Synapse
Energy Economics, Inc.

Atrazine:
Consider the Alternatives

October 8, 2013

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Thanks to the Natural Resources Defense Council (NRDC) for their financial support of this report, and to Maria Bowman, Jennifer Sass, Andrew Wetzler, and Mae Wu for helpful comments on an earlier draft. This report represents the analysis and conclusions of the authors alone, not of NRDC or any of its staff.

1. Executive Summary

Every year, atrazine is applied to tens of millions of acres of corn grown in the United States, making it one of the world's most widely used agricultural chemicals. Atrazine is a potent weed killer—and is also the subject of persistent controversy about its health and environmental effects. It is known to be an endocrine disrupter even at extraordinarily low concentrations, with extensively studied, harmful impacts on many species of wildlife. It weakens immune systems in wildlife; there is some evidence from laboratory studies that it may be a carcinogen (although debate continues on this point); and exposure during pregnancy may increase risks of birth defects and low birth weight in humans. Produced by Syngenta, a European company, atrazine is subject to strict regulations that effectively prevent its use in the European Union—but it remains a staple of American agriculture.

The Atrazine Benefits Team

While the health impacts of atrazine use have been the subject of extensive research, much less has been written about the economic impacts. In a 2007 article, Frank Ackerman (one of the authors of this report) found that most studies showed only limited benefits from atrazine, and that a Syngenta-sponsored economic analysis contained serious errors that cast doubt on the validity of its conclusions. More recently, Syngenta assembled an "Atrazine Benefits Team" of researchers who released five studies in 2011, claiming to show huge benefits from atrazine use and alleging that Ackerman's conclusions were now outdated.

This report examines the Atrazine Benefits Team papers, and identifies three major flaws in their analysis:

1) They exaggerate the effectiveness of atrazine and offer an incomplete analysis of both chemical and non-chemical alternatives. Some important alternative herbicides receive little or no attention, and the option of non-chemical or low-chemical integrated weed management techniques is not discussed.
2) Much of their analysis relies on the unrealistic assumption that crop prices are unaffected by changes in crop yields—producing misleading and unfounded estimates of large economic benefits from atrazine use.
3) In the one Atrazine Benefits Team analysis that considers changes in crop prices as well as yields, the withdrawal of atrazine would lead to a 4.4 percent decrease in corn production and an 8.0 percent increase in corn prices. The result is that under Syngenta's own assumptions, corn growers' revenues would actually *increase* by 3.2 percent if atrazine became unavailable. The author of the paper fails to mention this benefit. While an 8.0 percent price increase would affect the largest buyers of corn—primarily ethanol producers and animal feedlots—the resulting impact on consumer prices for gasoline and beef would only amount to pennies per gallon or pound, respectively, in exchange for significant health and environmental benefits.

In the following sections we summarize key findings related to each of these major flaws.

Incomplete analysis of alternatives

Chemical alternatives

Most of the weed pressure on corn is caused by ten common weeds; atrazine resistance has been detected in six of these weeds. Common waterhemp, the third-most noxious corn weed in the United States, displayed atrazine resistance in more than half of a large sample of Iowa weed populations studied by one of the Atrazine Benefits Team authors. Meanwhile, several other herbicides appear to be equivalent or superior to atrazine in effectiveness, especially when used in appropriate combinations. The Atrazine Benefits Team analysis, however, is built upon a comparison between atrazine and other single-herbicide alternatives—and appears to omit or inadequately assess several highly effective herbicides.

Alternative weed management methods

U.S. agriculture has shifted toward simplified, highly chemical-dependent systems, such as reliance on “Roundup Ready” corn and other herbicide-tolerant crops. This has created a situation in which weeds resistant to common herbicides—such as glyphosate (Roundup) and atrazine—are more likely to succeed and proliferate than non-resistant weeds, thereby increasing the herbicide-resistant weed population over time. In response, many producers have turned to integrated weed management (IWM), analogous to the better-known methods of integrated pest management. IWM employs multiple non-chemical techniques, including crop rotation, intercropping, enhanced crop competitiveness, cover crops, conservation tillage methods, and banded fertilizer placement. A study of IWM found that these techniques have synergistic effects, with much greater weed reduction when multiple techniques are combined. The Atrazine Benefits Team did not discuss these approaches as alternatives to atrazine.

Assuming crop yields do not affect crop prices

Because the most effective chemical and non-chemical alternatives were not considered in the Atrazine Benefit Team’s analyses, it seems likely that they overstated the effect on crop yields that would result from eliminating atrazine. Even if their estimate of yield effects were accurate, however, there are serious flaws in their economic analysis of the market for corn.

The United States produces more than 11 billion bushels of corn annually. Most of it is used either for ethanol production (40 percent in 2012) or for animal feed (37 percent). Like other agricultural products, its price frequently moves up or down in response to changes in supply and demand. The surge in demand for ethanol, following the adoption of the federal ethanol mandate in 2005-2007, was accompanied by a doubling of the price of corn, from less than $3 per bushel in 2006 and earlier, up to $6 per bushel in 2011 and 2012. Yet despite such price volatility, two of the three Atrazine Benefits Team papers that estimate economic impacts assume that corn and other crop prices remain constant, even when crop yields and production change significantly. Under this unrealistic assumption, any assumed yield loss from the withdrawal of atrazine would automatically translate into a comparable loss of farm revenues; these assumed revenue losses are emphasized by the Atrazine Benefits Team.

Disregarding key implications of their own analysis

In the one case where the Atrazine Benefits Team used a more sophisticated model, allowing crop prices to change, they obtained a result opposite from the two papers discussed above: withdrawal of atrazine reduces corn yields, but increases corn prices by a greater percentage, resulting in an *increase* in farm revenues. Under a key scenario (assuming moderate tillage and constant glyphosate use), they estimate that corn production drops by 4.4 percent without atrazine, but the price of corn increases by 8.0 percent. Corn growers' revenue therefore increases by 3.2 percent, or $1.7 billion, if atrazine is withdrawn from the market. This benefit to farmers is never mentioned by the Atrazine Benefits Team, but is clearly implied by their results.

Other research on the "price elasticity" of corn—that is, the relationship between price changes and quantity changes—points in the same direction. Corn, like most agricultural products, is said to have "inelastic" demand, meaning that small quantity changes are associated with larger price changes. For any product with inelastic demand, a small percentage drop in output is associated with a larger percentage increase in price, raising the total sales revenues received by producers.

Corn without atrazine: who wins and who loses?

Suppose, consistent with the Atrazine Benefits Team scenario described above, that the withdrawal of atrazine would cause 4.4 percent less corn production and an 8.0 percent increase in the price of corn. Using these numbers, who wins and who loses from the withdrawal of atrazine?

Corn growers, as we have seen, would be winners, enjoying a 3.2 percent increase in sales revenue. Other winners would include people and animals that would no longer suffer the health and environmental impacts of atrazine. The biggest losers are the industries that buy corn, such as ethanol and livestock producers; they would have to pay 8 percent more for a key input to their industries. The Atrazine Benefits Team focuses on these losses, described as a decrease in "consumer surplus"—a technical term used by economists to refer to the impact of price increases on the buyers of a product.

What would an 8 percent increase in the price of corn mean for consumers? In the case of ethanol, it would cause a price increase, although probably less than 8 percent, since other costs of ethanol production would not be affected. Ethanol is blended into gasoline; percentages vary by region of the country, but it generally represents 10 percent or less of the total volume of gasoline. So even if ethanol increased in price by the full 8 percent, gasoline prices would increase less than 1 percent. At today's prices, the increased price at the gas pump would amount to about $0.03 per gallon.

For beef, two very different analyses both suggest that a 1 percent increase in the price of corn is associated with a 0.17 percent increase in the price of beef. That is, the beef price impact is one-sixth as large as the change in the price of corn. So an 8 percent increase in the price of corn would translate into a 1.4 percent price increase for beef: $0.05 per pound for ground beef or $0.10 per pound for sirloin steak. The cost of a hamburger would rise by about a penny; the cost of an 8-ounce steak would rise by a nickel.

In terms of narrow economic self-interest, ethanol producers and animal feedlots may have good reasons to favor atrazine, but corn growers have equally good reasons to explore the alternatives. Consumers, meanwhile, have only pennies per person at stake—in a question with profound impacts on health and the environment.

2. Introduction

Every year, atrazine is applied to tens of millions of acres of corn grown in the United States, making it one of the world's most widely used agricultural chemicals (Grube, et al. 2011). A powerful, low-cost herbicide, atrazine is also the subject of persistent controversy. It is an endocrine disrupter, causing feminization in male frogs at incredibly low concentrations; it harms immune systems in exposed aquatic wildlife, especially when interacting with other pesticides; and exposure to it during pregnancy may increase risks of birth defects and low birth weight in humans. Produced by Syngenta, a European chemical company, atrazine is subject to strict regulation that effectively prevents its use in Europe[1]—but it remains a staple of American agriculture.

