Atrazine and Water Quality: An Evaluation of Restricting Atrazine Use on Corn and Sorghum to Postemergent Applications
CEEPES Atrazine Project Research Memo 6

CEEPES Project Team

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ABSTRACT

Atrazine is the most widely used herbicide for corn and sorghum and the most commonly encountered in ground and surface water. In addition to water quality problems, atrazine poses hazards through atmospheric transport, food residues, and exposure of applications and wildlife. If atrazine use is restricted, substitute herbicides will come into wider use, increasing the likelihood of occurrence of their own sets of potentially undesirable side effects and imposing cost or efficacy penalties.

This report updates the CEEPES evaluation of the economic and environmental costs of restricting atrazine to postemergent applications only. The policy results summarized in this paper highlight nominal impact on the economic welfare of domestic producers and consumers and a moderate decline in the at-risk area. In the short term the brunt of the impact was on producers, while in the long term the burden was shifted from producers to consumers. Concentrations of herbicides in groundwater were well within EPA benchmarks. Atrazine exposure index in surface water decreased markedly; however, exposures for several substitute chemicals increased, particularly simazine.

ATRAZINE AND WATER QUALITY: AN EVALUATION OF RESTRICTING ATRAZINE USE ON CORN AND SORGHUM TO POSTEMERGENT APPLICATIONS

This paper summarizes the Comprehensive Environmental Economic Policy Evaluation System (CEEPES) evaluation of a policy restricting the use of atrazine to postemergent applications only. CEEPES is an integrated modeling system developed to estimate the economic and environmental consequences of alternative agricultural and environmental policies. CEEPES integrates diverse simulation models constructed around four components—policy, agricultural decisions, fate and transport, and health and ecological risk. Figure 1 illustrates the general CEEPES system. The CEEPES study region includes the Corn Belt and Lake States region, plus a portion of the Northern Plains region and five other U.S. Department of Agriculture (USDA) agricultural producing regions. Figure 2 shows the CEEPES study region.

The CEEPES system is updated to characterize weed control strategies separately for predominantly sandy soils and predominantly clay soils, resulting in nearly 500 alternative weed control strategies for corn and 150 strategies for sorghum. These strategies are aimed at controlling both grasses and broadleaf weeds. Each strategy now includes a primary and a backup application, a set of herbicides used either individually or in tank mixes, a tillage practice (no-till, reduced, and conventional), chemical application rates, an application mode (broadcast or incorporated), a timing of application (early preplant, preplant incorporated, preemergent, postemergent), windows of application and effectiveness for both the primary and the secondary strategies, and a soil type. Weed control strategies have also been updated to reflect new information, including information about the effectiveness of sulfonylureas (nicosulfuron and primisulfuron). As a result of this new information primisulfuron is no longer included in our weed control strategies. See Bouzaher et al. (1992a,b) for details of the weed control model WISH (Weather Impact Simulation for Herbicide).

The weed control information generated by WISH is fed into RAMS (Resource Adjustable Modeling System), a regional, short-term, static, profit-maximizing, linear programming (LP) model of agricultural production that is the economic decision model for CEEPES. The objective function of RAMS maximizes total returns from marketings and government programs excluding the total cost of production and weed control. A detailed weed control subsector linked to crop production through herbicide management practices, productivity response, resource use, and chemical cost is

