%), and at relatively low levels in the southern tier of counties as well as the northeastern part of the state (less than 20%). Risk-neutral farmers with a $400-per-acre or higher expected revenue would find at a 40% or higher infestation level that it would be economically viable to adopt Bt corn at an $8-per-acre technology fee (Table 1). Farmers who are risk-averse, at revenues from $350 per acre and a 40% or higher proftability of infestation, also would find it economically profitable to adopt Bt corn (Table 1).

Southwest Kansas results: Southwestern Kansas (Fig. 6) has a very high infestation level of both European and Southwestern corn borer. This is a region of Kansas where continuous corn is grown frequently under irrigated conditions. Hence, corn borer infestations are relatively high and farmers are producing a fairly high-value crop due to investment in irrigation and expected high yields. The calculations for southwest Kansas indicate that spraying, in fact, is profitable. Under risk-neutral conditions, the value of spraying is $30.21 per acre for irrigated fields and $3.34 per acre for dryland fields. Bt corn was found to return $29.35 per acre above a spraying program for irrigated fields and $21 per acre above expected returns from spraying in dryland fields.

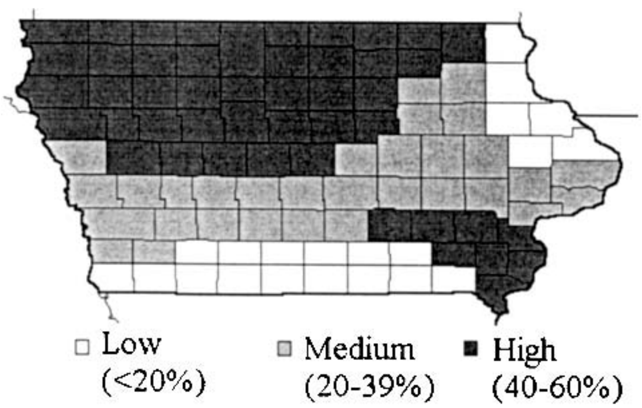

FIG. 5. European Corn Borer Infestation—Iowa

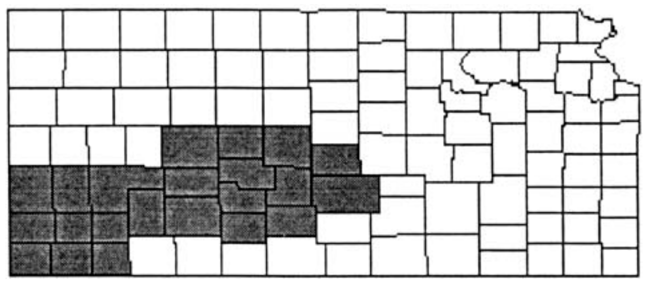

FIG. 6. European Corn Borer Infestation—Southwest Kansas

CONCLUSIONS

This study suggested that the value of Bt corn adoption tends to increase from east to west across the U.S. Corn Belt. Bt corn was found to be especially valuable in southwest Kansas, where both the Southwestern and European corn borer are present. Farmers must adopt a 20% refuge program if they plant Bt corn to comply with the contract they must sign when they purchase the seed. The Bt corn example suggests that farmers face a number of important issues that they must consider before adopting a transgenic crop. These issues include the technology fee, probability of a pest infestation level, potential yield drag, impacts on insecticide costs, potential adjustments in the cropping system due to refuge requirements, possible impacts on beneficial insects, and appropriate adjustments in the tillage system. In addition, farmers may wish to separate Bt corn fields from non-Bt corn fields to capture potential benefits from premiums for non-Bt corn. However, the markets for non-GMO corn may be limited to those locations where exports are important and (or) where food processors are located that will not accept GMO corn. If farmers choose to grow a non-Bt corn, they also must take into account any additional costs associated with market segregation. Clearly, transgenic crops offer new opportunities and challenges for farmers. While they allow farmers a means to potentially protect against yield losses and reduce production costs, they also may create new marketing challenges.

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