While the health and environmental effects of atrazine have been researched in depth, there has been only limited analysis of the economic impacts of atrazine use. Frank Ackerman (2007) found that defenders of atrazine generally claimed that it added 6 percent or less to corn yields per acre. He also found that a pro-atrazine economic study sponsored by Syngenta contained serious, elementary errors, while more careful and detailed studies suggested that atrazine might increase corn yields by as little as 1 to 3 percent.

The atrazine debate has continued and intensified in recent years. Additional research has steadily deepened the understanding of health and environmental impacts of atrazine. A group of Midwestern water districts filed a class action suit against Syngenta, seeking to recover the high costs of removing atrazine from their municipal water supplies, and won a $105 million settlement —but not an admission that any harm had been done to them (Syngenta 2012, Berry 2012).

Syngenta, meanwhile, assembled an "Atrazine Benefits Team" of researchers, who produced five research papers claiming to show huge benefits from atrazine use in U.S. agriculture. One of these papers alleges that their work has made Ackerman's 2007 article outdated (Mitchell 2011a).

It is certainly true that Syngenta's latest economic defense of atrazine avoids the embarrassing mistakes of its earlier report. But do the Atrazine Benefits Team papers prove their case? Or is atrazine still producing only marginal economic benefits in exchange for significant health and environmental risk?

This report re-evaluates the economic costs and benefits of atrazine in light of the Atrazine Benefits Team papers and other new data that are now available. We focus on U.S. field corn production, which is the largest and best-documented market for atrazine, and the locus of almost all the alleged economic benefits of atrazine use.[2] We begin with a brief review of research on the health and environmental effects of atrazine in Section 3, and a description of the Atrazine

[1] Atrazine has been excluded from the re-registration process in the European Union since 2003 due to the manufacturer's inability to demonstrate that its use would not result in groundwater concentrations greater than 0.1 μg/l (European Commission Health and Consumer Protection Directorate-General 2003).

[2] In the Atrazine Benefits Team papers, field corn accounts for roughly 80 percent of all estimated economic gains from triazine scenarios in one calculation (Mitchell 2011a), and 96 percent under another, more detailed calculation (Mitchell, Estimating Soil Erosion and Fuel Use Changes and Their Monetary Values with AGSIM: A Case Study for Triazine Herbicides 2011b). See discussion below.

Benefits Team papers and our principal criticisms of them in Section 4. In Sections 5 and 6 we discuss important chemical and non-chemical options for weed management, which were largely overlooked by the Atrazine Benefits Team. Section 7 examines the economics of corn and atrazine, and shows that, according to the most detailed calculation from the Atrazine Benefits Team, corn growers would benefit financially if atrazine were withdrawn from the market. Finally, in Section 8, we estimate the impacts of atrazine withdrawal on consumers, under the assumptions made by the Atrazine Benefits Team. This analysis suggests that if atrazine were withdrawn, gasoline prices would rise by $0.03 per gallon or less, while the price of ground beef might rise by $0.05 per pound—about a penny per hamburger.

3. Atrazine Hazards: A Brief Review

There is a massive and growing scientific literature on the hazards associated with atrazine. A 2011 article, written by a team of 22 researchers from eight countries, reviewed more than 100 studies of the effects of atrazine, finding that:

> Atrazine demasculinizes male gonads producing testicular lesions associated with reduced germ cell numbers in teleost fish, amphibians, reptiles, and mammals, and induces partial and/or complete feminization in fish, amphibians, and reptiles (Hayes, et al. 2011, 64).

Experiments, primarily with laboratory rodents, have demonstrated that atrazine also causes

> …induced abortion, impaired mammary development, the induction of reproductive and hormone-dependent cancers as well as … impaired immune function … and impaired neural development (Hayes, et al. 2011, 70).

Similarly, a meta-analysis of research on the effects of atrazine on fish and amphibians found that

> Atrazine reduced size at or near metamorphosis in 15 of 17 studies and 14 of 14 species. Atrazine elevated amphibian and fish activity in 12 of 13 studies, reduced antipredator behaviors in 6 of 7 studies, and reduced olfactory abilities for fish but not for amphibians. Atrazine was associated with a reduction in 33 of 43 immune function end points and with an increase in 13 of 16 infection end points. Atrazine altered at least one aspect of gonadal morphology in 7 of 10 studies and consistently affected gonadal function, altering spermatogenesis in 2 of 2 studies and sex hormone concentrations in 6 of 7 studies (Rohr and McCoy 2010, 20).

The state of atrazine research is also summarized in two reports from the Natural Resources Defense Council (NRDC), with a focus on the widespread contamination of drinking water and surface water (Wu, Quirindongo, et al. 2009, Wu, Quirindongo, et al. 2010). Some studies suggest that atrazine may contribute to cancer risk in humans, particularly non-Hodgkin's lymphoma, which may be more likely when people are exposed to atrazine in combination with other pesticides. However, others feel that there is not yet sufficient evidence from human data to draw firm conclusions regarding its carcinogenic potential (IARC 1999).

The NRDC reports summarize scientific studies that report elevated risk of non-malignant human health effects from atrazine. A study of babies born in Indiana found a significant correlation between prenatal atrazine exposure and low birth weight (Kerby and Storfer 2009). A large-scale study of births across the United States found an increased risk of birth defects when mothers became pregnant between April and July, the peak season for pesticides in waterways (de Bie, Oostrom and Delemarre-van de Waal 2010). Among pesticides monitored in the study, birth defect risks were most closely associated with atrazine levels. Another Indiana study found a significant association between atrazine levels and birth defects in the gut wall, which are more common in Indiana than in the United States as a whole (Winchester, Huskins and Ying 2009). Other studies of farm workers and rural men in general have found that atrazine levels in urine are correlated with low sperm count and reduced sperm motility (Bakke, et al. 2009, Swan, Kruse, et al. 2003, Swan 2006).

In 2010, EPA reviewed the available research on non-cancer human health risks associated with atrazine (Christensen 2010). According to EPA's scientific review, the strongest evidence for effects of atrazine arose in the areas of:

- *Women's reproductive health* – atrazine exposure was associated with increased odds of long and missed menstrual cycles, delayed timing of menopause, and, for those exposed during pregnancy, doubled risk of gestational diabetes.
- *Men's reproductive health* – one study found that men with detectable atrazine in their urine were 11 times more likely to have poor semen quality than men without atrazine; EPA noted that this small study needed to be replicated.
- *Fetal and infant outcomes* – multiple studies found correlations between atrazine exposure during pregnancy and several types of birth defects; two studies found that third-trimester atrazine exposure increased the odds of small-for-gestational-age births. Evidence was mixed on pre-term delivery and low birth weight.

In this report, we will not attempt a detailed summary or description of the adverse effects of atrazine. Rather, we assume as a starting point that atrazine is known to be hazardous to human and animal health. Our focus is on the other side of the cost-benefit balance: what is the tradeoff, the economic benefit that might justify widespread use of a dangerous chemical? Is atrazine essential to the security of our food supply, guaranteeing access to affordable corn in the United States? Or are we being "poisoned for pennies" (Ackerman 2008), accepting an ominous chemical hazard in exchange for a minor increase in yields of an already abundant crop?

4. The Atrazine Benefits Team Papers

Syngenta's "Atrazine Benefits Team" of researchers released five papers in November 2011, making a series of interrelated arguments about the benefits of and need for the continued use of atrazine in the United States.[3] The papers, and their main points, are as follows:

[3] The papers are available at http://www.weeds.iastate.edu/weednews/2011/atrazine%20new1.html.

- Richard Fawcett, "Efficacy of best management practices for reducing runoff of chloro-*s*-triazine herbicides to surface water: a review," describes a decline in atrazine concentrations in surface water, despite continuing widespread atrazine usage. Fawcett attributes this to adoption of best management practices, including increased use of conservation tillage and no-till systems, and other improvements in planting practices and herbicide application.
- Michael Owen, "The importance of atrazine in the integrated management of herbicide-resistant weeds," asserts that atrazine is needed for weed management because so many weeds are developing resistance to other herbicides. Glyphosate (Roundup) resistance is becoming particularly problematic due to overuse of and often exclusive reliance on glyphosate with genetically modified, "Roundup Ready" crops. Owen only briefly mentions atrazine resistance, which he views as a less serious threat.
- David Bridges, "A biological analysis of the uses and benefits of chloro-*s*-triazine herbicides in U.S. corn and sorghum production," calculates yield losses under a range of assumptions about alternate herbicide treatments. Bridges examines replacement of atrazine with a single treatment (that is, use of a single alternative herbicide), and with combinations of two or three treatments (i.e., combining two or three herbicides, a common practice). Only the single-treatment results are reported in detail, although he mentions that the average yield loss from all of the two-treatment alternatives is only 2 percent. Almost nothing is said about the results of the three-treatment combinations. Bridges also calculates some economic impacts, assuming single-treatment replacements for atrazine and fixed prices for crops (including $3.75 per bushel for field corn).
- Paul Mitchell's first paper, "Economic assessment of the benefits of chloro-*s*-triazine herbicides to U.S. corn, sorghum, and sugarcane producers," applies the yield losses from Bridges' single-treatment alternatives to field corn, sweet corn, and sorghum, along with selected growers' personal judgments about sugarcane yield losses. This paper, like Bridges (2011), assumes fixed prices for crops, including $3.75 per bushel for field corn. Under these assumptions, the estimated value of atrazine is $3.0 – $3.3 billion per year, of which $2.4 - $2.6 billion comes from increased yields in field corn.
- Mitchell's second paper, "Estimating soil erosion and fuel use changes and their monetary values with AGSIM: A case study for triazine herbicides," develops detailed estimates of soil erosion impacts, assuming that atrazine allows greater use of no-till and conservation tillage systems. The monetary value assigned to these soil erosion impacts, however, is less than 10 percent of the total benefit attributed to atrazine. The paper also applies the AGSIM model to estimate the overall economic impacts of atrazine use on ten major crops, including induced changes in prices and acreage.

