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The Impact of Corn Rootworm Protected Biotechnology Traits in the United States

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Recently, one type of corn rootworm has developed resistance to a single strain of Bacillus thuringiensis (Bt) that is genetically engineered into corn seed. This resistance development has occurred in small, localized areas of the Corn Belt, where corn has been grown continuously for a period of time. Some have suggested that the remedy for this problem is to revert back to a significantly higher-percentage, structured refuge to avoid further resistance development. This article explores the economic consequences of such a plan. Those consequences include lower average corn yields, leading to higher corn prices for all consumers of corn (including livestock producers) and corn sweetener, ethanol producers, and consumers of corn globally; less net income for corn producers; higher yield variability, leading to higher price volatility; negative environmental impacts; and higher human-safety risks. A more balanced approach to the problem is recommended; this includes best management, integrated pest-management practices, a phasing out of single corn rootworm-traited corn, and increased use of multiple corn rootworm-traited corn.

Key words: crop biotechnology economics, corn rootworm, refugia.

Introduction

Corn rootworm (*Diabrotica spp*.) causes extensive economic damage in the United States. Before the advent of the corn-rootworm-resistant biotech traits, populations of western corn rootworm (*D. virgifera virgifera*) and northern corn rootworm (*D. barber*) together were estimated to cause annual yield losses and control costs that exceeded $1 billion in 2002 (Mitchell, Gray, & Steffey, 2002). The larvae hatch in the spring and feed on corn roots for several weeks. The damage to the roots can result in stunted growth of the corn plant, lodging, and eventual yield losses. Root damage may also make the corn plant less tolerant to environmental stresses such as heat and drought. In general, corn rootworms (CRW) cannot complete their life cycle without the food supplied by corn plants. A one-year corn rotation has been an effective strategy to limit the damage caused by rootworms. Lately, however, two opportunistic variants of the CRW have developed, making this former management strategy somewhat less effective. One variant, the rotation-resistant, or soybean-variant (SBV), CRW has developed the ability for females to lay their eggs in crops other than corn. A variant of the northern CRW, the extended diapause variant (EDV) has adapted such that some of the eggs hatch after two winters and, thus, the larval stages are able to feed on corn roots even in rotated corn. These variants have resulted in decreasing yield and increasing control costs in recent years. Figures 1 and 2 reveal the extent of the infestation of the northern and western CRW types in the United States as of 2009. As one can see from these figures, CRW has become a problem in the major corn-growing areas.

Biotech traits for CRW protection were first introduced in the United States in 2003 with Monsanto's YieldGard® rootworm trait, which was closely followed by Dow Agrosciences' Herculex RW® trait in 2005 and Syngenta Seeds' MIR 604 in 2007. In 2005, the first trait combination consisting of above- and below-ground insect protection and herbicide tolerance (or stacked hybrids) was introduced by Monsanto with its YieldGard® Plus with Roundup Ready® Corn 2, which was closely followed by similar products from other industry providers. These first-generation products contained a single insecticidal protein for above-ground protection of lepidopteron larvae and a single insecticidal protein for protection against CRW larvae. To prolong the durability of these insect protected products, Monsanto successfully combined two proteins each for above- and below-ground insect protection, thereby protecting the plant with multiple modes of action targeting the same insects. Perhaps the most unique innovation yet in this regard is the introduction of SmartStax® corn, which includes eight biotechnology traits "stacked" together—six for insect protection (Bt) and two for herbicide tolerance. SmartStax® was created through collaboration between Monsanto and Dow AgroSciences

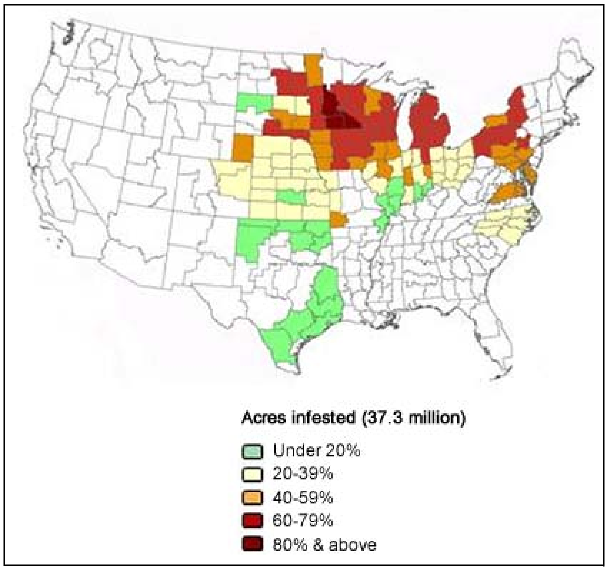

Figure 1. Percent corn acres infested: Northern corn rootworm, 2009.

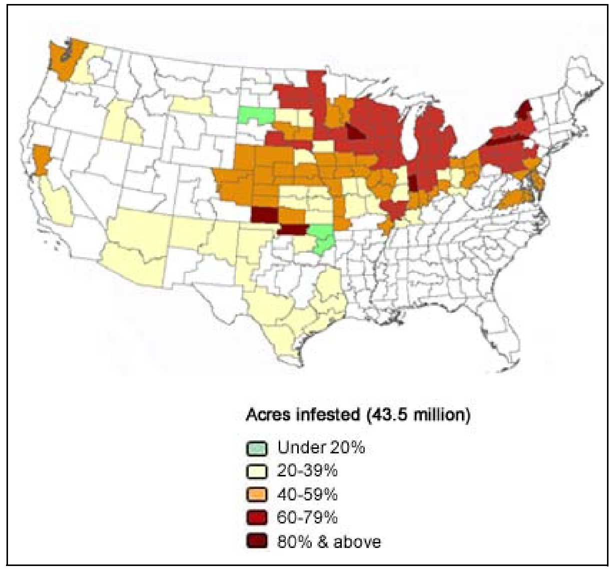

Figure 2. Percent corn acres infested: Western corn rootworm, 2009.

and was the first product in the industry effectively combining two modes of action against the CRW pest.