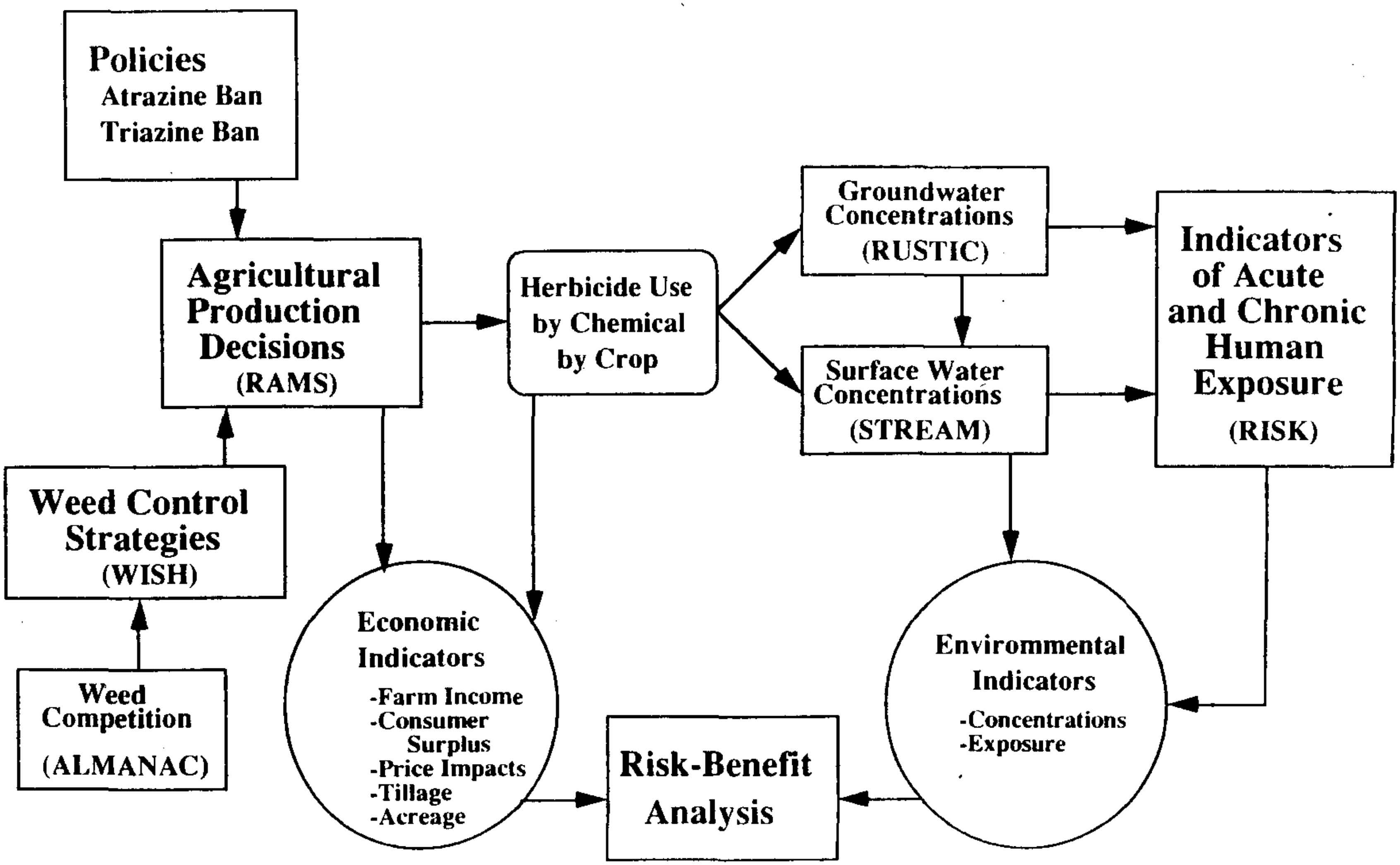

Figure 1. CEEPES configuration for atrazine

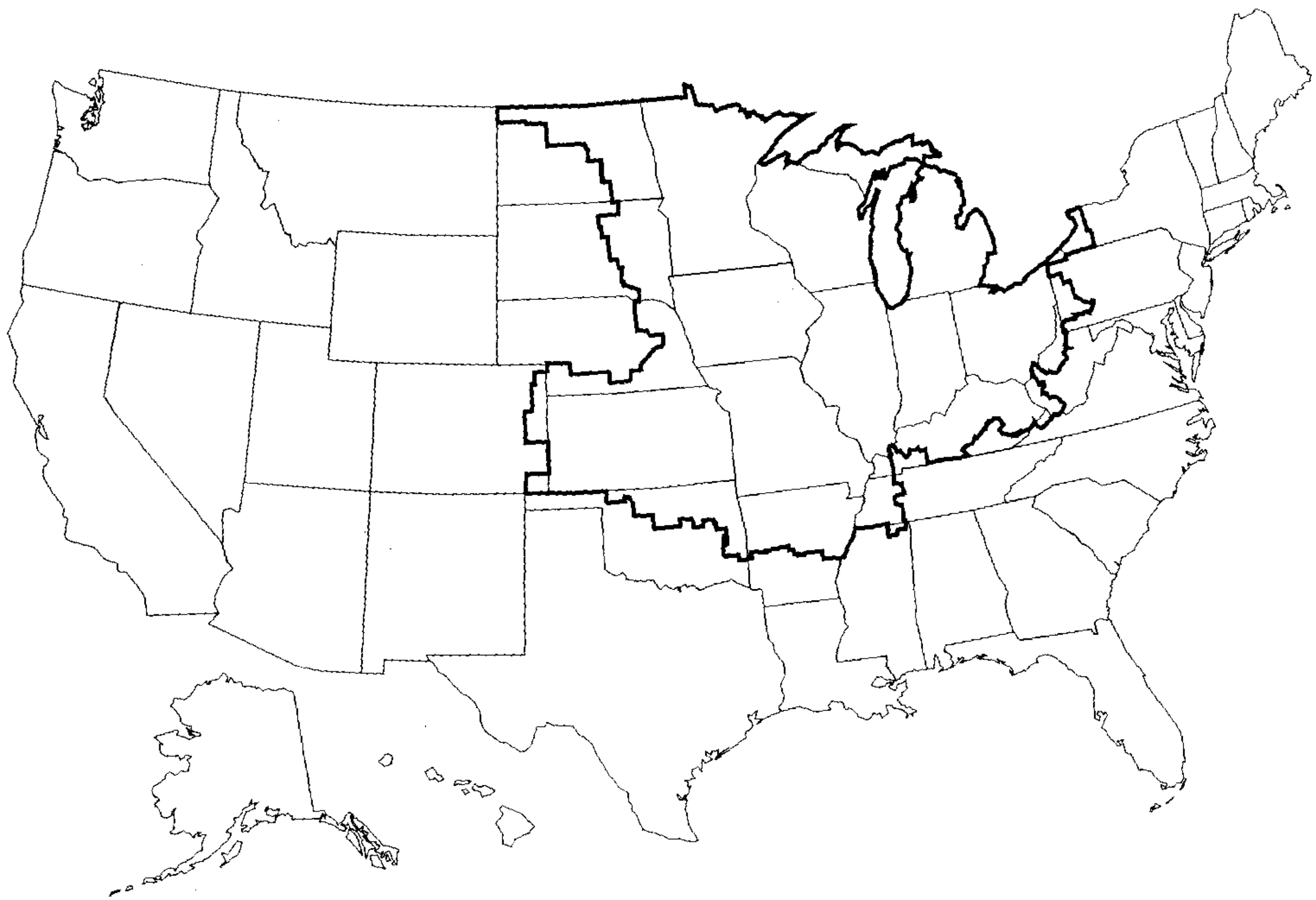

Figure 2. CEEPES study region

incorporated in RAMS to simulate substitution between weed control strategies. RAMS simulates behavior of a representative producer at the producing area (watershed) level. The optimal agricultural production practices from RAMS, for each policy scenario, are then linked to the fate and transport models STREAM (Stream Transport and Agricultural Runoff of Pesticides for Exposure Assessment) and RUSTIC (Risk of the Unsaturated/Saturated Transport and Transformation of Chemical Concentrations). This linkage is accomplished through metamodels.

Because of the nonavailability of data on ground and surface water pollution from herbicides, using mathematical models to simulate herbicide fate and transport is the practical approach for ex ante evaluation of herbicide policies. However, integrating these complex simulation models with the regional economic model for alternative herbicide policy evaluation poses additional limitations. Therefore, a novel procedure called *metamodeling* is used to predict the impact of optimal agricultural production practices on water quality. Metamodeling is a statistical method to abstract away from unneeded detail for regional analysis by approximating outcomes of a complex mathematical process model through statistically validated response functions. This process then allows the researcher to construct alternative policy evaluations without additional simulations. See Bouzaher et al. (1993) for details of the metamodeling procedure and the specific metamodels developed for CEEPES evaluation. Metamodels to predict herbicide concentrations in groundwater at 1.2 and 15 meters and surface water were fitted from 7,518 area-wide simulations of corn and sorghum under alternative tillage practices and timing of herbicide applications. The area-wide simulations captured the spatial heterogeneity (ubiquitous in nonpoint pollution processes) introduced by soil, hydrology, and weather using a statistically sampled distribution of these spatial parameters.