Mitchell's "Estimating Soil Erosion" paper is the only one of the Atrazine Benefits Team papers to analyze the crop price changes resulting from alternative herbicide choices and the resulting crop yield changes. It is also the only one of the papers to measure the economic benefit of atrazine in terms of changes in "consumer surplus"—i.e., the benefits to consumers of lower crop prices. Although estimates are developed for all ten crops in the analysis, corn accounts for 96 percent of the total consumer surplus created by the use of atrazine. However, in reality the consumers who enjoy the benefit of lower corn prices are primarily industries, not households: "Among end users, the benefits of triazine herbicides mostly flow to those using large amounts of corn – the livestock and ethanol industries." (Mitchell 2011b, p.43)

There are at least three major problems with the Atrazine Benefits Team papers:

- *Exaggeration of the effectiveness of atrazine, and incomplete analysis of alternatives:* Owen (2011) understates the importance of atrazine-resistant weeds, a growing problem; Bridges (2011) provides only a poorly explained and partially documented account of the alternatives he analyzed. Some of the chemical alternatives that score best in weed suppression are overlooked, as is the entire area of non-chemical approaches to weed management. We address these questions in Sections 5 and 6, below.
- *Reliance on the unrealistic assumption of unchanged prices:* two of the three papers that estimate economic impacts of atrazine, Bridges (2011) and Mitchell (2011a), assume that crop prices are unchanged when crop yields and production change. This assumption is inconsistent with common sense, farming experience, and elementary economics. It does, however, produce misleading, multi-billion-dollar estimates of the benefits of atrazine use.
- *Failure to notice that, according to their own analysis, corn growers lose money from atrazine:* the one paper that allows crop prices to vary, Mitchell (2011b), provides separate estimates of changes in crop prices and production, but never multiplies the two to calculate the effect on farm revenues from atrazine use. Compared to a scenario in which alternative herbicides (other than glyphosate) are used in place of atrazine, the use of atrazine *decreases* corn growers' revenues by $1.7 billion annually. The increase in corn production made possible by atrazine is more than offset by the decrease in corn prices due to the additional supply of corn, resulting in an overall decline in net revenues for corn growers.[4] In other words, as atrazine boosts corn supply, the price falls and farmers lose out. This result is never mentioned in any of the Atrazine Benefits Team papers.

In the following sections of this report, we address each of these points in turn, culminating in estimates of consumer impacts of the Atrazine Benefits Team scenarios in Section 8. The appendix presents key results from Mitchell (2011b) supporting our conclusion that, under the Atrazine Benefits Team analysis, corn growers would be economically better off without atrazine.

5. Atrazine's Effectiveness

The economic benefits estimated by the Atrazine Benefits Team are based largely on atrazine's purported effectiveness in controlling weeds present in U.S. field crops, primarily corn. A closer look at the assumptions made by the Atrazine Benefits Team, however, indicates that these benefits are overstated. In particular, the analyses funded by Syngenta understate the magnitude of the problem of atrazine-resistant weeds, and fail to adequately assess the effectiveness of alternative herbicides.

[4] This is a common characteristic of many agricultural markets, as seen when a bumper crop results in decreased total farm revenue due to the price suppression effect of the large amount of supply.

Corn, atrazine, and weed control

Atrazine is used to control weeds, including many of those most damaging to corn crops. Nationally, approximately 70 percent of the potential corn yield loss due to weed pressure is caused by only ten weeds (see Table 1), of which all but foxtails can be classified as broadleaf weeds.[5]

Table 1. Weed Pressure in Corn

Rank	Weed	Potential loss from unchecked weed growth (millions of bushels)	Approximate area infested (millions of acres)	Resistance to atrazine found in United States?
1	Foxtails	3,477	61	Yes
2	Pigweeds (amaranths other than Palmer amaranth)	2,564	47	Yes
3	Common/Tall waterhemp	2,305	46	Yes
4	Common lambsquarters	1,901	38	Yes
5	Velvetleaf	1,694	35	Yes
6	Other ragweeds	1,538	21	No
7	Giant ragweed	1,496	18	No
8	Palmer pigweed (Amaranthus palmeri, also called "Palmer amaranth")	1,194	19	Yes
9	Cockleburs	1,119	22	No
10	Morningglories	1,118	27	No

Source: Resistance data from Heap (2012); other data derived from Bridges (2011), Tables 2 and 8. [6]

Atrazine has long been employed as an herbicide to combat many of these weeds, although its effectiveness varies by the particular weed type and whether atrazine-resistant weeds are present. Owen (2011), one of the Atrazine Benefits Team papers, discusses the growing resistance of weeds to glyphosate and other herbicides as a reason why atrazine is needed—and suggests in passing, with very limited documentation, that resistance to atrazine is much less important. Recent empirical evidence, however, suggests that atrazine-resistant weeds are an expanding problem. Over the past 20 years, 10 more weed species have developed resistance to atrazine,

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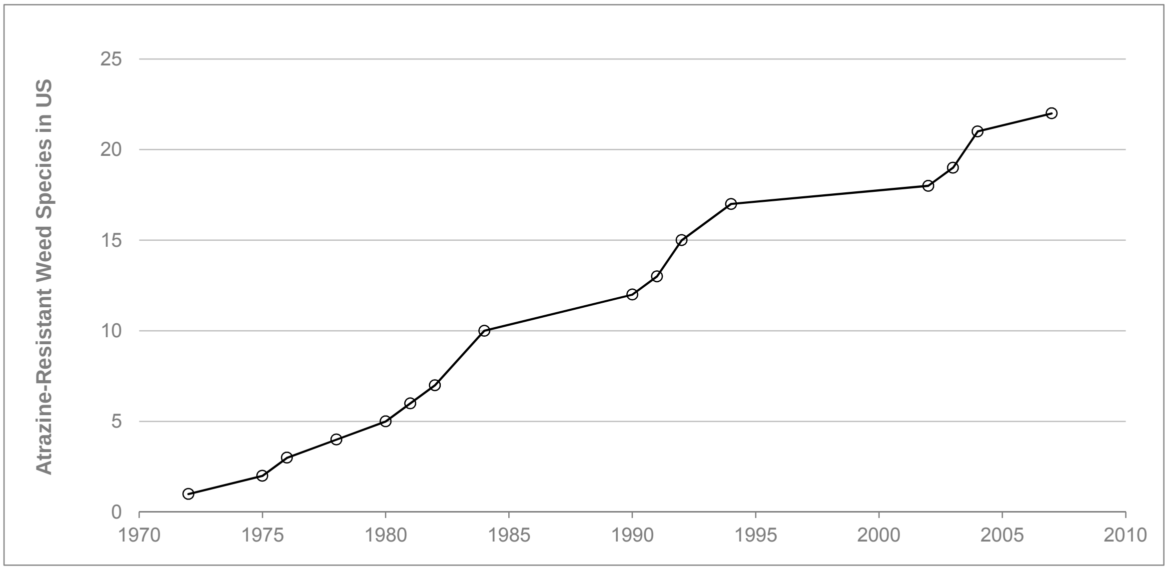
[5] Weed pressure data derived from Bridges' (2011) data on infestation and yield reduction (Tables 2 and 8).

[6] Acreage infested is derived from Bridges' estimates of the percent of crop acres containing a population of the weed which, if left uncontrolled, would be sufficient to result in yield reduction. This percentage, for each agricultural region, was multiplied by the region's total acres of corn to arrive at an approximate number of acres infested. The potential bushel loss was calculated from Bridges' estimates of the average percent yield loss expected to occur in infested acreage if the specified weed was left uncontrolled, multiplied by the region's average yield per acre and number of infested acres.

as depicted in Figure 1, below (Heap 2012). In fact, the list of atrazine-resistant weeds now includes six of the top ten weeds with the greatest damage potential to corn in the United States, as shown in Table 1.

Figure 1. Atrazine-resistant Weed Species in the United States



Source: Heap (2012)

Owen's own recent empirical work, in fact, contradicts his 2011 claim that atrazine resistance is not problematic or rapidly expanding. In the *2013 Herbicide Guide for Iowa Corn and Soybean Production*, Owen and a coauthor report on the initial results of an analysis of weeds from more than 220 fields across Iowa, finding that among populations of common waterhemp, the third-most noxious corn weed in the United States, 57 percent had developed resistance to atrazine (Hartzler and Owen 2012). While atrazine-resistant weeds are not problematic in all regions, their increasing prevalence heightens the need to shift away from triazine herbicides to other methods of weed management, including non-chemical methods.

