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Estimating Soil Erosion and Fuel Use Changes and Their Monetary Values with AGSIM: A Case Study for Triazine Herbicides

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Estimating Soil Erosion and Fuel Use Changes and Their Monetary Values with AGSIM: A Case Study for Triazine Herbicides

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Abstract

This technical report describes a method to use the AGSIM policy model to estimate changes in soil erosion and diesel fuel consumption for tillage that result from agricultural policy changes. This report uses triazine herbicides as a case study to explain the development of the method and illustrate its use.

The method assumes farmers shift their adoption of different tillage systems as a result of the agricultural policy being examined. Based on these shifts in tillage adoption rates, changes in farmer costs, erosion rates, and consumption of diesel fuel for tillage occur. The changes in farm costs are used as input by AGSIM, along with other changes in costs and/or yields due to the agricultural policy being examined. Based on these inputs, AGSIM then projects crop acreage and prices, as well as changes in consumer surplus, that would occur as a result of the policy. Based on projected crop acreage changes, the method estimates changes in soil erosion and consumption of diesel fuel for tillage, as well as the monetary value of soil erosion changes and the carbon dioxide emission changes resulting from the fuel use changes. As an illustration of the method, this report presents an updated assessment of the benefits of triazine herbicides to the U.S. economy.

For the base year of 2009, this assessment finds that **triazine herbicides provide total benefits to the U.S. economy of $3.8 to $4.8 billion per year.** Because the triazine herbicides increase the total supply of corn and sorghum, which decreases grain prices, most of these benefits accrue to consumers, especially the livestock and ethanol industries that are major users of corn. These consumer benefits are the sum of the benefits flowing to everyone along the supply chain – livestock farmers, processors and handlers, distributors, retailers, and final consumers. Triazine herbicides also reduce the use of tillage for crop production and the conversion of land to crop production, which reduces soil erosion from U.S. cropland by 56 to 85 million tons per year. Based on these reductions, **triazine herbicides provide $210 to $350 million per year in benefits from reduced soil erosion as part of this total benefit to the U.S.**

economy. In addition, **triazine herbicides reduce consumption of diesel fuel for tillage by 18 to 28 million gallons per year, implying a decrease in carbon dioxide emissions of 180,000 to 280,000 metric tons per year.**

This total benefit of \$3.8 to \$4.8 billion is a lower bound on the full value of triazine herbicides to the U.S. economy, because several benefits are not accounted for in this assessment. Among the most substantial benefits missing from this assessment are estimates of the resistance management benefits of triazine herbicides for other herbicides and crops, environmental benefits other than reduced soil erosion, and the benefits to crops not modeled by AGSIM (e.g., sweet corn, sugarcane, citrus, grapes, and other fruits and nuts).

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1.0 INTRODUCTION

AGSIM is a modeling system used to analyze effects of agricultural policy changes. Because agriculture contributes significantly to soil erosion and greenhouse gas emissions, a transparent and easy-to-implement method is developed to assess changes in soil erosion and diesel fuel consumption as part of the policy analysis provided by AGSIM. Triazine herbicides are used as a specific case study to illustrate these methods. This method of estimating changes in soil erosion is not intended as a complete substitute for more comprehensive and detailed models of soil erosion linked to agricultural supply and demand models (e.g., Larson et al. 2010). Rather, the methods described here are intended to be faster and easier to implement and more transparent, to serve as an initial assessment to indicate the likely magnitude of estimated soil erosion and fuel consumption changes if a more comprehensive analysis were conducted. The purpose of this report is to document and to explain the technical details of this method, using triazine herbicides as an example.

1.1 Overview of AGSIM

AGSIM is an econometric model of supply and demand for U.S. crop production that estimates changes in consumer surplus for different policy scenarios. Taylor (1993) provides a detailed description of AGSIM, but the model is regularly updated to examine new agricultural issues, with the most recent update occurring in 2009 to analyze biofuels policies (Taylor and Lacewell 2009a, 2009b, 2009c). AGSIM models supply and demand for ten major crops in the nine USDA Farm Resource Regions illustrated in Figure 1 (USDA-ERS 2000). AGSIM projects market prices, quantities produced and crop acreage after they have moved to a new equilibrium in response to policy scenarios developed by the user. Differences between scenarios estimate how each policy affects equilibrium prices and supplies for each crop, and from these results, impacts on consumer welfare are measured by changes in consumer surplus.

AGSIM has a long history, with the first version developed in 1977, and has been used to analyze a wide variety of agricultural policies, by both academics and government analysts (Taylor 1993). TECHSIM, an early predecessor of AGSIM, was used to examine the economics of pesticide bans and other pesticide regulatory issues (Osteen and Kuchler 1986, 1987; Osteen and Suguiyama 1988). Tauer (1989) used AGSIM to estimate the effects of possible future nitrogen fixation technology for crops and Tauer and Love (1989) used it for an ex ante assessment of the economic benefits of herbicide tolerant corn. Dinan et al. (1988, 1991) used AGSIM to analyze the impact of the Environmental Protection Agency's (EPA) environmental regulations more broadly. AGSIM's developer used it to examine aggregate economic impacts of federal commodity price supports (Taylor 1994), CRP lands returning to crop production (Taylor et al. 1994), and pesticide use reductions (Taylor et al. 1991). Carlson (1998) and Ribaudo and Hurley (1997) used AGSIM to estimate the economics effects of an atrazine ban. AGSIM was used by White et al. (1995) in their analysis of the economic benefits of areawide pest management and Szmedra (1997) used AGSIM to estimate the economic effects of bans of 2,4-D and phenoxy herbicides. The EPA has also used AGSIM to estimate the agricultural benefits and costs of air pollution regulation (US EPA 1997, 2002).

Analyzing agricultural policies with AGSIM requires specifying the effect of each policy on average per-acre yields and costs for each crop in each Farm Resource Region for each year. Given these yield and cost effects, AGSIM then determines national prices, quantities produced and crop acreage allocations for each crop in each region. Based on these results, AGSIM then determines consumer surplus by crop and by major end user.

Given its the long history of use by academics and by USDA and EPA analysts to estimate the impacts of various agricultural policies, AGSIM seems well-suited for estimating the benefits of triazine herbicides, the empirical application examined here. Furthermore, since a tradeoff exists between herbicides and tillage – growers can use either to control weeds – incorporating soil erosion and fuel consumption changes into the policy analysis capabilities of AGSIM to estimate the benefits of triazine herbicides seems particularly relevant.

1.2 Importance of Soil Erosion

Soil erosion is among the largest environmental impacts of U.S. crop production. Pimentel et al. (1992; 1995) finds that soil erosion costs U.S. society $44 billion annually, while similar costs for pesticides total $8 billion annually. Tegtmeier and Duffy (2004) also reach a similar conclusion – that soil erosion from U.S. agricultural production imposes greater costs on society than pesticide use. Beginning in the 1930s, the USDA began a more formal and concentrated effort to reduce soil erosion from U.S. farmland (Helms 1985). With passage of the 1985 Farm Bill, conservation compliance became a requirement for farmers receiving federal commodity support payments. Conservation compliance and the overall increased understanding of the benefits of reduced tillage have been an important part of the increase in farmer adoption of conservation tillage practices that has occurred over the last several years (Esseks and Kraft 1991, Claassen 2005; Knowler and Bradshaw 2007). The impact of these practices, along with farmer adoption of practices such as grassed waterways, contouring, strip cropping, and terracing, has been a large and continuous decline in aggregate measures of soil erosion from U.S. crop land – total soil erosion from U.S. cropland decreased 43% between 1982 and 2007 (USDA-NRCS 2010).

Weed control is a major problem in conservation tillage and no-till crop production systems (Buhler 1991, 1992; Gebhardt et al. 1985; Kroskinen and McWhorter 1986). As a result, herbicides are an important component of weed control in these reduced tillage systems, though evidence indicates that total herbicide use is generally no greater than for conventional tillage systems (Fuglie 1999). Atrazine has been and continues to be quite popular for weed control in corn and sorghum (Mitchell 2011) and thus an important part of reduced tillage systems for rotations including these crops. With the commercialization of herbicide tolerant crops, reduced tillage systems became even more economically viable, with the linkage between herbicide tolerant crops and reduced tillage examined by many (e.g., Young 2006; Frisvold et al. 2009; Givens et al. 2009; Fulton and Keyowski 1999; Ward et al. 2002; Fernandez-Cornejo and Caswell 2006; National Research Council 2010). However, glyphosate resistant weeds threaten current levels of conservation tillage and no-till adoption among corn, soybean, and cotton farmers (Davis et al. 2009; Foresman and Glasgow 2008, National Research Council 2010; Scott and VanGessel 2007). As a result, total soil erosion from U.S. cropland may begin to increase for the first time in almost 30 years (Marsh et al. 2006; USDA-NRCS 2010).

Given the environmental importance of soil erosion and the potential for changes in soil erosion as a result of agricultural policies affecting herbicide use, this economic assessment of the benefits of the triazine herbicides includes an estimate of the value of soil erosion reductions due to triazine use. The method used here projects changes in adoption of conventional tillage, conservation tillage and no-till for corn, sorghum, soybeans and cotton under various scenarios, as farmers adjust tillage practices to address growing problems with glyphosate resistant weeds. As a result, aggregate levels of soil erosion from cropland in the U.S. will increase, as will farmer costs of production and consumption of diesel fuel, due to more tillage passes on fields.

2.0 DATA AND METHODS

This section documents the modeling system developed and linked to AGSIM to estimate changes in soil erosion and the economic value of these changes. A key goal is to provide sufficient detail so that others can replicate the methods, as well as understand the assumptions used to develop the modeling system. Several sections follow, including descriptions of the policy scenarios and associated changes in yield and herbicide costs, as well as the shifts in tillage system adoption rates under the scenarios and the associated changes in tillage costs and diesel fuel use. Next follows a description of how changes in soil erosion are estimated for each policy scenario using the crop acreage allocations estimated by AGSIM and how dollar value estimates of the net benefit resulting from these soil erosion changes are calculated.

2.1 Description of Triazine Scenarios

To determine the consumer benefits and erosion reduction benefits of triazine herbicides in U.S. crop production, AGSIM requires careful definition of scenarios. To estimate the benefits generated by farmer use of triazine herbicides, scenarios are developed that estimate changes that would result if triazine herbicides were not available for use in corn and sorghum production. Specifically, a status quo baseline scenario and two non-triazine scenarios are defined and differences between these non-triazine scenarios and the status quo baseline indicate how the agricultural economy would change if either of the non-triazine scenarios were realized. These differences provide an estimate of the benefits of triazine herbicides.

This analysis uses 2009 as its base year. The status quo baseline scenario assumes no changes in current yield trends and production costs. The non-triazine scenarios impose yield and cost changes and then let markets and crop acreage allocations stabilize in response to these changes. Because glyphosate is the most widely used herbicide on corn in the U.S., applied to 75% of planted acres in 2009 (Mitchell 2011), if atrazine and simazine were not available for weed control in corn, an increase in the percentage of corn acres treated with glyphosate seems likely, but how much is unclear. To bracket the range of likely farmer responses, two non-triazine scenarios are defined for corn to reflect different assumptions regarding how much farmers increase glyphosate use on corn if triazine herbicides were not available.

The first non-triazine scenario, "increasing glyphosate use on corn acres," assumes that if atrazine and simazine were not available, farmers switch to using glyphosate as a substitute herbicide. As a result, corn acres treated with glyphosate increase, reaching 100% in all but one region. The second non-triazine scenario, "2009 glyphosate use on corn acres," assumes that, even if atrazine and simazine are not available for weed control in corn, farmers switch to non-triazine herbicides other than glyphosate as substitutes. As a result, the percent of corn acres treated with glyphosate equals the percent in 2009, but the percent of acres treated with other non-triazine herbicides increases. These two scenarios are intended to bracket the likely response of U.S. corn farmers if atrazine and simazine were not available. However, note that only a single non-triazine scenario is defined for sorghum, a scenario that assumes atrazine and propazine are not available for sorghum.

These non-triazine scenarios assume herbicide use does not change as a result of increases in herbicide resistant weeds. Furthermore, these scenarios assume farmers shift toward more intensive tillage as a substitute for herbicide-based weed control and to address increased problems with herbicide resistance, particularly glyphosate resistant weeds, not only in corn and sorghum, but also in soybeans and cotton. The data and methods for estimating this shift in tillage and the specific cost effects are described later in this document. Actual farmer responses in terms of herbicide use and tillage in corn if triazine herbicides were not available is likely somewhere between the two non-triazine scenarios for corn, so results are reported for both scenarios and interpreted as a range for the expected impact.

2.2 Yield and Herbicide Cost Changes

This AGSIM analysis uses the same yield and herbicide cost changes for corn and sorghum as Mitchell (2011), based on the work of Bridges (2011). In short, without triazine herbicides, corn and sorghum growers would have lower yields and experience small herbicide cost changes. Corn growers would suffer yield losses between 1.4% and 9.6% depending on the region (Table 1). Yield losses would be greater under the non-triazine scenario holding corn acres using glyphosate acres at the 2009 level because growers do not increase reliance on glyphosate, a relatively low cost and effective alternative. Sorghum growers would experience greater yield losses (more than 20%) because they have fewer herbicide alternatives to atrazine and propazine, and so would be forced to use less efficacious herbicides. In general, for both corn and sorghum growers, modeled herbicide cost changes would be less than $3/ac, with costs actually decreasing in some regions as growers switched to less expensive and/or less effective herbicides. Table 1 reports the yield and herbicide cost changes for corn and sorghum by region used for this AGSIM analysis. It is important to note that these yield loss and cost changes are averages, and so miss the range of effects that would be experienced by individual famers. Furthermore, these averages are spread over all corn and sorghum acres, not just those acres currently treated with triazine herbicides. Finally, these cost changes do not include costs for extra passes to apply herbicides, only the net change in the cost of herbicide active ingredients.

2.3 Tillage System Shifts

The connection between adoption of glyphosate-tolerant crops and reduced tillage systems is well established (Young 2006; Frisvold et al. 2009; Givens et al. 2009; Fulton and Keyowski 1999; Ward et al. 2002; Fernandez-Cornejo and Caswell 2006). However, atrazine and the other triazine herbicides are also important for weed control in reduced tillage systems, particularly in corn and for crops rotated with corn (Mitchell 2011). Furthermore, as problems with weeds resistant to glyphosate and other herbicides have developed and spread, academics and extension specialists have been emphasizing the importance of alternative modes of action (including triazine herbicides) to help delay development of herbicide resistance and to manage weeds resistant to other herbicides, though growers have been reluctant to adopt such practices (Givens et al. 2011; Wilson et al. 2011). Thus triazine herbicides also play a role in helping farmers adopt reduced tillage systems and this role will likely increase as problems with herbicide resistant weeds spread. Because increased adoption of reduced tillage systems are a key benefit of triazine herbicides, this analysis includes shifts in tillage system adoption for the non-triazine scenarios. This section describes the tillage system adoption data and projected shifts in tillage system adoption rates under the status quo and non-triazine scenarios to estimate the effect of these shifts on farm costs and aggregate soil erosion.

Annual tillage system adoption data by region from 1998 to 2009 (12 years) for corn, soybeans and cotton based on survey data were collected by GfK Kynetec (2010). No comparable data were available for sorghum. Collected data included the number of planted acres of each crop in conventional tillage, conservation tillage and no-till systems, where tillage system definitions follow standard classifications (Conservation Tillage Information Center 2010). Specifically, conventional tillage is any system having less than 15% of the soil surface covered with crop residue after planting; conservation tillage is any system having 15% to 30% of the soil surface covered with crop residue after planting, and finally, no-till is any tillage system leaving at least 30% of the soil surface covered with residue. Tables 2-4 report the annual acreage-weighted average adoption rate for each tillage system for corn, soybeans and cotton from 1998 to 2009 for the Farm Resource Regions examined in this analysis.

The data in Tables 2-4 show various trends and difference by crop and region. In general, adoption rates for no-till and conservation tillage systems are much higher for soybeans and much lower for cotton, with corn in the middle, but with adoption rates more like soybeans than cotton. Regionally, adoption of no-till and conservation tillage systems in corn is higher in the Prairie Gateway and Northern Great Plains than in the Heartland and Northern Crescent. This pattern generally holds for soybeans as well, except for the Northern Great Plains, which see high use of conventional tillage for soybeans. Finally, adoption rates for no-till in cotton are noticeably lower in the Prairie Gateway relative to other southern states in the combined Rest of Nation. In the most recent year, gains in no-till adoption among farmers over the last decade may be reversing in soybeans, with a subsequent increase in conventional tillage in many regions. Trends for the most recent year in corn are more mixed, with increases and decreases in most regions. Trends for recent years in cotton show a steady decrease in conventional tillage and increase in conservation tillage in the Prairie Gateway, but the reverse trend in the combined Rest of Nation.

This analysis uses the 2009 tillage adoption rates for each crop for the status quo scenario. Projected tillage adoption rates for both non-triazine scenarios assume that glyphosate resistant weeds become an expanding problem and accelerate under the non-triazine scenarios. Without atrazine as a residual herbicide option in corn and sorghum, among the effects would be a shift towards more intensive tillage by farmers to control weeds, especially in corn and sorghum, but also in soybeans and cotton, common rotational crops following corn and sorghum. Rather than develop an econometric model to project changes in tillage adoption rates, a simple approach is used based on a few assumptions.

The shift toward more intensive tillage is assumed to be greater for corn and sorghum than for soybeans and cotton, as triazine herbicides are not used on soybeans and cotton. Also, no-till corn and sorghum are assumed to be most reliant on triazine herbicides (as a pre-plant and early post-emergence herbicide with residual activity), and so are more affected compared to conservation and conventional tillage under the non-triazine scenarios. This larger effect on no-till adoption is assumed to occur for soybeans and cotton as well. However, famers will be reluctant to move towards higher tillage due to cost savings and generally good performance of reduced tillage systems. Thus, some no-till farmers would move to conservation tillage and some to conventional tillage and some using conservation tillage would begin to use conventional tillage. Separate adoption rates were not developed for the two non-triazine scenarios in this initial analysis. However, because the effect of the non-triazine scenarios on tillage system adoption rates are uncertain, three levels of tillage system shifts are assumed: a minor shift, the moderate shift and a substantial shift in tillage adoption rates.

Table 5 reports the tillage system shifts that would occur under a minor, a moderate and a substantial effect of the non-triazine scenarios on tillage system adoption rates. For example, the net effect for corn is that planted acres under no-till would decrease by 6.0 percentage points under a moderate shift, but by only 4.5 percentage points under a minor shift and 7.5 percentage points under a substantial shift. These tillage system adoption rates are the adoption rates that would have occurred in 2009 if triazine herbicides were not available. For example, the adoption rate for no-till corn in the Heartland will decrease from 24.3% of planted acres under the status quo scenario (Table 2) to 18.3% under the non-triazine scenarios assuming a moderate tillage system shift, a decrease of 6.0 percentage points as reported in Table 5. For other regions, the initial adoption rates differ, as reported in Table 2, but the shift of 6.0 percentage points as reported in Table 5 will be applied under a moderate shift. Table 6 reports the final tillage system adoption rates for each crop and region under the three levels of tillage system shifts.

The moderate tillage shift was chosen so that no-till adoption rates decreased to levels prevalent in 2000-2003. This tillage shift was then allocated so that slightly less than half of it went to a net increase in conservation tillage and slightly more than half went to a net increase in conventional tillage. The tillage system shifts for a minor effect and a substantial effect were chosen so that the no-till decrease was approximately 25% smaller and 25% larger than for the moderate shift, and then the shifts were allocated to increase conservation and conventional tillage as before. These assumptions imply that under the non-triazine scenarios, tillage system adoption rates would shift to levels generally similar to those prevailing less than ten years ago.