Details on the CEEPES system are available in CARD Research Memos 3, 4, and 5 (also CARD 1993). This study focuses on evaluating a policy of allowing only postemergent applications of atrazine on corn and sorghum. This policy is considered as an alternative to a total ban on the use of atrazine. The idea is to eliminate atrazine use when there are substitute herbicides that may achieve similar levels of control, and allow the continued use of atrazine for postemergent application where substitute herbicides may not be as effective. This policy also shifts atrazine applications to a typically drier part of the season, reducing the potential for runoff. The results here are aggregated over the entire study region, but they are available for states or USDA farm production regions. It should also be noted that the policy impacts measured as relative shifts from baseline are of more merit than the actual or absolute values.

The results of the baseline reported here are different from earlier results published in Research Memo 5 (CARD Staff Report 93-SR 59) because of the modifications made to WISH. The major changes include decoupling sand and clay strategies and excluding one of the two sulfonylureas—primisulfuron (Beacon). Some recommendations by weed scientists on herbicide efficacy have been incorporated, but information on crop injury has not been included because the necessary data are not yet available. We use the common chemical names of herbicides and their brand names interchangeably in this report. Appendix A provides a cross-reference for the herbicides modeled and their brand names. Appendix B shows the shifts in weed control strategies for corn and sorghum under alternative policies. Appendix C reports the estimated area-wide average ground and surface water concentrations of corn and sorghum herbicides. Appendix D repeats some results from other tables, but the results from two scenarios—atrazine post restriction and atrazine ban—are combined for easy reference. The results of the atrazine ban are different from the earlier results because of the modifications researchers have made to WISH.

Baseline Use of Triazine Herbicides

The basic data used to calibrate the baseline herbicide use in CEEPES were obtained from Resources for the Future (Gianessi and Puffer 1991). We do not calibrate the baseline use in CEEPES to exactly match the RFF data for two reasons. First, the RFF data are based on a single year survey, while the results in CEEPES represent average use over several years. Second, the sulfonylurea herbicide nicosulfuron was introduced following the RFF survey and we assume its potential benefit is fully understood and adopted by producers. Table 1 presents the amounts of atrazine and other triazines used in the study region. Baseline atrazine use in the CEEPES system is approximately 37.6 million pounds active ingredient (a.i.) on corn and about 4.1 million pounds active ingredient on sorghum. The use of all triazines combined is about 70.2 million pounds active ingredient for corn and 4.2 million pounds active ingredient for sorghum.

Economic Impacts

Table 2 presents changes in acreage of major crops. For the atrazine restriction scenario, corn acreage and sorghum acreage decline while soybean acreage increases. Corn acreage decreases by 2.6 percent from the baseline of 72.46 million acres and soybean acreage increases by 3.5 percent from the baseline of 43.87 million acres. Sorghum acreage decreases slightly, 0.5 percent from the

Table 1. Current use of atrazine and all triazines in the study region

Crop	Chemical	RFF 1991[a]	CEEPES[a] Baseline	NAPIAP Study[b]
			million pounds a.i.	
Corn	Atrazine	39.9	37.6	50.6
	All Triazines	58.7	70.2	72.3
Sorghum	Atrazine	6.3	4.1	4.1
	All Triazines	6.3	4.2	4.1

Note: NAPIAP (1992) figures are used as references for comparison.

[a]Value reported is for the CEEPES study region.

[b]Value reported is for 12 midwestern states.

baseline of 5.41 million acres. A notable reduction in summer fallow of 2.3 percent also occurs in response to shifts in the relative profitability of crops. Table 3 shows changes in yields for major crops. Corn yields decrease by 1.1 percent for an atrazine restriction while sorghum yields increase slightly, 0.4 percent from a baseline of 79.9 bushels per acre. While producers are able to maintain baseline yields under the atrazine restriction, they incur significantly higher herbicide costs to achieve these yields. Table 4 shows weed control costs per acre increasing 17.5 percent for sorghum while weed control costs for corn increase 5.7 percent.

Table 5 shows average per acre atrazine use on corn declining 75 percent for label rates over 1.5 pounds active ingredient (a.i.) per acre, while atrazine use on corn at label rates under 1.5 pounds per acre drops to zero. Per acre atrazine use on sorghum at label rates greater than 1.5 pounds drops to zero, while atrazine use on sorghum at label rates under 1.5 pounds per acre declines 19 percent. Under an atrazine restriction, average per acre use of atrazine decreases sharply as atrazine is used largely as a backup strategy and no longer as a primary strategy. Average per acre herbicide use is calculated for each weed control strategy as the average of herbicide applications over a 50-year period using years when the herbicide is applied at the label rate and years when the herbicide is not applied. Average per acre use of chemicals as part of the backup strategy is typically lower because they are applied only when the primary strategy fails. Restricting atrazine to postemergent applications tends, however, to increase per acre herbicide use for other triazines used on corn. The average per acre use of cyanazine increases by 56 percent, implying an increase of 0.31 pounds per acre, and the average per acre use of simazine increases by 16 percent, implying an increase of 0.25

Table 2. Crop acreage shifts from baseline for atrazine restriction

Crop	Baseline	Atrazine Post Restriction	Change
	million acres		percent
Barley	5.22	5.22	0.0
Corn	72.46	70.58	-2.6
Cotton	1.23	1.23	0.0
Hay	52.71	53.08	0.7
Oats	4.88	4.94	1.2
Sorghum	5.41	5.38	-0.5
Soybeans	43.87	45.39	3.5
Summer fallow	6.15	6.00	-2.3
Sunflowers	1.05	1.05	1.05
Wheat	23.52	23.62	0.4

Table 3. Changes in crop yields from baseline for atrazine restriction

Crop	Baseline	Atrazine Post Restriction	Change
	Units		percent
Barley (bu)	48.2	48.2	0.0
Corn (bu)	109.1	107.9	-1.1
Corn silage (tons)	10.6	10.7	1.7
Cotton (bales)	1.5	1.5	0.0
Legume hay (tons)	4.4	4.4	0.0
Nonlegume hay (tons)	1.0	1.0	0.0
Oats (bu)	52.6	52.6	0.0
Sorghum (bu)	79.9	80.3	0.4
Sorghum silage (tons)	11.4	11.4	0.0
Soybeans (bu)	36.3	36.4	0.2
Sunflowers (bu)	13.2	13.2	0.0
Spring wheat (bu)	32.0	32.1	0.2
Winter wheat (bu)	56.1	56.1	0.1

Table 4. Changes in herbicide cost per treated acre

Crop	Baseline	Atrazine Post Restriction	Change
	$ per acre		percent
Corn	10.80	11.41	5.7
Sorghum	8.55	10.04	17.5

pounds per acre. In corn, the atrazine restriction also results in average per acre use of pendimethalin and 2,4-D each increasing by about 0.2 pounds of active ingredient per acre. Another interesting result is that the average per acre use of alachlor on corn declines by 16 percent, implying a decrease of 0.12 pounds per acre.