Incomplete analysis of other herbicide options

Other herbicides, such as Sharpen (saflufenacil), Callisto (mesotrione), and Equip (foramsulfuron + iodosulfuron), have been developed as alternatives to atrazine. When used in some combinations (depending on the field-specific weed pressure), these alternative herbicides may offer equivalent or superior protection to atrazine, as indicated by the effectiveness ratings in Iowa State University's *2013 Herbicide Guide* (Hartzler and Owen 2012), reported in Table 2 and Table 3 below. These efficacy ratings challenge the assertion by Bridges (2011) that use of alternative herbicides would necessarily result in significant yield losses.

Table 2 displays the effectiveness of alternative pre-emergence herbicides (applied before the crop emerges from the ground) relative to atrazine for the weed species that are most threatening to corn yields in the United States.[7] Similarly, Table 3 displays this information for post-emergence herbicides. The effectiveness of atrazine in both tables assumes no resistance to atrazine, which is a questionable assumption for foxtails, pigweeds and waterhemp, lambsquarters, and velvetleaf.

Table 2. Effectiveness Ratings: Alternative Pre-Emergence Herbicides Relative to Atrazine[8]

Herbicide	Trade Name	Foxtail	Amaranthus spp (Pigweeds & Waterhemp)	Lambsquarters	Velvetleaf	Common ragweed	Giant ragweed	Cocklebur	Herbicide Site of Action	Chemical Family
Atrazine (for comparison)		2	4	4	3	4	2.5	3	Photosystem II inhibitor	Triazine
Saflufenacil	Sharpen	1	3.5	3.5	3.5	3	3	3	PPO inhibitor	Pyrimidinedione
Mesotrione	Callisto	1	3.5	4	4	2.5	2	2.5	HPPD inhibitor	Triketone
Flumetsulam + Clopyralid	Hornet WDG	1	3.5	3	3	3	3	3	ALS Inhibitor; Synthetic auxin	Triazolopyrimidine sulfonanilides; Pyridinecarboxylic acid

Effectiveness ratings: 1 = Poor, 2 = Fair, 3 = Good, 4 = Excellent

Source: Chemical family: Peachey, Miller and Hulting (2012); All else: Hartzler and Owen (2012)

All three of the alternative pre-emergence herbicides—saflufenacil, mesotrione, and flumetsulam + clopyralid—demonstrate significant weed control abilities against the major weeds facing corn growers. Sharpen (saflufenacil) and Callisto (mesotrione) in particular offer the added benefit of having modes of action that remain effective against weeds with resistance to atrazine, glyphosate, and ALS inhibitors.

Table 3 below displays similar information for four alternative post-emergence herbicides. These herbicides, working alone or in combination, offer an alternative to atrazine with similar or potentially greater protection value.

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[7] Some species, such as pigweeds and waterhemp, are combined under their shared genus. Morningglories were not included due to omission in the source document.

[8] Table data are for weeds in Iowa, the top corn-producing state, but the effectiveness of these herbicides is likely to be similar for other corn-producing states.

Table 3. Effectiveness Ratings: Alternative Post-Emergence Herbicides Relative to Atrazine[9]

Herbicide	Trade Name	Foxtail	Amaranthus spp (Pigweeds & Waterhemp)	Lambsquarters	Velvetleaf	Common ragweed	Giant ragweed	Cocklebur	Herbicide Site of Action	Chemical Family
Atrazine (for comparison)		2	4	4	4	4	3	4	Photosystem II inhibitor	Triazine
Foramsulfuron + Iodosulfuron	Equip	3.5	3	3	3.5	4	3	4	ALS inhibitor	Sulfonylurea
Flumetsulam + Clopyralid	Hornet WDG	1	3.5	2	3.5	4	3.5	4	ALS inhibitor	Triazolopyrimidine sulfonanilides; Pyridinecarboxylic acid
Mesotrione	Callisto	1	4	3	4	2	3	3.5	HPPD inhibitor	Triketone
Imazethapyr	Pursuit	2.5	2.5	3	3.5	3	2	3.5	ALS inhibitor	Imidazolinone

Effectiveness ratings: 1 = Poor, 2 = Fair, 3 = Good, 4 = Excellent

Source: Chemical family: Peachey, Miller and Hulting (2012); All else: Hartzler and Owen (2012)

The herbicides listed in the tables above are only a small number of the alternative herbicides and combinations of herbicides available to farmers, and other studies (discussed below) have demonstrated that many alternative herbicides are profitable for farmers—and frequently more profitable than atrazine.

Despite the availability of many effective alternative herbicides, including the chemical alternatives listed in the tables above, the Atrazine Benefits Team papers failed to assess the viability of these options in numerous ways. In particular, the papers failed to:

- Assess the full range of pre- and post-emergence alternatives
- Consider the alternatives' potential for synergistic sequencing
- Anticipate that newer herbicides may gain market share (likely leading to lower cost, as they are produced in greater volume) as their effectiveness becomes better understood

First, in evaluating atrazine's effectiveness relative to alternative pre-emergence herbicides, Bridges (2011) failed to assess mesotrione and flumetsulam + clopyralid as pre-emergence herbicides, although he evaluated them as post-emergence herbicides. Moreover, two of the post-emergence herbicide treatments identified in Table 3, foramsulfuron + iodosulfuron and imazethapyr, are entirely absent from Bridges' assessment.

Second, the yield loss estimates from Bridges (2011) that are used in economic calculations by Bridges (2011) and Mitchell (2011a, b) are based entirely on a one-for-one substitution of a single

[9] Table data are for weeds in Iowa, the top corn-producing state, but the effectiveness of these herbicides is likely to be similar for other corn-producing states.

alternative herbicide treatment for atrazine. This is unrealistic, as many herbicides work best in concert with other herbicides. No such combinations were included in the scenarios analyzed by Mitchell.

In contrast, Prato and Woo (2008) found that non-atrazine herbicides applied in a pre- and post-emergence sequence were typically as profitable or more profitable for farmers than using atrazine. The authors conducted simulations for northern Missouri corn production using the widely used and field-tested WeedSOFT program, a bioeconomic model for simulating various alternative weed management practices and producer net returns.[10] The study evaluated hundreds of herbicide treatment combinations across nine different weed pressure scenarios of the ten most common weed species in Missouri,[11] and subsequently ranked each herbicide treatment by profitability. Prato and Woo's analysis found that in eight of nine weed pressure scenarios, a two-pass system, consisting of a pre-emergence herbicide followed by a post-emergence herbicide, yielded the highest profits. Atrazine was included in only 20 percent of the numerous profitable two-pass treatments.[12] And crucially, in each of the nine weed pressure scenarios, the most profitable treatment did not include atrazine at all.

The Atrazine Benefits Team papers, however, base their yield estimates on the substitution of single herbicide treatments for atrazine, rather than considering more profitable herbicide combinations as done by Prato and Woo. The substitutes used by Bridges in estimating yield impacts were chosen according to recent (2009) market share of the alternative herbicide, rather than based on the treatments most likely to yield the highest economic return. It is therefore of little surprise that a bioeconomic model such as WeedSOFT, which considers producers' net returns, would select a different set of alternatives, including many more profitable than atrazine.

Bridges assesses, but does not report in detail, the results of multiple herbicide treatments to replace atrazine. He does report that the average of the 41 treatments containing two herbicides in sequence resulted in an average "protection value" (defined as yield x crop price, i.e. revenue per acre) 2 percent lower than the atrazine treatments. However, the range of results is not disclosed, so it is unclear whether some of the 41 treatments actually resulted in protection values greater than that of the atrazine options.

Finally, Bridges' estimates of yield reduction due to atrazine alternatives are likely skewed by the relative novelty of saflufenacil. The two atrazine alternative scenarios that the Atrazine Benefits Team papers consider in detail hinge on either increasing use of glyphosate, and/or increasing

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[10] WeedSOFT was developed by weed scientists and is widely used in the Midwest. Several peer-reviewed articles such as (Jeschke, et al. 2009) and (Schmidt, et al. 2005) have evaluated the accuracy of WeedSOFT's predictions based on pooled data from numerous site-years and found that observed and predicted corn yield-loss values were similar.

[11] These weed species include most of the top ten worst corn weed species nationally. The weed species analyzed were fall panicum, giant foxtail, common cocklebur, common ragweed, common sunflower, ALS resistant waterhemp, giant ragweed, hemp dogbane, pitted morningglory, and velvetleaf.

[12] Prato and Woo (2008) identified 70 different profitable two-pass treatments, 25 profitable post-emergence-only treatments, and 17 profitable pre-emergence-only treatments. Atrazine was present in the majority of profitable pre-emergence-only treatments, but these were uniformly less profitable for farmers than post-emergence-only and two-pass treatments.

other herbicides in proportion to their 2009 use (Bridges 2011, 19). Although mesotrione has been in use since 2001, saflufenacil is a very new herbicide, having been registered in the United States only in 2009 (Papiernik, Koskinen and Barber 2011). As a result, this highly effective herbicide was likely to have been nearly ignored in Bridges' calculations, which were based on herbicide market share in 2009.