2.4 Tillage System Costs and Changes

Determining average costs for the three tillage systems (conventional, conservation and no-till) is difficult because farmers classified within the same tillage system use a wide variety of tillage implements. As a result, tillage systems are typically defined based on the proportion of the soil surface covered with crop residue remaining after all tillage operations are complete and the crop is planted (Conservation Tillage Information Center 2010). Because the tillage adoption data for this analysis are based on GfK Kynetec data, we use their tillage system definitions. Specifically, conventional tillage is any system having less than 15% of the soil surface covered with crop residue after planting; conservation tillage is any system having 15% to 30% of the soil surface covered with crop residue after planting, and finally, no-till is any system having more than 30% of the soil surface covered with crop residue after planting. Other organizations use different names for these categories, but generally keep the same definitions in terms of the percentage of crop residue remaining. For example, the Conservation Tillage Information Center (CTIC) uses “conventional tillage” for any system with less than 15% of crop residue remaining after planting, but uses “reduced tillage” for any system with 15% to 30% of crop residue remaining and “conservation tillage” for any system with more than 30% of crop residue remaining (Conservation Tillage Information Center 2010). This final CTIC “conservation tillage” group includes a variety of practices, including no-till, strip-till (both Midwest and Southeast versions), vertical tillage, fluffing harrows, ridge-till and mulch-till (Conservation Tillage Information Center 2010). Notice that both systems use the same percentages of residue remaining to define categories, but use different and conflicting terms for naming each category.

To estimate average costs for each tillage system, specific field operations are assigned for each system and then custom rates or budgeted cost estimates for these sets of field operations are obtained from several states. This method captures the essence of cost differences between tillage systems (conventional tillage costs more than conservation tillage which costs more than no-till) while maintaining some consistency across states, yet is easy to implement. By using common tillage implements for each system, cost estimates from several states can be developed. However, this system does not follow the standard tillage system definitions, which use the amount of residue remaining after planting (not the number of tillage passes), but the method captures the essence of the differences between the systems in terms of average costs and fuel use—less tillage implies lower costs and less fuel use.

The cost for conventional tillage in corn uses the per-acre cost for a chisel plow, plus a tandem disk and a field cultivator for corn following corn, but only the per-acre cost for a tandem disk plus a field cultivator for corn following soybeans (Duffy 2009). Thus on average, farmers make about two and a half tillage passes for conventional tillage corn, plus one more pass for planting, and the average custom rate for these machinery operations (including planting) is the estimated average cost of conventional tillage in each state. The cost for conservation tillage in corn uses the per-acre cost for a tandem disk for corn following corn and a field cultivator for corn following soybeans. The per-acre cost for strip tillage is also used when available, in which case then the average of the per-acre cost for a tandem disk, field cultivator and strip tillage is used as the cost estimate in that state. Thus on average, farmers make one tillage pass for conservation tillage, plus one more for planting. Finally, the per-acre cost for no-till planting is the only cost for no-till corn.

For the corn tillage cost estimates, custom rates for these tillage and planting operations are used for most states instead of crop budget costs because in many states, crop budgets were not available and in states with available budgets, the budgets did not report sufficiently detailed machinery costs to develop separate tillage costs (e.g., Schnitkey et al. 2010). Custom rates for the 2010 season were available from seven states, plus one state for the 2009 season and another for the 2008 season, while budgets were available for two other states in 2010 (Table 7). Based on these custom rates and cost estimates, Table 7 reports the calculated cost of each tillage system in these eleven states. Over these states, the average cost for tillage for corn is $41.82 per acre for conventional tillage, $25.24 for conservation tillage, and $15.14 for no-till (Table 8).

This process was repeated for soybeans in these same eleven states. The average cost for conventional tillage for soybeans was the per-acre cost for a chisel plow, plus a tandem disk and a field cultivator; soybeans following soybeans is essentially non-existent in the Midwest due to problems with diseases, so the average cost for this system was not included. The average cost for conservation tillage for soybeans was either the per-acre cost of a tandem disk, or the average of the per-acre cost for a tandem disk and strip tillage when available, plus the custom rate for planting. Finally, the cost for no-till for soybeans was the custom rate for no-till planting, either for drilled or no-till row planted soybeans, whichever was available in the state data. The average for drilled and row planted no-till soybeans was used for the few states reporting custom rates for both planting methods.

Again, custom rates for the 2010 season were available from seven states, plus one state for the 2009 season and another for the 2008 season, while budgets were available for two other states in 2010 (Table 7). Based on these budgets and custom rates, Table 8 reports the calculated cost of each tillage system in these eleven states. Over these states, the average cost for tillage for soybeans is $48.15 per acre for conventional tillage, $25.93 for conservation tillage, and $14.95 for no-till (Table 8). These costs are comparable to tillage costs for corn, except for conventional tillage soybeans, which are higher because all conventional tillage soybeans are assumed to follow corn and thus require additional tillage (here assumed to be a chisel plow), which is not the case for conventional tillage corn.

For cotton tillage systems, custom rate data were not as readily available as for corn and soybeans, but cotton crop enterprise budgets were available from nine states. These budgets differed greatly in terms of the tillage operations assumed for each state and in the detail provided regarding costs. For example, in Texas, 22 different cotton budgets were available for different tillage systems, as well as for both dryland and irrigated systems and for different genetic traits (Kaase 2008), while in Arkansas and Louisiana, only a single unique budget for conventional tillage cotton was available (Flanders et al. 2009; Guidry 2010). As examples of tillage operations, Texas cotton budgets report machinery costs for some of the following tillage operations in different budgets: chisel, V ripper, pull/ripper, moldboard plow, heavy disk, offset disc, tandem disc, lister, bedder, field cultivator, harrow, stalk cutter, shredder, shredder/flail, bedder, bedder/hipper and bedder/roller. Budgets for other states also list the following other tillage machinery operations: paratill, subsoiler bedder, row conditioner, ditcher, roller, seed bed finisher and cultimulch.

Given this diversity in tillage systems and implements, a table comparable to Table 7 for cotton was not constructed. Rather, budgets were classified into conventional and conservation tillage based on the number of tillage passes. For this analysis, the average tillage cost for conventional tillage cotton in a state was the average tillage cost for all budgets with four or more tillage passes before planting. The average tillage cost for conservation tillage cotton in a state was the average tillage cost for all budgets with two or three tillage passes before planting. Finally, the average tillage cost for no-till cotton was the average tillage cost for all budgets with one or no tillage passes before planting. Again, this classification system does not follow standard system definitions based on the amount of residue remaining after planting, but the classification captures the essence of the differences between these systems in terms of costs and fuel use—less tillage implies lower costs and less fuel use.

Table 9 reports the calculated costs for the three tillage systems for each state. Over these states, the average cost for tillage for cotton is \$26.26 per acre for conventional tillage, \$18.29 for conservation tillage, and \$11.38 for no-till (Table 9). Note that costs were not available for all three systems in each state. Also, note the variation in costs across states, which is greater than for corn and soybean tillage systems, and how tillage costs generally seem to increase when moving west across the Cotton Belt.

The basic geographic unit of analysis for AGSIM is the USDA Farm Resource Region (Figure 1). Thus the state-level cost data in Tables 8 and 9 were aggregated to the Farm Resource Region level by averaging over the states in each region for which cost data were available. Table 10 lists the specific states used for each region by crop. States that are partially contained in some Farm Resource Regions received less weight. For example, the tillage cost estimates for the Prairie Gateway for corn and soybeans uses the full tillage costs for Kansas, but only half the tillage costs for Nebraska because about half of the state of Nebraska is contained in the defined region (Figure 1). Thus the cost calculations in Table 10 are the cost for Kansas and half the cost for Nebraska, with the sum divided by 1.5; cost data for the other states in the Prairie Gateway were not available, and so were not used. Cost estimates for sorghum are the cost of tillage for corn in the Prairie Gateway, as that region accounts for well more than half of all sorghum planted in the U.S. The results in Table 10 reflect the cost data in Tables 8 and 9. Tillage costs for corn and soybeans are lower than average in the Heartland, Northern Great Plains and the Prairie Gateway, while tillage costs are higher than average for cotton in the Prairie Gateway.

The cost data by tillage system in Table 10 were combined with the tillage system adoption rates in Tables 2-4 for 2009 and tillage system shifts in Table 5 to determine the effect of the projected tillage system shifts under the non-triazine scenarios on the average cost of production for each crop. Specifically, using the tillage adoption rates derived from Tables 2-5 as weights, Table 11 reports the weighted-average cost of tillage by crop for the status quo and the non-triazine scenarios for the three levels of tillage shifts (minor, moderate and substantial) and the Farm Resource Regions analyzed here. Table 11 also reports the tillage cost difference between the status quo and non-triazine scenarios for each crop and region for each tillage shift.

The results in Table 11 indicate that the shift towards more intensive tillage if triazine herbicides were not available imply average cost increases ranging $0.95 to $1.39 per acre for corn under the moderate tillage shifts. These costs changes are about $0.25 to $0.35 per acre lower under a minor tillage shift and about $0.25 to $0.35 per acre higher under a substantial tillage shift. For soybeans, the cost increase under the moderate tillage shift is about $0.10 to $0.15 per acre lower than for corn, with the cost changes under a minor tillage shift and a substantial tillage shift also slightly smaller. For cotton, the cost increase is small for most regions, $0.32 to $0.50 per acre over the three assumed tillage shifts, but large in the Prairie Gateway, ranging from about $1.00 to $1.50 per acre over the same tillage shifts. By definition, tillage cost changes for sorghum are equivalent to those for corn in the Prairie Gateway.

For the AGSIM analysis of the two non-triazine scenarios (2009 glyphosate acres, increasing glyphosate acres), the tillage cost changes in Table 11 are added to the herbicide cost changes in Table 1. With two non-triazine scenarios (expanding glyphosate use on corn, 2009 glyphosate use on corn) and three tillage shifts (minor, moderate, substantial), AGSIM results are generated for six different non-triazine scenarios, with different yield and cost changes for each.

2.5 Estimating Soil Erosion with AGSIM

AGSIM was recently updated to examine various economic effects arising from ethanol and biodiesel production in the U.S. (Taylor and Lacewell 2009a, 2009b, 2009c). Among the additions to AGSIM was a method for estimating changes in soil erosion as a result of crop acreage shifts (Taylor and Lacewell 2009c). The analysis here uses this AGSIM capability to estimate changes in soil erosion if triazine herbicides were not available as an illustration. A few modifications are made to this capability as described here. In brief, AGSIM uses average soil erosion rates for each crop in each USDA Farm Resource Region to estimate changes in total soil erosion resulting from shifts in crop acreage allocations. The analysis here uses these same erosion rates, but updates the average erosion rates for corn, cotton, sorghum and soybeans based on projected changes in tillage practices under the status quo and non-triazine scenarios.

The National Nutrient Loss and Soil Carbon Database (Potter et al. 2004, 2006a, 2006b; Potter 2008) provides the fundamental data used to develop the crop- and region-specific average annual erosion rates used by AGSIM (Table 12). The database contains results for over a million simulation runs of EPIC (Williams et al. 1989; Williams 1995) for thousands of National Resource Inventory (NRI) (USDA-NRCS 2000) cropland data points across the U.S. to estimate nutrient losses and soil erosion from both wind and water. For each 1997 NRI cropland data point examined, EPIC simulations were conducted for a variety of nutrient management and tillage systems common in that region (Potter et al. 2009). For the AGSIM analysis, these erosion losses were averaged for each crop in each county, with weights for each tillage system based on state-level tillage system adoption rates in 2000. Separate estimates were maintained for cropland officially designated as highly erodible land (HEL) by the USDA. These crop-specific county estimates were then averaged to the Farm Resource Region level, weighting by the number of crop acres in each county. Thus the erosion rates reported in Table 12 are averages of the estimated annual erosion in 2000 for each crop in each Farm Resource Region, weighted by the acres in each tillage system (conventional, reduced and no-till).

2.5.1 Adjusting Average Erosion Rates for Tillage Shifts

The erosion rates used by AGSIM are based on tillage adoption patterns prevalent in 2000; however, tillage adoption patterns have been changing since that time (Tables 2-4).

Because shifts in tillage systems greatly affect rates of soil erosion, the annual average soil erosion rates reported in Table 12 are adjusted to reflect changes in tillage adoption rates.

The average erosion rates in Table 12 are the average erosion rates in 2000 for each crop derived from the National Nutrient Loss and Soil Carbon Database (Potter et al. 2009), weighted by the acres in each tillage system. Thus, for crop *i* on land type *l* in region *r* under scenario *s*, the annual average erosion rate (E_{ilrs}) is:

(1) $$E_{ilrs} = A_{irs}^{NO} E_{ilr}^{NO} + A_{irs}^{CS} E_{ilr}^{CS} + A_{irs}^{CV} E_{ilr}^{CV},$$

where A_{irs}^{t} and E_{ilr}^{t} are, respectively, the adoption rate (proportion) and erosion rate (tons/ac) for tillage system *t* (*t* = *NO* for no-till, *t* = *CS* for conservation tillage, and *t* = *CV* for conventional tillage) for crop *i* on land type *l* in region *r* under scenario *s*. For this analysis, the crops indexed by *i* include the ten crops listed in Table 12 (not including CRP or CRP as crop), the land types indexed by *l* are either not highly erodible land or highly erodible land, and the regions indexed by *r* include the nine USDA Farm Resource Regions also listed in Table 12. Note that the crop-, land type-, and region-specific erosion rate E_{ilr}^{t} does not have an index for the scenario *s*, as scenarios in this analysis only affect tillage adoption rates (A_{irs}^{t}), while the tillage adoption rate A_{irs}^{t} does not have an index for land type *l*, as this analysis assumes land type does not affect tillage adoption rates. However, the average erosion rate (E_{ilrs}) has an index for both scenario *s* and land type *l* because it depends on both the scenario-specific tillage adoption rates (A_{irs}^{t}) and the land type-specific erosion rate (E_{ilr}^{t}). Finally, $\sum_t A_{irs}^{t} = 1$, as all land must be in one of the three tillage systems. In brief, equation (1) implies that the average erosion rate for each crop on each land type in each region under each scenario is the average of the erosion rates for each tillage system, weighted by the adoption rate for each tillage system.

Next, following Fawcett (2007), the average erosion rate for each of the three tillage systems (E_{ilr}^{t}) is expressed as a percentage of the average erosion rate for tillage with a moldboard plow (E_{ilr}^{MP}). Specifically, based on Table 2 in Fawcett (2007), the erosion rate for no-till following soybeans is 3% of the erosion rate for a moldboard plow based system, or $E_{ir}^{NO} = F^{NO} E_{ir}^{MP}$, where the factor F^{NO} = 0.03. For conservation tillage, the average erosion rate following soybeans of the four systems reported by Fawcett (2007) using one or two tillage passes of a disk and/or a field cultivator is (43% + 36% + 15% + 11%)/4 = 26.25% of the erosion rate for a moldboard plow, or $E_{ir}^{CS} = F^{CS} E_{ir}^{MP}$, where the factor F^{CS} = 0.2625. Finally, for conventional tillage, the average erosion rate following soybeans of the three systems reported by Fawcett (2007) using a chisel plow or disk followed by a disk and/or a field cultivator is (57% + 82% + 65%)/3 = 68% of the erosion rate for a moldboard plow, or $E_{ir}^{CV} = F^{CV} E_{ir}^{MP}$, where the factor F^{CV} = 0.68. Notice that the factor F^{CV} implies that the "modern" conventional tillage system actually erodes at 68% of the moldboard plow erosion rate, the conventional tillage system during previous decades, showing the evolution and improvement in crop tillage.

Repeating this process for crops following corn, the factor for no-till is again F^{NO} = 0.03, but for conservation tillage the factor is F^{CS} = (16% + 11% + 7% + 4%)/4 = 0.095 and for conventional tillage, the factor is F^{CV} = (25% + 39% + 19%)/3 = 0.2767. Because corn creates more biomass per acre, more residue remains after a corn crop, and so erosion rates are lower. Thus the erosion rate for conservation tillage for a crop following corn is 9.5% of the moldboard erosion rate and 27.67% of the moldboard plow erosion rate for conventional tillage. Also note that the traditional definitions of tillage systems based on the proportion of the soil surface covered by crop residue (e.g., < 15% residue is conventional tillage: Conservation Tillage

Information Center 2010) are not strictly consistent with the systems as defined here. For example, based on Table 2 in Fawcett (2007), none of the tillage systems following corn achieve less than 15% of the soil surface covered with residue (i.e., conventional tillage according to the traditional definition), but rather all of them are no-till, as they maintain at least 30% of the soil surface covered with crop residue. This result occurs partly because of the greater residue production by corn, but also from not including factors such as overwinter decomposition, and the reduction in residue coverage due to planting (Kohl 1990). These factors also show the evolution and improvement of tillage systems towards less erosion.

Next, substitute these definitions ($E_{ilr}^{NO} = F^{NO} E_{ilr}^{MP}$, $E_{ilr}^{CS} = F^{CS} E_{ilr}^{MP}$, and $E_{ilr}^{CV} = F^{CV} E_{ilr}^{MP}$) into equation (1) and re-organize it:

$$(2) \qquad E_{ilrs} = \left(A_{irs}^{NO} F^{NO} + A_{irs}^{CS} F^{CS} + A_{irs}^{CV} F^{CV} \right) E_{ilr}^{MP} .$$

By rearranging equation (2), the erosion rates for moldboard plow tillage implied by the erosion rates in Table 12 can be calculated as:

$$(3) \qquad E_{ilr}^{MP} = E_{ilrs} / (F^{NO} A_{irs}^{NO} + F^{CS} A_{irs}^{CS} + F^{CV} A_{irs}^{CV}) .$$

For example, the average annual erosion rate for corn on non-highly erodible land in the Heartland in Table 12 is 3.25 tons/ac, and in 2000, adoption rates are 21.0% for no-till, 36.7% for conservation tillage and 42.4% for conventional tillage (Table 2). Using equation (3) and the factors F^{NO}, F^{CS}, and F^{CV} for crops following soybeans, these values imply an annual erosion rate for tillage using a moldboard plow of $8.27 = 3.25 / (0.03 \times 0.210 + 0.2625 \times 0.367 + 0.68 \times 0.424)$. Table 13 reports results by region using this process for corn, cotton, sorghum and soybeans.

For corn and sorghum in Table 13, the factors F^{NO}, F^{CS}, and F^{CV} for crops following soybeans are used, as corn commonly follow soybeans in the Corn Belt and sorghum commonly follows cotton in southern regions. However, for soybeans and cotton in Table 11, the factors

F^{NO}, F^{CS}, and F^{CV} for crops following corn are used, as soybeans commonly follow corn in the Corn Belt and cotton commonly follows either corn or sorghum in southern regions. Table 13 reports these implied erosion rates for tillage using a moldboard plow only for corn, cotton, soybeans and sorghum. Erosion rates for the other crops in Table 11 are assumed not to change and so are not reported.

The average annual erosion rates for these four crops for the 2009 status quo baseline and for the minor, moderate and substantial tillage system shifts assumed for the non-triazine scenarios can be calculated by substituting the implied moldboard plow erosion rates from Table 13 and the tillage adoption rates for these scenarios from Tables 2-4 into equation (2). Tables 14-17 report the resulting annual average erosion rates for these four crops on both types of land in all Farm Resource Regions for the 2009 status quo baseline and for the three levels of tillage shift assumed (minor, moderate and substantial). Note that average annual erosion rates in Table 11 for the other crops remain unchanged for these scenarios and so are not reported.

The results in Tables 14-17 imply that for corn, sorghum, cotton and soybeans, average erosion rates under the status quo 2009 baseline scenario decreased relative to average erosion rates in 2000 as reported in Table 11, from 8% to as much as 24%. The largest decreases occur in Prairie Gateway and Northern Great Plains regions and the smallest decreases occur in the Heartland. In this analysis, these decreases occur because of increased adoption of conservation and no-till systems between 2000 and 2009.

