The Economics of Refuge Design for Bt Corn

Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel,
Craig L. Dobbins, and C. Richard Edwards*

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ABSTRACT: Planting Bt corn on large areas may lead to European corn borer (ECB) resistance to Bt. Scientists recommend planting a non-Bt corn refuge as part of a resistance management strategy. Different refuge configurations may impact farm profits differently. This paper analyzes the economics of alternative refuge configurations in Indiana.

* Hyde is a Graduate Research Assistant in the Department of Agricultural Economics, Purdue University. Martin, Preckel, and Dobbins are Professors in the Department of Agricultural Economics, Purdue University. Edwards is Professor in the Department of Entomology, Purdue University

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Introduction: The European corn borer (ECB), *Ostrinia nubilalis (Hubner)*, costs U.S. corn farmers between $1 and $2 billion every year (Russnogle). Farmers have several options to help control ECB damage. Some examples include, but are not limited to (Pilcher and Rice):

1. destroying corn stalk residue to reduce the number of overwintering ECB and thus ECB pressure the next year
2. mowing "action sites," grassy areas where ECB breed
3. varying planting dates
4. conserving beneficial insects which kill the ECB
5. harvesting early to reduce stalk breakage and lodging
6. using ECB insecticide applications

None of these methods are fully effective against ECB damage. Estimates of insecticide efficacy, even with optimal timing of application, are about 80% against first generation and 67% against second (Ostlie, Hutchison, and Hellmich). A recent study showed that scouting and spraying for ECB is not economical, on average, in Indiana (Hyde, Martin, Preckel, and Edwards, 1999). That study showed that the cost of scouting for ECB far outweighed the potential benefits from spraying.

A more effective control tool, Bt corn, was commercially introduced in 1996. Bt (short for *Bacillus thuringiensis*) is a natural soil bacterium that has been used for many years as an insecticide. The Bt gene has been placed into corn DNA so that Bt corn produces a crystal-like protein that becomes toxic to ECB once ingested. There are now five distinct types of Bt corn licensed by the EPA for use in the U.S. Only those types sold under the brand name YieldGard®, MON810 and BT11, are analyzed in this research.

Previous work has shown that Bt corn is generally uneconomical in Indiana (Hyde et al., 1999). There are two main reasons for this result. First, heavy ECB infestations are infrequent across Indiana. Statewide, infestations occur on average about once every four years (Hyde et al., 1998) while that probability may be seven or more years out of ten in the Western Corn Belt (Brunoehler). The second reason is that average Indiana yields are low relative to some other Corn Belt states. In 1998, Indiana's 137 bushels per acre was less than other states such as Illinois, Iowa, Kansas, Minnesota, and Nebraska (USDA). The general rule determined in earlier work is that the more the farmer has to protect (in terms of gross revenue per acre) and the greater the likelihood of loss, the more he or she will be willing to pay to protect it.

This suggests that Bt corn is more likely to be adopted in states other than Indiana. Total Bt corn acreage was estimated between 15 and 16 million acres in 1998 (USDA). This represents about 20% of total U.S. corn acreage in only the third year of commercial availability of Bt corn. Scientists worry that extensive adoption of Bt corn in a region may lead to the development of an ECB population that is resistant to the Bt insecticide, both from Bt corn and foliar applied Bt insecticides. The objective of this paper is to expand previous Indiana Bt corn adoption research to estimate the cost differences that exist between alternative configurations of non-Bt corn refuge as part of insect resistance management plans when farmers adopt Bt corn.

<u>Concerns About Resistance Development</u>: The presence of Bt corn in large areas of the environment would provide genetic selection pressure in favor of insects that are not susceptible to Bt insecticides. Therefore, several groups including the Environmental Protection Agency (EPA), North Central Regional Research Committee NC-205

(Ecology and Management of European Corn Borer and Other Stalk-Boring Lepidoptera), and the Union of Concerned Scientists advocate the use of a high-dose/refuge strategy for resistance management.