6. Alternative Weed Management Methods

Since the development of highly effective herbicides, and especially since the introduction of herbicide-tolerant crops such as "Roundup Ready" corn, U.S. agricultural practices have shifted toward simplified systems, highly reliant on chemicals to control weeds (Vencill, et al. 2012, Anderson 2007). Initially extremely effective, herbicides came to be perceived as a "silver bullet" for weed management. However, herbicides have not achieved long-term weed control and are declining in effectiveness as herbicide-resistant weeds, including those resistant to atrazine, grow in number (Anderson 2007).

Overreliance on chemicals to control weeds, and particularly on chemicals like atrazine with a single herbicidal mode of action,[13] has created a situation in which weeds resistant to common herbicides are more likely to succeed and proliferate than non-resistant weeds, thereby increasing the herbicide-resistant weed population over time. Herbicide-resistant weeds have been a known problem since the early 1970s (Vencill, et al. 2012), but as described in the preceding section, resistance to common herbicides such as glyphosate and atrazine—the two most widely used herbicides in the country—is spreading and threatening crop yields across the country.

For these reasons, as well as the desire to lower chemical costs, along with concerns about herbicides' health and ecosystem impacts, many producers have begun to turn to integrated weed management (IWM) to prevent and manage weeds. The methods employed by IWM include numerous non-chemical strategies, many of which have been shown to significantly reduce weed pressure, thereby increasing corn yields. Such techniques, however, are overlooked by the Atrazine Benefits Team in favor of continued reliance on traditional herbicides.

Integrated Weed Management

IWM focuses not on the complete control (i.e., elimination) of weeds, but rather on preventing weed reproduction, reducing weed emergence after crop planting, and reducing weed competition with the crop (Buhler 2002). Like integrated pest management, IWM employs multiple non-chemical techniques for weed prevention and management, which may include:[14]

- Crop rotation

[13] "Mode of action" is the mechanism by which the herbicide interferes with the plant's normal functioning, for example, by interfering with the production of a key enzyme. For example, glyphosate is an enolpyruvyl shikimate phosphate synthase (EPSPS) inhibitor, glufosinate is a glutamine synthetase inhibitor, and atrazine is a photosystem II inhibitor.

[14] These methods are described in greater detail in numerous articles and publications, including Buhler (2002).

- Intercropping
- Enhanced crop competitiveness
- Cover crops
- Tillage and cultivation
- Fertility management

With IWM, traditional herbicide use can often be greatly reduced or eliminated, and overreliance on a single mode of action is avoided.

Weed management techniques that are most likely to be beneficial to corn growers are presented below, with the understanding that no single method will be appropriate for every field. Each weed management system must be tailored to the particular situation, taking into account the specific crop grown, weeds present, field and climatic factors, and farmer's goals and resources.

Mechanical methods

Tillage was historically a primary means of weed management, and can still be used today. In the past, tillage typically meant use of the traditional mold-board plow or other conventional techniques that disturb a large amount of soil and remove the majority of crop residue, leading to high levels of erosion. Both Fawcett (2011) and Mitchell (2011b) assume that one of the benefits of atrazine use is the reduction in tillage required. However, there are reduced-tillage methods available, such as ridge tillage, that result in little erosion while simultaneously sustaining high crop yields and avoiding the use of herbicides.

Ridge tillage is a crop production system involving reduced soil disturbance in which crops are planted in ridges built during cultivation in the previous growing season. The top of the ridges are pushed aside at planting, removing a large portion of residue and weed seeds to the middle of the row. Inter-row cultivation can then be used to manage weeds in between the crop rows.

Ridge tillage has proven to be very effective against weeds and ideal for managing water and soil erosion, as it encourages water infiltration and decreases runoff (Rao 2000), resulting in higher soil organic matter and enhanced yields. For example, in both model simulations and field observations, a long-term study at a USDA research station in Iowa demonstrated that the use of ridge tillage increased corn grain yields by nearly 4 percent over conventional tillage (Wang, et al. 2008). Ridge tillage has also been shown to be an economically viable alternative to conventional tillage, as it can reduce fuel, labor, and equipment costs (Archer, Pikul Jr. and Riedell 2002, Lane 1998).

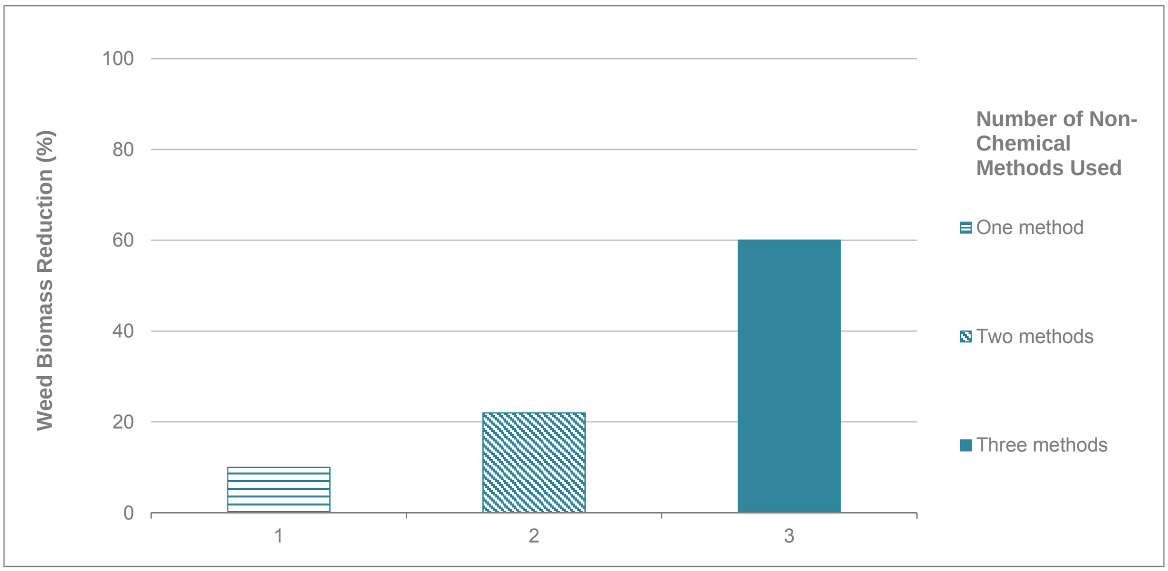
When coupled with decision support systems for monitoring weed emergence and growth, such as USDA's WeedCast Software, mechanical cultivation can be used to manage weeds even more effectively while reducing reliance on herbicides. Instead of using herbicides prior to planting, growers can use WeedCast predictions to help determine the best date for seedbed cultivation to destroy weeds, thereby enhancing yields and profits (Davis 2001, Comis 1997).

Enhancing crop competitiveness

A crop's competitiveness can be improved through the use of cultural techniques that optimize field conditions for crops relative to weeds. Several of these methods center on accelerating the crop's canopy formation to block out light needed by weeds for growth and seed production. Vencill (2012) reports numerous studies that have found narrower row spacing and higher seeding rates improve the competitiveness of crops. Another technique is to apply fertilizers in narrow bands near the crop's roots (rather than broadcast over the entire field), which allows the crop to absorb the vital nutrients while denying weeds the same opportunity, and may reduce the use of chemicals (Riedell, Beck and Schumacher 2000).

Anderson (2003) has found that combining multiple techniques that enhance crop competitiveness yields synergistic results. In trials combining narrow row spacing, higher seeding rates, and banded nitrogen fertilizer placement, weed suppression was six times higher than in comparable trials using only a single one of these practices, as shown in Figure 2 below.

Figure 2. Synergism of Multiple Techniques to Enhance Crop Competitiveness and Reduce Weed Biomass



Adapted from Anderson (2003)

Anderson found that combining cultural tactics resulted in high levels of weed suppression; weed-related yield losses were reduced to only 13 percent, as compared to yield losses of 43 percent in the conventional system (Anderson 2003, Anderson 2007).

The timing of weed management is another important aspect to consider. Too often, effective weed management is assumed to mean controlling 100 percent of weeds. However, total control is not as important as minimizing weed competition with young corn (Gower, et al. 2003). Weed competition can be manipulated through the timing of crop planting and through weed management methods (either chemical or mechanical) during periods when the crop is particularly sensitive to weed pressure.

Such effective alternative weed management practices imply that our agricultural systems can significantly reduce or even avoid reliance on chemical herbicides, particularly as herbicide-resistant weeds become an ever-increasing problem. Instead, crop losses from weeds can be minimized through mechanical methods and by applying cultural tactics to improve the crop's competitiveness. Integrated weed management that uses a multi-pronged approach offers an effective and more sustainable method of crop production without the harmful side-effects of toxic chemicals. Yet the Atrazine Benefits Team failed to consider these established and practical alternatives in its analysis.