Under the non-triazine scenarios, erosion rates for all four crops increase relative to the 2009 status quo baseline, with the increase larger when moving from the minor to the moderate and to the substantial shift in tillage adoption rates. The largest increases in erosion rates generally occur in the Prairie Gateway and Northern Great Plains regions and the smallest generally in the Northern Crescent. Among the crops, the largest increases occur for sorghum and corn and the smallest in cotton. For the tillage adoption shifts, the erosion rates are 1 to 3 percentage points greater for the moderate tillage shift compared to the minor shift and again for the substantial tillage shift compared to the moderate shift. The increase for cotton is 1 percentage point, the increase for sorghum is 3 percentage points, the increase for soybeans is around 2 percentage points, and the increase for corn ranges 2 to 3 percentage points among the regions. Overall, among all crops, regions and tillage shifts, the range of increases is fairly small – the largest increase in erosion rates compared to the status quo baseline is 14.1% for corn (and sorghum) in the Prairie Gateway under the substantial shift in tillage adoption rates and the smallest is 3.3% for cotton in the Prairie Gateway under the minor shift in tillage adoption rates.

In summary, the results in Tables 14-17 imply that average annual erosion rates for corn, cotton, sorghum and soybeans will increase around 4% to 11% under the non-triazine scenarios relative to erosion rates under the 2009 status quo scenario, assuming the moderate shift in tillage adoption rates. If the shift in tillage adoption rates is larger, erosion rates will increase 5% to 14%, and if the tillage shift is smaller, erosion rates will increase 3% to 8%. These increases occur in this analysis because of the assumed shift towards more intensive tillage as a result of the accelerated spread of glyphosate resistance weed problems under the non-triazine scenarios, with the specific assumptions for the minor, moderate and substantial shift in tillage adoption rates as reported in Table 5.

2.5.2 Accounting for Land Type

The erosion rates in Tables 14-17 differ for highly erodible and non-highly erodible land, but AGSIM does not distinguish between these land types. In other words, AGSIM does not separately model acreage allocation for highly erodible and non-highly erodible land. More specifically, AGSIM estimates total acreage for each crop *i* in each region *r* under each scenario *s*: $AC_{irs} = \sum_{l} AC_{ilrs}$, but AGSIM does not estimate the individual AC_{ilrs}. Hence, a method is needed to apportion AGSIM estimates of AC_{irs} to the land type-specific allocations AC_{ilrs}.

The 2007 National Resources Inventory (USDA-NRCS 2010) reports total acres of highly erodible and non-highly erodible land in ten different state-based regions equivalent to the USDA Farm Production Regions (USDA-ERS 2000). Unfortunately, these regions are not consistent with the Farm Resource Regions used by AGSIM. The top half of Table 18 reports the total acres of both land types for these NRI regions and the associated percentages of the total crop acres of each land type. The bottom half of Table 18 reports how these NRI percentages were used to develop percentages to apportion total crop acres in each Farm Resource Region to highly erodible and non-highly erodible land. Because the region definitions do not exactly match, the apportionment between the NRI regions and Farm Resource Regions is approximate. The results in the bottom half of Table 18 show that for most regions, 20% to 30% of cropped acres are highly erodible land. The only exceptions are the Basin and Range with more than 60% of acres highly erodible and the Mississippi Portal with not even 7% of acres highly erodible.

Based on these results, if the AGSIM estimate of acres for crop *i* in region *r* under scenario *s* is AC_{irs}, then the estimate of acres for crop *i* on land type *l* in region *r* under scenario *s* is $AC_{ilrs} = W_{lr}AC_{irs}$, where W_{lr} is the percentage of crop acres of land type *l* in region *r* as reported in the bottom half of Table 18. For example, if AGSIM estimates 40 million acres of corn in the Heartland, then 30.38 million (76.7% of 40 million) are on non-highly erodible land and 9.32 million (23.3% of 40 million) are on highly erodible land. The average annual soil erosion rate for crop in a region is the average of the erosion rates for highly erodible and non-highly erodible land for that crop in that region, weighted by the percentage of land of each type in the region:

(4) $$E_{irs} = \sum_{l} W_{lr} E_{ilrs} = W_{non\text{-}HEL,r} E_{i,non\text{-}HEL,rs} + W_{HEL,r} E_{i,HEL,rs}.$$

In equation (4), the weights $W_{non\text{-}HEL,r}$ and $W_{HEL,r}$ are the respective percentages of non-highly erodible (non-HEL) and highly erodible (HEL) land from Table 18 for each region. Using barley in the Heartland as an example, Table 12 reports annual average erosion rates of 0.61 and 3.34 tons/ac for non-highly erodible and highly erodible land, respectively, and Table 18 reports 76.7% of the land in the Heartland is non-highly erodible and 23.3% is highly erodible. Based on equation (4), the average annual erosion rate for barley in the Heartland is 0.767 x 0.71 + 0.233 x 3.34 = 1.25 tons/ac as Table 19 reports.

Based on equation (4), the top part of Table 19 reports weighted average erosion rates by crop and region for the status quo baseline. For the calculations, erosion rates are from Table 12 for the first six crops and from Table 14 for corn, cotton, sorghum and soybeans, and the weights are the percentages of highly erodible and non-highly erodible land in Table 18. The bottom part of Table 19 reports the weighted average erosion rates for the three shifts in tillage adoption rates assumed for the non-triazine scenarios. Calculations use the same percentages as weights, but the erosion rates are from Tables 15-17 for corn, cotton, sorghum and soybeans.

For the four main regions examined here (Heartland, Northern Crescent, Northern Great Plains, Prairie Gateway), Table 19 shows generally higher erosion rates for crops in the Heartland and lower rates for crops in the Northern Great Plains. In terms of crops, corn is typically the most erosive, with soybeans and sorghum also having high erosion rates, while crops such as hay and cotton have low erosion rates. Also, as previously discussed, soil erosion rates increase when moving towards more intensive tillage as assumed for the tillage shift scenarios. Finally, Table 19 does not report weighted average erosion rates for non-cropped land in either a non-crop use (such as CRP) or when used as a crop, as these erosion rates are only for highly erodible land and are reported in Table 12.

2.5.3 Calculating Changes in Total Soil Erosion

Based on the annual average erosion rates in Table 19, the total erosion from U.S. cropland devoted to the ten AGSIM crops can be estimated for each scenario by multiplying these erosion rates by the acres allocated to each crop in each region:

$$E_{Cropland,s} = \sum_r \sum_i AC_{irs} E_{irs} \quad (5)$$

AC_{irs} is acres planted to crop i in region r under scenario s as reported by AGSIM and E_{irs} is the average erosion rate as reported in Table 19. The aggregate benefit of triazine herbicides in terms of erosion control can then be estimated as the difference in total erosion ($E_{Cropland,s}$) between the non-triazine scenarios and the status quo baseline. This calculation captures changes in aggregate soil erosion as a result of reallocating land among the ten crops for the scenarios, but equation (5) does not include erosion changes due to changes in total cropland acres or in acres enrolled in CRP. More specifically, because land in non-crop uses such as CRP is not included as a crop indexed by i, equation (5) does not estimate erosion from land in non-crop uses and in CRP, and so does not capture erosion changes from either of these land uses.

CRP acres and land converted from non-crop uses to crop production are likely highly erodible land, as such land is targeted for CRP enrollment or is currently in uses such as pasture and hence available for conversion. Thus, converting land of this sort to crop production increases the erosion rate at more than the average cropland erosion rate for each acre added to crop production. The same trends work in reverse as well—land taken out of crop production or enrolled into CRP generally is highly erodible land as it is less productive for crops and targeted for CRP enrollment, and thus will reduce soil erosion at more than the average erosion rate for each acre removed from crop production. The National Nutrient Loss and Soil Carbon Database estimates the more erosive nature of these lands. In Table 12, the erosion rates for "As Non-Crop" and "As Crop" are the respective average annual soil erosion rates for highly erodible land currently in non-crop uses (such as in CRP) and the same land if it were converted to crop production. The increases in erosion rates for converting this land to crop production are large. For example, the annual average erosion rate is 1.27 tons/ac for CRP acres in the Heartland, but 20.40 tons/ac for the same land if used for crop production.

The "As Non-Crop" and "As Crop" erosion rates in Table 12 are used to adjust the aggregate soil erosion estimates from cropland to capture the effects of using highly erodible land for crop production, or removing such land from crop production. The assumption is that when land is brought out of CRP or other non-crop uses and into crop production, the erosion rate is much higher than the average erosion rate for the crop, because the land is typically highly erodible. Hence, land converted to crop production is assumed to have been eroding at the "As Non-Crop" rate in Table 12 and to begin eroding at the "As Crop" rate in Table 12, while the reverse occurs for land removed from crop production and converted to CRP or non-crop uses.

Based on these assumptions, calculating the effects of changes in CRP acres and total crop acres requires multiplying the net change in CRP acres and in total crop acres by the net change in the erosion rate. First, the calculations to adjust for changes in CRP acres are presented, and then the calculations to adjust for changes in total crop acres are presented.

Define the net change in CRP acres for scenario *s* relative to scenario *u* in region *r* as $\Delta AC_{CRP,r,u\ to\ s} = AC_{CRP,rs} - AC_{CRP,ru}$. Increases in CRP acres imply decreases in crop acres and vice versa (i.e., acres removed from CRP are assumed to be put into crop production, not pasture, and acres enrolled in CRP are assumed to be from crop land, not pasture). As a result, the net change in crop acres from scenario *u* to scenario *s* as a result of the net change in CRP acres in region *r* is $-\Delta AC_{CRP,r,u\ to\ s}$. Note that $\Delta AC_{CRP,r,u\ to\ s}$ does not include an index for land type *l*, as the land is assumed to be highly erodible. Next, define the net increase in the erosion rate when converting land from CRP to crop production in region *r* as $\Delta E_{CRP,r} = E_{As\ Crop,r} - E_{As\ Non-Crop,r}$, which is the difference between the average erosion rates for "As Crop" and "As Non-Crop" in Table 12 for region *r*. Based on these definitions, the net increase in soil erosion as a result of changes in CRP acres for scenario *s* relative to scenario *u* is

(6) $$E_{\Delta CRP\ Adjustment,s} = \sum_r -\Delta AC_{CRP,r,u\ to\ s}\Delta E_{CRP,r}\ .$$

Equation (6) uses the net change in cropped acres ($-\Delta AC_{CRP,r,u\ to\ s}$), not the net change in CRP acres ($\Delta AC_{CRP,r,u\ to\ s}$), because the erosion rate change is defined as the change when converting to crop acres, not to CRP acres, and the net change in cropped acres is opposite the net change in CRP acres.

The process is similar to adjust estimated total erosion for changes in total crop acres. Define the net increase in cropland acres (not including CRP acres) for each region *r* for scenario *s* relative to scenario *u* as $\Delta AC_{crop,r,u\ to\ s} = AC_{crop,rs} - AC_{crop,ru}$, where $AC_{crop,rs} = \sum_i AC_{irs}$ is total cropped acres in region *r* under scenario *s* and $AC_{crop,rt} = \sum_i AC_{iru}$ is total cropped acres in region *r* under scenario *u*. Based on this definition, the net increase in soil erosion for scenario *s* relative to scenario *u* as a result of changes in total cropped acres (not including CRP acres) is

(7) $$E_{\Delta Acres\ Adjustment,u\ to\ s} = \sum_r \Delta AC_{crop,r,u\ to\ s}\Delta E_{CRP,r}\ .$$

Equation (7) uses the same erosion rate change ($\Delta E_{CRP,r}$) as equation (6) because land converted from a non-crop use to crop production is assumed to be highly erodible land that had been eroding at the same rate as land in CRP.

Based on equations (6) and (7), the total change in aggregate erosion from cropland for scenario *s* relative to scenario *u* is

(8) $$\Delta E_{u\ to\ s}^{total} = E_{Cropland,s} - E_{Cropland,u} + E_{\Delta CRP\ Adjustment,u\ to\ s} + E_{\Delta Acres\ Adjustment,u\ to\ s}.$$

Equation (8) adjusts the difference in total erosion from cropland under scenarios *s* and *u* to account for the highly erodible nature of land converted between crop production and CRP or non-crop uses. For this analysis, scenario *u* is the status quo scenario and scenario *s* is one of the non-triazine scenarios. Thus, equation (8) estimates the net change in soil erosion that would occur if triazine herbicides were not available under the assumptions of scenario *s,* thus providing a measure of the soil erosion benefit of the triazine herbicides.

2.6 Economic Value of Soil Erosion Changes

This section describes the method used to derive region-specific estimates of the value of a one ton change in aggregate soil erosion. The primary source is the data provided by Hansen and Ribaudo (2008), who developed per-ton estimates of these values for use in assessing soil conservation benefits in the U.S. They developed estimates of the per-ton costs of soil erosion for all counties in the contiguous 48 states for 14 different types of benefits from soil conservation – twelve for the value of water quality improvements, one for the value of reduced household dust cleaning, and one for the value of enhanced soil productivity. The types of water quality values include less sediment in reservoirs, improved navigation for inland and coastal shipping, cleaner water for recreation, reduced costs for cleaning irrigation and road ditches and channels, less flood damage, lower costs for municipal water treatment, and improved marine and freshwater fisheries. Hansen and Ribaudo (2008) also explain their methods and some weaknesses of their benefit estimates, emphasizing the types of benefits that are missing and so, they describe their values as a lower-bound estimate of the public willingness to pay for reduction in soil erosion and the associated improved environmental quality. They also emphasize that their estimates are appropriate for regional and national level analysis, not for smaller scale assessments. Furthermore, they provide specific equations for aggregating their county values to the USDA Farm Resource Region, the same unit of analysis used by AGSIM, so that their estimates are particularly well suited for estimating the value of the soil erosion benefits of triazine herbicides using AGSIM.

Following links reported in Hansen and Ribaudo (2008), county-level data were downloaded and aggregated to the Farm Resource Region level using the equations reported by Hansen and Ribaudo (2008). Next, these values were adjusted for inflation using the consumer price index to convert from Hansen and Ribaudo's (2008) base year of 2000 to equivalent values in 2009 (Bureau of Labor Statistics 2010). Table 20 reports specific measures for the three types of values – for water quality, for reduced dust cleaning, and for enhanced soil productivity – for each Farm Resource Region. The water quality values are the value of a change of one ton per acre in soil erosion from water (sheet and rill). The values for reduced dust cleaning are for a change of one ton per acre in soil erosion from wind. Finally, the productivity values are the value of a one ton change in total soil erosion (both wind and water) due to changes in land productivity for crops. Based on these values, in the Heartland, a reduction in water erosion is worth $4.86/ton as a result of water quality improvements, a reduction in wind erosion is worth

$0.09/ton as a result of reduced dust cleaning, and a reduction in total erosion (both wind and water) is worth $1.21/ton as a result of enhanced soil productivity.

To apply the per-ton values in Table 20, the total erosion estimates for each region must be separated into water erosion and wind erosion. This apportionment is based on the water and wind erosion estimates reported by Potter et al. (2006a), who report total erosion for seven regions (e.g., Potter et al 2006a, p. 4). Table 21 reports total wind and water erosion for these regions and how they were apportioned to Farm Resource Regions to estimate the proportion of total erosion in each region that is wind and water. These apportionments are not meant to estimate total water and wind erosion in each Farm Resource Region, but rather to approximate the proportion of total erosion from each source. Finally, because the region definitions do not exactly match, the apportionment between the NRI regions and Farm Resource Regions is approximate. The results in Table 21 show that in most regions, water erosion is by far the dominant cause of soil erosion from cropland, except for the Northern Great Plains and the Prairie Gateway, where wind erosion dominates.

Based on the percentages in Table 21 and the values in Table 20, a weighted value ($/ton) of eroded soil can be determined for each Farm Resource Region. Specifically, if $\Delta E^{total}_{r,s\ to\ u}$ is the change in total erosion in region *r* in tons per year for scenario *s* relative to scenario *u*, then the monetary value of this erosion change to society (or cost if $\Delta E^{total}_{r,s\ to\ u} < 0$) is:

$$B_{r,s\ to\ u} = B^{WaterQ}_{r} W^{water}_{r} \Delta E^{total}_{r,s\ to\ u} + B^{DustCl}_{r} W^{wind}_{r} \Delta E^{total}_{r,s\ to\ u} + B^{SoilP}_{r} W^{total}_{r} \Delta E^{total}_{r,s\ to\ u}\,. \tag{9}$$

$B^{v}_{r,s\ vs\ t}$ is the per-ton benefit in region *r* as reported in Table 20 for value *v* = (*WaterQ*, *DustCl*, *SoilP*) for water quality, dust cleaning and soil productivity. W^{e}_{r} is the percentage of total erosion in region *r* as reported in Table 21 for erosion type *e* = (*water*, *wind*, *total*) for water erosion, wind erosion and total (water plus wind) erosion (W_r^{total} = 100%). The weighted values reported in the final column of Table 20 were calculated for each region using equation (9). Conceptually, these weighted values measure the benefit to society for reducing soil erosion by one ton in each region, or equivalently, the cost of increasing soil erosion by one ton.

Based on the weighted values in Table 20, erosion is substantially more costly in the Northern Crescent than elsewhere ($12.06/ton). Examining the individual erosion control benefits (not reported) in the region, water recreation is the largest contributor, which is much larger for this region than for any other region, and the value of soil productivity is also largest in this region as well. On the other extreme, reducing erosion in the Prairie Gateway is not particularly beneficial (nor is increasing erosion costly) to society, with a value of only $1.29/ton of eroded soil. This low value occurs in the Prairie Gateway because most of the erosion in the region is wind erosion, which is not particularly costly relative to water erosion.

Hansen and Ribaudo (2008) explain how their values are lower bounds on the public willingness to pay for soil erosion reductions, as several types of benefits are not included. They also describe various weaknesses inherent in their estimates. Nevertheless, their values are useful as a method to estimate the benefits of reduced soil erosion, or conversely, the cost of increased soil erosion, between the 2009 status quo and non-triazine scenarios. These values provide a metric to put these benefits/cost into the same units as other measures of value, such as consumer and producer surplus.

The per-ton values of soil erosion in Table 20 are consistent with other values that can be derived from the work of Tegtmeier and Duffy (2004) and Pimentel et al. (1995), lending further credence to their validity. Tegtmeier and Duffy (2004) estimate that the external or offsite costs of soil erosion in the U.S. range from $2.243 to $13.395 billion annually. They cite the USDA-

NRCS (2000) estimate of 969 million Mg of soil eroded by water from cropland and CRP land in 1997. Together, these numbers imply an average annual cost of $2.31 to $13.82/Mg in 2002 dollars for water-eroded soil. After adjusting for inflation to 2009 dollars (Bureau of Labor Statistics 2010), the cost ranges from $2.76 to $16.48/Mg, with the simple average of this range equal to $9.62/Mg. Converting these values to a per-ton basis gives a range of $2.50 to $14.95/ton and a simple average of $8.73/ton, which is consistent with the values reported in Table 20. Also, note that the erosion costs of Tegtmeier and Duffy (2004) do not include soil erosion from rangeland or pasture, only cropland, and do not include costs for wind erosion, human health impacts or productivity losses.

Pimentel et al. (1995) estimate that annual off-site costs of eroded soil were $17.0 billion in 1992 dollars, with $9.6 billion from wind erosion and $7.4 billion from water erosion. Adjusting these average costs for inflation from 1992 to 2009 dollars gives $14.7 billion in damage from water-eroded soil and $11.3 billion in damage from wind-eroded soil, for $26.0 billion in total off-site costs from soil erosion (Bureau of Labor Statistics 2010). Dividing total damage estimates by the estimated amount of erosion is problematic using the numbers reported in Pimentel et al. (1995), as some of the reported aggregate erosion values and land areas are inconsistent.[1] However, based on USDA (1989) estimates for 1982 (a reference cited by Pimentel et al. (1995)), there were 170.6 million ha of cropland and 54.0 million ha of pasture, with 1.843 billion Mg of soil eroded by water and 1.249 billion Mg by wind from cropland and 0.180 billion Mg eroded by water from pasture and none by wind, for a total loss of 3.272 billion

[1] For example, Pimentel et al. (1995) report (p. 1120) 4 billion Mg of soil eroded annually in the U.S. from 160 million ha of cropland, which implies an average annual loss rate of 4 billion Mg/160 million ha = 25 Mg/ha, which is not consistent with the annual average loss rate of 17 Mg/ha stated several times in the text. Pimentel et al. (1995) also report that "the total cost of erosion from agriculture in the United States is about $44 billion per year, … or about $100 per hectare of cropland and pasture" (p. 1121), which implies a total of about 440 million ha of cropland and pasture in the U.S., which greatly exceeds the 224.6 million ha of cropland and pasture reported by the USDA (1989) in the assessment of soil erosion in the U.S. in 1982 that Pimentel et al. (1995) cite. For additional issues, see Crosson (1995) and Trimble (2007).