Under this strategy, the Bt corn must express the Bt toxin at a high enough concentration to kill nearly all corn borers including those that may have a recessive gene for Bt resistance along with a dominant gene for Bt susceptibility. (The underlying strategy is based on a two-gene model of susceptibility. Details may be found in Onstad and Gould). The YieldGard® varieties express a high dose of the Bt toxin throughout the entire corn plant, throughout the growing season. Thus, they are believed to satisfy the high-dose requirement. However, Bt expression in Event 176 and DBT418 declines as the corn senesces. Because these types do not meet the high-dose requirement later in the growing season, there is concern that these Bt types might accelerate resistance development (Andow and Hutchison). These types are not analyzed in this research.

The goal of the refuge within the high-dose/refuge strategy is to maintain Bt-free areas in which Bt susceptible ECB can intermingle and mate with Bt non-susceptible ECB. Through this mingling of genetic material, the expectation is that the Bt susceptible genes will be maintained at a relatively high frequency in the ECB population. Due to the migratory habits of ECB, it is important that the refuge be located sufficiently close to, or within, fields of Bt corn to allow the refuge to effectively serve its purpose.

A number of approaches to refuge design are currently under evaluation in field trials (Horstmeier). These include blocks of non-Bt corn either at the ends of, within, or surrounding fields of Bt corn and strips (a few rows wide) of non-Bt corn running through fields of Bt corn. An alternative refuge strategy based on smaller blocks of crops, such as popcorn, which is highly attractive to ECB, may serve the goal of a refuge. These are expected to be so heavily infested that harvest will typically be uneconomical (Hellmich). These so-called sacrificial refuges are beyond the scope of the current analysis.

The EPA is expected to make formal recommendations on refuge requirements in the near future. It is expected that the recommendations will be similar to those of the North Central Regional Committee NC-205, namely that the refuge should cover 20-30% of total corn acreage if the corn is not treated with corn borer insecticides or 40% if treated with insecticide (Ostlie, et al.). Under EPA's earlier agreement with Monsanto to market YieldGard® Bt corn, farmers must agree to plant a 20% refuge in treated corn and only 5% if untreated (Hurley, Babcock, and Hellmich, 1997). Recently, the seed corn industry and the National Corn Growers Association (NCGA) have forged a unified position that proposes a 20% refuge regardless of whether it is sprayed or not.

The effectiveness of alternative refuge designs with respect to a single field is assumed to be the same in this work. That is, when comparisons are made across configurations, Bt yields are the same, as are non-Bt yields. One potentially important factor that may prove this assumption incorrect is what some researchers have described as a "halo of suppression" around Bt corn (Buschman, Sloderback, and Higgins; Andow and Alstad). If the halo effect is significant, then total ECB damage in non-Bt corn adjacent to Bt corn would be less than normal damage levels in non-Bt corn alone. Thus, planting 20% of a field in non-Bt corn may provide less than a 20% effective refuge. That is, the population of borers not challenged by Bt toxins will be insufficient to maintain the low frequency of resistance. However, the analysis here does not account for this effect.

The cost of implementation of the alternative refuge designs will be affected by several factors that vary by region. It is expected that total planting costs may differ among refuge configurations. For example, planting strips within a field may require more time than planting a block along the edge of a field or planting a perimeter around the field. Increased planting time means increased labor costs. It may also affect yields in those acres for which planting is delayed due to extended planting time.

Given a set of effective strategies for resistance management, farmers will likely choose the least-cost strategy. However, despite the important economic implications of ECB resistance management, little research has been published on the economics of refuge selection. Simulation techniques have been used to estimate the amount of time it may take for ECB to develop resistance to Bt corn given assumptions on ECB behavior and refuge size (Onstad; Onstad and Gould). An economic assessment of refuge, based on Iowa conditions has been published by Hurley et al. (1997, 1998). Their objective was to determine the refuge size, as a percentage of total corn planted, that would maximize the net present value of the income stream generated over time by that field. The refuge was assumed to be non-Bt corn. Onstad and Guse replicated Hurley et al.'s model for Illinois ECB conditions. Although these studies determined economically optimal refuge sizes, the configuration of the refuge was not addressed.

Methodology: A detailed enterprise budget approach is used to analyze labor cost differences associated with alternative refuge configurations. Two field sizes (40 and 80 acre) and three possible refuge designs (Figure 1) are analyzed.