7. The Economics of Corn

As we have seen in Sections 5 and 6, there are multiple reasons to believe that the Atrazine Benefits Team analyses have overstated the yield losses that would occur if atrazine were withdrawn. We now turn to a different, equally important issue: even if their estimates of yield impacts in corn were completely accurate, withdrawal of atrazine from the market would substantially boost corn growers' incomes, while the effects on consumer prices would be merely pennies per pound of beef or gallon of gasoline. In order to explain this point, we begin with a look at the market for corn in the United States.

Production and cost trends

The U.S. Department of Agriculture (USDA) reports that 11.2 billion bushels of corn were produced in the United States during the 2012 market year (September 2011 through August 2012), as shown in Figure 3.[15] Total corn production doubled from 1975 to its all-time peak of 13 billion bushels in 2009;[16] average annual production over the past ten years has been about 11.8 billion bushels. Principal markets for corn include feed and residual use; ethanol production; food, industrial, seed, and non-ethanol alcohol use; and exports. Less than 1 percent is sweet corn, used directly for human consumption; almost all is field corn, used as an industrial input or animal feed.[17] In 2002, feed and residuals constituted the largest market, accounting for 58 percent of corn production. In that year, ethanol accounted for only 10 percent of the corn market. By 2012, feed and residuals had shrunk to 37 percent, while ethanol had grown to 40 percent of total corn production.[18]

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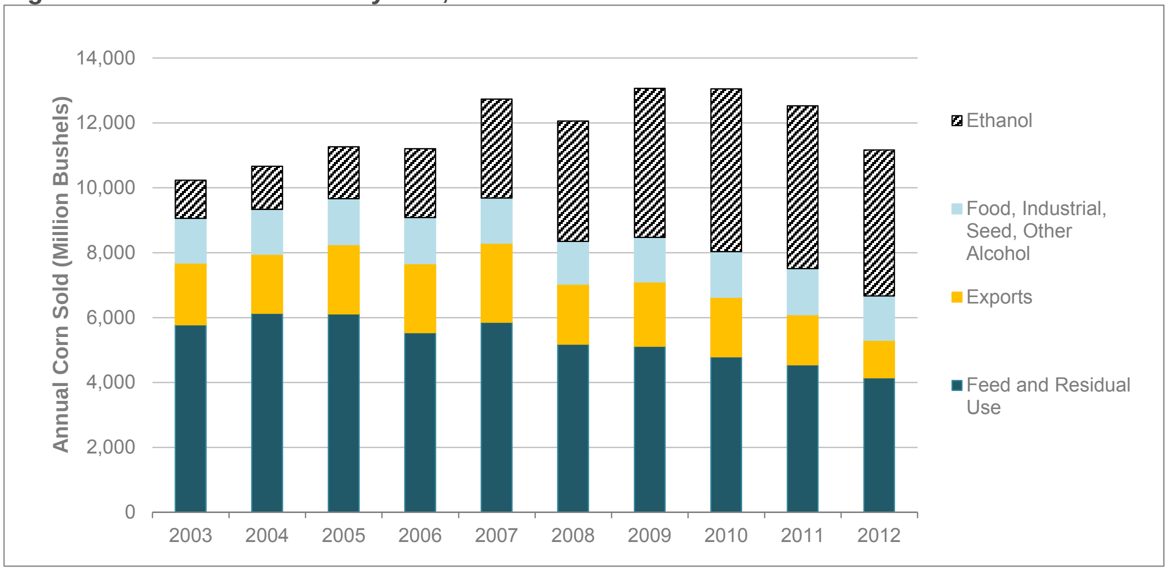
[15] USDA. Feed Grains Database. Available at http://www.ers.usda.gov/data-products/feed-grains-database/.

[16] Corn production data cited here are all for market years; e.g., 2009 means September 2008 – August 2009.

[17] E.g., compare Table 2 (field corn) and Table 4 (sweet corn) in (Mitchell 2011a), for 2007-2009 data.

[18] Note the decrease in corn sold in 2012, compared to 2011. This is likely due in part to the extensive 2012 drought. See http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx.

Figure 3. Annual Corn Sold by Use, 2003-2012

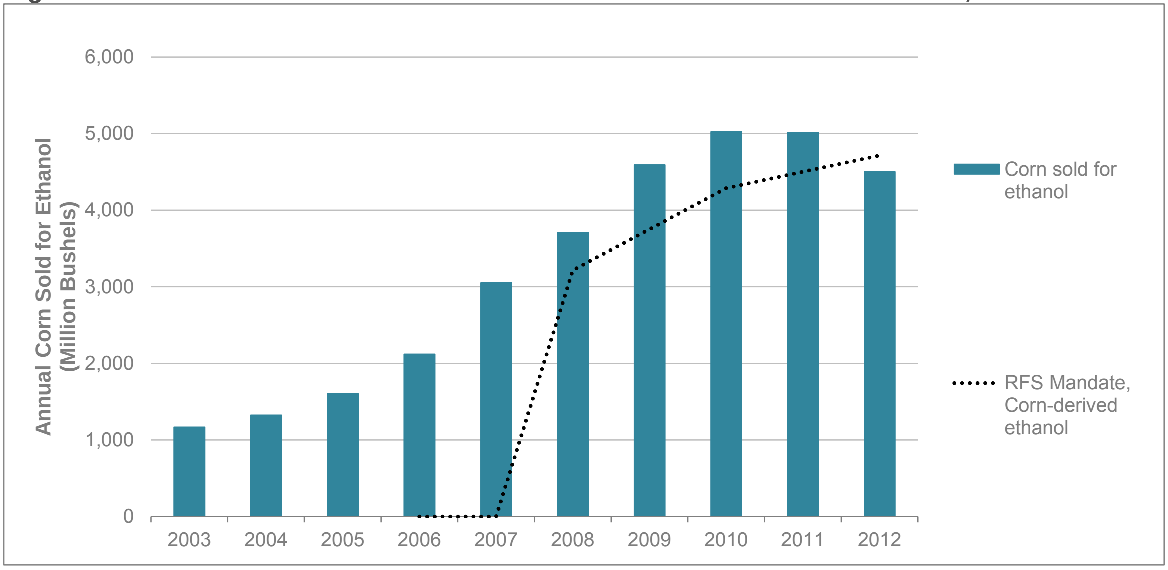


Source: USDA Feed Grains Database (Feed Grains Database 2013)

Figure 3 shows the sharp rise in ethanol as a market for corn over the last decade. Federal government standards and subsidies have greatly increased the percentage of corn being converted to ethanol. While the federal tax credit for ethanol, which dated back to 1978, expired at the end of 2011, EPA's Renewable Fuel Standard (RFS) continues to require high levels of ethanol production. Originally a part of the Energy Policy Act of 2005 and updated with the Energy Independence and Security Act of 2007, this standard requires the use of minimum volumes of a variety of biofuels, including ethanol. Figure 4 compares the corn used for ethanol to the requirements of the Renewable Fuel Standard (converted from gallons to bushels) for 2003 through 2012.[19]

[19] RFS mandate data from Schnepf and Yacobucci (2012); bushels of corn converted to gallons using the factor of 2.8 gallons of ethanol per bushel. Corn for ethanol data from USDA Feed Grains Database, available at http://www.ers.usda.gov/data-products/feed-grains-database/.

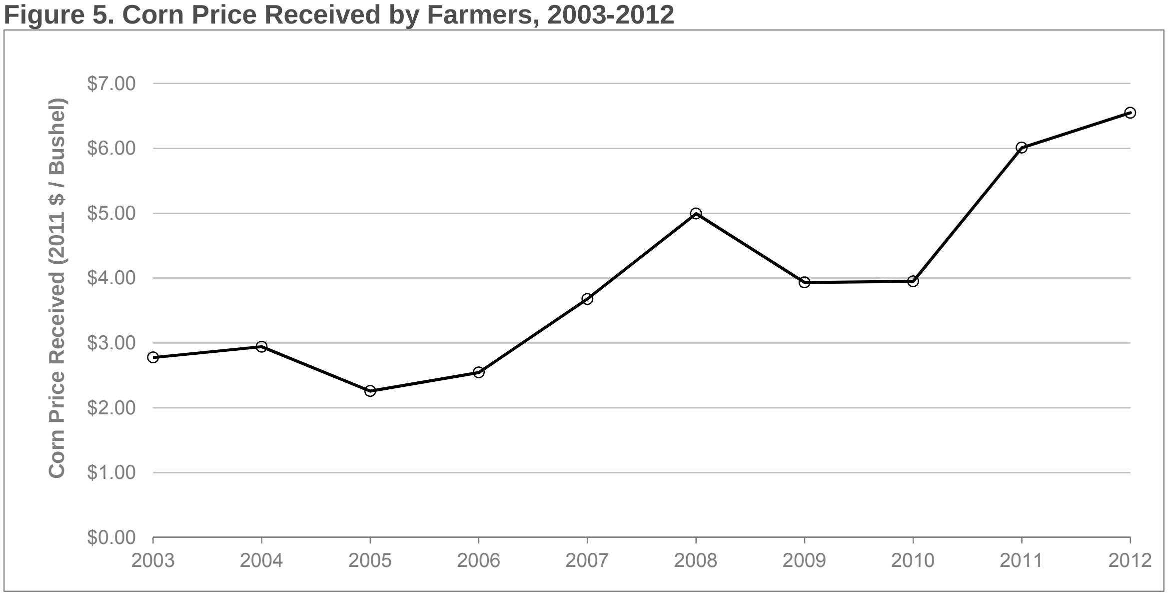
Figure 4. Corn Sold for Ethanol versus RFS-mandated Corn-derived Ethanol, 2003-2012



Source: Ethanol sales data from USDA Feed Grains Database (2013), ethanol mandate data from Schnepf and Yacobucci (2012).