Mg of soil eroded by wind and water from cropland and pasture in 1982 (USDA 1989, p. 26). Dividing the estimated costs of soil erosion (adjusted to 2009 dollars) by this aggregate soil loss estimates gives a total cost of $7.95/Mg for all soil erode from cropland and pasture by wind and water. Converting to a per-ton basis gives a cost of $7.21/ton, which is comparable to the value derived for Tegtmeier and Duffy (2004) and the values reported in Table 20. Also note that, like Tegtmeier and Duffy (2004), this estimate does not include the cost of lost soil productivity.

The simple average of the weighted values in Table 20 is $5.54/ton, which is lower than the estimates of Tegtmeier and Duffy (2004) ($8.73/ton) and Pimentel et al. (1995) ($7.21/ton) after adjusting all values to equivalent 2009 dollars. These comparisons lend credence to Hansen and Ribaudo's (2008) assessment that their values are indeed lower bounds. The analysis here of the erosion benefits of triazine herbicides will use the weighted values in Table 20, based on Hansen and Ribaudo (2008), but also report in the text the value of these erosion benefits using values based on Tegtmeier and Duffy (2004) and Pimentel et al. (1995).

2.7 Tillage System Fuel Use and Changes

Estimates of diesel fuel use for tillage are developed for the three tillage systems (conventional tillage, conservation tillage and no till) for the following nine crops modeled by AGSIM: barley, corn, cotton, oats, peanuts, rice, sorghum, soybeans and wheat. Estimates of fuel use for tillage were not developed for hay or land enrolled in the Conservation Reserve Program (CRP), as tillage is minor for these crops. These fuel use estimates were then used to determine changes in total fuel use implied by the shifts in tillage system adoption rates and crop acreage for the non-triazine scenarios.

The USDA-NRCS's tool "Energy Estimator: Tillage" (USDA-NRCS 2007b) serves as the primary data source for estimates of diesel fuel use for tillage. This online tool provides estimates of fuel use for tillage by tillage system for major crops in 74 different crop management zones (Figure 2). These estimates are based on the fuel use estimates for specific field machinery operations as reported by Downes and Hansen (1998). Users enter a zip code to determine the crop management zone for that location, and then enter acreage for each crop grown. The tool then reports an estimate of the total diesel fuel use for tillage for each crop for different tillage systems. All locations in a crop management zone have the same estimated fuel use for each crop and tillage system, regardless of the location within the zone.

Crops in each crop management zone are pre-determined by the tool. For example, in crop management zone 4 stretching across the heart of the Corn Belt, the pre-determined crops are corn, oats, soybeans, sugar beets and wheat. Other zones have different pre-determined crops. For tillage systems, the tool defines conventional tillage, mulch till, ridge till, strip till, and no-till each crop. However, fuel use is only reported for some of these tillage systems. For example, in crop management zone 4, fuel use for corn is reported only for conventional tillage, mulch till, ridge till, and no till, but not for strip till. However, for wheat in crop management zone 5 in the western Great Plains, the tool only reports fuel use for mulch till and no till. All locations in a crop management zone have the same pre-determined crops and pre-defined tillage systems, and the tool reports the same estimated fuel use for each crop and tillage system, regardless of the location within the zone.

For each crop management zone, the estimated fuel use was obtained for each AGSIM crop included in the list of pre-determined crops for each pre-defined tillage system. For zones reporting fuel use estimates only for either mulch till or strip till, this single value was considered conservation tillage for this analysis. For zones reporting fuel use for both mulch till and strip till, the average of these two values was considered conservation tillage for this analysis.

To develop fuel use estimates for each crop in each farm resource region, these fuel use estimates for the crop management zone were averaged to the farm resource region level, using county-level planted acres for each crop in 2009 as a weight (USDA-NASS 2011). Crop management zones generally follow county lines, except that in many western states, several counties have parts contained in two or more crop management zones. For counties contained in more than one crop management zone, 2009 planted acres were divided equally among all crop management zones contained in the county when calculating the weighted average. Thus the estimated fuel use for tillage in each farm resource region is the average of the fuel use for all crop management zones contained in each farm resource region, using the 2009 planted acres of the crop planted in each zone to weight the average. For example, suppose a farm resource region had 10 million acres of corn planted within it in 2009, with 3 million acres in crop management zone A and 7 million in crop management zone B. If zone A has a fuel use of 2 gallons per acre and zone B has a fuel use of 4 gallons per acre for conservation tillage, then the acreage-weighted average fuel use for corn in this farm resource region is $0.3 \times 2 + 0.7 \times 4 = 3.4$ gallons per acre for conservation tillage.

Table 22 reports the resulting average diesel fuel use for tillage for each crop and tillage system in each farm resource region. Averages are not reported if AGSIM does not model acreage of that crop in that region (e.g., barley in the Mississippi Portal). As expected, conservation tillage uses less fuel than conventional tillage and no-till uses less fuel than conservation tillage. In general, estimated fuel use is fairly similar across regions and crops for each tillage system. However, differences among crops are apparent, with cotton, peanuts and rice generally using more fuel for tillage than other crops. Regional differences also exist, with the Fruitful Rim and the Basin and Range often using more fuel for tillage than other regions.

Averaging the diesel fuel use rates in Table 22 using the tillage system adoption rates as weights gives the average use of diesel fuel for tillage for each crop. Changing the tillage system adoption rates then changes this average fuel consumption for a crop. For example, for corn in the Heartland, the fuel use rates are 2.77, 3.60, and 4.98 gallons of diesel per acre for tillage for no till, conservation tillage, and conventional tillage (Table 22) and the tillage adoption rates under the baseline are 24.3%, 38.9%, and 36.8% for no till, conservation tillage, and conventional tillage (Table 2). Thus, the average fuel use rate for tillage for corn in the Heartland, weighted by the tillage system adoption rates, is (2.77 x 0.243) + (3.60 x 0.389) + (4.98 x 0.368) = 3.91 gallons per acre. The tillage system adoption rates for corn, soybeans and cotton in 2009 Tables 2-4 are used for the baseline for these crops, the tillage system adoption rates in Table 6 for the non-triazine scenarios to calculate weighted average fuels use rates for the non-triazine scenarios. For sorghum, tillage adoption rates for corn are used. For the other crops (barley, oats, peanuts, rice, and wheat), the simple average of the diesel fuel use rates in Table 22 are used, which is equivalent to assuming that tillage system adoption rates are equal (i.e., 33.3% in each tillage system).

Table 23 reports the resulting weighted average diesel fuel use for tillage for each crop in each farm resource region for all scenarios. Because no tillage system shifts occur for barley, oats, peanuts, rice and wheat, diesel use rates do not vary from the 2009 baseline for these crops under the non-triazine scenarios. Because farmers shift towards more intensive tillage, the average diesel fuel use rates increase relative to the baseline, with the greatest increase for the substantial shift in tillage. The same patterns evident in Table 22 remain as well, with higher fuel use for some crops (cotton, peanuts, rice) and in some regions (Fruitful Rim, Basin and Range).

Multiplying the average diesel fuel use rates in Table 23 by the acreages for each crop for the baseline and as projected by AGSIM for each non-triazine scenario gives the total diesel fuel use for tillage under each scenario. The difference between total fuel use under each non-triazine scenario and the baseline then is the net increase in diesel fuel used for tillage for each non-triazine scenario. This increase in fuel use can be converted to the net increase in carbon dioxide emissions using the EPA conversion factor of 10.084 g of CO_2 per gallon of diesel (US EPA 2005). Note that these calculations only estimate the net increase in CO_2 emissions due to increased fuel use for tillage under the non-triazine scenarios and do not capture CO_2 emissions due to reduced carbon sequestration in agricultural soils as a result of increased tillage and associated soil erosion (e.g., Lal 2004; Lal and Pimentel 2008; Van Oost et al. 2007).

3.0 RESULTS

The next several sections report AGSIM results for these non-triazine scenarios to illustrate the type of output generated. The yield and cost changes in Table 1 and the tillage cost changes in Table 11 were imposed in the AGSIM model and then the effects on crop prices, acreage, total production, and consumer surplus are projected by AGSIM. Based on the acreage changes projected by AGSIM, the estimated increase in total soil erosion was calculated for each non-triazine scenario using the erosion rates in Table 19 and the social cost of these erosion increases calculated using the values in Table 20. In addition, based on the acreage changes projected by AGSIM, the estimated increase in diesel fuel use for tillage for each non-triazine scenario was calculated using the fuel use rates in Table 23. This analysis illustrates these new capabilities of AGSIM, using estimation of the benefits of triazine herbicides as a case study.

3.1 Price, Acreage, and Production Effects of Triazine Herbicides

Table 24 shows that, relative to the 2009 baseline, the non-triazine scenarios imply noticeably higher prices for corn and sorghum: \$0.24 to \$0.30/bu for corn and \$0.62 to \$0.66/bu for sorghum, which represent a 7%-8% increase for corn and a 19%-20% increase for sorghum. All other projected crop price changes for the non-triazine scenarios are typically small, less than 1% relative to the baseline. The largest relative increases are for oats and barley, while the largest relative decrease is for rice, but in general these price changes are minor. Across the scenarios, price changes are larger for the non-triazine scenario in which the use of glyphosate on corn is held at 2009 levels. As a scenario that imposes more restrictions on farmer responses, this result is not surprising. Price changes vary little across the tillage shift scenarios (minor, moderate, substantial), implying that the small increases in the cost of production under these scenarios had little effect on market prices. Based on these results in Table 24, a benefit of triazine herbicides is lower crop prices, especially for corn and sorghum; the value of these lower prices is examined in Table 27.

Table 25 reports the crop acreage changes for all non-triazine scenarios relative to the 2009 baseline. Given the corn yield decreases in Table 1 and the price increases in Table 24, farmers expand corn by about one million acres, or about 1%. Even with much higher sorghum prices, sorghum acres decrease by almost half a million acres (about 6%), because the yield decrease in Table 1 is so large that it becomes less profitable than other crops for many farmers. The other major acreage shift is for CRP acres, which decrease about 610,000 to 880,000 acres (about 2%) for the U.S. as a whole. Wheat acres also increase, about 160,000 to 180,000 acres (less than 0.5%). Across the scenarios, acreage shifts are larger for the non-triazine scenario in which the use of glyphosate on corn is not allowed to expand, because this scenario imposes more restrictions on farmer responses. Acreage changes vary little across the tillage shift scenarios, implying that the small increases in the cost of production under these scenarios had little effect on farmer acreage allocations.

In Table 25, the acreage shift from sorghum and CRP essentially equals the acreage shift to corn and wheat; acreage shifts for the other crops are minor in comparison. In general, results show that land more marginal for corn production (land currently in CRP and/or planted to sorghum) would be converted to corn as a result of the higher corn prices that would result without triazine herbicides, with some reallocation of acres from oats and barley to wheat. Thus a benefit of triazine herbicides is that they promote more diverse crop planting—less acres devoted to corn and more acres in sorghum and non-crop uses such as CRP. Tables 28-30 examine the soil erosion implications of these acreage shifts.

Table 26 reports the total production of each crop for each non-triazine scenario. For most crops, the difference between total production for each non-triazine scenario and the baseline is less than 1%. The two largest effects are a decrease in total sorghum production of about 27% and a decrease in total corn production of about 4%. The large decrease for sorghum occurs because sorghum planted acres and yield both decrease. For corn, per-acre yields decrease around 5% to 6% (Table 1) and corn planted acres increase about 1% (Table 24). Because total corn production decreases about 4%, the effect of the yield decrease dominates the effect of the acreage expansion.

3.2 Consumer Benefits of Triazine Herbicides

Table 27 reports the total change in consumer surplus for each non-triazine scenario relative to the 2009 baseline, as well as the incidence of these changes—both by crop for all end users and by end user for all crops. The total change is a loss to consumers of $3.6 billion to

$4.4 billion per year depending on the assumptions regarding the expansion of glyphosate use in corn and the extent of the tillage shift. Thus, at the aggregate level, triazine herbicides increase consumer surplus from $3.6 to $4.4 billion per year by contributing to lower crop prices. The crop specific and end-user specific changes in Table 27 show which types of consumers derive these benefits from lower crop prices as a benefit of triazine herbicides.

Among the crops, by far the largest benefit of triazine herbicides is for corn consumers ($3.5 to $4.3 billion per year), which is not surprising, as the quantity of corn produced annually in the U.S. dwarfs the other grains and the corn price changes were relatively large. The next largest consumer benefit is for sorghum consumers, at about $225 million per year. The effects of triazine herbicides on other crop consumers are relatively minor.

Among end users, the benefits of triazine herbicides mostly flow to those using large amounts of corn – the livestock and ethanol industries. The livestock industry, largely consisting of beef, hogs, dairy and poultry/eggs, derives the greatest benefit from the triazine herbicides, around $1.4 to $1.8 billion annually. As the sum of the benefits accruing to livestock farmers, processors/handlers, distributors, retailers and final consumers, these benefits aggregate across the entire supply chain. Separating this livestock benefit further into the portion accruing to each type of entity along this supply chain requires data and modeling beyond the current capability of AGSIM. Separating this benefit into the portion accruing to each type of livestock is also difficult, since the necessary USDA data are not available and are difficult to develop (Baker 1998).

With a consumer surplus benefit of $1.2 to $1.5 billion annually, the ethanol industry is a close second to the livestock industry in terms of the value of the benefits derived from triazine herbicides. Because the livestock industry uses ethanol by-products as animal feed, and thus is part of the ethanol supply chain, a portion of this benefit also accrues to the livestock industry in addition to the benefits calculated above. Foreign consumers of U.S. grain also derive benefits from triazine herbicides due to the lower crop prices, especially for corn. In Table 27, these consumer benefits are measured by the Exports category and range from about $610 to $750 million annually. These benefits are for the entire range of uses of corn and grain exports to other nations, including for livestock feed, as well as for food and other industrial uses, and for all consumers along the supply chain, including processors/handlers, distributors, retailers and final consumers. Lastly, U.S. consumers other than the livestock and ethanol industry derive benefits from lower crop prices, ranging in value from about $300 to $390 million annually. These values are for all other uses of corn and other grains, including food, seed, and any other industrial uses, and again, are for all consumers along the supply chain.

The magnitude of these consumer benefits – $3.6 to $4.4 billion – can be difficult to grasp, so examples of various other agricultural industries generating similar magnitudes for the value of farm gate receipts are presented. Wisconsin is widely recognized as an important dairy state, second in the U.S. in total milk production. For 2007 and 2008, the annual average farm gate value of all milk production in Wisconsin was almost $4.6 billion, which was a record value as a result of relatively high prices during those years; the annual average for 2004 and 2005 was $3.6 billion (USDA-NASS 2010a). The U.S. is the world's fourth largest potato producer and the average annual farm gate value of all U.S. potato production for 2007 to 2009 was $3.5 billion (FAOSTAT 2010; USDA-NASS 2010b). The U.S. is also the world's third largest cotton producer and the average annual farm gate value of all U.S. cotton lint production for 2007 to 2009 was $4.1 billion (FAOSTAT 2010; USDA-NASS 2010b). Florida is an important agricultural state, producing a wide variety of crops (grains, oilseeds, fiber, sugar, commercial vegetables and fruits and nuts). The annual average farm gate value of all major crops produced in Florida for 2007 to 2009 was $4.4 billion (USDA-NASS 2010b). Finally, the USDA Natural Resource Conservation Service (NRCS) funds almost all USDA conservation programs, including the Conservation Reserve Program (CRP) and the Environmental Quality Incentives Program (EQIP), with most expenditures for cost share assistance, incentive payments, and technical assistance to retire highly erodible land from production and to encourage farmers adopt various best management practices. The total budget for the USDA Natural Resource Conservation Service (NRCS) in 2009 was almost $3.5 billion and is projected to increases to almost $4.0 billion for 2010 and 2011 (USDA 2010). These examples were chosen to provide some context for the magnitude of the benefits generated by triazine herbicides for consumers.

3.3 Soil Erosion Benefits of Triazine Herbicides

Table 28 reports the estimated change in soil erosion from U.S. cropland relative to the 2009 baseline for each non-triazine scenario. The estimated increase in total soil losses varies across the non-triazine scenarios, ranging from 56 to 85 million tons per year, about a 9% to 13% increase from the baseline. Soil erosion increases are greater for the scenarios not allowing corn acres using glyphosate to expand beyond the current level (Non-Expanding) and for the scenarios assuming a greater shift in tillage system adoption towards more intensive tillage (Moderate or Substantial). These aggregate quantities are estimates of the soil erosion benefit of atrazine – how much annual soil erosion from U.S. cropland would increase if triazine herbicides were not available.

These increases in soil erosion for the non-triazine scenarios are not trivial – total soil erosion from U.S. cropland decreased 43% between 1982 and 2007 and has been decreasing since the mid-1980s (USDA-NRCS 2010). An increase in soil erosion as projected under these non-triazine scenarios would represent a substantial reversal of this trend. Atrazine and the other triazine herbicides have contributed to the observed decrease in soil erosion by providing an effective residual herbicide for weed control in conservation tillage and no-till systems. If triazine herbicides were not available to U.S. farmers, this analysis shows that aggregate soil erosion from U.S. cropland would begin to increase and reverse the tremendous advances in soil management that U.S. farmers have made in the last 30 years to reduce soil erosion.

To better understand the relative contribution of the different changes to the estimated increase in erosion for the non-triazine scenarios, Table 28 reports the separate contribution of four different sources to the total soil erosion for each region. The sources for the soil erosion increase in this analysis are 1) acreage reallocations to different crops because of changes in relative profitability (Acreage Shift); 2) shifts to more intensive tillage practices that increase average erosion rates for corn, sorghum, soybeans and cotton (Tillage Shift); 3) a decrease in total acres enrolled in CRP (CRP Shift); and 4) an increase in total crop acres by converting additional non-crop land to crop production (New Land).

The reallocation of crop acres represents only about 1.5%-2.5% of the total estimated increase in soil erosion for the non-triazine scenarios. Because farmers shift more acres under the non-triazine scenarios to slightly more erosive crops (e.g., corn), total erosion increases somewhat, but the overall effect is not large relative to the other changes that increase soil erosion.

The increase in tillage intensity is the largest source of the estimated increase in soil erosion, as it represents about 40% to more than 60% of the total soil erosion increase depending on the non-triazine scenario. These results show the strong connection between reducing tillage and reducing soil erosion. In this analysis, weed control in reduced tillage systems becomes more difficult due to projected problems with glyphosate resistant weeds, and so some farmers shift to more intensive tillage. The estimates reported in Table 28 are based on the assumption that farmers return to tillage levels generally prevalent in the early to mid-2000s for corn, cotton, soybeans and sorghum. The impact of this tillage shift on estimated soil erosion is large and shows the importance of tillage systems for controlling soil erosion and a major benefit of herbicide-based weed control in reduced tillage systems.

Converting land to crop production from non-crop uses is the other source of the increased soil erosion. Of the total estimated increase in soil erosion, 17% to 27% is due to moving land out of CRP and into crop production, while moving land from non-crop uses into crop production accounts for another 19% to 31%. Together, these two changes account for 36% to 58% of the total increase in soil erosion, depending on the non-triazine scenario. For the non-triazine scenarios as defined for this analysis, highly erodible land is converted to crop production, mostly to corn acres, which increases soil erosion. Farmers shift acres out of CRP and non-crop uses into corn to take advantage of the higher prices and returns resulting from the overall decrease in the corn supply, which substantially increases soil erosion.

The first two sources in Table 28 represent soil erosion changes due to intensive margin effects – changes resulting from internal reallocations and shifts in crop production practices. The other two sources represent soil erosion changes from extensive margin effects – changes resulting from on overall expansion in crop production. Without triazine herbicides, farmers make both internal changes on acres currently in crop production and bring more acres into crop production, with about half of the total increase in soil erosion due to intensive margin changes and about half to changes on the extensive margin.