At the outset, the US Environmental Protection Agency (EPA) required that a refuge—a certain percentage of the total corn area on a farm—be planted alongside or near the insect-protection-traited corn. The refuge requirement was instituted to slow or eliminate insect resistance build-up to the in-plant Bt incorporated in the insect-protection-traited corn. The idea is that if resistant insects breed with non-resistant insects, then the susceptibility of the targeted insect populations would be maintained. Further, by pyramiding multiple proteins in the same plant, a reduction in the relative amount of refuge seed that is required in order to maintain durability of the product can be achieved. The commercial introduction of the SmartStax® hybrids by Monsanto and DOW AgroSciences in 2010, for instance, allowed growers in the Corn Belt to conveniently reduce required refuge from the standard 20% required for single-mode-of-action products to 5%. Just one year later, the first true seed-blend product with above- and below-ground protection was introduced as Genuity® SmartStax® RIB Complete™. This product no longer required a set-aside structured refuge, since each bag contains a precise blend of 95% Genuity SmartStax®-traited and 5% non-Bt seeds.[1] In 2012, a similar reduced-refuge seed blend was introduced by Monsanto in their above-ground insect-protected platform (Genuity VT Double Pro RIB Complete). Similar blended products are under development by all major corn seed companies. Considering the yield advantage of pyramided products that require less refuge, the added convenience at planting, and the assurance of compliance, we believe the industry has instituted a value-added component in terms of absolute dollar value. For example, the 2013 pricing difference between RIB Complete hybrids and structured refuge products will be less than $3.00/acre for Monsanto brands, which is approximately 1% of the whole bag price in relative terms.

This added convenience and benefit of having the higher-yielding and risk-reducing products on 15% more of a farm's acres and not being concerned with a structured refuge without a substantial increase in the seed cost leads to a net increase in the true economic benefits, making RIB adoption more profitable, more convenient, and less of a problem in terms of refuge compliance than continuing to employ the more costly structured refuges.[2]

At the time rootworm-resistant corn hybrids were introduced in 2003, planted corn acreage in the United States was 78.6 million. Since then, planted corn acre-

1. *Hence the name RIB, which is the acronym for "Refuge in a Bag."*

2. *RIB ensures that refuge requirements are carefully adhered to since the refuge is not dependent upon placement or other production decisions.*

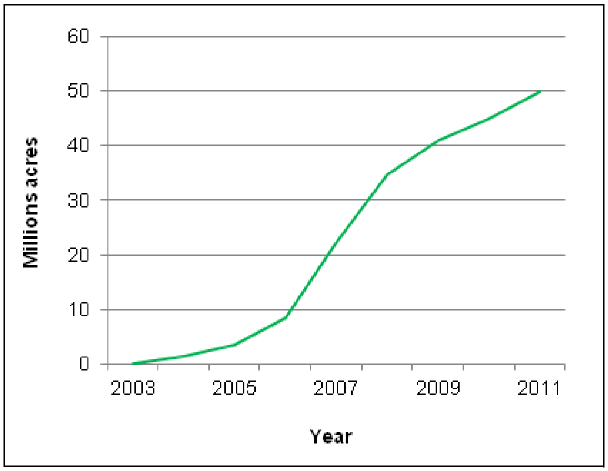

Figure 3. US planted corn acres with CRW traits, including stacked-trait hybrids: 2003-2011.

Source: Monsanto proprietary data source.

age has experienced an increasing upward trend that was accentuated by an astonishing 15.2 million acre (19.4%) increase in 2007, when planted acres leapt from 78.3 million acres in 2006 to 93.5 million acres in 2007 (US Department of Agriculture [USDA], National Agricultural Statistics Service [NASS], 2012b). This acreage increase was fueled by an aggressive biofuels policy utilizing corn and concomitant high corn prices. Planted corn acreage declined the following year by 7.5 million acres, due to competing crops' acreage successfully bidding some of these corn acres into other crops, which resulted in a move back to 86 million acres in 2008. Since 2009, planted corn acreage has increased each year such that in 2012 the United States' planted corn acreage is projected to have risen 9.5 million acres from 2009 levels to 96.4 million acres (USDA, 2012b). This increase was boosted by increasing demand for corn and a continuation of the development of innovative technologies—predominantly CRW traits—which are yield-enhancing and risk-reducing at the grower level. The 2012 projection of 96.4 million acres is the largest corn acreage planted since 1937 (or a 75-year high), representing a 4.9% increase from 2011's 91.9 million acres. Figure 3 plots the substantial increase in acreage planted to corn hybrids that include the rootworm trait since 2003, including hybrids that exhibit more than one CRW trait, among other traits in the same plant.

Concurrently, this 75-year record high planting has been subjected to the "worst-in-a-lifetime" drought for many current farmers (Doane Advisory Service, 2012). The Doane report states that the National Climatic Data Center determined that by the end of June 2012, 55% of the contiguous United States was in moderate to extreme drought—something that had not been experienced since December 1956. The effect of this adverse weather (heat stress and a lack of moisture) on expected corn yields was reflected in USDA's World Agricultural Supply and Demand Estimates (WASDE) from July 2012 (USDA, 2012b), which projected a downward revision for the 2012/2013 US corn yield to 146 bushels per acre—a startling decline of 20 bushels per acre (or 12% decline) compared to the previous monthly June 2012 estimate (USDA, 2012a).[3] Careful observation of the important role that CRW biotechnology has played as a production risk-management tool is appropriate at this juncture. That is, the CRW biotechnology has arguably prevented a bad situation from being much worse. In 2012, it is estimated that 88% of the US corn crop was planted to all biotechnologies (USDA NASS, 2012a)—52% to stacked corn hybrids, 21% to herbicide-tolerant corn hybrids, and 11% to insect-resistant corn hybrids. If the current projection of 146 bushels per acre is accurate (the current market sentiment is that it may decline further due to the current drought expected to persist through August 2012), then the 2012 US crop will be the lowest-yielding corn crop since 2003, when the US average corn yield was 142.2 bushels per acre. Note that 2003 was also the first year that CRW-traited corn seed was available. Furthermore, the projected 146 bushels per acre is 8 bushels below the most recent five-year (2007-2011) average US corn yield of 154 bushels per acre and 3.9 bushels per acre below the ten-year (2002-2011) average US corn yield of 149.9 bushels. It is noteworthy that in 2003, only 40% of the US corn crop was planted using genetically modified corn (USDA NASS, 2003)—4% to stacked hybrids, 11% to herbicide-tolerant hybrids, and 25% to insect-resistant hybrids. While it is difficult to disentangle the precise impact of the various innovations that have transpired for US corn hybrids over the period 2003 to 2012 on the significant yield boost observed on this scale, it is reasonable to conclude that the widespread use of traited hybrids—in particular the dramatic adoption of stacked hybrids that include the CRW trait (which has increased from 4% to 52% of corn planted)—has played a significant role in *lessening* the expected adverse impact from this historically disastrous drought. Given the primordial role of the root system as a means to access and

3. *See the July 11, 2012 WASDE (USDA, 2012b) reduction of projected corn yields in 2012 from an estimated 166 bushels per acre to 146 bushels per acre from June 2012 to July 2012, respectively.*

transport water and nutrients from the soil and for the crops' standability and thus harvestability, effectively protecting the root system from CRW feeding is critically important for a plant under insect pressure. It is reasonable to conclude that those protective effects are further magnified under drought conditions—be it on a local scale in any given year or field, or on an exceptionally widespread scale as currently experienced across the United States in 2012—and that if it were not for the CRW traits as a production risk-management tool, a much larger impact would be experienced this year, compounded by both insect pressure and environmental stress.