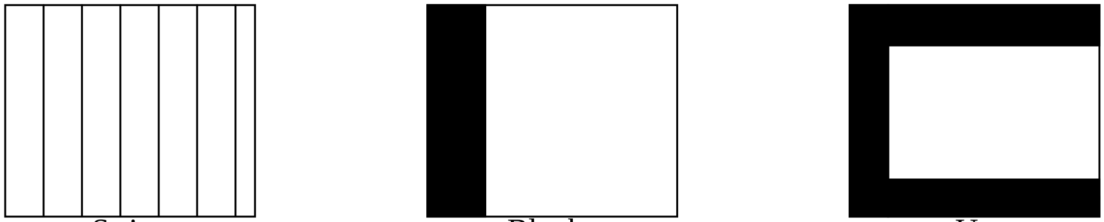

Figure 1. Three refuge configurations

Several assumptions have been made in this analysis.

- Farmer uses a 12-row planter with 30-inch rows
- Seeding rate is 30,000 seeds per acre
- Planting efficiencies are 65% for 40 acre field and 70% for 80 acre field (Hunt)
- Planter runs at top field speed of five miles per hour (Beck)
- Farmer uses an 8-row combine
- It takes 2 minutes per hopper for seed filling when hopper is empty (Nielsen)
- It takes 4 minutes per hopper to empty and fill with new seed (used when farmer switches from Bt to non-Bt, or vice-versa, without running out of seed in the field) (Nielsen)
- Each hopper holds 1.6 bu, or 156,800 "normal"-sized seed (Doane's)
- Each hopper plants up to 5.23 acres (62.7 acres total) when filled to capacity
- YieldGard® Bt corn costs $26 more per unit than a non-Bt iso-line (Hopf)
- Bt corn and its iso-line yield the same in the absence of ECB pressure
- Non-Bt refuge is planted on at least 20% of each field regardless of configuration
- The wage rate for labor is $10 per hour
- The farm uses 1.5 labor hours per machine hour to plant (Doster, 1999)
- The U-shaped refuge is planted first in the end rows while the block refuge is the last seed planted in the field

Empirical Results: This section presents estimated cost differences based on alternative refuge configurations. The difference in planting costs among refuge configurations is due to the extra time spent planting certain configurations. Thus, labor costs are the sources of differences in total costs for the alternative refuge configurations. The total refuge must be at least eight acres in the forty-acre field and 16 acres in the eighty-acre field. Also, it is assumed that the entire field is harvested together. Results are presented separately for each of the refuge configuration-field size combinations.

40 Acre – Strips: This configuration requires the farmer to fill three hoppers with non-Bt seed, nine with Bt seed, and then plant 32 acres. At this point, the farmer empties the three hoppers, fills with Bt seed, and finishes planting the field. This would require an additional 12 minutes (4 minutes to empty and refill X 3 hoppers) within the field. Without a refuge, three hours and 23 minutes would be required to plant the field. However, the new time is now three hours and 35 minutes. The difference in labor costs due to extra time is $3.00 for the entire forty-acre field.

40 Acres – Block: This configuration requires one change of all hoppers at 32 acres, planting the remaining eight acres in non-Bt corn. This represents 48 minutes (4 minutes X 12 hoppers), or a difference in labor costs of $12.00 for the field.

40 Acres – U: This is similar to the forty acres-block scenario except that the eight refuge acres are planted before planting the Bt corn because the refuge is planted in the end rows where the farmer will later turn. However, this still requires one seed change and so the difference in labor costs is the same as for the block refuge, $12.00.

80 Acres – Strips: This configuration requires three hoppers to be filled with non-Bt seed and then plant 62.7 acres. At this point, nine hoppers are filled with Bt seed and the other three with non-Bt seed to plant an additional 1.3 acres to meet the refuge requirement. The non-Bt hoppers are then emptied and filled with Bt seed to finish planting the field. Thus, the net increase in time is twelve minutes, which adds only $3.00 to total planting costs for the eighty-acre field

80 Acres – Block: This configuration is problematic for planting 16 acres of refuge with "normal" sized seed. With normal seed, the maximum acreage that can be planted is 62.7 acres. Eighty-percent of the field would be 64 acres. Therefore, planting exactly 20% refuge requires a fill and plant for 1.3 acres. Thus, the farmer must decide if it is more economical to fill and plant the 1.3 acres or to plant 17.3 acres of refuge, or 21.6%, rather than refilling an extra time.