Table 28 also reports results by region, providing some indication of the geographic differences in the soil erosion benefits of triazine herbicides. Relative to the other sources of increased soil erosion for the non-triazine scenarios, the crop acreage shifts had little effect, but the effect was largest for both scenarios in the Prairie Gateway, as corn acres expanded in this region and in Table 19, corn is more erosive than other crops. The shift toward more intensive tillage was the leading source of increased soil erosion for the non-triazine scenarios, but by far most of the increase in soil erosion from the tillage shift occurred in the Heartland, with the Prairie Gateway and the Northern Crescent a distant second and third in rank. The availability of atrazine and the other triazine herbicides is important for weed control as a substitute for tillage in these regions, which contributes to a substantial reduction in soil erosion. Conversion of land currently enrolled in CRP and in other non-crop uses is projected to be a leading source of increased erosion in the Prairie Gateway and the Northern Great Plains, and to a lesser extent in the Heartland. As a result of the availability of triazine herbicides, highly erodible land in these regions can economically be maintained in non-crop uses, which implies a sizeable reduction in soil erosion.

Considering the regional totals, the triazine herbicides contribute the greatest reductions in soil erosion in the Heartland and the Prairie Gateway, but for different reasons. In the Heartland, atrazine and the other triazine herbicides are a key part of reduced tillage, while in the Prairie Gateway, the effect of triazine herbicides on crop prices and profitability is important for maintaining highly erodible land in non-crop uses. The erosion reductions in the Northern Great Plains and the Northern Crescent are notably smaller, but derived from similar sources – from reduced tillage in the Northern Crescent and from maintaining land in non-crop uses in the Northern Great Plains. The availability of triazine herbicides generates minor erosion effects in the other regions, since corn and sorghum are generally not important crops in these regions. Cropland erosion in the Heartland and Northern Crescent is generally water (sheet and rill) erosion, while in the Prairie Gateway and Northern Great Plains wind erosion predominates (USDA-NRCS 2010).

3.4 Monetary Value of Soil Erosion Benefits

Table 29 reports the monetary value of the erosion reduction benefits provided by triazine herbicides using equation (9) and the monetary values of soil erosion in Table 20 and the projected total soil erosion changes for each non-triazine scenario in Table 28. The total value is about $210 to $350 million per year, with more than half of the benefit occurring in the Heartland and another 18% to 21% occurring in the Northern Crescent, and 11% to 15% in the Prairie Gateway. The total value is largest in the Heartland because triazine herbicides generate the largest soil reductions in the region and the value per ton is fairly moderate for the region. The total value is large in the Northern Crescent because the value per acre is quite high and triazine herbicides generate fairly moderate soil erosion reductions in the region. On the other hand, the total value is fairly moderate in the Prairie Gateway, even though triazine herbicides generate large reductions in soil erosion in the region, because the value per ton is quite small in the region.

Pimentel et al. (1995) and Tegtmeier and Duffy (2004) both develop estimates of the total costs for soil erosion in the U.S., from which an average cost per ton of eroded soil was derived. After converting to 2009 dollars, the average cost for Pimentel et al. (1995) is $7.21 per ton and $8.73 per ton for Tegtmeier and Duffy (2004). These values are average values for across the U.S., not region-specific values as developed by Hansen and Ribaudo (2008). Using the total changes in soil erosion in Table 28, the total monetary value of the soil erosion reductions generated by triazine herbicides range from \$400 to almost \$615 million per year using the Pimentel et al. (1995) cost per ton and from \$490 to almost \$745 million per year using the Tegtmeier and Duffy (2004) cost per ton. These values indicate the conservative nature of the values estimated using the data and methods of Hansen and Ribaudo (2008). The actual social value of the soil erosion benefits generated by triazine herbicides are likely larger than the \$210 to \$350 million per year reported in Table 29.

3.5 Reduction in Diesel Fuel Use and CO_2 Emissions

Tables 30 and 31 report the total reduction in diesel fuel used for tillage for each non-triazine scenario using the average per-acre diesel fuel use rates in Table 23 and the acreage changes in Table 25. Table 30 reports reductions by region while Table 31 reports reductions by crop. The total reduction in diesel fuel use ranges from 18 to 28 million gallons, with an expected value of about 23 million gallons. Across scenarios, reductions vary both with the magnitude of the assumed tillage shift (Minor, Moderate, Substantial) and the assumptions regarding the expansion of glyphosate use on corn acres (Expanding, Non-Expanding). As expected, the greater the shift toward more tillage, the greater the increase in diesel fuel use for tillage. Examining differences across regions in Table 30, about 45% of the total increase in diesel fuel use for tillage occurs in the Heartland, a little more than 20% in the Prairie Gateway, and a little more than 10% each in the Northern Crescent and the Northern Great Plains. Examining differences among the crops in Table 31, not quite two-thirds of the total increase in diesel fuel use for tillage occurs for corn, and about one-third for soybeans, with a non-insignificant increase for cotton and a noticeable decrease for sorghum.

Table 32 reports the increase in annual carbon dioxide emissions implied by this increased diesel fuel use. The range is about 180,000 to 280,000 metric tons of carbon dioxide per year, with an expected value of about 230,000 metric tons. Because these emissions are proportional to the increased fuel use, these values follow the same patterns as fuel use. Thus emissions vary both with the tillage shift and the assumptions regarding expansion of glyphosate use in corn. Also, emissions are greatest in the Heartland and the Prairie Gateway regions and for corn and soybeans.

4.0 CONCLUSION

This technical report describes a method to use the AGSIM policy model to estimate changes in soil erosion and diesel fuel consumption for tillage that result from agricultural policy changes, using triazine herbicides as a case study to explain the development of the method and illustrate its use. A key criterion was to develop a transparent and easy to implement method as a first cut at estimating changes in soil erosion and fuel use. The method is not intended as a complete substitute for more comprehensive and detailed models of soil erosion linked to agricultural supply and demand models (e.g., Larson et al. 2010).

For the analysis, a 2009 base case and various non-triazine scenarios are developed based on different assumptions regarding the increased use of glyphosate on corn and the magnitude of the farmer shift toward more intensive tillage if triazine herbicides were not available. Without triazine herbicides, yield losses would occur for corn and sorghum, farmer costs for weed control would change (Table 1) and farmers would shift toward more intensive tillage for weed control (Table 5). As a result of these shifts in tillage adoption rates, changes in farmer tillage costs occur (Table 11), as well as changes in soil erosion rates (Table 19) and consumption of diesel fuel for tillage (Table 23). Based on these yield and cost changes, AGSIM projects crop acreages and prices (Tables 24 and 25), as well as changes in consumer surplus (Table 27), that would occur for each non-triazine scenario relative to the 2009 baseline. Based on projected crop acreage changes, the method developed here estimates changes in total soil erosion (Table 28) and consumption of diesel fuel for tillage (Tables 30 and 31), as well as the monetary value of soil erosion changes (Table 29) and the carbon dioxide emission changes resulting from the fuel use changes (Table 32).

Table 33 summarizes the results of this economic assessment of the benefits of triazine herbicides in the U.S. economy, based on the changes in consumer surplus and the estimated monetary value of changes in soil erosion for each non-triazine scenario. Combining these estimates gives a range of $3.8 to $4.8 billion per year for the benefits of triazine herbicides in the U.S. However, this estimate is likely a lower bound, as this assessment does not include values for several benefits generated by triazine herbicides. For example, this assessment does not include the value of the benefits of triazine herbicides for specialty crops not modeled by AGSIM or for weed resistance management for other herbicides such as glyphosate and other such benefits (Mitchell 2011). Also, the cost changes reported in Table 1 for the non-triazine scenarios only include the costs for herbicide substitution at 2009 prices, which likely underestimate what actual cost increases would be. Atrazine and glyphosate currently dominate the corn herbicide market, with other herbicides capturing much small market shares. If atrazine, simazine and propazine were not available, prices for substitute herbicides would increase, implying larger costs increases than reported in Table 1. This assessment developed a method to estimate the monetary value of the erosion reduction benefits of triazine herbicides, but the estimated value of these soil erosion benefits is a lower bound (Hansen and Ribaudo 2008).

Even without accounting for these and other benefits of triazine herbicides, this assessment finds that they provide benefits in the range of $3.8 to $4.8 billion per year. Carlson (2008) summarizes several previous assessments of the benefits of triazine herbicides, with estimated benefits generally falling in the range of $1 billion per year, but these studies were published in the 1980s and 1990s. The last comprehensive study comparable to this assessment, Carlson (1998), found annual benefits ranging around $1.2 to $1.3 billion. The substantially larger benefits estimated in this study occur primarily because the overall economic size of the corn market has increased since the early 1990s – yields, planted acres, and prices have increased (USDA-NASS 2011). These and similar trends for other crops show that these previous estimates of the benefits of triazine herbicides are outdated. The economic assessment reported here has updated the analysis for a base year of 2009 and finds that the triazine herbicides generate substantial benefits for the U.S. economy, even without accounting for various factors such as discussed above. This paper provides an updated economic assessment of the benefits of triazine herbicides to better inform the debate as policy analysts balance the benefits and costs of triazine herbicides.

Table 1. Regional yield and herbicide cost changes for corn and sorghum for the two non-triazine scenarios.[a]

	Increasing Glyphosate Use on Corn Acres		2009 Glyphosate Use on Corn Acres	
Crop and Region	Yield Change (%)	Cost Change ($/ac)	Yield Change (%)	Cost Change ($/ac)
Corn				
Heartland	-5.26%	$2.66	-6.04%	-$0.29
Northern Crescent	-3.45%	$1.25	-5.23%	-$2.56
Northern Great Plains	-1.39%	$1.13	-2.27%	$0.59
Prairie Gateway	-1.84%	$0.26	-2.39%	-$0.23
All Other Regions	-6.24%	$1.74	-9.61%	$0.05
Sorghum	Non-Triazine Scenario			
All Regions[b]	-20.49%	-$2.99		

[a]Source: Bridges (2011). Yield and herbicide cost changes for non-triazine scenarios are spread over all corn and sorghum acres, not just those currently treated with a triazine herbicide, and cost changes do not include additional application costs, only the cost of alternative single-pass herbicide products.
[b]Yield and cost changes estimated for the Prairie Gateway region and used for all regions.

Table 2. Regional, acreage-weighted average tillage system adoption rates for corn for 1998 to 2009.

	-------------- Heartland --------------			--------- Northern Crescent ---------			------- Northern Great Plains -------		
Year	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional
1998	20.4%	40.5%	39.1%	14.0%	30.3%	55.7%	19.8%	21.8%	58.4%
1999	17.3%	37.5%	45.2%	14.6%	25.9%	59.5%	17.9%	26.9%	55.2%
2000	21.0%	36.7%	42.4%	17.0%	27.0%	56.0%	29.5%	23.9%	46.6%
2001	19.9%	37.4%	42.7%	16.9%	34.8%	48.3%	33.4%	24.7%	41.9%
2002	21.1%	35.0%	43.8%	19.3%	29.2%	51.5%	28.1%	30.9%	41.0%
2003	21.6%	32.0%	46.4%	22.7%	28.6%	48.7%	38.5%	16.5%	45.0%
2004	22.8%	32.7%	44.5%	20.4%	31.6%	48.0%	41.7%	18.6%	39.7%
2005	25.1%	32.1%	42.8%	20.2%	29.0%	50.7%	39.1%	24.4%	36.5%
2006	26.2%	30.8%	43.0%	23.9%	25.8%	50.3%	42.9%	20.0%	37.2%
2007	27.3%	33.2%	39.6%	25.1%	30.0%	44.9%	54.8%	12.5%	32.7%
2008	27.2%	34.1%	38.7%	23.9%	36.9%	39.3%	32.8%	21.8%	45.4%
2009	24.3%	38.9%	36.8%	25.0%	30.9%	44.1%	41.8%	25.9%	32.3%

Source: GfK Kynetec (2010).

Table 2 (cont.). Regional, acreage-weighted average tillage system adoption rates for corn for 1998 to 2009.

	---------- Prairie Gateway ----------			----------- Rest of Nation -----------		
Year	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional
1998	21.0%	31.2%	47.8%	27.6%	18.9%	53.4%
1999	20.9%	28.5%	50.6%	32.5%	16.0%	51.5%
2000	37.0%	24.5%	38.5%	34.3%	15.9%	49.8%
2001	29.0%	30.1%	41.0%	33.8%	17.4%	48.8%
2002	34.7%	28.0%	37.3%	39.0%	15.2%	45.8%
2003	30.3%	22.8%	46.9%	37.2%	14.3%	48.5%
2004	29.5%	27.0%	43.5%	38.8%	15.4%	45.8%
2005	38.7%	29.5%	31.8%	41.8%	16.1%	42.0%
2006	48.1%	26.7%	25.2%	42.6%	16.8%	40.6%
2007	48.4%	26.9%	24.8%	44.4%	21.5%	34.1%
2008	44.4%	25.7%	29.9%	48.7%	17.4%	34.0%
2009	46.2%	29.5%	24.3%	37.2%	23.6%	39.2%

Source: GfK Kynetec (2010).

Table 3. Regional, acreage-weighted average tillage system adoption rates for soybeans for 1998 to 2009.

	-------------- Heartland --------------			--------- Northern Crescent ---------			------- Northern Great Plains -------		
Year	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional
1998	34.9%	29.6%	35.4%	27.1%	27.0%	45.9%	13.6%	14.1%	72.3%
1999	33.5%	30.2%	36.2%	28.7%	22.7%	48.6%	17.8%	23.8%	58.4%
2000	37.8%	26.6%	35.6%	33.4%	23.5%	43.1%	24.4%	13.7%	61.9%
2001	40.5%	25.3%	34.2%	40.6%	27.8%	31.6%	28.6%	20.4%	51.1%
2002	38.8%	26.0%	35.2%	40.4%	20.8%	38.8%	37.2%	16.5%	46.3%
2003	41.7%	24.2%	34.1%	38.6%	20.5%	40.9%	35.7%	15.5%	48.8%
2004	42.6%	23.1%	34.3%	41.7%	22.6%	35.7%	42.1%	9.9%	48.0%
2005	42.8%	22.4%	34.8%	40.6%	22.8%	36.5%	39.0%	15.7%	45.3%
2006	47.5%	20.3%	32.2%	43.6%	20.5%	35.9%	37.3%	18.4%	44.4%
2007	50.8%	19.5%	29.7%	50.3%	19.6%	30.1%	38.0%	14.5%	47.4%
2008	52.6%	19.2%	28.2%	45.0%	19.3%	35.6%	36.8%	17.7%	45.5%
2009	46.5%	22.8%	30.7%	39.4%	27.4%	33.3%	36.3%	22.3%	41.4%

Source: GfK Kynetec (2010).

Table 3 (cont.). Regional, acreage-weighted average tillage system adoption rates for soybeans for 1998 to 2009.

	---------- Prairie Gateway ----------			----------- Rest of Nation -----------		
Year	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional
1998	27.3%	30.8%	42.0%	30.0%	16.1%	53.9%
1999	20.4%	25.2%	54.5%	32.6%	13.0%	54.3%
2000	34.6%	22.4%	43.1%	40.3%	15.1%	44.6%
2001	35.4%	26.0%	38.6%	43.2%	17.4%	39.4%
2002	38.4%	30.0%	31.6%	45.2%	16.9%	37.9%
2003	36.7%	21.0%	42.3%	46.1%	14.8%	39.1%
2004	42.1%	29.2%	28.7%	46.1%	14.6%	39.3%
2005	47.1%	19.7%	33.2%	47.5%	19.2%	33.4%
2006	50.9%	17.0%	32.0%	54.5%	14.7%	30.8%
2007	63.5%	14.6%	21.9%	49.1%	16.1%	34.9%
2008	73.9%	12.5%	13.6%	59.3%	15.8%	24.9%
2009	64.6%	14.6%	20.8%	48.3%	18.1%	33.6%

Source: GfK Kynetec (2010).

Table 4. Regional, acreage-weighted average tillage system adoption rates for cotton for 1998 to 2009.

	---------- Prairie Gateway ----------			----------- Rest of Nation -----------		
Year	No-Till	Conservation	Conventional	No-Till	Conservation	Conventional
1998	4.4%	13.7%	81.9%	7.8%	14.8%	77.4%
1999	2.0%	13.3%	84.7%	11.4%	15.3%	73.2%
2000	5.4%	23.4%	71.2%	15.7%	20.5%	63.8%
2001	7.2%	22.0%	70.9%	23.1%	26.4%	50.6%
2002	4.8%	26.6%	68.6%	24.7%	26.0%	49.3%
2003	5.5%	21.0%	73.5%	22.4%	28.1%	49.6%
2004	5.7%	23.0%	71.4%	27.1%	29.5%	43.3%
2005	10.3%	24.4%	65.3%	30.9%	31.4%	37.7%
2006	14.9%	25.1%	60.0%	27.6%	32.7%	39.7%
2007	11.1%	29.3%	59.6%	27.8%	32.7%	39.5%
2008	14.4%	30.1%	55.6%	23.9%	29.6%	46.5%
2009	10.8%	38.7%	50.5%	23.4%	27.9%	48.7%

Source: GfK Kynetec (2010).

Table 5. Percentage point shift in tillage system adoption rates for corn, soybeans and cotton for the non-triazine scenarios and implied tillage adoption rates for all scenarios.

Crop	Tillage Shift	No-Till	Conservation	Conventional
Corn	Minor	-4.5%	2.0%	2.5%
	Moderate	-6.0%	2.5%	3.5%
	Substantial	-7.5%	3.0%	4.5%
Cotton	Minor	-3.5%	1.5%	2.0%
	Moderate	-4.5%	2.0%	2.5%
	Substantial	-5.5%	2.5%	3.0%
Sorghum	Minor	-4.5%	2.0%	2.5%
	Moderate	-6.0%	2.5%	3.5%
	Substantial	-7.5%	3.0%	4.5%
Soybeans	Minor	-3.5%	1.5%	2.0%
	Moderate	-4.5%	2.0%	2.5%
	Substantial	-5.5%	2.5%	3.0%

Table 6. Tillage system adoption rates by crop and region under the minor, moderate and substantial tillage system shifts for the non-triazine scenarios.

	------------ Minor ------------			---------- Moderate ----------			--------- Substantial ---------		
Corn and Region	No-Till	Conser-vation	Conven-tional	No-Till	Conser-vation	Conven-tional	No-Till	Conser-vation	Conven-tional
Heartland	19.8%	40.9%	39.3%	18.3%	41.4%	40.3%	16.8%	41.9%	41.3%
Northern Crescent	20.5%	32.9%	46.6%	19.0%	33.4%	47.6%	17.5%	33.9%	48.6%
Northern Great Plains	37.3%	27.9%	34.8%	35.8%	28.4%	35.8%	34.3%	28.9%	36.8%
Prairie Gateway	41.7%	31.5%	26.8%	40.2%	32.0%	27.8%	38.7%	32.5%	28.8%
Rest of Nation	32.7%	25.6%	41.7%	31.2%	26.1%	42.7%	29.7%	26.6%	43.7%
Soybeans									
Heartland	43.0%	24.3%	32.7%	42.0%	24.8%	33.2%	41.0%	25.3%	33.7%
Northern Crescent	35.9%	28.9%	35.3%	34.9%	29.4%	35.8%	33.9%	29.9%	36.3%
Northern Great Plains	32.8%	23.8%	43.4%	31.8%	24.3%	43.9%	30.8%	24.8%	44.4%
Prairie Gateway	61.1%	16.1%	22.8%	60.1%	16.6%	23.3%	59.1%	17.1%	23.8%
Rest of Nation	44.8%	19.6%	35.6%	43.8%	20.1%	36.1%	42.8%	20.6%	36.6%
Cotton									
Prairie Gateway	7.3%	40.2%	52.5%	6.3%	40.7%	53.0%	5.3%	41.2%	53.5%
Rest of Nation	19.9%	29.4%	50.7%	18.9%	29.9%	51.2%	17.9%	30.4%	51.7%
Sorghum									
All Regions	41.7%	31.5%	26.8%	40.2%	32.0%	27.8%	38.7%	32.5%	28.8%

Table 7. Per-acre costs for select tillage operations in eleven states.