Table 6 shows changes in acres treated with herbicides. Under the atrazine restriction, acres of corn treated with atrazine applied at more than 1.5 pounds per acre increase by 54 percent since atrazine is no longer applied at rates less than 1.5 pounds per acre. About 43 million acres of corn were treated with atrazine at rates less than 1.5 pounds per acre in the baseline. Conversely, sorghum acres treated with atrazine at less than 1.5 pounds per acre increase by 40 percent because atrazine is no longer used at rates greater than 1.5 pounds per acre. The atrazine restriction also increases corn acres treated by simazine (an increase of 5.6 million acres or 70 percent) and the acres treated by the nontriazine herbicides bentazon, butylate, alachlor, and metolachlor. Even though alachlor-treated acres increased by 17 percent the average use per acre declined by 16 percent, implying a net reduction in alachlor use of 0.4 million pounds active ingredient. In sorghum, the atrazine restriction increases the acres treated by cyanazine and the acres treated by the nontriazine herbicides alachlor, pendimethalin, and propachlor.

Table 7 summarizes total corn and sorghum herbicide use in the study region. Under the atrazine restriction, atrazine use on corn decreases 91 percent from a baseline of 37.6 million pounds active ingredient and atrazine use on sorghum decreases 44 percent from a baseline of 4.1 million pounds active ingredient. Less atrazine on corn is offset by an increase in other triazines (an increase of 22.5 million pounds or 69 percent) and nontriazines. As a result, total pounds of active ingredient of all herbicides used on corn decrease by less than 1 percent. Most of the decline in atrazine use on sorghum is attributable to a reduction in average per acre herbicide use rather than a decrease in acres treated and an offsetting increase in other triazines (an increase of 0.4 million pounds or 400 percent)

Table 5. Average per acre herbicide use

Chemical	Crop	Baseline	Atrazine Post Restriction	Change
		lb. a.i. per acre		percent
Atrazine >1.5 lb/a	Corn	0.83	0.20	-75.47
	Sorghum	2.14	0.00	-100.00
Atrazine <1.5 lb/a	Corn	0.66	0.00	-100.00
	Sorghum	0.82	0.66	-19.05
Nicosulfuron	Corn	0.01	0.01	33.20
	Sorghum	0.00	0.00	0.00
Dicamba	Corn	0.04	0.05	15.64
	Sorghum	0.06	0.09	41.18
Cyanazine	Corn	0.54	0.85	56.18
	Sorghum	0.76	0.69	-9.36
Bromoxynil	Corn	0.01	0.02	19.12
	Sorghum	0.06	0.06	11.81
Bentazon	Corn	0.04	0.03	-12.54
	Sorghum	0.05	0.06	13.70
Metolachlor	Corn	0.72	0.54	-24.41
	Sorghum	1.14	1.19	3.89
EPTC	Corn	0.00	0.00	0.00
	Sorghum	0.00	0.00	0.00
Alachlor	Corn	0.72	0.60	-16.26
	Sorghum	0.89	1.13	26.75
Simazine	Corn	1.52	1.77	16.16
	Sorghum	0.00	0.00	0.00
Pendimethalin	Corn	0.06	0.30	383.81
	Sorghum	0.70	0.73	4.40
Propachlor	Corn	2.12	0.00	-100.00
	Sorghum	1.93	1.40	-27.69
Glyphosate	Corn	0.00	0.00	0.00
	Sorghum	0.85	0.85	0.00
Butylate	Corn	2.04	1.90	-6.85
	Sorghum	0.00	0.00	0.00
2,4-D	Corn	0.06	0.27	320.78
	Sorghum	0.08	0.18	129.55

Table 6. Acres treated in study region

Chemical	Crop	Baseline	Atrazine Post Restriction	Change
		million acres		percent
Atrazine >1.5 lb/a	Corn	11.09	17.09	54.08
	Sorghum	0.97	0.00	-100.00
Atrazine <1.5 lb/a	Corn	43.25	0.00	-100.00
	Sorghum	2.50	3.50	39.98
Nicosulfuron	Corn	50.04	39.77	-20.52
	Sorghum	0.00	0.00	0.00
Dicamba	Corn	65.19	52.60	-19.31
	Sorghum	3.08	2.41	-21.78
Cyanazine	Corn	38.05	37.40	-1.71
	Sorghum	0.06	0.75	1209.10
Bromoxynil	Corn	52.39	49.88	-4.79
	Sorghum	0.86	0.70	-17.98
Bentazon	Corn	2.36	10.11	329.40
	Sorghum	0.86	0.70	-17.98
Metolachlor	Corn	29.82	30.66	2.80
	Sorghum	1.27	1.16	-8.78
EPTC	Corn	0.00	0.00	0.00
	Sorghum	0.00	0.00	0.00
Alachlor	Corn	26.03	30.57	17.41
	Sorghum	0.51	0.62	20.45
Simazine	Corn	7.82	13.20	68.82
	Sorghum	0.00	0.00	0.00
Pendimethalin	Corn	2.16	1.02	-52.80
	Sorghum	2.50	3.50	39.98
Propachlor	Corn	0.16	0.00	-100.00
	Sorghum	0.21	0.87	316.87
Glyphosate	Corn	0.00	0.00	0.00
	Sorghum	0.00	0.00	-0.26
Butylate	Corn	2.33	9.48	306.14
	Sorghum	0.00	0.00	0.00
2,4-D	Corn	13.62	12.16	-10.70
	Sorghum	2.04	1.56	-23.58

Table 7. Herbicide use in study region

Herbicide Group	Crop	Current Use in CEEPES (baseline)	Atrazine Post Restriction	Change
		mil. lb. a.i.		percent
Atrazine	Corn	37.6	3.5	-91
	Sorghum	4.1	2.3	-44
All triazines	Corn	70.2	58.6	-17
	Sorghum	4.2	2.8	-32
Nontriazines	Corn	50.2	60.8	21
	Sorghum	4.5	6.4	43
All herbicides	Corn	120.4	119.4	-1
	Sorghum	8.7	9.3	7

and nontriazines. As a result, total pounds active ingredient of all herbicides used on sorghum increase 7 percent from a baseline of 8.7 million pounds.