Figure 5 shows that the price of corn was more than twice as high in 2012 as in 2003.[20] It is interesting to note that the price of a bushel of corn has risen by more than $4.00 since 2005, in large part due to the ethanol mandate. In comparison, Mitchell's analysis projects that corn prices would increase by only $0.30 per bushel due to a shift away from atrazine (Mitchell 2011b).

Figure 5. Corn Price Received by Farmers, 2003-2012

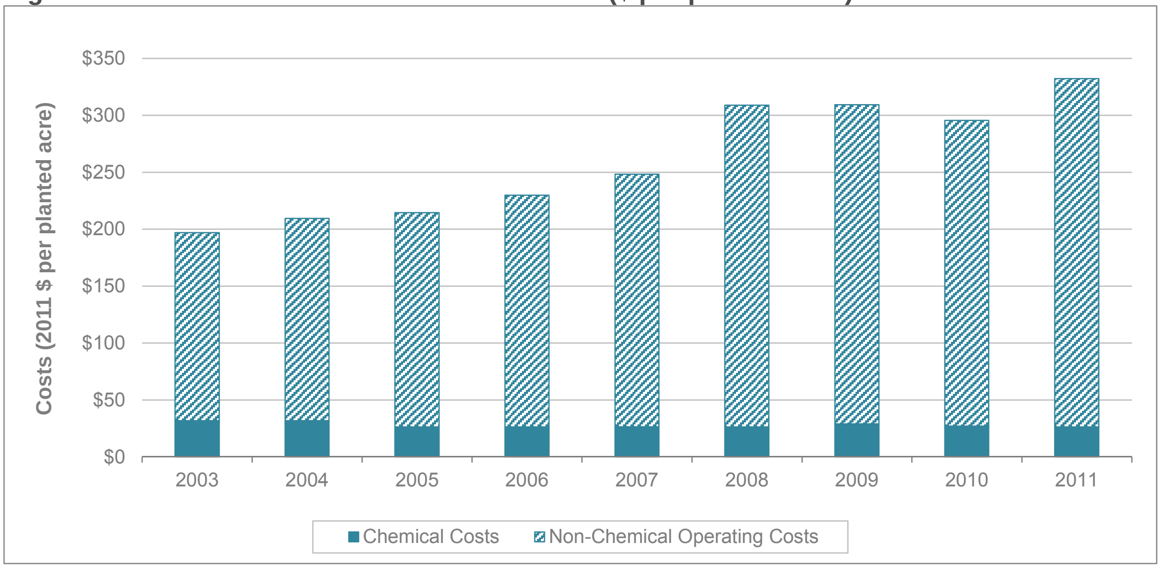


Source: USDA National Agricultural Statistics Service (2013)

[20] USDA National Agricultural Statistics Service. Available at http://www.nass.usda.gov/index.asp.

At the same time that prices have increased, so has the cost of producing corn. Figure 6 shows that while overall costs have increased from 2003 to 2011, the chemical cost component has remained relatively constant at an average of $28 per planted acre.[21] As a result, the cost of chemicals has shrunk from 16 percent of total production cost in 2003 to 8 percent in 2011. Chemicals have consistently represented less than 10 percent of corn production costs since 2008.

Figure 6. Variable Costs of Production for Corn ($ per planted acre)



Non-chemical operating costs include seed, fertilizer, fuel, repairs, irrigation, and interest costs, but not labor or land costs. Source: USDA Commodity Costs and Returns (2012)*.*

Based on 2010 data,[22] atrazine represents less than 13 percent of the total cost of chemicals applied to a typical acre of corn.[23] Since chemicals as a whole made up 9 percent of the costs of producing corn in 2010, atrazine accounted for just 1 percent of the total cost of corn. Thus an alternative that costs two or three times as much per acre as atrazine would add only 1 - 2 percent to production costs.

Price elasticity and revenues

When the price of corn changes, as it has in recent years, what happens to sales? Economists measure the impact of price changes by the "price elasticity of demand"—the percent change in quantity purchased that is associated with a 1 percent increase in price, assuming no change in any other factors that affect sales. Table 4 presents the range of price elasticities of demand for

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[21] USDA. Commodity Costs and Returns. Available at: http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx

[22] Chemical application totals and planted corn acreage data are from USDA National Agricultural Statistics Service (2013); chemical cost information is from Cullen, et al. (2013), and Moechnig, et al. (2011).

[23] Costs per acre were available for 18 of the top 20 chemicals applied to corn; atrazine represents 13 percent of the cost of these 18 chemicals. Hence it would be an even smaller percentage of all chemicals applied to corn.

corn found in the literature. As expected, all are negative—that is, demand goes down when price goes up. But they are very small negative numbers; with the exception of one estimate for corn exports, all the elasticity estimates are less than or equal to 0.5.[24]

When the price elasticity for a good is less than 1, demand for that good is referred to as "inelastic," meaning that it is relatively unresponsive to price. A 1 percent increase in price causes a decrease of less than 1 percent in the quantity that is purchased. Conversely, a 1 percent reduction in quantity would be associated with an increase of more than 1 percent in price. For example, if the price elasticity for corn is -0.5, a 1 percent decrease in the quantity supplied would be associated with a price increase of 2 percent.

Table 4. Price Elasticities of Demand for Corn

Author	**Womack**	**Subotnick and Houck**	**Gallagher**	**Wescott and Hoffman**	**Park and Fortenbery**
Study Year	*1976*	*1982*	*1994*	*1999*	*2007*
Corn price elasticity (general)			-0.23	-0.3 to -0.5	
Corn price elasticity for feed	-0.4	-0.2			
Corn price elasticity for food	-0.08	-0.014			
Corn price elasticity for exports		-1.11			
Corn price elasticity for ethanol					-0.16

Source: Vittetoe (2009)

The consensus in the literature that the price elasticity for corn (aside from exports) is much less than 1 is not surprising. Food, feed, and fuel, the principal uses of corn, all face inelastic demand. The inelastic demand for corn, however, is the key to an important but unadvertised result: according to Mitchell (2011b), the only one of the Atrazine Benefits Team papers to analyze price changes, eliminating atrazine would significantly increase farm revenues.

Mitchell (2011b) models impacts on ten crops of two no-atrazine scenarios, one that maintains glyphosate use at a constant level, and one that increases glyphosate use above 2009 levels. Compared to the baseline with atrazine, the no-atrazine, constant-glyphosate scenario would decrease corn production by 4.4 percent, but would increase the price of corn by 8.0 percent (see appendix). Similar results occur in the increased glyphosate scenario. The implied price elasticity in Mitchell's modeling is approximately -0.55, around the high end of the estimates from the literature.[25]

The combination of Mitchell's estimated 4.4 percent decrease in production and 8.0 percent increase in price leads to a 3.2 percent increase in revenues for corn growers from the withdrawal of atrazine.[26] As shown in the appendix, this implies a gain of $1.7 billion for corn growers under

[24] We follow common usage in referring to elasticities with smaller absolute values as "smaller"; e.g., "less than 1" is understood to mean "less than 1 in absolute value" when discussing elasticities.

[25] The implied price elasticity is the ratio of these percentage changes: -4.4 / 8.0 = -0.55.

[26] If production drops 4.4%, to 95.6% of its original value, while price rises to 108% of the original value, then sales revenue = production * price = 0.956 * 1.08 = 1.032 times the original value.

2009 conditions with constant glyphosate use.[27] The key to this result is that the decrease in corn production happens nationwide. If a single farmer grows 4.4 percent less but no one else's yield changes, then the price is likely to be unchanged, and that unlucky farmer just suffers a 4.4 drop in sales revenue. But if everyone, on average, produces 4.4 percent less, then prices rise by more than enough to offset the reduction in output, leaving all farmers with increased revenue. This important result has to be calculated from separate production and price estimates in Mitchell (2011b); it is never reported in the paper.

Two other Atrazine Benefits Team papers, Bridges (2011) and Mitchell (2011a), emphasize the decrease in farm revenues that would be caused by withdrawal of atrazine under the implausible assumption that corn yields would decline but corn prices would not change.[28] Yet the more sophisticated economic modeling of Mitchell (2011b), allowing prices to change, talks only about a different measure of economic benefit, the "consumer surplus" created by atrazine. While corn growers would be better off without atrazine, corn buyers—primarily the ethanol and livestock industries—would be worse off.