In Indiana, the expected ECB damage is 2.09% of total yield given that the overall probability of ECB infestation is 40% (based on the model of Hyde et al.). Assuming a corn price of $2.50 and an expected yield of 150 bushels per acre, this amounts to an expected loss of $10.17 on the 1.3 acres when planted to non-Bt corn rather than Bt corn.

If the farmer chooses to plant 17.3 acres of refuge, then only one seed refill will be required. If the farmer chooses to plant the 1.3 acres to Bt corn before changing seed to plant the refuge, then one seed refill is required as well as one seed empty and fill. In net, four minutes per hopper, or 48 minutes, is added to total planting time with the larger refuge. This represents an increased labor cost of $12.00. Thus, planting the larger refuge saves the farmer about $1.83 ($12.00 - $10.17) in avoided labor costs.

80 Acres – U: As in the case of an 80-acre block configuration, the farmer must choose to 1) plant 17.3 acres in non-Bt corn before filling to plant the remaining 62.7 acres or 2) plant 16 acres of refuge, empty and refill with Bt seed, and then refill with Bt seed to plant the final 1.3 acres. Planting 17.3 acres of refuge requires one empty and refill of all hoppers. Planting 16 acres requires one empty and refill as well as one additional refill. Planting the 16 acre refuge adds 24 minutes, or an additional $6.00 in labor costs. The farmer is, therefore, better off to plant only 16 acres of refuge when using the U-shaped refuge. This configuration leads to an expected decrease in costs of $4.17 for the entire 80-acre field when compared to planting a 17.3-acre refuge and losing $10.17 to ECB damage. Note that the difference in labor costs between the block ($12.00) and U ($6.00) configurations stems from emptying and refilling hoppers in the block configuration and only filling hoppers in the U configuration.

Table 1. Summary of results

Field Size-Configuration	**Extra per-acre planting cost compared to planting no refuge**
40 Acre-Strips	$0.075
40 Acre-Block	$0.30
40 Acre-U	$0.30
80 Acre-Strips	$0.0375
80 Acre-Block	$0.127
80 Acre-U	$0.075

Note: The 80 Acre-Block result represents planting a 17.3-acre, or 21.6%, refuge.

These results suggest that planting strips is the most economical method to meet the refuge percentage requirements. The results also show that the trade-off between yields lost in a larger refuge and the cost of planting a 20% refuge may differ depending upon the type of refuge planted. With block refuges, results show that planting a slightly larger refuge is more economical than adding an extra planter change and paying the associated labor costs. With a U-shaped refuge, however, the farmer is better off to plant only 16 acres, the required 20%, and add an additional fill of the hoppers because the labor costs for a fill are half that of emptying and refilling.

Delayed Planting: The total cost of time lost is greater than represented in the previous section. Whenever the farmer increases the time to plant a given field, he or she increases the total time required to plant the entire farm. Corn planted later in the growing season typically yields less than corn planted early. Thus, the extra time spent in a given field leads to an indirect cost in the form of lower total farm yields.

Table 2. Suitable field hours, yield losses, and acreage of corn planted

Period	**Field Hours**	**Yield Loss**	**Acreage Planted (Corn Production in bushels)**			
			Single type[a]	**Strips**	**Block**	**U**
Before May 10	73.2	0%	897	828 (123,682)	715 (106,785)	683 (102,022)
May 10-16	37.2	5%	103	172 (24,408)	285 (40,436)	317 (44,984)
		Total	1000	1000 (148,090)	1000 (147,222)	1000 (147,006)

Note: Assume a maximum expected yield of 150 bushels per acre in Bt corn and 146.87 bushels per acre in non-Bt corn. The 2.09% difference is the expected loss in Indiana due to ECB in a given year. Yield loss estimates assume that harvest is done at an optimal time (Doster, 1995).
[a] Assumes that only a single type of non-Bt corn is planted. Corn production is not presented in this column because comparing a single seed type to a Bt – Non-Bt mix is irrelevant for this work.