The welfare measures associated with yield and cost impacts of restricting atrazine to postemergence applications were estimated using the AGSIM (Agricultural Sector Integration Model) developed by Robert Taylor of Auburn University (Penson and Taylor 1992). Table 8 presents both short-term (1993-96) and long-term (2005-2008) welfare effects, including producer income, domestic consumption, foreign consumption, and government outlays. In the short term, average annual decreases in total economic welfare would be about $159 million under a restriction of atrazine to postemergent applications. Producer income would decline by $204 million compared with a baseline of $37 billion. Crop producers in the Corn Belt bear most of the burden, with producer income from crops being reduced by $147 million. The effect of the restriction on both international and domestic consumers is negligible with a decrease in domestic consumer surplus of $19 million and a decrease in foreign consumer surplus of $1 million. Considering that annual domestic food expenditures are $655 billion (ERS 1992), the $19 million decrease in domestic consumer surplus is very small. While expenditures and surplus measures are not directly comparable, expenditures do provide perspective. Changes in government outlays are also small, dropping by $65 million from a baseline of $3.3 billion.

Long-term impacts may not be as meaningful for this analysis because no information was included on new, potentially more effective, weed control technologies like biological controls or new

Table 8. Aggregate economic effects of atrazine post restriction

Welfare Effects	Short-term	Long-term
	million $	
Producer income	-204	-50
Domestic consumer effect	-19	-193
Foreign consumer effect	-1	-52
Government outlays	(-65)	(-1)
Total economic effect	-159	-294

chemical substitutes. Under the current assumptions, however, total welfare impacts would be of the same magnitude as in the short run, but some of the burden is shifted from producers to consumers.

Table 9 shows the corresponding commodity price effects both for the short and the long term. In the short term, all commodity prices change less than 1 percent. The largest price effects are a 0.4 percent increase in the corn price and a 0.6 percent decrease in the hay price. Sorghum prices decrease 0.2 percent. These changes in crop prices have almost no short-term effect on livestock prices. In the long term, price impacts are slightly higher, with corn and barley prices showing the largest price changes. The corn price is expected to increase 1.1 percent while the price of barley is expected to decrease 1.0 percent. Sorghum prices are expected to be almost unchanged.

Table 9. Price effects of atrazine post restriction on selected commodities

Crop[a]	Short-term	Long-term
	percent change	
Corn	+0.4	+1.1
Sorghum	-0.2	+0.1
Soybeans	-0.2	+0.5
Oats	+0.1	-0.2
All hay	-0.6	-0.6
Wheat	-0.2	-0.2
Barley	~0.0	-1.0
Cotton	~0.0	+0.1

[a] Price effects on livestock and livestock products in the short term are close to zero.

Input Substitution Effects

The use of herbicides under the various scenarios is indicated by the distribution of corn and sorghum acres treated by different herbicide strategies (Appendix B). In the baseline, more than 50 percent of corn acres and more than 55 percent of sorghum acres are treated with a mix of strategies containing atrazine. Under the atrazine restriction the percentage of corn acres treated with atrazine drops to less than 25 percent, while the percentage of sorghum acres treated with atrazine remains above 55 percent. In corn, primary strategies consisting of tank mixes of atrazine and Bladex, atrazine and Lasso, and atrazine and Dual are replaced with Bladex and Dual tank mixes and Bladex and Lasso tank mixes. The atrazine restriction leads to the use of more two-part primary applications for both corn and sorghum consisting of a preplant application of grass herbicides such as Sutan, Lasso, or Dual, and a postemergent application of broadleaf herbicides such as Banvel, Buctril, and 2,4-D. These two-part applications account for more than 15 percent of sorghum acres treated under the atrazine post scenario. Strategies containing the sulfonylurea herbicide nicosulfuron are used on more than 50 percent of corn acres in the baseline, and this usage is maintained under the atrazine restriction.

Environmental Impacts

Environmental indicators complete the picture of the welfare impacts of an atrazine restriction in the study region. Since a single average indicator of water quality across the study region would be almost meaningless, we present results indicating *relative risk* to humans and ecosystems, and the spatial distribution of these indicators identifying the most vulnerable soils (hot spots), which is useful for targeting purposes. In addition, results are separated by crop, tillage, surface water and groundwater, and chemical. Since some of the results are shown by tillage it is important to know the estimated distribution of tillage for corn, sorghum, and *all* crops under alternative scenarios. Table 10 presents the estimated share of different tillage practices. Note that an atrazine restriction decreases the share of no-till corn and sorghum, which is offset by an increase in no-till in other crops.

The peak and average chemical concentration levels found in surface and groundwater are transformed into a unitless measure of risk that we call an *exposure value*, whereby pesticide-specific benchmarks for human health and aquatic habitat are used to weight the relative importance of pesticide concentrations. The term *exposure value* is used to prevent confusing such values with

Table 10. Estimated proportion of acreage under different tillage practices

Tillage	Crop	Baseline	Atrazine Post Restriction
Conventional	Corn	0.5774	0.5721
	Sorghum	0.4516	0.4491
	All Crops	0.6941	0.6933
Reduced	Corn	0.3686	0.3837
	Sorghum	0.5468	0.5489
	All Crops	0.2797	0.2805
No-till	Corn	0.0540	0.0442
	Sorghum	0.0016	0.0020
	All Crops	0.0262	0.0262

estimates of absolute risk. Instead, their purpose is solely for comparing policies and practices and serving as rough indicators of water quality. Using a benchmark for environmental hazards, such as drinking water Maximum Contaminant Levels (MCLs) for long-term exposures and ten-day Health Advisories for short-term exposures, we calculate the exposure for each chemical as:[1]

$$\text{Exposure Value (hazard-weighted exposure)} = \frac{\textit{predicted concentration}}{\textit{environmental benchmark}} .$$