A cursory look at the estimated demand and supply situation for the 2011 corn crop and the projections for the 2012 corn crop is also helpful in understanding the important role that the widespread adoption of traited corn hybrids has played in the market and in determining the expected price.[4] Coincidentally, the substantial 20-bushel reduction in 2012 projected corn yields between June and July (USDA, 2012b) now pegs projected 2012 US corn yield in proximity to the previous year's crop yield (within 2 bushels per acre). When combined with the record acreage planted, 2012 corn production is actually still projected to increase from 2011 levels to 612 million bushels. On the demand side, an increase in feed demand (a 250 million bushels increase) is expected to be mostly offset by a reduction in corn used for food, seed, and industrial use of 135 million bushels (corn used for ethanol is projected to decline 150 million bushels, while corn used for seed and food and feed is projected to increase 15 million bushels). With exports projected to decline 300 million bushels from the June 2012 projections to be back at 2011 levels, a small increase in total demand of 115 million bushels in 2012 from 2011 levels is projected. Comparing the 2012 projected demand and supply reveals 2012 ending-stocks are projected to increase by 280 million bushels to 1,183 million bushels, which is remarkable given the current widespread drought. So, this begs the question as to why nearby corn futures (September 2012 corn futures) have broken the $8.00 per bushel level for the first time ever and new crop corn futures (December 2012) are currently trading around the $7.80 per bushel level. This sharp increase in prices to historically high levels is fueled by the fear of a continuation of the drought, which will only serve to lower yield expectations further. Prices must therefore increase to further ration the possible projected shrinking supply.

With the advent of total corn demand being more inelastic due to the significantly greater role of the relatively more inelastic demand for ethanol in total use, any supply shocks such as further reductions in projected yields mean larger increases in prices are required to reach market equilibrium, hence the substantial increase in price volatility to historically high levels. One remedy to counteract this substantial increase in price volatilities is to stabilize the supply of total corn as much as possible by employing more risk-reducing hybrid seeds (such as stacked-trait corn hybrids and inputs that are less susceptible to adverse weather) and therefore experience less reduction in yields than otherwise would have occurred with non-traited hybrids. This, in turn, minimizes the size of the supply shocks and reduces the amount of price volatility experienced in the market place. This application of risk-reducing hybrids and inputs is purely the result of market forces, and further regulation is not required to achieve the goal of supply stabilization. This role of CRW protection traits and the cost savings it brings the agricultural economy in terms of the reduction in costs of price risk management is often unappreciated or not taken into account when calculating the economic value of biotechnology to the agricultural economy. As highlighted throughout this article, the CRW trait has played a significant role in reducing the corn price volatility as compared to what would have been the experience if this technology was not being utilized.

The fact that corn demand has become relatively more inelastic is exemplified by the 2012 new crop corn (December 2012 corn futures) prices fluctuating in the relatively tight range of $5.00-$5.40 per bushel from

4. *The WASDE July 2102 report projects feed and residual corn use at 4.8 billion bushels, slightly less than ethanol & by-products use of 4.9 billion bushels (USDA, 2012b). The demand for corn for feed is more price elastic, as livestock producers have some flexibility in substituting other feed grains or selling off some of the herd if corn prices become more expensive, whereas demand for corn for ethanol production is more price inelastic because there are less substitutes for producers of ethanol to utilize when corn prices increase. This relative difference in the demand elasticities for corn used for feed (more elastic) and corn used for ethanol production (more inelastic) is due to differences in the range of substitutes for each of the users, as well as the recent increase in the share of corn being used in ethanol production in total use due to an aggressive biofuels policy; this has meant that the total demand elasticity for US corn has become more price inelastic. This relatively more inelastic total demand for corn leads to increased price volatility due to supply shifts, such as a drought (where supply decreases cause prices to rise).*

April 2012 through mid-June 2012, before exploding in a fierce upward trajectory from mid-June 2012 to late July 2012, leading to new corn crop futures trading in the $7.80-$8.00 range. This crop year provides an interesting *natural experiment* to illustrate the likely effect of a similar yield decrease that would be realized by re-imposing a significantly higher refuge requirement on CRW-protected corn in a market with a more inelastic total demand for corn than previously.[5] The 20 bushels per acre reduction in projected corn yields that occurred between the June 2012 (166 bushels per acre; USDA, 2012a) and July 2012 (146 bushels per acre; USDA, 2012b) USDA WASDE reports (a 12% decline in expected corn yields), fueled an increase in 2012 new crop corn (December 2012 corn futures) prices from $5.20 (using the mid-point of the trading range of April 2012 through mid-June 2012 period) to $7.80 (the lower bound of recent trading ranges), which amounts to a gain of $2.60 per bushel, or a 50% increase. Stated differently, for every 1% decline in expected yield, the expected corn price increase was an astounding 4.2%. A similar increase in corn price would be expected to arise from the reduction in yield that would result from changing the refuge requirement back to 20% or 50% for corn containing CRW protection traits, which has been recommended by some (e.g., Tabashnik & Gould, 2012).[6] In recent research based on commercial field trials data, the trait advantage between the benchmark Roundup Ready® Corn 2 (RR2)[7] and Genuity® SmartStax® was found to be 15.78 bushels (USDA Risk Management Agency [RMA], Federal Crop Insurance Corporation [FCIC], 2009). Assuming the total impacts on yield reduction are linear, this means that a reduction in refuge requirements for a grower from 5% to 50% could mean a decline in their overall corn yields by 7.1 bushels per acre (0.45×15.78 bushels per acre) and a loss in revenue, using the current new crop corn price of $7.80 per bushel, of $55.39 per acre.