State	Crop Year	Chisel Plow	Tandem Disk	Field Cultivate	Strip Till	Conventional Plant Corn	Conventional Plant Soybean	No-Till Plant Corn	No-Till Plant Soybean	Source
Illinois	2010	$12.80	$10.30	$8.80	$13.60	$11.10	$11.40	$13.80	$14.60	Schnitkey et al. 2010
Indiana	2008	$13.21	$10.54	$10.03	---	$14.69	$14.80	$14.39	$14.29	Dobbins and Matli 2007
Iowa	2010	$13.30	$11.60	$10.85	---	$14.20	$14.25	$15.70	$15.35	Edwards and Johanns 2010
Kansas	2009	$10.06	$9.06	$8.84	---	$12.52	$12.58	$13.70	$13.68	Twete et al. 2009
Kentucky	2010	$14.00	$12.00	$10.50	---	$14.00	$14.50	$15.50	$15.25	Halich 2010
Michigan	2010	$13.50	$11.40	$9.90	$16.55	$14.60	$14.60	$16.30	$15.30	Stein 2009
Minnesota	2010	$9.14	$8.85	$5.47	---	$10.85	$10.85	$12.85	$12.85	Lazarus and Smale 2010
Missouri	2010	$13.40	$11.44	$11.95	---	$12.95	$13.34	$14.23	$14.27	Plain et al. 2009
Nebraska	2010	$10.93	$9.96	$9.83	$15.54	$15.47	$13.00	$14.96	$13.64	Jose and Janousek 2010
Ohio	2010	$14.05	$12.60	$11.10	$17.30	$15.70	$15.75	$16.00	$16.10	Ward 2010
Pennsylvania	2010	$16.90	$15.70	$15.30	---	$17.30	$17.30	$19.10	$19.10	Pike 2010

Table 8. Estimated cost ($/ac) for corn and soybean tillage systems, including the cost of planting, by state.

State	Corn No-Till	Corn Conservation	Corn Conventional	Soybeans No-Till	Soybeans Conservation	Soybeans Conventional
Illinois	$13.80	$22.30	$36.60	$14.60	$23.35	$43.30
Indiana	$14.39	$24.72	$41.87	$14.29	$25.34	$48.58
Iowa	$15.70	$25.05	$43.30	$15.35	$25.85	$50.00
Kansas	$13.70	$21.36	$35.45	$13.68	$21.64	$40.54
Kentucky	$15.50	$24.50	$43.50	$15.25	$26.50	$51.00
Michigan	$16.30	$27.83	$42.65	$15.30	$28.58	$49.40
Minnesota	$12.85	$16.32	$29.74	$12.85	$19.70	$34.31
Missouri	$14.23	$24.90	$43.04	$14.27	$24.78	$50.13
Nebraska	$14.96	$28.16	$40.73	$13.64	$25.75	$43.72
Ohio	$16.00	$29.90	$46.43	$16.10	$30.70	$53.50
Pennsylvania	$19.10	$32.60	$56.75	$19.10	$33.00	$65.20
Average	$15.14	$25.24	$41.82	$14.95	$25.93	$48.15

Table 9. Estimated cost ($/ac) for cotton tillage systems, including the cost of planting, by state

State	Crop Year	Conventional Tillage	Budgets	Conservation Tillage	Budgets	No-Till	Budgets	Source
Arkansas	2010	$23.30	1	---		---		Flanders et al. 2009
Georgia	2010	$19.63	2	$7.00	1	---		Smith et al. 2009
Louisiana	2010	$29.57	1	---		---		Guidry 2010
Mississippi	2010	---		$24.68	3	$15.20	2	Riley et al. 2009
North Carolina	2010	$17.36	2	$10.59	1	---		Bullen et al. 2010
South Carolina	2010	$16.32	1	$9.87	1	$4.50	1	Jones 2010
Tennessee	2010	$23.08	1	---		$6.21	1	McKinley et al. 2010
Texas	2008	$54.54	7	$39.29	9	$19.62	4	Kaase 2008
Average		$26.26		$18.29		$11.38		

Table 10. Estimated cost ($/ac) for tillage, including the cost of planting, by crop and region.

Crop	Region	States Included in Average*	No-Till	Conservation	Conventional
Corn	Heartland	IL, IN, IA, KY, MN, MO, ½NE, ½OH	$14.56	$23.83	$40.23
	Northern Crescent	MI, ½MN, ½OH, PA	$16.61	$27.85	$45.83
	Northern Great Plains	½MN, ½NE	$13.91	$22.24	$35.23
	Prairie Gateway	KS, ½NE	$14.12	$23.63	$37.21
	All Other Regions	KY, MO, OH, PA	$16.21	$27.98	$47.43
Soybeans	Heartland	IL, IN, IA, KY, MN, MO, ½NE, ½OH	$14.50	$24.82	$46.56
	Northern Crescent	MI, ½MN, ½OH, PA	$16.29	$28.93	$52.84
	Northern Great Plains	½MN, ½NE	$13.25	$22.73	$39.02
	Prairie Gateway	KS, ½NE	$13.67	$23.01	$41.60
	All Other Regions	KY, MO, OH, PA	$16.18	$28.75	$54.96
Cotton	Prairie Gateway	TX	$19.62	$39.29	$54.54
	All Other Regions	AR, GA, LA, MS, NC, SC, TN	$8.64	$13.04	$21.54
Sorghum	All Regions	KS, ½NE	$14.12	$23.63	$37.21

*States with a ½ received half the weight of the other states when calculating the average because the state was only partially contained in the region.

Table 11. Annual average cost ($/ac) for tillage, weighted by tillage system adoption rates, for the status quo and non-triazine scenarios and the cost change for the non-triazine scenarios relative to the status quo scenario.

		---------- Average Tillage Cost ----------				-------- Tillage Cost Change --------		
		Status Quo	--- Non-Triazine Scenarios ---			--- Non-Triazine Scenarios ---		
Crop	Region	Scenario	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Corn	Heartland	$27.61	$28.44	$28.74	$29.04	$0.83	$1.13	$1.43
	Northern Crescent	$32.97	$33.92	$34.27	$34.62	$0.96	$1.30	$1.65
	Northern Great Plains	$22.96	$23.66	$23.91	$24.17	$0.70	$0.95	$1.21
	Prairie Gateway	$22.53	$23.30	$23.57	$23.85	$0.77	$1.05	$1.32
	All Other Regions	$31.23	$32.24	$32.61	$32.98	$1.02	$1.39	$1.76
Soybeans	Heartland	$26.69	$27.49	$27.70	$27.91	$0.80	$1.01	$1.22
	Northern Crescent	$31.90	$32.82	$33.07	$33.31	$0.92	$1.17	$1.41
	Northern Great Plains	$26.04	$26.69	$26.87	$27.05	$0.66	$0.83	$1.01
	Prairie Gateway	$20.83	$21.53	$21.72	$21.90	$0.70	$0.89	$1.07
	All Other Regions	$31.47	$32.44	$32.69	$32.95	$0.96	$1.22	$1.48
Cotton	Prairie Gateway	$44.86	$45.85	$46.12	$46.39	$0.99	$1.27	$1.54
	All Other Regions	$16.15	$16.47	$16.56	$16.64	$0.32	$0.41	$0.50
Sorghum	All Regions	$22.53	$23.30	$23.57	$23.85	$0.77	$1.05	$1.32

Table 12. Annual average soil erosion (tons/ac) in 2000 by crop and region for highly erodible and non-highly erodible land

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
	---------- Not Highly Erodible Land ----------								
Barley	0.61	0.96	0.60	0.32	1.13	1.06	0.18	0.26	0.82
Corn	3.25	2.11	1.18	2.42	3.24	1.79	1.73	0.05	3.63
Cotton	1.60	---	---	1.46	6.66	4.20	0.98	---	6.26
Hay	0.36	0.16	0.08	0.05	0.44	0.14	0.01	0.04	0.18
Oats	1.36	1.37	0.74	1.27	2.98	3.35	0.64	---	2.55
Peanuts	---	---	---	1.97	---	3.35	3.37	---	1.81
Rice	1.04	0.16	0.42	0.98	2.16	2.05	0.82	0.33	2.53
Sorghum	2.63	1.77	1.76	2.24	3.14	1.91	1.30	---	2.64
Soybeans	2.12	1.30	0.73	3.44	2.31	1.77	1.97	---	2.33
Wheat	1.42	1.10	0.42	1.14	2.48	1.99	0.45	0.16	1.97
	---------- Highly Erodible Land ----------								
Barley	3.34	2.98	0.37	0.18	0.64	3.46	0.45	0.46	---
Corn	6.89	5.79	0.73	1.46	5.43	4.64	1.63	0.06	7.14
Cotton	---	---	---	0.60	9.70	9.73	1.44	0.02	17.87
Hay	1.70	0.80	0.16	0.09	2.07	0.38	0.04	0.06	2.95
Oats	4.32	3.57	1.08	1.85	2.35	2.06	0.63	0.32	---
Peanuts	---	---	---	1.02	---	5.70	1.83	---	---
Rice	---	---	---	4.20	2.49	---	---	---	3.29
Sorghum	6.32	5.20	1.61	1.33	3.58	2.74	0.84	---	7.55
Soybeans	4.68	3.80	0.59	4.21	3.47	3.58	4.98	---	5.75
Wheat	4.35	3.59	0.46	0.70	4.32	4.57	0.74	0.37	5.56
	---------- Land Not Currently in Crop Production ----------								
As Non-Crop	1.27	1.21	1.35	2.13	1.17	1.17	1.44	1.68	1.32
As Crop	20.40	13.25	15.44	28.93	18.11	16.06	17.72	14.27	20.85

Source: Based on the National Nutrient Loss and Soil Carbon Database (Potter et al. 2004, 2006a, 2006b; Potter 2008).

Table 13. Derived average annual soil erosion (tons/ac) for moldboard plow based tillage in 2000 for corn, cotton, sorghum and soybeans by region

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
--------------- Not Highly Erodible Land ---------------									
Corn	8.33	4.63	3.04	7.17	8.29	4.57	4.42	0.12	9.30
Cotton	7.97	---	---	6.59	33.20	20.91	4.88	---	31.19
Sorghum	7.80	5.25	5.23	6.65	9.32	5.65	3.84	---	7.84
Soybeans	13.38	6.98	4.54	24.43	14.15	10.88	12.08	---	14.28
--------------- Highly Erodible Land ---------------									
Corn	17.65	12.67	1.87	4.33	13.89	11.88	4.18	0.14	18.28
Cotton	---	---	---	2.74	48.34	48.46	7.17	---	89.05
Sorghum	18.75	15.42	4.76	3.93	10.62	8.13	2.50	---	22.41
Soybeans	29.55	20.47	3.68	29.86	21.30	21.92	30.53	---	35.25

Table 14. Estimated average annual soil erosion (tons/ac) for corn, cotton, sorghum and soybeans by region under the 2009 status quo baseline scenario

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
--------------- Not Highly Erodible Land ---------------									
Corn	2.99	1.80	0.91	1.84	2.82	1.55	1.50	0.04	3.16
Cotton	1.34	---	---	1.18	5.59	3.52	0.82	---	5.25
Sorghum	2.00	1.35	1.34	1.70	2.39	1.45	0.99	---	2.01
Soybeans	1.95	1.11	0.57	2.66	2.01	1.55	1.72	---	2.03
--------------- Highly Erodible Land ---------------									
Corn	6.34	4.92	0.56	1.11	4.72	4.03	1.42	0.05	6.21
Cotton	---	---	---	0.49	8.13	8.15	1.21	---	14.98
Sorghum	4.81	3.95	1.22	1.01	2.72	2.08	0.64	---	5.75
Soybeans	4.31	3.25	0.47	3.26	3.03	3.11	4.34	---	5.01

Table 15. Estimated average annual soil erosion (tons/ac) for corn, cotton, sorghum and soybeans by region under the non-triazine scenarios assuming a minor tillage system shift

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
				Not Highly Erodible Land					
Corn	3.17	1.90	0.98	1.99	2.99	1.65	1.59	0.04	3.35
Cotton	1.39	---	---	1.22	5.78	3.64	0.85	---	5.43
Sorghum	2.16	1.46	1.45	1.84	2.58	1.57	1.07	---	2.17
Soybeans	2.05	1.16	0.61	2.85	2.12	1.63	1.81	---	2.14
				Highly Erodible Land					
Corn	6.71	5.19	0.60	1.20	5.01	4.28	1.51	0.05	6.59
Cotton	---	---	---	0.51	8.42	8.44	1.25	0.02	15.51
Sorghum	5.20	4.28	1.32	1.09	2.95	2.25	0.69	---	6.21
Soybeans	4.53	3.40	0.49	3.48	3.18	3.28	4.57	---	5.27

Table 16. Estimated average annual soil erosion (tons/ac) for corn, cotton, sorghum and soybeans by region under the non-triazine scenarios assuming the moderate tillage system shift

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
				Not Highly Erodible Land					
Corn	3.23	1.93	1.00	2.04	3.05	1.68	1.63	0.04	3.43
Cotton	1.40	---	---	1.23	5.83	3.67	0.86	---	5.48
Sorghum	2.22	1.50	1.49	1.89	2.66	1.61	1.09	---	2.23
Soybeans	2.09	1.18	0.62	2.91	2.16	1.66	1.84	---	2.18
				Highly Erodible Land					
Corn	6.85	5.28	0.61	1.23	5.12	4.37	1.54	0.05	6.73
Cotton	---	---	---	0.51	8.49	8.51	1.26	0.02	15.64
Sorghum	5.34	4.39	1.36	1.12	3.03	2.32	0.71	---	6.39
Soybeans	4.62	3.46	0.50	3.56	3.24	3.34	4.65	---	5.37

Table 17. Estimated average annual soil erosion (tons/ac) for corn, cotton, sorghum and soybeans by region under the non-triazine scenarios assuming a substantial tillage system shift

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
-- Not Highly Erodible Land --									
Corn	3.29	1.97	1.02	2.10	3.12	1.72	1.66	0.04	3.50
Cotton	1.41	---	---	1.24	5.88	3.71	0.86	---	5.53
Sorghum	2.28	1.54	1.53	1.95	2.73	1.65	1.12	---	2.29
Soybeans	2.13	1.20	0.63	2.98	2.20	1.69	1.87	---	2.22
-- Highly Erodible Land --									
Corn	6.98	5.38	0.63	1.27	5.22	4.47	1.57	0.05	6.87
Cotton	---	---	---	0.52	8.57	8.59	1.27	0.02	15.78
Sorghum	5.48	4.51	1.39	1.15	3.11	2.38	0.73	---	6.56
Soybeans	4.70	3.52	0.51	3.65	3.30	3.40	4.74	---	5.47

Table 18. Acres of highly erodible and non-highly erodible cropland by Farm Production Region and their apportionment to Farm Resource Regions to determine weights for averaging

Farm Production Region[a]	Acres Highly Erodible (1000s)	Acres Non-Highly Erodible (1000s)	Acres Highly Erodible	Acres Non-Highly Erodible
Appalachian	7,632	10,441	42.2%	57.8%
Corn Belt	20,254	66,664	23.3%	76.7%
Delta States	1,157	16,033	6.7%	93.3%
Lake States	5,169	33,392	13.4%	86.6%
Mountain	20,201	12,822	61.2%	38.8%
Northeast	5,655	8,053	41.3%	58.7%
Northern Plains	21,546	64,332	25.1%	74.9%
Pacific	4,187	15,369	21.4%	78.6%
Southeast	1,300	10,027	11.5%	88.5%
Southern Plains	10,670	22,119	32.5%	67.5%
Farm Resource Region[b]				
Heartland	20,254	66,664	23.3%	76.7%
Northern Crescent	10,824	41,445	20.7%	79.3%
Northern Great Plains	21,546	64,332	25.1%	74.9%
Prairie Gateway	10,670	22,119	32.5%	67.5%
Eastern Uplands	8,932	20,469	30.4%	69.6%
Southern Seaboard	8,932	20,469	30.4%	69.6%
Fruitful Rim	4,187	15,369	21.4%	78.6%
Basin and Range	20,201	12,822	61.2%	38.8%
Mississippi Portal	1,157	16,033	6.7%	93.3%

Source: USDA-NRCS (2010), Table 38.
[a]See USDA-ERS (2000) for map designating the old state-based Farm Production Regions.
[b]See Figure 1 for map of Farm Resource Regions' (USDA-ERS 2000).

Apportionment: Heartland = Corn Belt, Northern Crescent = Lake States + Northeast, Northern Great Plains = Northern Plains, Prairie Gateway = Southern Plains, Eastern Uplands = Appalachian + Southeast, Southern Seaboard = Appalachian + Southeast, Fruitful Rim = Pacific, Basin and Range = Mountain, Mississippi Portal = Delta States.

Table 19. Weighted average annual soil erosion (tons/ac) by crop and region for the 2009 baseline and three assumed tillage shifts

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
				Status Quo Baseline					
Barley	1.25	1.38	0.54	0.27	0.98	1.79	0.24	0.38	0.76
Hay	0.67	0.29	0.10	0.06	0.94	0.22	0.02	0.05	0.36
Oats	2.05	1.83	0.82	1.46	2.79	2.96	0.64	0.19	2.38
Peanuts	---	---	---	1.66	---	4.06	3.04	---	1.69
Rice	0.80	0.13	0.31	2.03	2.26	1.43	0.64	0.13	2.59
Wheat	2.10	1.62	0.43	1.00	3.04	2.77	0.51	0.29	2.21
Corn	3.77	2.45	0.82	1.60	3.39	2.31	1.48	0.05	3.36
Cotton	1.03	---	---	0.96	6.36	4.93	0.90	0.01	5.90
Sorghum	2.65	1.89	1.31	1.48	2.49	1.64	0.91	---	2.26
Soybeans	2.50	1.55	0.55	2.86	2.32	2.02	2.28	---	2.23
				Minor Tillage Shift					
Corn	3.99	2.58	0.88	1.73	3.60	2.45	1.58	0.05	3.57
Cotton	1.06	---	---	0.99	6.58	5.10	0.94	0.01	6.11
Sorghum	2.87	2.04	1.42	1.60	2.69	1.78	0.99	---	2.44
Soybeans	2.63	1.63	0.58	3.05	2.44	2.13	2.40	---	2.35
				Moderate Tillage Shift					
Corn	4.07	2.62	0.90	1.78	3.68	2.50	1.61	0.05	3.65
Cotton	1.07	---	---	1.00	6.64	5.15	0.94	0.01	6.16
Sorghum	2.95	2.10	1.46	1.64	2.77	1.83	1.01	---	2.51
Soybeans	2.68	1.65	0.59	3.12	2.49	2.17	2.44	---	2.39
				Substantial Tillage Shift					
Corn	4.15	2.67	0.92	1.83	3.76	2.55	1.64	0.05	3.72
Cotton	1.08	---	---	1.01	6.70	5.19	0.95	0.01	6.22
Sorghum	3.03	2.15	1.50	1.69	2.84	1.87	1.04	---	2.58
Soybeans	2.73	1.68	0.60	3.20	2.53	2.21	2.49	---	2.43

Table 20. Value ($/ton) of the benefits from reduced soil erosion by Farm Resource Region

Region	Value of Water Quality Benefit	Value of Reduced Dust Cleaning	Value of Enhanced Soil Productivity	Weighted Value*
Heartland	4.86	0.09	1.21	5.69
Northern Crescent	11.34	0.00	1.52	12.06
Northern Great Plains	2.55	0.63	0.62	1.72
Prairie Gateway	4.61	0.58	0.45	1.29
Eastern Uplands	5.72	0.00	0.78	6.07
Southern Seaboard	5.99	0.00	0.65	6.19
Fruitful Rim	6.98	0.87	0.44	6.83
Basin and Range	4.57	0.83	0.38	4.59
Mississippi Portal	5.23	0.00	0.57	5.37

Source: Based on Hansen and Ribaudo (2008), adjusted for inflation to 2009 values.
*Calculated with equation (9) using values in this table and erosion percentages in Table 20.