The exposure value normalizes concentration levels, thereby allowing us to compare risks across herbicides and across policies. If the exposure value exceeds unity, the concentration exceeds the benchmark. A chemical detected in groundwater or surface water represents a greater risk in proportion to the exceedance of the benchmark. Note that more reliance should be placed on exposure values rather than concentrations and on relative differences rather than absolute values (USEPA 1992). The surface water concentrations shown here are "in-stream" concentrations calculated from the "edge-of-field" loading, and are considered accurate within an order of magnitude and typically overestimate actual concentrations. This is especially important for the in-stream concentrations that were estimated on the basis of edge-of-field loading from RUSTIC. This implies

[1] Usually the peak (acute) concentrations are evaluated against a short-term benchmark, while the average (chronic) concentrations are evaluated against a long-term benchmark.

that every field lies adjacent to a stream, and does not account for buffer effects of other fields, riparian zones, and so forth. Also, it does not account for decay, soil adsorption, or other chemical processes that often occur in actual chemical runoff between a field and a surface water body.

Table 11 presents the human health exposure values, as percentage of treated acres in which the concentrations exceed the benchmark, for surface water from peak loadings in stream, by chemical and tillage, under baseline use, and under the restriction of atrazine to postemergent applications in corn production. For the set of weed control strategies and the acres of crop activity chosen by RAMS under each scenario, the peak concentration in surface water was calculated using the surface water metamodel. These herbicide concentrations which were calculated by soil type, are compared with the benchmark for 10-day HA for human health exposure. The acreage of each soil in which the concentrations exceed the benchmark are aggregated for each herbicide. This value, which is termed *at-risk area* is shown in Table 11 as percentage of total corn acres treated with that herbicide. The percentage of exceedance by tillage is the estimated at-risk acres relative to corn acres treated. For example, the first row in Table 11 shows that about 5.44 percent of corn acres under conventional tillage would have concentrations of atrazine in surface water exceeding the benchmark of 100 parts per billion (the 10-day HA for short-term exposure) under baseline conditions. For reduced tillage it is 3.76 percent and for no-till it is 61.24 percent. Since the total no-till acres is small compared to other two tillages and since a large portion of no-till acres is treated with atrazine at rates greater than 1.5 pounds active ingredient per acre, the percentage of exceedance under no-till is significantly larger. Therefore, in the last column of this table a weighted sum across tillage is shown.

The percentage of exceedance is reported separately for acres of atrazine applied at more than 1.5 pounds active ingredient per acre and for atrazine applied at less than 1.5 pounds active ingredient per acre. Under an atrazine post scenario, the percentage of at-risk acres from atrazine applied at more than 1.5 pounds active ingredient per acre drops by more than one-half of what it was in the baseline for conventional and no-till, and there are no at-risk acres under reduced tillage. On a tillage-weighted basis, at-risk acres decrease from 7.8 percent under the baseline to 2.3 percent under the atrazine post scenario. The percentage of at-risk acres from atrazine applied at less than 1.5 pounds per acre drops to zero for all three tillages because atrazine is no longer used for weed control at the lower rate. However, the proportion of at-risk area from other herbicides increases under the atrazine post scenario. Cyanazine, bentazon, and simazine under conventional tillage, cyanazine and metolachlor under reduced tillage, and alachlor and simazine under no-till show increases. In

Table 11. Percentage of corn acres treated with herbicides that are at risk

Chemical	Conventional Tillage	Reduced Tillage	No-till	Weighted Sum
		percent		
Baseline				
Atrazine >1.5	5.44	3.76	61.24	7.83
Atrazine <1.5	38.44	3.26	5.14	23.67
Cyanazine	19.41	3.39	0.00	12.46
Bentazon	1.76	7.06	0.00	3.62
Metolachlor	0.17	0.30	30.63	1.86
Alachlor	11.69	4.22	2.58	8.44
Simazine	58.50	1.63	11.38	34.99
Propachlor	0.00	2.43	0.00	0.90
Atrazine Post				
Atrazine >1.5	2.33	0.00	23.48	2.37
Cyanazine	21.89	13.65	0.00	17.76
Bentazon	10.50	0.00	0.00	6.01
Metolachlor	0.01	0.74	24.61	1.38
Alachlor	2.13	2.91	12.79	2.90
Simazine	64.37	0.41	34.37	38.50

Note: Risk is measured as peak surface water concentration exceeding the 10-day HA benchmark of the ppb. Chemicals not shown in the baseline imply zero at-risk acres. If a chemical appears in the baseline but does not show up in the policy scenario, this implies disappearance of at-risk acres.

groundwater, both average and peak, concentrations were below the long-term exposure benchmarks for all soils and all tillage systems under the baseline and atrazine post scenarios. Therefore the percentage of exceedance was invariably zero. Appendix C provides the details of predicted concentration levels for each chemical in the study region (areawide average) for the baseline and atrazine post scenarios.

In Table 12 we report the relative impacts of alternative policies on soil erosion, groundwater and surface water quality, and ecosystem risk. The impact on soil erosion under atrazine post restriction is shown relative to the baseline. At the study region level of aggregation, soil erosion

Table 12. Relative impacts of policies on soil erosion, ground and surface water quality, and ecosystem

Medium	Ref. Benchmark	Baseline	Atrazine Post
Soil erosion	Change (baseline)	1.00	0.9978[a]
Groundwater, 1.2m	10-day HA	0.1122/0.0554	0.0717/0.0610
	Long-term MCL	0.3633/0.2591	0.0489/0.0415
Groundwater, 15m	10-day HA	0.0008/0.0005	0.0005/0.0005
	Long-term MCL	0.0161/0.0118	0.0047/0.0045
Surface water	10-day HA	2.2218/0.8893	1.7715/0.8975
Ecosystem risk	Aquatic	32.47/8.84	27.95/9.16

[a] This policy run is performed with conservation compliance enforced in the economic model.