The economic impact of such a refuge change would have rippling detrimental impacts throughout the US agricultural economy and the US economy in general. Adverse impacts on the profitability of the livestock industry would be expected, and the price of many food products would rise. Note the attention the reduction in yield due to the heat stress and drought is currently receiving in the national and international press. The same results would be expected from an increase in the refuge requirement. A detailed discussion of the possible ramifications of such a change and the impacted sectors of the agricultural economy is beyond the scope of this article. Foremost, the attention and discussion of corn consumers impacted most by high corn prices is most often limited to the livestock industry and ethanol industry because they utilize corn in the largest volumes. However, high corn prices are felt widely across the food chain and the economy, as corn and its by-products and residuals are utilized in a host of products. Some examples include corn meal (used to make corn flakes, cornbread, and deep-fry batter); corn flour (used for pancakes, donuts, breading, and baby food); corn syrup (derived from corn starch, which, with some additional processing, produces high-fructose corn syrup used widely as a sweetener—most notably in the production of soft drinks); corn starch (used as a thickening agent for liquid food, to make confectioners' sugar, and biodegradable plastic). Other products that are derived from corn (but still very much an incomplete list) include glue, oil, and penicillin. Thus, higher corn prices—given the wide-spread and diverse utilization of corn in the US economy—clearly lead to concerns about possible inflationary impacts because eventually at least some of the higher input costs must be passed onto the consumer if manufactures are to remain profitable.

Another subtle point about high corn prices and the increased price volatility experienced is worth briefly discussing. For businesses for which corn is a major input, it is not just the actual immediate spot price costs that must be absorbed; there is also an associated increase in the cost of risk management and inventory control. Large purchasers of corn typically hedge their input costs months in advance and when droughts such as the current one are experienced, the impact on subsequent crops makes hedging more economically challenging. The expected yield reductions from the drought substantially increase not only the spot and forthcoming new crop futures but also subsequent new crop futures such as the 2013 new crop futures in the case of this

5. *The idea being that the reduction in corn supply (or in the inward shift of the supply curve) would be the same end result, but the cause would be different. One result would be from the adverse impacts of drought the other would be a change in refuge requirements.*
6. *Such changes in price assume that farmers would adhere to the higher refuge requirement.*
7. *By 2008 conventional, non-traited corn had, for the most part, disappeared from the marketplace and RR2 was what was being planted on refuges; therefore, RR2 was the most appropriate benchmark to compare the yields of the non-refuge acres planted to Genuity® SmartStax® and the yield of the refugia.*

2012 drought. Combating price volatility more than 12-months ahead makes price risk management for procurement purposes a significant and more costly challenge. This can be directly observed in the increased cost of corn options as compared to 5 or 10 years ago when corn market prices were much more stable.

Economics of Corn Rootworm-Traited Corn Seeds

The first economic study of CRW-protected corn was published in 2002 and was an ex-ante, counterfactual study of the benefits from adoption of the YieldGard® rootworm-traited corn (Alston, Hyde, & Marra, 2002). This study estimated the benefits of the new trait as if it had been available in crop year 2000 (the counterfactual) by using 2000 control costs and prices and responses from a survey of farmers in early 2002. The study found that the total profit benefits to farmers would have been $231 million in 2000. Using the 10-year average corn price, the pecuniary benefits accruing to non-farmers (technology developers and seed companies), would have been $171 million, which was about 2.36% of the total value of the corn crop in the United States that year. The study also found that the total value, including the benefits of additional operator and worker safety, environmental safety, and convenience, which are valued as non-pecuniary benefits (see the section below on non-pecuniary characteristics) was about $3.80 per acre; this implied another $58 million in farmer benefits, yielding a total benefit of $460 million had the CRW trait been available in 2000.

Rice (2004) estimated the total annual farm-level benefits assuming 10 million acres of corn were planted with hybrids containing the CRW protection trait. They included

- "intangible benefits to farmers (safety due to reduced exposure to insecticides, ease and use of handling, and better pest control);
- tangible economic benefits to farmers ($231 million from yield gains);
- improved harvesting efficiency due to reduced stalk lodging;
- increased yield protection (9% to 28% relative to that in the absence of insecticide use and 1.5% to 4.5% relative to that with insecticide use);
- reduced insecticide use (a decrease of about 5.5 million pounds of active ingredient per 10 million acres);
- increased resource conservation (about 5.5 million gallons of water not used in insecticide application);
- conserved aviation fuel (about 70,000 gallons not used in insecticide application);
- reduced farm waste (about 1 million fewer insecticide containers used);
- increased planting efficiency; and
- improved safety of wildlife and other nontarget organisms" (Ervin et al., 2010, pp. 139-146).

Control methods for CRW larvae prior to the introduction of the rootworm-protected biotech traits included crop rotation and soil-applied insecticides to control the CRW larvae.[8] The opportunity cost of crop rotation is the foregone profit from growing corn less the profit generated by the rotation crop. The opportunity cost of rotation is assumed to be positive in many areas, given the large acreage of continuous corn. Another external cost of crop rotation may be the cost of increases in the acreage used for growing corn, given the increased demand for corn for biofuels in the recent past. One way to mitigate this cost would be to plant more continuous corn. Another way would be to increase yields on land already planted to corn.

When expected corn prices increase substantially, as they have over the past few years, farmers are expected to react rationally by applying more inputs, such as fertilizer and pesticides, even on their insect-protection-traited corn because the benefit of doing so is higher and more profit can be earned. This is because each extra bushel of corn they can produce is more valuable. Note that this increase in input use is a result of higher corn prices alone, and is observed whenever relative crop prices rise, all other things equal. This change in input use is self-regulating in that, when the relative price of the crop decreases, growers will lower their input use because an additional bushel of corn is worth less.

Another plausible reason for increased input use during this period is that higher input use serves, in general, to ensure a more stable yield. Gray (2012) points this out and argues that the term *Insurance* Pest Management, rather than Integrated Pest Management, may describe farmers' actions more appropriately under these circumstances. This is a general result (as is the one described above in response to higher relative crop price) in the agricultural economics literature in that

8. Sometimes the adult insects are sprayed when there is a large infestation, but the total impact of this on control costs is negligible.

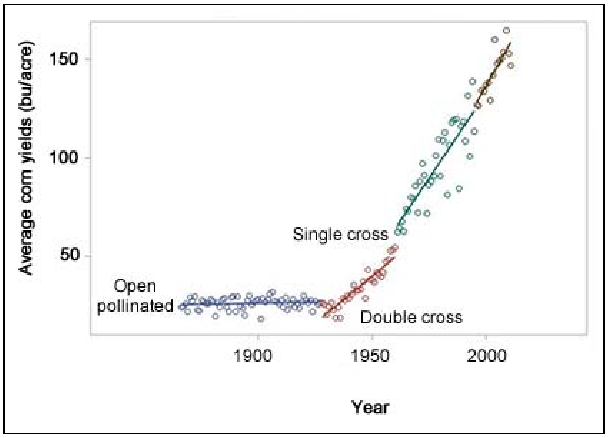

Figure 4. Corn yield advances across technology eras in the United States.
Source: USDA NASS.

risk-averse farmers will apply risk-reducing inputs when yield is more variable (e.g., Beattie & Taylor, 1985).