In short, according to the Atrazine Benefits Team's best modeling effort, the benefit of atrazine is that it allows lower corn prices, making corn growers worse off so that corn-using industries can benefit from cheaper purchases. Consumer goods, however, are only very slightly cheaper as a result. The impacts on consumers—the value to the public of the "consumer surplus" created by atrazine—turn out to be surprisingly small, as explained in Section 8.

8. Corn Without Atrazine: Who Wins and Who Loses?

According to the most detailed (but as we have seen, still flawed) analysis by Syngenta's Atrazine Benefits Team (Mitchell 2011b), elimination of atrazine would result in the production of 4.4 percent less corn. Yet the Syngenta analysis ignores those who would benefit from an atrazine-free future. If U.S. agriculture moved away from atrazine, the winners would include farmworkers, farmers and their families, and others who are exposed to atrazine either directly from field uses or indirectly from contaminated tap water, along with the natural ecosystems that are currently damaged by atrazine.

The winners would also include the nation's corn growers, whose revenues would, according to Syngenta's own analysis, be $1.7 billion greater without atrazine. Elimination of atrazine would lead to both a reduction of 4.4 percent in corn production and an 8.0 percent increase in corn prices, thus leaving farmers better off financially. The losers include the buyers of corn, primarily

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[27] This $1.7 billion revenue gain to corn growers is partially offset by small revenue decreases in the other crops analyzed by Mitchell, and by decreased payments under the Conservation Reserve Program (CRP), as some CRP land is pulled into corn production by the higher corn price. The gains in corn revenues, however, are much larger than these offsetting reductions. There is still a net increase of $1.4 billion in farm revenues from all ten crops combined (see appendix) plus CRP payments. (The decline in CRP payments, not shown in the appendix, is less than $50 million.) Similar but somewhat smaller results occur in Mitchell's scenario in which glyphosate use increases.

[28] In technical terms, this would imply infinite price elasticity, since a non-zero percent change in quantity would be associated with a zero change in price.

the ethanol and livestock industries. Paying 8 percent more for corn, these industries would have to raise their own prices, switch to other inputs, and/or reduce their own production.

The projection of an 8 percent corn price hike is undoubtedly too extreme. The Syngenta analyses overlooked many of the most attractive alternatives to atrazine, including the newest and most promising chemical alternatives and the wide range of non-chemical techniques for managing weeds and increasing yields. Pursuing these alternatives will be important in order to address the growing threat of atrazine resistance and to continue the development of non-toxic, sustainable agricultural techniques. With these alternatives, the reduction in corn output caused by elimination of atrazine should be less than Syngenta's projected 4.4 percent, and the price increase and other economic impacts should be correspondingly muted.

Suppose, however, that the Atrazine Benefits Team estimate is precisely correct, and that the end of atrazine causes a 4.4 percent slump in corn production and an 8.0 percent increase in price. The only losers from this change, aside from Syngenta itself, would be the corn-using industries—and to a lesser extent, their customers. What would happen if the producers of ethanol and beef, the top corn-using industries, had to pay 8 percent more for corn?

The importance of the ethanol industry is heavily dependent on federal and state policies that mandate or support ethanol use. Once touted as a sustainable, biomass-based alternative to petroleum products, ethanol has become increasingly controversial. Some environmental analysts now find that greenhouse gas emissions from the production of corn ethanol may be almost as great as the emissions from the equivalent petroleum-based fuels (Hill, et al. 2009).

If ethanol producers had to pay 8 percent more for corn, they would either produce less (if allowed by government policy) or raise their own prices. The price of corn is not the only cost of ethanol production; thus an 8 percent increase in corn prices should mean less than an 8 percent increase in ethanol costs. Consider, however, a worst-case scenario in which ethanol prices go up by 8 percent. Since ethanol is only a fraction of the fuel delivered to motor vehicles, the price rise at the gas pumps would be much smaller than 8 percent.

In 2011, ethanol made up 9 percent of the volume of gasoline consumed in the United States; the amounts vary by region, but in general do not exceed 10 percent by volume.[29] If ethanol makes up 10 percent of the fuel used by your car, then an 8 percent increase in the price of ethanol means a 0.8 percent increase in overall fuel price (assuming the costs of the other 90 percent of fuel are unchanged). At $4.00 per gallon, this would mean a fuel price increase of only $0.03 per gallon.

For the beef industry, corn is a major cost of production, but far from the only cost. A detailed academic study implies that a 1 percent increase in the price of corn leads to only a 0.165 percent increase in beef prices.[30] A very similar result is reached by a different, simpler route, which estimates the impacts of passing through corn price increases to beef consumers. Such an

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[29] U.S. Energy Information Administration, "Frequently Asked Questions," http://www.eia.gov/tools/faqs/faq.cfm?id=27&t=4, accessed April 2, 2013

[30] Marsh (2007) finds that a 1 percent increase in corn prices is associated with a 0.28 percent decrease in the quantity of cattle slaughtered, and that a 1 percent increase in cattle slaughtered is associated with a 0.59 percent decrease in the price of cattle. The effect of corn prices on cattle prices is equal to (-0.28)*(-0.59) = 0.165.

analysis implies that a 1 percent increase in the price of corn would cause a 0.174 percent rise in beef prices.[31] Both of these studies imply that a 1 percent increase in the price of corn causes about a 0.17 percent rise in the price of beef—roughly speaking, corn price changes are 6 times as large as beef price changes. The true impact could be even lower: another recent study finds, unexpectedly, that in the years since the adoption of the federal ethanol mandate (during which corn prices have risen significantly as discussed in Section 7), short-run changes in corn prices have had no impact on beef prices.[32]

To estimate the impact of an atrazine ban on consumers, assume that a 1 percent increase in corn prices implies a 0.17 percent increase in beef prices. Mitchell's projection that an atrazine ban would cause an 8 percent increase in corn prices then translates into a 1.4 percent increase in the retail price of beef. Ground beef that now sells for an average of $3.81 per pound[33] would increase to $3.86; the cost of a quarter-pound hamburger would rise by just over $0.01. Top-quality sirloin would rise from an average of $7.08 per pound[34] to $7.18; the cost of a half-pound entrée at a steakhouse would jump up by $0.05 (plus tax and tip). These price impacts appear to be too small to cause a noticeable change in beef consumption.

In short, the elimination of atrazine would improve human health and the natural environment in farming regions; prompt the development of more sustainable, less toxic agricultural practices; increase farm revenues; and have impacts on consumer prices measured in pennies. So where's the beef?

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[31] Leibtag (2008) calculates that a 50 percent jump in corn prices would raise beef prices by 8.7 percent, implying a beef price increase of (8.7/50) = 0.174 percent per percentage point increase in corn prices. His estimates of impacts on other corn-based foods are even smaller.

[32] Tejeda and Goodwin (2011).

[33] February 2013 U.S. city average, all uncooked ground beef, from U.S. Bureau of Labor Statistics, http://www.bls.gov/ro3/apmw.htm, accessed April 1, 2013.

[34] *Ibid.*, average price for choice sirloin.

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10. Appendix: Crop Revenues With and Without Atrazine

This table provides the data behind the calculation, discussed in the text, that farm revenues from the sale of corn would be higher without atrazine. All data and assumptions are taken directly from Mitchell (2011b), Tables 24 and 26.

	Prices (Mitchell 2011b Table 24)			Production (Mitchell 2011b Table 26)			Farm revenues (million 2009 dollars)		
	Baseline	No-atrazine scenarios		Baseline	No-atrazine scenarios		Baseline	No-atrazine scenarios	
Crop	with atrazine	Constant glyphosate	Increasing glyphosate	with atrazine	Constant glyphosate	Increasing glyphosate	with atrazine	Constant glyphosate	Increasing glyphosate
Barley	$3.95	$3.97	$3.97	248	247	247	$980	$981	$981
Corn	$3.75	$4.05	$3.99	14,505	13,862	13,975	$54,394	$56,141	$55,760
Cotton	$0.64	$0.63	$0.63	18,255	18,278	18,292	$5,608	$5,527	$5,532
Hay	$120.55	$120.42	$120.42	159	159	159	$19,167	$19,147	$19,147
Oats	$2.35	$2.37	$2.37	101	100	100	$237	$237	$237
Peanuts	$0.23	$0.23	$0.23	4,558	4,549	4,556	$1,048	$1,046	$1,048
Rice	$11.78	$11.74	$11.71	236	236	237	$2,780	$2,771	$2,775
Sorghum	$3.35	$4.01	$3.98	405	297	296	$1,357	$1,191	$1,178
Soybeans	$8.80	$8.79	$8.80	3,259	3,263	3,261	$28,679	$28,682	$28,697
Wheat	$5.45	$5.44	$5.43	2,301	2,304	2,305	$12,540	$12,534	$12,516
						Total	$126,791	$128,256	$127,870

Units for prices vary by crop (e.g. price per bushel for corn); in all but one case, production is in millions of the corresponding unit
For cotton, Mitchell reports prices per pound but mislabels them as prices per 480-pound bale; production is in thousand bales.
Mitchell presents three variants of each no-atrazine scenario, using differing tillage assumptions. Data shown here are for the moderate tillage assumption; results for the other assumptions are quite similar.