Note: The first number in a cell represents the weighted sum (weighted across tillage and crop—corn and sorghum) of the pesticide exposure values for a given medium and the second is the highest weighted exposure value for any pesticide predicted in a medium.

dropped by a marginal fraction. However, in the Corn Belt region, where the brunt of the impacts of the atrazine restriction policy will be, soil erosion increases. The water quality impacts are evaluated by the cumulative exposure values (sum of individual herbicide exposures) and the maximum exposure value of any single herbicide. Both of these values, referred to as *sum-exposure* and *max-exposure*, are weighted across tillage and crop (corn and sorghum). Both short and long-term values of *sum-exposure* are generally lower under an atrazine post restriction. However, the acute max-exposure values (that is, acute exposure from a single herbicide) are larger under an atrazine post restriction, while chronic *max-exposure* values are lower. Ecosystem risk, evaluated as peak stream concentrations relative to aquatic benchmark, decreases under the atrazine post scenario. Table 13 shows the impacts of alternative tillage practices on soil erosion. Note that the policy runs are performed with conservation compliance enforced in the economic model.

Table 13. Impacts of tillage on soil erosion

Tillage	Baseline	Atrazine Post	Change
	metric tons		percent
Conventional tillage	754	751	-0.4
Reduced tillage	219	221	0.9
No-till	6	5	-16.7

Conclusions

This CEEPES analysis of a policy restricting atrazine use to postemergent applications leads to two key conclusions. The policy will have only a nominal impact on the economic welfare of consumers and producers. Overall, the at-risk area would decline moderately because the reduction attributed to lower atrazine use more than offsets increases from other chemicals. The relative water quality impacts are generally lower under this scenario and soil erosion decreases marginally. With an atrazine post restriction we estimate a decrease in overall economic welfare of $159 million for the entire country, but producers will be affected the most in the short term. Chemical concentrations in groundwater would not exceed EPA benchmark values for any herbicide with any tillage in any region. Atrazine exposure in surface water would be markedly reduced; however, surface water exposures for several substitute chemicals increase. By restricting atrazine use, producers would shift to other triazines (simazine and cyanazine) and other nontriazines (dicamba, bentazon, alachlor, metolachlor), leading to triazine and nontriazine concentrations in surface water that could significantly exceed benchmark values. Of particular concern is simazine, which is used on 5.4 million additional acres relative to the baseline, because average per acre use increases by 16 percent and the at-risk acreage increases substantially.

APPENDIX A. HERBICIDES INCLUDED IN CEEPES CONFIGURATION FOR ATRAZINE AND WATER QUALITY

Code	Chemical	Trade Name
LAS	Alachlor	Lasso
ATR	Atrazine	AAtrex
BAS	Bentazon	Basagran
BUC	Bromoxynil	Buctril
SUT	Butylate	Sutan
BLA	Cyanazine	Bladex
BAN	Dicamba	Banvel
ERA	EPTC	Eradicane
ROU	Glyphosate	Round-up
DUA	Metolachlor	Dual
ACC	Nicosulfuron	Accent
GRA	Paraquat	Gramaxone
PRO	Pendimenthalin	Prowl
BEA	Primisulfuron	Beacon
RAM	Propachlor	Ramrod
PRI	Simazine	Princep
TFD	2,4-D	2,4-D

APPENDIX B. SHIFTS IN WEED CONTROL STRATEGIES

Table B.1. Percentage of corn acres treated, baseline

Strategy Number	Primary Strategy	Secondary Strategy	Treated
			percent
96	Atrazine[a]-Bladex preemergence	Accent-Banvel postemergence Accent-Buctril postemergence	16.4
240	Atrazine[a]-Bladex preplant inc.	Accent-Banvel postemergence Accent-Buctril postemergence	11.7
252	Atrazine[a]-Lasso preplant inc. Atrazine[a]-Dual preplant inc.	Accent-Banvel postemergence Accent-Buctril postemergence	9.5
141	Bladex-Lasso preplant inc. Bladex-Dual preemergence	Accent-Banvel postemergence Accent-Buctril postemergence	8.3
251	Atrazine[a]-Lasso preplant inc. Atrazine[a]-Dual preplant inc.	2,4-D postemergence Banvel-2,4-D postemergence	6.8
273	Princep preplant inc.	Accent-Banvel postemergence Accent-Buctril postemergence	5.7
239	Atrazine[b]-Bladex preplant inc.	2,4-D postemergence Banvel-2,4-D postemergence	4.2
15	Atrazine[b]-Lasso early preplant	Accent-Banvel postemergence Accent-Buctril postemergence	3.7
220	Rotary hoe and row cultivate	2,4-D postemergence Banvel-2,4-D postemergence	3.7

[a]Atrazine applied at a rate < 1.5 lb/acre.
[b]Atrazine applied at a rate > 1.5 lb/acre.

Table B.2. Percentage of corn acres treated, atrazine post

Strategy Number	Primary Strategy	Secondary Strategy	Treated
			percent
141	Bladex-Lasso preemergence Bladex-Dual preemergence	Accent-Banvel postemergence Accent-Buctril postemergence	14.7
339	Sutan preplant inc. & 2,4-D post Lasso preplant inc. & 2,4-D post Dual preplant inc. & 2,4-D post	Banvel postemergence Buctril postemergemce Basagran postemergence	12.2
273	Princep preplant inc.	Accent-Banvel postemergence Accent-Buctril postemergence	11.5
221	Rotary hoe and row cultivate	Accent-Banvel postemergence Accent-Buctril postemergence	10.4
253	Bladex preplant inc.	Atrazine[a] postemergence	9.7
117	Bladex preemergence	Accent-Banvel postemergence Accent-Buctril postemergence	8.8
275	Bladex-Lasso preplant inc. Bladex-Dual preplant inc.	Atrazine[a] postemergence	8.1
263	Princep preplant inc.	Atrazine[a] postemergence	2.5

[a]Atrazine applied at a rate > 1.5 lb/acre.

Table B.3. Percentage of sorghum acres treated, baseline

Strategy Number	Primary Strategy	Secondary Strategy	Treated
			percent
1061	Prowl-Atrazine[a] postemergence	None	20.8
1072	Rotary hoe and row cultivate	2,4-D postemergence Banvel-2,4-D postemergence	16.8
1143	Rotary hoe and row cultivate	Prowl-Atrazine[a] postemergence	13.1
1069	Rotary hoe and row cultivate	Banvel postemergence Buctril postemergence Basagran postemergence	12.8
1074	Atrazine[a] preplant inc.	2,4-D postemergence Banvel-2,4-D postemergence	10.8
1078	Atrazine[a]-Dual preplant inc	Prowl-Atrazine[a] postemergence	8.8
1076	Atrazine[a]-Dual preplant inc.	Banvel-2,4-D postemergence	4.0

[a]Atrazine applied at a rate < 1.5 lb/acre.
[b]Atrazine applied at a rate > 1.5 lb/acre.