The Effect of Corn Rootworm Traits on Corn Yield

A study by Ma, Meloche, and Wei (2009) found that corn yield increases as a result of the CRW traits varied in both spatial and temporal dimensions. Bt CRW hybrids yielded from 11% to 66% more than untreated, untraited hybrids that were a near genetic match, depending on year and location. If one assumes a 154-bushel expected corn yield (the five-year US average, 2007-2011), the yield increase found in the study ranges from 16.9 bushels per acre to 101.6 bushels per acre. Of course, the yield advantage depends on the extent of CRW infestations in a particular year and location. Generally, a yield advantage due to the CRW trait was found to be present at least one of every three years. Taking the midpoint of the yield benefits found by Ma et al. (2009) and dividing by three, the expected yield increase in any single year is about 19.75 bushels per acre. At the current new crop corn futures (December 2012 corn futures) price of about $7.80 per bushel (Chicago Mercantile Exchange [CME], 2012), the total revenue gain would be expected to be about $154.05 per acre.

Figure 4 shows the steady increase in the US corn yield trend line over time by technology era. Little advancement was made in corn yields until about the mid-1920s when hybrid corn was introduced. Then in the mid-1960s the breeding technique of double crossing was developed, along with the passage of the Plant Variety Protection Act, which allowed plant cultivars to enjoy patent protection. These two events resulted in tremendous yield gains. When biotech corn was introduced in the mid-1990s, corn yields soared even higher and average corn yields in the United States are now at unprecedented levels.

Since the adoption of the CRW traits reached significant levels in the Corn Belt in the mid-2000s, the rate of growth of corn yields increased significantly. Tannura, Irwin, and Good (2008) hypothesized that good weather in recent years largely explains this increased growth rate. However, Vados, Goodwin, and Marra (2012) found that, after accounting for the good weather during the period of 1981 to 2008 and steady germplasm improvement, there is still a significant, positive effect of the adoption of the CRW-protected traits on corn yield of about 7%. Given an average corn yield of 154 bushels per acre at the beginning of the period, this would result in a 10.8-bushel increase in corn yield simply due to the adoption of the CRW insect-protection traits after all weather and other technology effects are considered. At current expected corn prices of about $7.80 per acre, this would result in an increase in revenue from corn of $84.11 per acre. Given the rapid adoption of the CRW traits since 2003, either alone or in combination with the traits for controlling the above-ground insects, combined with the above-mentioned increase in total corn acres of 17.3 million acres (from 2003 to 2012), the advent of CRW-protected corn has arguably significantly contributed to the prosperity and record-level net farm income US corn farmers have recently experienced.

Combinations of insect-protection traits have led to even larger yield benefits. Goodwin, Piggott, Marra, Anderson, and Hennesey (2007) conducted a study of more than 10,000 side-by side comparisons of conventional hybrids with no insect-protection traits with hybrids having one trait for controlling corn-borer-like insects and one trait for controlling CRW. They found that these triple-stack hybrids were estimated to have an average 11.32 bushel per-acre yield advantage over the non-traited or just herbicide-tolerant hybrids. This is similar to the advantage found in the Ma et al. (2009) and the Vados et al. (2012) studies. When more than one trait is added to individually control for corn borer and CRW, such as is the case with SmartStax® corn hybrids, this yield advantage increases by an *additional* 6-8 bushels per acre over the single-traited CRW protected hybrids (Marra, Piggott, & Goodwin, 2010).

Profit vs. Utility

As noted above, CRW traits have provided both increased revenue and reduced costs, therefore increasing profits for farmers in the areas where CRW is an economically significant pest. This increased revenue comes from the yield gains realized by the advantages provided by the CRW traits, while the decreased costs come primarily from the elimination of soil-applied insecticides. An estimate of the yield gains and expected revenues can be derived from several sources of data. First, yield gains were noted during focus groups conducted by Market Probe, Inc., (an internationally known market research firm) in the Fall of 2008 within states that included Pilot Biotechnology Endorsement (BE)-approved geography; growers estimated that they expected an average yield of 183 bushels per acre from triple-stack corn, compared to an average of 170 bushels per acre on their refuge acres. This estimate revealed that if SmartStax® performance is at least as good as the performance of triple-stack hybrids, corn farmers would gain approximately 13 bushels per acre for every acre that does not have to be planted to refuge corn. A relatively small number of experiments were employed because, at the time of the BE SmartStax™ submission to the USDA Risk Management Agency (RMA) in January 2009, only a limited number of commercial field trials were available for analysis. When aggregated to the experiment level (the level of analysis most consistent with actual crop insurance experience), the trait advantage between the benchmark Roundup Ready® Corn 2 (RR2) and SmartStax® was found to be 15.78 bushels per acre (USDA RMA FCIC, 2009). Thus, SmartStax® performance was indeed found to be at least as good as their triple-stack hybrids counterparts by 2.78 bushels per acre. In sum, it was found that non-refuge acres planted to SmartStax® versus refuge acres planted to RR2 corn displayed a yield advantage of 15.78 bushels per acre. This meant that a reduction in refuge requirements for a grower from 20% to 5% could mean an increase in their overall corn yields by 2.37 bushels per acre (0.15×15.78 bushels per acre) if a producer substituted all their triple-stack acres with the superior SmartStax® and were only required to plant the 5% refuge. If we value this increased yield advantage at the current new 2012 corn crop price of $7.80 per bushel, it amounts to an additional $18.46 per acre. This advantage would be taken away if the refuge requirement were increased back to 20% for these growers. If the refuge requirement were to be increased to 50%, the pecuniary loss to farmers would be 7.1 bushels per acre (0.45×15.78 bushels per acre), valued at $7.80 per bushel, or $55.39 per acre. Other factors also offset the increased cost of the CRW-traited hybrid seeds. Farmers also consider the value of these additional factors in their decision to adopt a new technology. That is, economists say the farmers maximize their own utility, rather than just maximizing profits, by taking into account the value of some intangible characteristics of the new technologies.