Table 21. Soil erosion from water and wind for state-based regions of Potter et al. (2006a) and their apportionment to Farm Resource Regions to determine weights for averaging

Region[a]	Water Erosion (1000 tons)	Wind Erosion (1000 tons)	Water Erosion	Wind Erosion
Northeast	43,467	1,076	98%	2%
Northern Great Plains	33,628	103,286	25%	75%
South Central	125,565	11,511	92%	8%
Southeast	21,520	201	99%	1%
Southern Great Plains	11,506	165,092	7%	93%
Upper Midwest	218,991	18,695	92%	8%
West	4,944	528	90%	10%
Heartland	218,991	18,695	92%	8%
Northern Crescent	262,458	19,771	93%	7%
Northern Great Plains	33,628	103,286	25%	75%
Prairie Gateway	11,506	165,092	7%	93%
Eastern Uplands	147,085	11,712	93%	7%
Southern Seaboard	147,085	11,712	93%	7%
Fruitful Rim	4,944	528	90%	10%
Basin and Range	4,944	528	90%	10%
Mississippi Portal	125,565	11,511	92%	8%

Source: Potter et al. (2006a), Tables 22 and 28.
[a]See Map 1 (Potter et al. 2006a, p. 4) for designation of these regions.
Apportionment: Heartland = Upper Midwest, Northern Crescent = Upper Midwest + Northeast, Northern Great Plains = Northern Great Plains, Prairie Gateway = Southern Great Plains, Eastern Uplands = South Central + Southeast, Southern Seaboard = South Central + Southeast, Fruitful Rim = West, Basin and Range = West, Mississippi Portal = South Central.

Table 22. Average diesel fuel use (gallons per acre) for tillage by crop and tillage system for each Farm Resource Region.

Crop	Region	No-Till	Conservation Tillage	Conventional Tillage
	Heartland	1.88	4.11	4.98
	Northern Crescent	2.00	3.85	4.73
	Northern Great Plains	1.88	4.23	5.10
	Prairie Gateway	1.88	3.73	4.90
Barley	Eastern Uplands	2.01	3.84	4.76
	Southern Seaboard	2.01	3.84	4.72
	Fruitful Rim	2.15	4.70	6.01
	Basin and Range	1.88	4.30	5.22
	Mississippi Portal	-----	-----	-----
	Heartland	2.77	3.60	4.98
	Northern Crescent	2.73	3.54	5.07
	Northern Great Plains	2.76	3.74	5.04
	Prairie Gateway	2.67	3.77	5.12
Corn	Eastern Uplands	2.27	3.06	5.00
	Southern Seaboard	3.81	4.51	5.38
	Fruitful Rim	2.58	5.13	8.12
	Basin and Range	2.51	5.68	6.88
	Mississippi Portal	2.58	3.52	5.19
	Heartland	2.71	3.97	7.81
	Northern Crescent	-----	-----	-----
	Northern Great Plains	-----	-----	-----
	Prairie Gateway	2.23	5.46	6.24
Cotton	Eastern Uplands	2.78	5.31	7.45
	Southern Seaboard	4.88	5.76	8.29
	Fruitful Rim	2.64	5.47	10.50
	Basin and Range	2.79	5.93	13.86
	Mississippi Portal	3.44	5.98	7.79
	Heartland	2.63	4.11	4.98
	Northern Crescent	2.61	4.10	4.97
	Northern Great Plains	2.51	4.15	5.02
	Prairie Gateway	1.96	4.11	4.90
Oats	Eastern Uplands	1.98	3.99	4.85
	Southern Seaboard	2.01	3.84	4.76
	Fruitful Rim	2.46	4.95	5.82
	Basin and Range	1.91	4.34	5.22
	Mississippi Portal	-----	-----	-----
	Heartland	-----	-----	-----
	Northern Crescent	-----	-----	-----
Peanuts	Northern Great Plains	-----	-----	-----
	Prairie Gateway	3.81	3.66	6.45
	Eastern Uplands	4.32	6.43	7.24

Table 22 (cont.). Average diesel fuel use (gallons per acre) for tillage by crop and tillage system for each Farm Resource Region.

Crop	Region	No-Till	Conservation Tillage	Conventional Tillage
Peanuts	Southern Seaboard	4.32	6.43	7.24
	Fruitful Rim	3.12	5.22	6.60
	Basin and Range	-----	-----	-----
	Mississippi Portal	2.74	4.83	6.42
Rice	Heartland	-----	5.41	6.56
	Northern Crescent	-----	-----	-----
	Northern Great Plains	-----	-----	-----
	Prairie Gateway	2.01	4.17	8.72
	Eastern Uplands	1.98	2.72	6.56
	Southern Seaboard	2.01	2.46	5.90
	Fruitful Rim	1.75	9.61	10.40
	Basin and Range	1.66	9.75	11.10
	Mississippi Portal	1.98	2.87	4.49
Sorghum	Heartland	1.97	3.72	4.98
	Northern Crescent	1.97	3.72	4.98
	Northern Great Plains	1.97	3.72	4.98
	Prairie Gateway	1.99	3.91	5.36
	Eastern Uplands	1.97	4.00	3.97
	Southern Seaboard	3.00	5.49	7.41
	Fruitful Rim	3.13	5.55	9.03
	Basin and Range	1.97	4.44	5.74
	Mississippi Portal	2.64	4.19	4.71
Soybeans	Heartland	1.97	3.47	4.98
	Northern Crescent	1.97	3.25	5.03
	Northern Great Plains	1.95	3.73	4.98
	Prairie Gateway	1.97	3.64	4.96
	Eastern Uplands	2.07	3.51	4.48
	Southern Seaboard	3.54	6.07	7.34
	Fruitful Rim	3.10	4.95	6.33
	Basin and Range	-----	-----	-----
	Mississippi Portal	2.10	3.70	4.52
Wheat	Heartland	1.91	3.23	4.87
	Northern Crescent	1.96	4.01	4.89
	Northern Great Plains	1.87	3.81	4.11
	Prairie Gateway	1.95	5.20	5.19
	Eastern Uplands	1.92	3.21	3.90
	Southern Seaboard	2.01	2.79	4.10
	Fruitful Rim	2.12	5.03	6.51
	Basin and Range	1.97	4.65	5.44
	Mississippi Portal	1.89	2.63	3.71

Table 23. Average diesel fuel use (gallons per acre) for tillage by crop for each Farm Resource Region and for all scenarios, weighted by tillage system adoption rates

Crop	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
				Status Quo Baseline					
Barley	3.66	3.53	3.74	3.50	3.54	3.52	4.29	3.80	----
Oats	3.91	3.89	3.89	3.66	3.61	3.54	4.41	3.82	----
Peanuts	----	----	----	4.64	6.00	6.00	4.98	----	4.67
Rice	4.65	----	----	4.97	3.76	3.46	7.26	7.51	3.12
Wheat	3.34	3.62	3.26	4.11	3.01	2.97	4.56	4.02	2.75
Corn	3.90	4.01	3.75	3.59	3.53	4.59	5.35	4.97	3.82
Cotton	5.54	----	----	5.50	5.76	6.79	7.25	9.06	6.27
Sorghum	3.22	3.22	3.22	3.38	3.05	4.81	5.28	3.61	3.60
Soybeans	3.24	3.34	3.60	2.84	3.14	5.27	4.52	----	3.20
				Minor Tillage Shift					
Corn	3.98	4.09	3.83	3.67	3.61	4.65	5.54	5.14	3.91
Cotton	5.67	----	----	5.63	5.89	6.87	7.45	9.32	6.39
Sorghum	3.33	3.33	3.33	3.50	3.15	4.97	5.47	3.76	3.68
Soybeans	3.32	3.42	3.69	2.92	3.21	5.39	4.61	----	3.28
				Moderate Tillage Shift					
Corn	4.00	4.11	3.86	3.70	3.64	4.66	5.61	5.20	3.94
Cotton	5.70	----	----	5.67	5.93	6.89	7.51	9.39	6.43
Sorghum	3.37	3.37	3.37	3.54	3.18	5.02	5.54	3.81	3.71
Soybeans	3.34	3.44	3.71	2.94	3.23	5.42	4.64	----	3.30
				Substantial Tillage Shift					
Corn	4.03	4.14	3.89	3.73	3.67	4.68	5.68	5.26	3.97
Cotton	5.73	----	----	5.71	5.96	6.91	7.56	9.47	6.46
Sorghum	3.40	3.40	3.40	3.59	3.21	5.08	5.61	3.86	3.74
Soybeans	3.36	3.46	3.74	2.97	3.25	5.45	4.66	----	3.32

Table 24. Projected price changes by crop for all non-triazine scenarios.

		Increasing Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley[a]	$3.95	$3.97	$0.02	0.5%	$3.97	$0.02	0.6%	$3.97	$0.02	0.4%
Corn[a]	$3.75	$3.99	$0.24	6.5%	$3.99	$0.24	6.5%	$3.99	$0.24	6.5%
Cotton[b]	$0.64	$0.63	$0.00	-0.2%	$0.63	$0.00	-0.2%	$0.63	$0.00	-0.2%
Hay[c]	$120.55	$120.43	-$0.12	-0.1%	$120.42	-$0.13	-0.1%	$120.41	-$0.14	-0.1%
Oats[a]	$2.35	$2.37	$0.02	1.0%	$2.37	$0.02	0.9%	$2.37	$0.02	0.9%
Peanuts[d]	$0.23	$0.23	$0.00	0.0%	$0.23	$0.00	0.0%	$0.23	$0.00	0.1%
Rice[e]	$11.78	$11.71	-$0.07	-0.6%	$11.71	-$0.07	-0.6%	$11.71	-$0.07	-0.6%
Sorghum[a]	$3.35	$3.97	$0.62	18.6%	$3.98	$0.63	18.7%	$3.98	$0.63	18.7%
Soybeans[a]	$8.80	$8.79	-$0.01	-0.1%	$8.80	$0.00	-0.1%	$8.80	$0.00	0.0%
Wheat[a]	$5.45	$5.43	-$0.02	-0.3%	$5.43	-$0.02	-0.3%	$5.43	-$0.02	-0.3%

		2009 Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley[a]	$3.95	$3.97	$0.02	0.6%	$3.97	$0.02	0.6%	$3.97	$0.02	0.5%
Corn[a]	$3.75	$4.05	$0.30	8.0%	$4.05	$0.30	8.0%	$4.05	$0.30	8.0%
Cotton[b]	$0.64	$0.63	$0.00	-0.2%	$0.63	$0.00	-0.1%	$0.63	$0.00	-0.1%
Hay[c]	$120.55	$120.43	-$0.12	-0.1%	$120.42	-$0.13	-0.1%	$120.41	-$0.14	-0.1%
Oats[a]	$2.35	$2.38	$0.03	1.1%	$2.37	$0.02	1.1%	$2.37	$0.02	1.0%
Peanuts[d]	$0.23	$0.23	$0.00	0.2%	$0.23	$0.00	0.2%	$0.23	$0.00	0.2%
Rice[e]	$11.78	$11.74	-$0.04	-0.3%	$11.74	-$0.04	-0.3%	$11.74	-$0.04	-0.3%
Sorghum[a]	$3.35	$4.01	$0.66	19.6%	$4.01	$0.66	19.7%	$4.01	$0.66	19.7%
Soybeans[a]	$8.80	$8.79	-$0.01	-0.1%	$8.79	-$0.01	-0.1%	$8.79	-$0.01	-0.1%
Wheat[a]	$5.45	$5.44	-$0.01	-0.2%	$5.44	-$0.01	-0.2%	$5.44	-$0.01	-0.2%

[a]Units are $/bushel. [b]Units are $/bale (480 pounds). [c]Units are $/ton (2,000 pounds). [d]Units are $/pound.
[e]Units are $/hundred weight (cwt).

Table 25. Projected crop acreage (1,000's) changes by crop for all non-triazine scenarios.

		Increasing Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley	4,000	3,980	-20	-0.5%	3,980	-20	-0.5%	3,981	-19	-0.5%
Corn	90,500	91,410	910	1.0%	91,399	899	1.0%	91,387	887	1.0%
Cotton	10,300	10,318	18	0.2%	10,317	17	0.2%	10,316	16	0.2%
Hay	60,890	60,954	64	0.1%	60,955	65	0.1%	60,957	67	0.1%
Oats	3,400	3,376	-24	-0.7%	3,377	-23	-0.7%	3,377	-23	-0.7%
Peanuts	1,267	1,266	-1	0.0%	1,266	-1	-0.1%	1,266	-1	-0.1%
Rice	3,100	3,106	6	0.2%	3,106	6	0.2%	3,106	6	0.2%
Sorghum	7,300	6,837	-463	-6.3%	6,835	-465	-6.4%	6,833	-467	-6.4%
Soybeans	71,000	71,071	71	0.1%	71,056	56	0.1%	71,041	41	0.1%
Wheat	59,500	59,659	159	0.3%	59,661	161	0.3%	59,663	163	0.3%
CRP	36,771	36,128	-643	-1.7%	36,142	-629	-1.7%	36,155	-616	-1.7%
Total	348,027	348,105	77	0.0%	348,093	66	0.0%	348,082	54	0.0%

		2009 Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley	4,000	3,975	-25	-0.6%	3,976	-24	-0.6%	3,976	-24	-0.6%
Corn	90,500	91,597	1,097	1.2%	91,585	1,085	1.2%	91,573	1,073	1.2%
Cotton	10,300	10,314	14	0.1%	10,313	13	0.1%	10,312	12	0.1%
Hay	60,890	60,959	69	0.1%	60,960	70	0.1%	60,962	72	0.1%
Oats	3,400	3,372	-28	-0.8%	3,372	-28	-0.8%	3,373	-27	-0.8%
Peanuts	1,267	1,264	-3	-0.2%	1,264	-3	-0.2%	1,264	-3	-0.2%
Rice	3,100	3,103	3	0.1%	3,103	3	0.1%	3,103	3	0.1%
Sorghum	7,300	6,855	-445	-6.1%	6,853	-447	-6.1%	6,851	-449	-6.2%
Soybeans	71,000	71,110	110	0.2%	71,095	95	0.1%	71,081	81	0.1%
Wheat	59,500	59,676	176	0.3%	59,678	178	0.3%	59,680	180	0.3%
CRP	36,771	35,893	-878	-2.4%	35,907	-864	-2.4%	35,920	-851	-2.3%
Total	348,027	348,117	90	0.0%	348,106	78	0.0%	348,094	67	0.0%

Table 26. Projected crop production changes for all non-triazine scenarios.

		Increasing Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley[a]	248	247	-1	-0.4%	247	-1	-0.4%	247	-1	-0.4%
Corn[a]	14,505	13,976	-529	-3.6%	13,975	-530	-3.7%	13,973	-532	-3.7%
Cotton[b]	18,255	18,293	38	0.2%	18,292	37	0.2%	18,291	36	0.2%
Hay[c]	159	159	0	0.0%	159	0	0.0%	159	0	0.0%
Oats[a]	101	100	-1	-0.9%	100	-1	-0.8%	100	-1	-0.8%
Peanuts[d]	4,558	4,556	-2	0.0%	4,556	-2	0.0%	4,556	-2	0.0%
Rice[e]	236	237	0	0.2%	237	0	0.2%	237	0	0.2%
Sorghum[a]	405	296	-109	-26.8%	296	-109	-26.9%	296	-109	-26.9%
Soybeans[a]	3,259	3,262	3	0.1%	3,261	2	0.1%	3,261	2	0.1%
Wheat[a]	2,301	2,305	4	0.2%	2,305	4	0.2%	2,305	4	0.2%

		2009 Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley[a]	248	247	-1	-0.5%	247	-1	-0.5%	247	-1	-0.4%
Corn[a]	14,505	13,863	-642	-4.4%	13,862	-643	-4.4%	13,860	-645	-4.4%
Cotton[b]	18,255	18,279	24	0.1%	18,278	23	0.1%	18,276	21	0.1%
Hay[c]	159	159	0	0.0%	159	0	0.0%	159	0	0.0%
Oats[a]	101	100	-1	-1.0%	100	-1	-1.0%	100	-1	-0.9%
Peanuts[d]	4,558	4,549	-9	-0.2%	4,549	-9	-0.2%	4,548	-10	-0.2%
Rice[e]	236	236	0	0.1%	236	0	0.1%	236	0	0.1%
Sorghum[a]	405	297	-108	-26.6%	297	-108	-26.6%	297	-108	-26.6%
Soybeans[a]	3,259	3,264	5	0.1%	3,263	4	0.1%	3,262	3	0.1%
Wheat[a]	2,301	2,304	3	0.1%	2,304	3	0.2%	2,305	4	0.2%

[a]Units are 1,000,000 bushels. [b]Units are 1,000 bales (480 pounds). [c]Units are 1,000,000 tons (2,000 pounds). [d]Units are 1,000,000 pounds. [e]Units are 1,000,000 hundred weight (cwt).

Table 27. Consumer surplus changes ($ million per year) for the non-triazine scenarios by crop and end use.

	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
Crop	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Corn	-3,464.2	-3,475.5	-3,486.8	-4,250.8	-4,262.2	-4,273.7
Sorghum	-218.7	-219.3	-219.8	-230.6	-231.1	-231.6
Barley	-4.5	-4.4	-4.3	-5.5	-5.4	-5.3
Oats	-2.3	-2.2	-2.2	-2.6	-2.5	-2.5
Peanuts	-0.4	-0.5	-0.6	-2.3	-2.4	-2.4
Wheat	34.8	35.5	36.3	28.5	29.3	30.1
Soybean	18.9	15.4	11.9	29.3	25.8	22.4
Hay	19.8	20.9	22.0	19.7	20.9	22.0
Rice	16.6	16.6	16.7	8.4	8.4	8.5
Cotton	12.9	12.6	12.2	8.5	8.1	7.7
Total[a]	-3,587.1	-3,600.8	-3,614.6	-4,397.2	-4,411.0	-4,424.9

	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
End Use	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Livestock[b]	-1,444.2	-1,447.8	-1,451.5	-1,764.8	-1,768.5	-1,772.1
Ethanol	-1,228.5	-1,232.5	-1,236.6	-1,513.4	-1,517.6	-1,521.8
Exports	-611.3	-614.5	-617.8	-743.6	-746.9	-750.1
Other[c]	-305.2	-307.9	-310.6	-380.3	-383.0	-385.7
Imports[d]	-2.2	-2.1	-2.0	-5.0	-4.9	-4.9
Total[a]	-3,587.0	-3,600.7	-3,614.4	-4,397.0	-4,410.8	-4,424.6

[a]Totals may not add due to rounding and changes in stocks.
[b]Not including distillers grain and other ethanol byproducts used as livestock feed.
[c]Includes food, seed and industrial uses other than ethanol production.
[d]Consumer surplus loss for importers is treated as a gain when summed over all end users.

Table 28. Total soil loss changes (million tons per year) from water and wind erosion by region for the non-triazine scenarios and contribution of the various effects to this total.