To illustrate, assume the farmer is planting 2000 acres in a corn-soybean rotation. It is assumed that the farmer plants corn first. It may be that he or she plants soybeans later or that the beans are planted at the same time by other machinery and labor. Thus, the corn fields are planted as early as possible on the farm. Within the 1000 acres, it is assumed that six fields are eighty acres (480 total) and 13 are forty acres (520 total). This yields about half of the total acreage in 40 acre fields and the other half in 80 acre fields. Estimates of suitable field hours and yield losses due to late planting (Doster et al., 1995) are needed for this illustration (Table 2). Also assume the farmer has 12 hours of field time available during each suitable field day. Finally, additional time required for seed changes is double what is required in the field because the farmer must change hoppers back to plant the next field.

When planting a single seed type (i.e., planting without regard to refuge), the farmer requires 81 hours and 36 minutes to plant the 1000 corn acres. To plant all with strips adds six hours and 48 minutes to total planting. To plant all with blocks adds twenty hours and 48 minutes. To plant using the U-shaped refuge adds 25 hours and 36 minutes. This extra time may impact total corn production significantly (Table 1).

Choice of refuge configuration has a small, but significant impact on total farm income. The extra time spent planting the U-shaped refuge leads to a decrease in yields of 1,084 bushels when compared to planting strips, or $2,710 in lost revenues at a corn price of $2.50 per bushel. These results, as well as those presented above, make strips appear to be the economical choice. But one caveat must be considered. If the halo effect is significant, it is likely to have the greatest impact upon this particular configuration because strips are bordered on either side by Bt corn, possible increasing the total halo effect. Thus, the effective refuge may be less in strips, and therefore a larger percentage of acres would need to be planted to refuge given this choice of configuration.

Corn Drying: Anecdotal evidence suggests that non-Bt corn dries more quickly than does a Bt iso-line. Thus, planting a refuge within the field may lead to more uneven drying across the field than normal. However, no data are available on the extent of this difference. Sensitivity analysis was used to determine the difference in drying costs associated with several differences in moisture content (Table 3).

Table 3. Per-acre drying costs for differences in moisture content between Bt and non-Bt

Non-Bt Moisture	**Range of average moisture**	**Cost of drying non-Bt**	**Range of drying costs**
20%	20.8 – 24%	$9.45	$11.13 - $17.85
21%	21.8 – 25%	$11.55	$13.23 – $19.95
22%	22.8 – 26%	$13.65	$15.33 - $22.05
23%	23.8 – 27%	$15.75	$17.43 – $24.15
24%	24.8 – 28%	$17.85	$19.53 - $26.25
25%	25.8 – 29%	$19.95	$21.63 - $28.35

Note: Assume 150 bushels per acre

To analyze the associated costs, consider a range for non-Bt corn moisture from 20 to 25%. Assume that Bt corn has one to five percent greater moisture content. The total moisture per bushel for the field is the weighted average of moisture between Bt and non-Bt corn. The final moisture target is 15.5% and the cost of LP gas is assumed to be $0.70 per gallon (Davis).

The difference in moisture content at harvest could add $8.40 per acre to drying costs if the Bt corn has a 5% higher moisture content at harvest. If significantly wetter, a second pass with the combine may be necessary to harvest the Bt corn later, allowing it to field dry. The farmer must decide if the reduced cost of drying later is worth the extra trip with the combine to harvest the Bt corn. The break-even point depends upon such factors as the distance to be traveled to get to the field as well as the total amount of good field time available during harvest.

Conclusion: This paper has shown that refuge configuration within a given field may indeed be of economic importance. Although there are small differences in direct planting costs between refuge configurations, the additional time required for planting the refuge and potentially higher drying costs may be more important. Delayed planting results in lower total farm corn production than would have occurred if a normal planting schedule could be maintained. Planting refuge in strips was shown to be the most economical both in terms of direct planting costs as well as less delayed planting of later fields. Planting blocks cost $2,330 more than strips while planting U-shaped refuges costs $2,844 more for a 2,000 acre farm with a 50-50 corn-soybean rotation. Further research should be conducted to analyze the issues of field sequencing and of harvesting Bt corn separately from non-Bt.

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