Non-pecuniary Impacts

Farmers realize additional gains that arise from characteristics of the CRW-traited corn hybrids that are not captured in the profit equation because these characteristics are not directly traded in markets and are, therefore, not directly priced. The values of these characteristics are termed “non-pecuniary” and include, but are not limited to, the additional safety of the hybrids for farm workers and operators, as well as important environmental benefits; the additional convenience, simplicity, and flexibility of growing these hybrids; and the reduction in risk represented by the CRW-traited hybrids relative to their non-CRW-traited counterparts. This reduction in risk alone has been estimated to be worth about $0.80 per acre per year to corn farmers for the single CRW-traited corn (Alston et al., 2002) and about $6.50 per acre per year for the multi-CRW-traited corn hybrids (Marra et al., 2010).

Biotechnology Adoption over Time in the Presence of Non-pecuniary Characteristics and Continued Innovation

Piggott and Marra (2008) established that the demand for a crop biotechnology will initially increase and then become more inelastic in response to price increases as adopters become accustomed to, and value more highly, the non-pecuniary benefits of the technology. These studies are summarized in Marra and Piggott (2006). These findings imply that, as biotechnology is adopted on more and more acres, the prices of the unique components of the technology will increase due to increased aggregate demand for them and, in response, the technology cost will rise, but the demand response to the higher cost will become smaller as time passes. However, higher costs are self-limiting due to intense competition from other technology sellers. Farmers may also be more reluctant to switch away from a new biotech technology and this reluctance becomes stronger over time, even if continued use of the new technology results in an effect such as weed- or insect-resistance.

Growers have demonstrated their ability to adapt to changing conditions and use agronomic practices or other inputs to effectively manage their crops. The opposite is also true such that when corn price falls, a producer may not shift out of corn production because of the increasing value of the non-pecuniary benefits and continued biotechnology innovation such as Genuity® SmartStax® with RIB Complete™.

Risk Reduction

In the middle part of the last decade, farmers and agronomists began to notice some interesting characteristics of the insect-protected biotech corn. CRW-traited hybrids tend to have larger and deeper root balls and tend to exhibit significant yield advantages relative to their conventional counterparts during periods of environmental stress. This was especially apparent in 2005 in Illinois, when a significant drought brought about substantial heat and drought stress on corn. Those hybrids with CRW traits fared significantly better than those hybrids without the traits in terms of plant health, decreased lodging, and—ultimately—yield. The yield risk reduction for the CRW-traited hybrids began to be recognized. In addition, the CRW-traited hybrids have been shown to be less susceptible to aflatoxin, a fungal disease that affects corn in storage.

In light of a significantly expanding crop-insurance program, policy observers and those in the academic community began to question whether the apparent lower degree of risk being observed for biotech corn might not have important implications for the pricing of crop insurance. The implications were important not just to farmers who were paying for coverage. Taxpayers were shouldering an increasing burden in subsidizing the program. In April 2007, Monsanto Company approached the RMA with a proposal to evaluate yield risk differences and their implications for the pricing of crop insurance coverage. Through a program introduced under provisions of the Agricultural Risk Protection Act (ARPA) of 2000, public and private entities were encouraged to submit proposals for new insurance programs or changes to existing programs. Monsanto proposed an endorsement to the existing crop-insurance programs that would provide a premium discount to farmers planting certain biotech hybrids that were statistically proven to have lower yield risk.

The proposal was submitted to the Federal Crop Insurance Corporation in April 2007. It was approved in September 2007 after rigorous third-party reviews, and in 2008 corn farmers in Illinois, Indiana, Iowa, and Minnesota could elect the "Biotech Yield Endorsement" and receive a premium discount if they planted approved biotech corn hybrids and agreed to a rigorous validation process that included in-field tissue sampling. Discounts of approximately 18% were realized in the first year.

The discounts were based upon the relationship of the difference between the biotech and conventional corn yields grown in the same field (the "biotech advantage") and the yield for the conventional corn hybrid. Anecdotal evidence suggested that the biotech advantage tended to be most prominent during times of yield stress—the very times that federal crop insurance realizes large payouts. In its first year, the Biotech Yield Endorsement covered more than 5.8 million acres in the four pilot states of Indiana, Illinois, Iowa, and Minnesota and resulted in savings of $29.4 million to corn farmers and $33.3 million to taxpayers. The savings reflected the lower total premium associated with the endorsement. The typical premium for conventional corn on those policies that took the endorsement was $59.01 per acre. On those same policies, the acreage qualifying for the endorsement had an average premium of $48.36, representing a savings of $10.65 per acre.

In 2009, the RMA added CRW-traited hybrids from Pioneer and Syngenta to the endorsement and also changed the name to the "Biotech Endorsement" (BE). In the second year of the program, participation doubled to almost 12 million acres. The total savings to farmers and taxpayers as a result rose to $131 million. Over the four-year period between 2008 and 2011, the program generated more than $532 million in savings, with corn farmers saving $214 million from lower premiums and taxpayers saving $318 in premium subsidies.

In 2011, RMA pointed out that biotech corn had become so ubiquitous as to minimize the need for differentiating between conventional and biotech corn. Most observers view the biotech endorsement as a significant success. The last year of the program was 2011 and afterwards no recognition of differences in risk according to technology will be applied in assigning premium rates.

The analysis used by RMA to establish crop-insurance premium discounts for insect-protection-traited corn hybrids can also be used to evaluate the effects of increasing the required refuge in the Corn Belt from 20% to 50% for single-mode-of-action technologies, or from 5% to 20% for multiple-mode-of-action technologies, as some have suggested (Tabashnik & Gould, 2012). That analysis used regression models of the difference in yields between insect-protection-traited and conventional corn on indicators of environmental stress (corn yields and the Palmer Z drought index). A statistically significant relationship between the insect-protection-traited corn yield advantage and growing conditions was confirmed, such that periods of significant stress (e.g., drought) exhibited larger differences in the biotech and conventional corn yields. In other words, during significant plant stress, both insect-protection-traited and conventional corn yields would decrease, but the insect-protection-traited corn yields would not decrease by as much as the conventional corn yields, thus increasing the yield difference between them. Using these regression models and historical data on Palmer's Z index, we evaluated exactly how in the theoretical scenario where structured refuge was increased from 20% to 50%, the 30% reduction in the level of acreage that could be planted to the higher yielding insect-protection-traited corn hybrids would have affected the total value of corn produced, had the traited hybrids been planted in past years. Using historical data for the Palmer Z index, our regression model implied that corn yields would have been lower by 5.4 bushels per acre in 1998 (the highest value of the index since 1980, indicating sufficient rainfall) to 14.1 bushels per acre in 1988 (the lowest value of the index since 1980, indicating insufficient rainfall). If we value these differences using the 2012 acreage of 96.4 million acres and the current price of $7.80 per bushel, the lost value associated with the foregone production resulting from a higher refuge ranges from $1.17 billion in 1998 to $3.05 billion in 1988. These calculations take account of not only the yield-increasing properties of the insect-protection hybrids but also their risk-reducing characteristics relative to the non-insect-protection-traited hybrids. Though these calculations extrapolate results for the Corn Belt to the entire 96.4 million acres of corn nationally, they serve to demonstrate the significant economic costs associated with foregone revenues resulting from the imposition of a higher refuge requirement that reduces biotech acreage by 30%. The time series of foregone revenues is illustrated in Figure 5. This purely economic analysis of lost value judges neither the supposed motives for such a change in refuge size, nor does it consider the sheer impracticality and compliance impact associated with such dramatic shifts in refuge. Non-compliance would mitigate the effects on lost value as calculated but would also not realize the new policy target.