	Increasing Glyphosate Use on Corn Acres, Minor Tillage Shift					2009 Glyphosate Use on Corn Acres, Minor Tillage Shift				
Region	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total
Heartland	0.3	17.2	1.0	1.3	19.8	1.0	17.3	2.8	4.6	25.6
Northern Crescent	0.5	2.1	0.4	0.8	3.8	0.5	2.1	0.4	0.9	3.9
Northern Great Plains	0.1	0.6	3.7	4.5	8.9	0.2	0.6	4.3	5.2	10.3
Prairie Gateway	0.6	3.2	7.9	10.2	21.8	0.8	3.2	10.4	13.4	27.8
Eastern Uplands	-0.1	0.5	0.0	-0.3	0.1	-0.2	0.5	0.0	-0.9	-0.6
Southern Seaboard	-0.1	1.1	0.0	-0.4	0.7	-0.1	1.1	0.0	-0.8	0.1
Fruitful Rim	0.0	0.3	0.0	-0.3	0.0	0.0	0.3	0.0	-0.4	-0.1
Basin and Range	0.0	0.0	0.0	-0.7	-0.7	0.0	0.0	0.0	-0.9	-0.9
Mississippi Portal	0.1	1.6	0.0	-0.1	1.5	0.0	1.6	0.0	-0.2	1.4
Total	1.3	26.6	13.0	15.1	56.0	2.0	26.6	18.0	20.8	67.4

	Increasing Glyphosate Use on Corn Acres, Moderate Tillage Shift					2009 Glyphosate Use on Corn Acres, Moderate Tillage Shift				
Region	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total
Heartland	0.3	23.6	0.9	1.2	26.0	0.9	23.6	2.7	4.4	31.8
Northern Crescent	0.5	2.8	0.4	0.8	4.5	0.5	2.8	0.4	0.9	4.6
Northern Great Plains	0.1	0.8	3.7	4.4	9.0	0.2	0.8	4.3	5.1	10.3
Prairie Gateway	0.6	4.3	7.8	10.0	22.7	0.8	4.4	10.3	13.2	28.6
Eastern Uplands	-0.1	0.7	0.0	-0.3	0.3	-0.2	0.7	0.0	-0.9	-0.5
Southern Seaboard	-0.1	1.4	0.0	-0.4	1.0	-0.1	1.4	0.0	-0.8	0.5
Fruitful Rim	0.0	0.4	0.0	-0.3	0.1	0.0	0.4	0.0	-0.4	0.0
Basin and Range	0.0	0.0	0.0	-0.7	-0.7	0.0	0.0	0.0	-0.9	-0.9
Mississippi Portal	0.0	2.2	0.0	-0.2	2.1	0.0	2.2	0.0	-0.2	2.0
Total	1.3	36.3	12.7	14.6	65.0	1.9	36.4	17.7	20.4	76.3

Table 28 (cont.). Source of soil loss changes (million tons per year) from water and wind erosion by region for the non-triazine scenarios.

	Increasing Glyphosate Use on Corn Acres, Substantial Tillage Shift					Increasing Glyphosate Use on Corn Acres, Substantial Tillage Shift				
Region	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total	Acreage Shift	Tillage Shift	CRP Shift	New Land	Total
Heartland	0.3	29.9	0.8	1.1	32.1	0.9	30.0	2.7	4.3	37.9
Northern Crescent	0.4	3.6	0.4	0.8	5.2	0.5	3.6	0.4	0.9	5.3
Northern Great Plains	0.1	1.0	3.6	4.3	9.1	0.2	1.0	4.2	5.0	10.4
Prairie Gateway	0.6	5.5	7.6	9.9	23.6	0.7	5.5	10.1	13.1	29.5
Eastern Uplands	-0.1	0.9	0.0	-0.3	0.4	-0.3	0.8	0.0	-0.9	-0.3
Southern Seaboard	-0.1	1.8	0.0	-0.4	1.3	-0.1	1.8	0.0	-0.9	0.8
Fruitful Rim	0.0	0.5	0.0	-0.3	0.2	0.0	0.5	0.0	-0.4	0.0
Basin and Range	0.0	0.0	0.0	-0.7	-0.7	0.0	0.0	0.0	-0.9	-0.9
Mississippi Portal	0.0	2.7	0.0	-0.2	2.6	0.0	2.7	0.0	-0.2	2.5
Total	1.2	46.0	12.5	14.2	73.9	1.9	46.1	17.4	19.9	85.3

Table 29. Cost ($/ton) of eroded soil by region and the total value ($1,000,000 per year) of soil erosion prevented by use of triazine herbicides.

	Cost	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
Region	($/ton)	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Heartland	5.69	112.9	147.8	182.7	145.8	180.9	215.9
Northern Crescent	12.06	45.5	54.1	62.8	46.9	55.6	64.3
Northern Great Plains	1.72	15.3	15.5	15.6	17.6	17.8	17.9
Prairie Gateway	1.29	28.1	29.2	30.4	35.8	36.9	38.0
Eastern Uplands	6.07	0.8	1.7	2.6	-3.7	-2.8	-2.0
Southern Seaboard	6.19	4.1	6.2	8.3	0.9	3.0	5.0
Fruitful Rim	6.83	0.0	0.7	1.3	-1.0	-0.3	0.3
Basin and Range	4.59	-3.0	-3.1	-3.1	-4.2	-4.3	-4.3
Mississippi Portal	5.37	8.3	11.2	14.1	7.6	10.5	13.4
	Total Value	212.0	263.4	314.7	245.7	297.1	348.6
Pimentel et al. (1995)	7.21	404.0	468.3	532.6	486.1	550.4	614.8
Tegtmeir and Duffy (2004)	8.73	489.2	567.0	644.9	588.5	666.5	744.5

Table 30. Projected changes in diesel fuel use (1,000,000 gallons) for tillage by region for all non-triazine scenarios.

	---------- Increasing Glyphosate Use on Corn Acres ----------								
	------- Minor -------			------- Moderate -------			------- Substantial -------		
Region	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Heartland	373.2	7.7	2.1%	375.6	10.0	2.7%	377.9	12.4	3.4%
Northern Crescent	79.3	2.1	2.7%	79.7	2.6	3.3%	80.2	3.0	3.9%
Northern Great Plains	119.9	1.8	1.6%	120.2	2.2	1.8%	120.5	2.5	2.1%
Prairie Gateway	205.1	3.9	1.9%	205.9	4.7	2.3%	206.7	5.5	2.7%
Eastern Uplands	13.9	0.0	0.3%	13.9	0.1	0.8%	14.0	0.2	1.2%
Southern Seaboard	54.9	0.6	1.0%	55.0	0.8	1.4%	55.2	0.9	1.7%
Fruitful Rim	53.7	0.7	1.4%	54.0	1.0	1.9%	54.3	1.3	2.4%
Basin and Range	17.4	0.0	0.0%	17.4	0.0	0.0%	17.4	0.0	0.1%
Mississippi Portal	52.9	0.9	1.7%	53.2	1.2	2.2%	53.5	1.4	2.8%
Total	970.2	17.7	1.9%	975.0	22.5	2.4%	979.7	27.2	2.9%

	---------- 2009 Glyphosate Use on Corn Acres ----------								
	------- Minor -------			------- Moderate -------			------- Substantial -------		
Region	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Heartland	373.9	8.3	2.3%	376.2	10.7	2.9%	378.6	13.0	3.6%
Northern Crescent	79.3	2.2	2.8%	79.8	2.6	3.4%	80.2	3.1	4.0%
Northern Great Plains	120.0	2.0	1.7%	120.3	2.3	1.9%	120.7	2.6	2.2%
Prairie Gateway	205.5	4.3	2.1%	206.3	5.1	2.5%	207.1	5.9	2.9%
Eastern Uplands	13.7	-0.1	-0.7%	13.8	0.0	-0.3%	13.9	0.0	0.2%
Southern Seaboard	54.7	0.4	0.8%	54.9	0.6	1.1%	55.1	0.8	1.5%
Fruitful Rim	53.7	0.7	1.3%	54.0	1.0	1.8%	54.2	1.2	2.4%
Basin and Range	17.4	0.0	-0.2%	17.4	0.0	-0.1%	17.4	0.0	0.0%
Mississippi Portal	52.9	0.9	1.7%	53.1	1.1	2.2%	53.4	1.4	2.7%
Total	971.1	18.6	2.0%	975.9	23.4	2.5%	980.6	28.1	3.0%

Table 31. Projected changes in diesel fuel use (1,000,000 gallons) for tillage by crop for all non-triazine scenarios.

		Increasing Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley	15.4	15.3	-0.1	-0.5%	15.3	-0.1	-0.5%	15.3	-0.1	-0.5%
Corn	354	364	10.4	2.9%	367	12.9	3.6%	369	15.4	4.3%
Cotton	63.7	65.2	1.4	2.3%	65.5	1.8	2.8%	65.9	2.2	3.4%
Oats	13.2	13.1	-0.1	-0.7%	13.1	-0.1	-0.7%	13.1	-0.1	-0.7%
Peanuts	7.1	7.1	0.0	-0.1%	7.1	0.0	-0.1%	7.1	0.0	-0.1%
Rice	12.8	12.8	0.0	0.1%	12.8	0.0	0.1%	12.8	0.0	0.1%
Sorghum	26.8	26.1	-0.6	-2.4%	26.4	-0.3	-1.2%	26.8	0.0	0.0%
Soybeans	237	243	6.1	2.6%	245	7.7	3.3%	246	9.3	3.9%
Wheat	222	223	0.6	0.2%	223	0.6	0.3%	223	0.6	0.3%
Total	953	970	17.7	1.9%	975	22.5	2.4%	980	27.2	2.9%

		2009 Glyphosate Use on Corn Acres								
		Minor			Moderate			Substantial		
Crop	Baseline	Projected	Change	Change	Projected	Change	Change	Projected	Change	Change
Barley	15.4	15.3	-0.1	-0.6%	15.3	-0.1	-0.6%	15.3	-0.1	-0.6%
Corn	354	365	11.1	3.1%	368	13.6	3.8%	370	16.1	4.5%
Cotton	63.7	65.1	1.4	2.2%	65.5	1.8	2.8%	65.9	2.1	3.3%
Oats	13.2	13.1	-0.1	-0.8%	13.1	-0.1	-0.8%	13.1	-0.1	-0.8%
Peanuts	7.1	7.1	0.0	-0.3%	7.1	0.0	-0.3%	7.1	0.0	-0.3%
Rice	12.8	12.8	0.0	0.0%	12.8	0.0	0.0%	12.8	0.0	0.0%
Sorghum	26.8	26.2	-0.6	-2.1%	26.5	-0.2	-0.9%	26.8	0.1	0.3%
Soybeans	237	243	6.3	2.6%	245	7.9	3.3%	247	9.4	4.0%
Wheat	222	223	0.6	0.3%	223	0.6	0.3%	223	0.6	0.3%
Total	953	971	18.6	2.0%	976	23.4	2.5%	981	28.1	3.0%

Table 32. Projected changes in annual carbon dioxide emissions (Mg) due to changes in diesel fuel use for tillage by region and by crop for the non-triazine scenarios

	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
Region	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Heartland	77,393	101,164	124,932	83,923	107,746	131,565
Northern Crescent	21,226	25,804	30,377	21,729	26,310	30,887
Northern Great Plains	18,518	21,814	25,102	19,821	23,123	26,417
Prairie Gateway	38,913	46,979	55,053	43,373	51,470	59,577
Eastern Uplands	371	1,051	1,729	-1,035	-374	285
Southern Seaboard	5,720	7,642	9,564	4,247	6,164	8,079
Fruitful Rim	7,531	10,261	12,992	7,132	9,858	12,585
Basin and Range	-70.2	58.3	187	-270	-142	-14.4
Mississippi Portal	9,112	11,799	14,486	8,686	11,372	14,057
Total	178,714	226,574	274,420	187,606	235,528	283,437

	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
Crop	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Barley	-742	-725	-707	-900	-883	-865
Corn	104,738	129,880	155,011	111,821	137,011	162,190
Cotton	14,485	18,103	21,721	14,172	17,788	21,405
Oats	-938	-918	-898	-1,112	-1,092	-1,072
Peanuts	-49.7	-54.2	-58.8	-182.0	-186.4	-190.8
Rice	97.1	97.1	97.0	39.0	39.0	38.9
Sorghum	-6,403	-3,219	-32	-5,678	-2,488	704
Soybeans	61,953	77,776	93,597	63,355	79,189	95,022
Wheat	5,574	5,633	5,690	6,091	6,150	6,207
Total	178,714	226,574	274,420	187,606	235,528	283,437

Table 33. Summary of the benefits from triazine herbicides.

Monetary Benefits ($ million/year)	Increasing Glyphosate Use on Corn Acres			2009 Glyphosate Use on Corn Acres		
	Minor	Moderate	Substantial	Minor	Moderate	Substantial
Consumer Surplus	$3,587	$3,601	$3,615	$4,397	$4,411	$4,425
Reduced Erosion	$212	$263	$315	$246	$297	$349
Total	$3,799	$3,864	$3,929	$4,643	$4,708	$4,773
Other Benefits						
Reduced Erosion (million tons/year)	56.0	65.0	73.9	67.4	76.3	85.3
Reduced Diesel Fuel for Tillage (million gallons/year)	17.7	22.5	27.2	18.6	23.4	28.1
Reduced Carbon Dioxide Emissions (1,000 Mg/year)	179	227	274	188	236	283

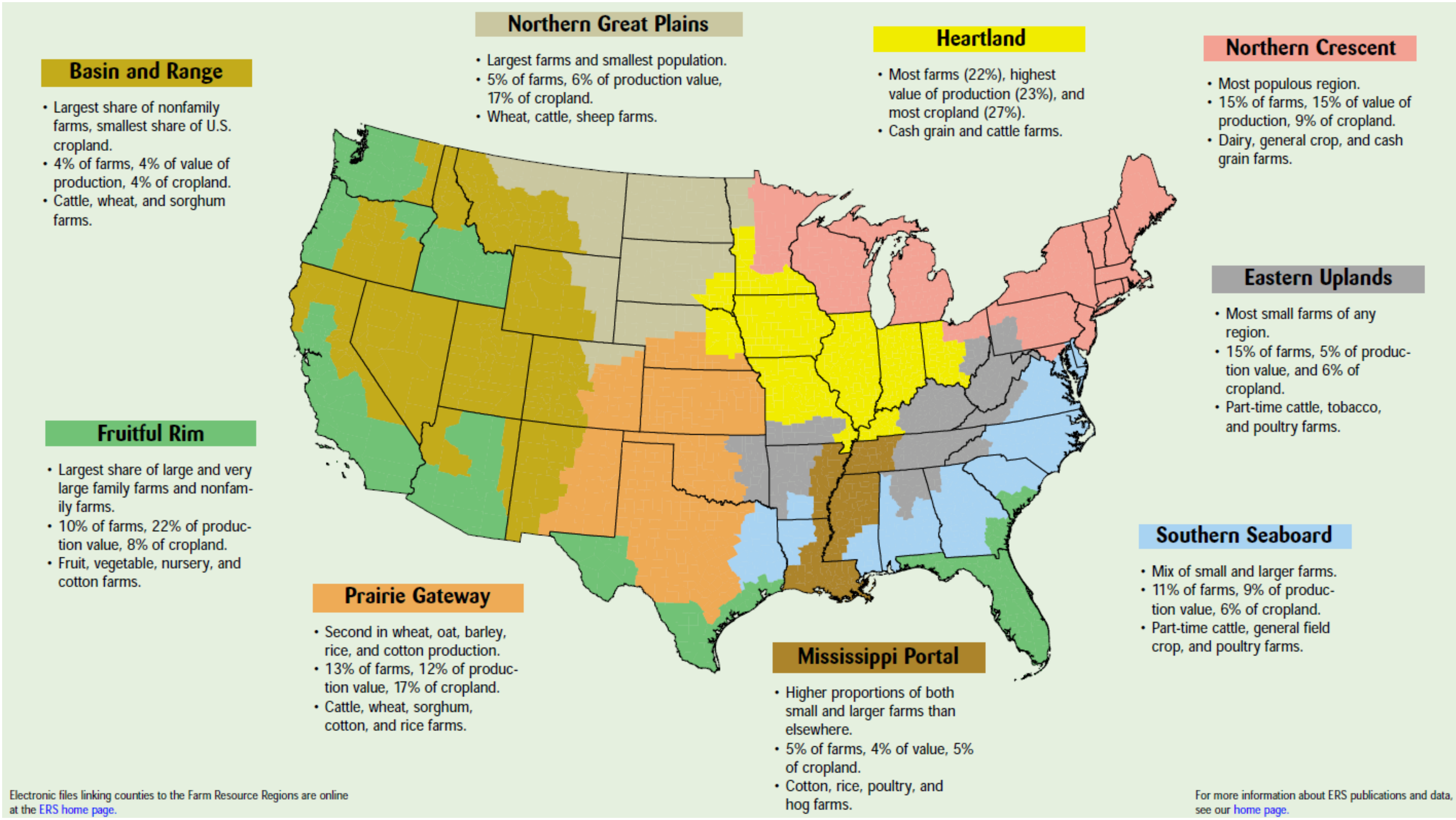

Figure 1. Map illustrating Farm Resource Regions and their agricultural characteristics (Source: USDA-ERS 2000).

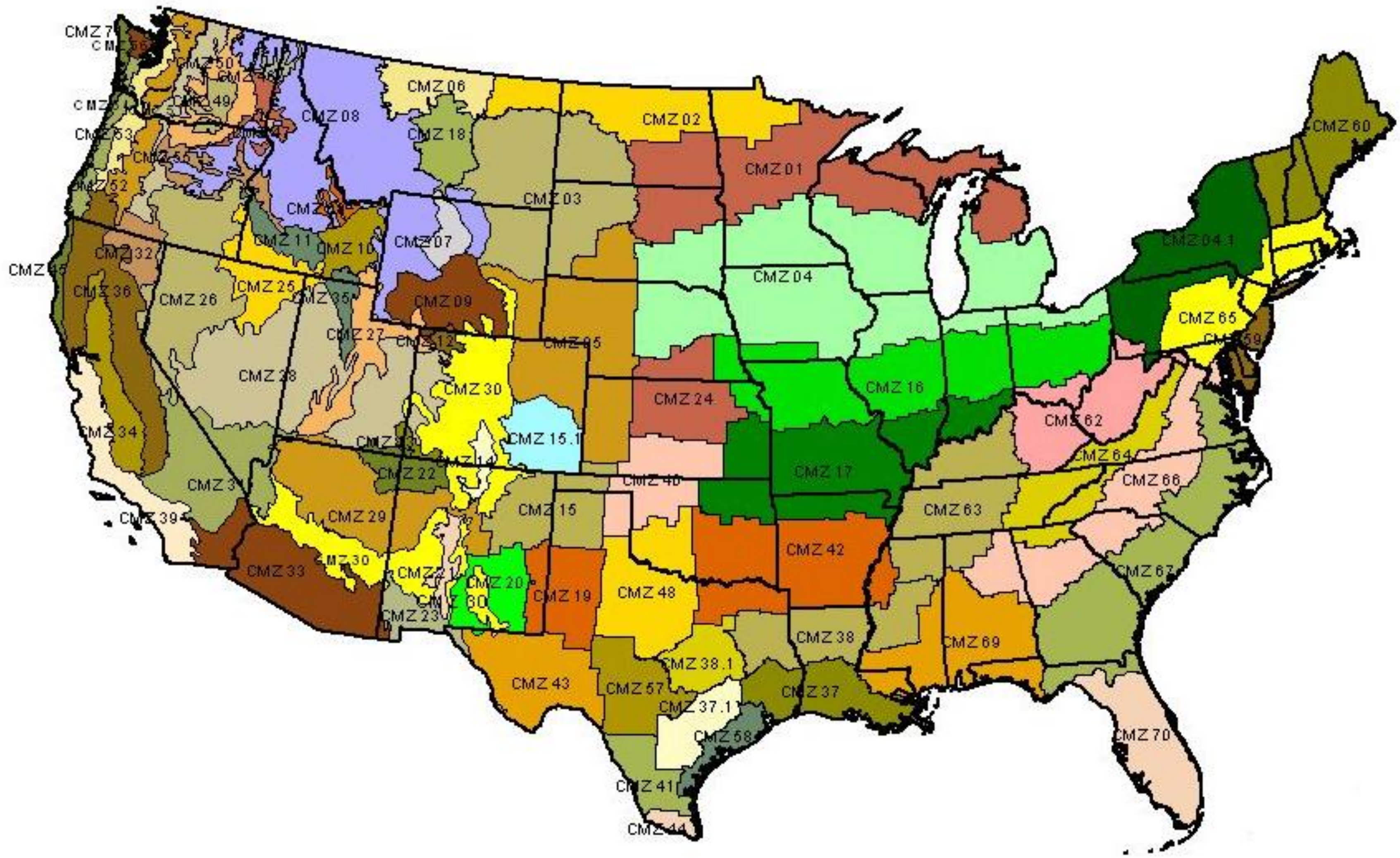

Figure 2. Map illustrating the crop management zones used for the tillage fuel use estimates (Source: USDA-NRCS 2007a).

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