Environmental Impacts

The evidence has shown that the biotech crops have had a less negative or an equivalent impact on the environment when compared to the conventional, non-biotech crops that they replaced (Ervin et al. 2010). The evidence on the impact of some of the biotech crops on groundwater is unclear and deserves further study. CRW-traited hybrids, however, trade a relatively toxic suite of soil-applied insecticides for in-plant insect protection that is unambiguously better for the environment.

Environmental Benefits

In two separate farmer surveys—one conducted in 2002 and one conducted in 2009—growers were asked to place a value on the environmental benefits of the CRW-traited corn hybrids. The first survey asked about the single-traited CRW-protected hybrids. Farmers responded in 2002 that they placed an average value of about $0.21 per acre per year on the environmental benefits (improvements in on-farm surface and groundwater quality and improvements in wildlife habitat) of the single-traited CRW-protected hybrids. When asked about the environmental benefits of the multi-traited CRW-protected hybrids, growers placed an average value in 2010 of more than $2.00 per acre per year on the same set of environmental benefits. It is evident that both the continued use of the traits and the addition of multi-traited CRW-protected hybrids have had an important impact on the value to farmers of the environmental benefits afforded by the CRW traits.

Refugia, Resistance, and Management

The original refuge requirement for the CRW trait with a single mode of action for rootworm protection is 20% and was the industry standard when the first rootworm-protected hybrids were introduced into the market. With the advent of corn seed with multiple modes of action through the insertion of more than one CRW-protection trait in the same seed, the EPA reduced the refuge requirement for the multi-CRW-traited corn to 5% in corn-growing areas and 20% in cotton-growing areas. This change reflected the fact that, when two or more modes of action for a single insect are inserted into a corn hybrid, the probability of the targeted insect developing resistance to the in-plant insecticides decreases by orders of magnitude. Shortly after the commercialization of SmartStax® (multiple modes of action for above-ground pests, multiple modes of action for CRW, and multiple modes of action for herbicide tolerance) with a

5% structured refuge, the EPA approved a new kind of refuge that was a mixture of 95% Genuity® SmartStax® and 5% non-traited seed in every bag of corn seed. In a survey conducted in 2011, growers in the Plains States, Corn Belt, and Northeastern United States estimated additional farm-level value of the 5% RIB over the 5% structured refuge to average $18.30 per acre (Monsanto Company, 2012). Earlier surveys, such as an internet survey of 367 corn growers conducted by Market Probe on October 30 and November 13, 2008, help to shed some light on additional farm-level benefits of the 5% RIB over the 5% structured refuge. Farmers identified in this survey were asked about reasons for considering refuge maintenance to be difficult/inconvenient. A majority (55%) stated that the time and costs associated with changing planters was difficult/inconvenient, and 12% of the respondents stated that getting the percentages right was difficult/inconvenient.

Further to this point, with the RIB concept there is no way for a grower to slight or ignore the refuge requirement. Post-market monitoring results indicate that about 1/3 of farmers have not adhered to the planted refuge requirements as well as they should have for structured-refuge products. This significant non-compliance with refuge requirements could result in jeopardizing the benefits of the planted refuge targeted to protect the longevity of the Bt technology. RIB completely eliminates this possibility and assures compliance with the refuge requirements.

In 2011, a study conducted by Gassman, Petzold-Maxwell, Keweshan, and Dunbar (2011) reported on the potential for the development of resistance to CRW-protected corn with a single mode of action (Cry3Bb). The first published data were related to insect collections from fields with high insect pressure and the continuous use of corn-on-corn rotation for more than three years. At the same time, growers with a history of corn-on-corn rotation noted challenges with CRW control in some fields. Over the years since CRW technologies have been introduced, there have been instances of high CRW populations that overwhelm some sections of some fields, attacking the plant late in the season when the plant is unable to compensate from the feeding, or under environmental stress, which causes the plant to fall over. Both result in more a more difficult harvest for growers. These are known as performance inquires (PI), and every CRW technology sold to growers today has had to deal with this phenomenon. Over the years, growers have adapted to these situations by using any one of several remedies: they rotate those problem fields to soybeans, apply insecticides for adult control or at

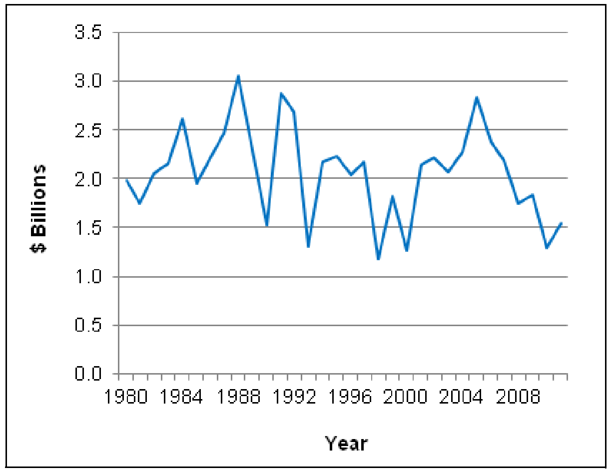

Figure 5. Lost corn revenues for the United States, resulting from higher refuge requirements (lost value from 30% higher refuge at $7.80/bushel over 96.4 million acres).

planting the following year, or even rotate technologies. All of these options are familiar to growers and this is essentially how they managed their fields before the advent of biotechnology. The industry has stepped up its efforts to increase awareness of managing corn-on-corn as well as working with academics to understand how best to manage these situations.

The economics of corn have increased the number of acres in continuous corn, and thus this added education of best management practices is warranted for the foreseeable future as the practice is likely to increase. However, growers understand that certain fields may require different practices and have adopted these rapidly. In any given year, growers face decisions on managing their crops. Some years, insecticides are required; in other years, fungicides and other inputs are more important. It would be illogical to conclude that an increase in refuge in RIB products will ever lead to a decrease in insecticide use. There will always be years when this input is required due to insect populations, but a higher percent of unprotected seed will forgo that decision, and insecticide use will increase.

Corn Rootworm Traits' Impacts on Non-corn Farmers

In addition to the farm-level impacts on corn farmers described above, others are impacted by the spread of the CRW-traited hybrids. Several studies have estimated the decline in the world corn price resulting from the widespread adoption of the Bt corn traits to range from 1.94% (Anderson & Jackson, 2005) to 2.5% (Fernandez-Cornejo, Lubowski, & Somwaru, 2007). In other words, but for the adoption of the Bt corn hybrids—primarily the CRW-traited hybrids because they have a much larger impact on corn yield compared with the above-ground insect-protection traits—corn prices would be about 2% to 2.5% higher now. This lower-than-otherwise-would-be corn price has benefited all users of corn, including livestock producers, producers of corn sweeteners or corn-sweetened products, and corn-ethanol producers, to name a few. At current expected new-crop corn prices of $7.80 and assuming a midpoint estimate of the above estimate's percentage corn price changes (which is 2.25%), this price decline amounts to about $0.1755 per bushel per year ($7.80×0.0225=$0.1755), and with an estimated 12.358 billion bushels produced in 2011 (USDA, 2012b), a total, annual, overall reduction in total expenditures by users of corn products of about $2.169 billion in the United States alone.

Conclusions and Policy Implications

Even though we cannot impute a precise number to the total net benefits of the CRW traits, it is clear that the corn-rootworm-traited corn hybrids have provided a huge benefit to corn farmers, non-corn farmers, the environment, and consumers, including those consumers in developing countries. Any attempt to further regulate the use of these traits by increasing refuge size must take these benefits into consideration and weigh them against the relatively small potential benefit of doing so. While it is difficult to disentangle the precise impact of the various innovations that have transpired for US corn hybrids over the period of 2003 to 2012, it is reasonable to conclude that the widespread proliferation of the traited hybrids—and, in particular, the stacked hybrids that include the CRW trait—have played a significant role in producing the yield advancements in US corn production in general and lessening the expected adverse impact of the disastrous drought experienced in 2012 in particular. The 20-bushels-per-acre reduction in projected corn yields that occurred between the June 2012 (166 bushels per acre; USDA, 2012a) and July 2012 (146 bushels per acre; USDA, 2012b) WASDE reports (a 12% decline in expected corn yields) provides a *natural experiment* to illustrate the anticipated price responses to increased refuge size as the reduction in corn yields fueled an increase in expected new 2012 crop corn prices from $5.20 to $7.80 in six weeks, which amounts to an increase of $2.60 per bushel, or a 50% increase. Stated differently, for every 1% decline in expected yield, the expected corn-price increase is an astounding 4.2%. A similar increase in corn price would be expected to arise from the reduction in yield that would result from changing the refuge requirement back to 20% or 50% for corn containing CRW-protection traits, which has been recommended by some (e.g., Tabashnik & Gould, 2012).[9]

At this time, some CRW-resistance build-up to one or more of the single-traited CRW protected hybrids has been reported in isolated locations where a single CRW trait has been used in continuous corn for more than three years. A significantly higher refuge requirement in response has been recommended by some. Rather than "throwing the baby out with the bath water," we strongly urge consideration of the tremendous cost to the industry, farmers, and consumers that would accrue if the single-mode-of-action products were to be removed from the market or if significant increases in mandatory refuge requirements were to be adopted. Increases in refuge size would not only be impractical in many cases, but would erode the value of the technology in US corn production in light of the small fraction of the acres affected (less than 0.2% in 2011) Instead, a combination of rotation, other integrated (best management) pest management practices, and adoption of multi-traited CRW hybrids is called for on the isolated fields where performance has been questioned. In any case, use of the single CRW-resistant traited corn is declining as growers are replacing these products with multiple-mode-of-action products due to the increased control they offer and the convenience of planting a smaller refuge, the single-mode-of-action products still have tremendous value in first-year corn and in areas where CRW is not the primary pest. So as not to disrupt markets too much, a multi-year phase-out of the single-traited CRW-protection corn is recommended. In addition, it is not clear if corn farmers will adhere to a larger refuge requirement after enjoying the benefits of the more recent lower-refuge requirements and, now, the RIB option. This article reported that a reduction in refuge requirements for a grower from 20% to 5% could mean an increase in their overall corn yields by 2.37 bushels per acre (0.15×15.78 per acre) if a producer substituted all their triple-stack acres to SmartStax® and were only required to plant the 5% refuge. If this increased yield advantage is valued at the current new 2012 corn crop price of $7.80 per bushel, it amounts to an additional $18.46 per acre. If the refuge were

9. *Such changes in price assume that farmers would adhere to the higher refuge requirement.*

required to increase to 50%, the overall pecuniary loss to the producer would be about $55.39 per acre. In addition to the pecuniary losses, the non-pecuniary losses should also be considered. Decreased operator and worker safety, decreased environmental benefits in terms of additional insecticide use and drift, decreased convenience, and increased risk would all decrease the value of the corn crop to farmers and to society in general.

The 2013 pricing difference between RIB and structured refuge products will be less than $3.00/acre for Monsanto Brands. The apparent additional value per acre of the Genuity® SmartStax® RIB Complete™ products versus the structured refuge products is apparent, and so it would be very difficult to make farmers adhere to a larger refuge requirement and to forgo the convenience of RIB. To enforce this requirement would require substantial, and probably prohibitive, monitoring costs. Even if the higher refuge requirements are incorporated into a RIB strategy, significant undue costs as outlined above would accrue to growing areas where CRW resistance is not a problem. These costs also would have to be incorporated into the decision calculus to require higher refuges.

All things considered, it is apparent that a significantly higher refuge requirement for CRW-traited corn is not the best way to solve a potential problem on isolated fields, even if resistance is suspected. At this time, drastic measures do not seem warranted given the rational solutions already being applied; an integrated approach using a combination of strategies taking account of all the costs and benefits is called for with a prime role for continued RIB enablement to remove the negative impact of non-compliance. The economic benefits of Genuity® SmartStax® RIB Complete™ (and RIB products in general) versus the structured refuge products is apparent and is advantageous for the agricultural economy and the economy in general, especially taking into consideration the current market situation and the impacts of the 2012 drought.

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