Table B.4. Percentage of sorghum acres treated, atrazine post

Strategy Number	Primary Strategy	Secondary Strategy	Treated
			percent
1061	Prowl-Atrazine[a] postemergence	None	21.7
1143	Rotary hoe and row cultivate	Prowl-Atrazine[a] postemergence	18.7
1034	Bladex-Ramrod preemergence	2,4-D postemergence	13.9
1069	Rotary hoe and row cultivate	Banvel postemergence Buctril postemergence Basagran postemergence	13.1
1085	Lasso preplant inc. & Banvel post	Prowl-Atrazine[a] postemergence	9.2
1137	Prowl-Atrazine[a] postemergence	None	7.3
1093	Lasso preplant inc. & 2,4-D post Dual preplant inc. & 2,4-D post	Prowl-Atrazine[a] postemergence	7.2

[a]Atrazine applied at a rate < 1.5 lb/acre.

Table B.5. Percentage of corn acres treated, atrazine ban

Strategy Number	Primary Strategy	Secondary Strategy	Acres Treated
			percent
141	Bladex-Dual pre	Accent-Banvel post Accent-Buctril post	19.7
273	Princep preplant inc.	Accent-Banvel post Accent-Buctril post	13.1
261	Bladex preplant inc.	Accent-Banvel post Accent-Buctril post	13.0
339	Dual ppi & 2,4-D post	Banvel post Buctril post Basagran post	8.4
283	Bladex-Dual ppi	2,4-D post Banvel-2,4D post	8.0
221	Rotary hoe and row cult.	Accent-Banvel post Accent-Buctril post	7.6
285	Bladex-Dual ppi	Accent-Banvel post Accent-Buctril post	6.0
117	Bladex preemergence	Accent-Banvel post Accent-Buctril post	5.9
259	Bladex preplant inc.	2,4-D post Banvel-2,4-D post	2.1
220	Rotary hoe and row cult.	2,4-D post Banvel-2,4-D post	2.0

Table B.6. Percentage of sorghum acres treated, atrazine ban

Strategy Number	Primary Strategy	Secondary Strategy	Acres Treated
			percent
1034	Bladex-Ramrod pre	2,4-D post Banvel-2,4-D post	37.1
1087	Dual ppi and Banvel post	Banvel post Buctril post Basagram post	14.9
1088	Dual ppi and Banvel post	2,4-D post Banvel-2,4-D post	13.6
1097	Dual ppi and 2,4-D post	2,4-D post Banvel-2,4-D post	13.0
1069	Rotary hoe and row cult.	Banvel post Buctril post Basagran post	12.1
1072	Rotary hoe and row cult.	2,4-D post Banvel-2,4-D post	3.6
1056	Dual pre and Banvel post Ramrod pre and Banvel post	2,4-D post Banvel-2,4-D post	2.2
1086	Dual ppi and Banvel post	Banvel post Buctril post Basagran post	2.1

APPENDIX C. GROUND AND SURFACE WATER CONCENTRATIONS OF HERBICIDES IN THE STUDY REGION FOR BASELINE AND ATRAZINE POST SCENARIOS, IN CORN AND SORGHUM PRODUCTION

Legend:

AVG12(15):	Average concentration of chemical at 1.2 (15) meters below the surface
PK12(15):	Peak concentration of chemical at 1.2 (15) meters below the surface
AVGSTRM:	Average concentration of chemical in surface water for the worst year during the 30-year simulation period
PKSTRM:	Peak concentration of chemical in surface water over the 30-2year simulation period.

Table C.1. Baseline herbicide concentrations in groundwater and surface water (ppb)

CHEMICAL	AVG12	PK12	AVG15	PK15	AVGSTRM	PKSTRM
CORN						
Conventional-till						
Atrazine>1.5	0.14173	1.22145	0.0006522	0.005411	3.2035	12.8140
Atrazine<1.5	0.72229	7.95983	0.0047779	0.036018	15.7145	62.8579
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0024	0.0095
Dicamba	0.00023	0.04718	0.0000000	0.000001	2.0707	8.2829
Cyanazine	0.00012	0.02358	0.0000000	0.000006	10.6306	42.5225
Bromoxynil	0.00000	0.00000	0.0000000	0.000000	0.0148	0.0590
Bentazon	0.00300	0.06665	0.0000017	0.000041	0.3474	1.3897
Metolachlor	0.00031	0.02283	0.0000004	0.000029	4.2615	17.0459
Alachlor	0.00024	0.03893	0.0000001	0.000014	9.7556	39.0222
Simazine	0.42942	3.52176	0.0042366	0.029152	15.8981	63.5923
Pendimethalin	0.00000	0.00000	0.0000000	0.000000	0.0000	0.0000
Butylate	0.00611	1.61889	0.0000000	0.000003	3.8670	15.4679
2,4-D	0.00004	0.01878	0.0000000	0.000000	5.1651	20.6602
Reduced-till						
Atrazine>1.5	0.09175	0.77076	0.0008685	0.0042966	1.52883	6.1153
Atrazine<1.5	0.15880	1.36292	0.0010300	0.0069467	4.98540	19.9416
Nicosulfuron	0.00000	0.00000	0.0000000	0.0000000	0.01025	0.0410
Dicamba	0.00065	0.16513	0.0000001	0.0000066	4.66530	18.6612
Cyanazine	0.00004	0.00630	0.0000000	0.0000012	6.48580	25.9432
Bromoxynil	0.00000	0.00003	0.0000000	0.0000000	0.05266	0.2107
Bentazon	0.01132	0.24252	0.0000183	0.0001384	0.56115	2.2446
Metolachlor	0.00004	0.00320	0.0000000	0.0000017	2.28256	9.1302
Alachlor	0.00002	0.00371	0.0000000	0.0000002	3.32755	13.3102
Simazine	0.01399	0.07887	0.0001771	0.0009205	0.52255	2.0902
Pendimethalin	0.00000	0.00000	0.0000000	.	0.00000	0.0000
Propachlor	0.00001	0.00332	0.0000000	0.0000000	2.47131	9.8852
2,4-D	0.00000	0.00057	0.0000000	0.0000000	0.63141	2.5256
No-till						
Atrazine>1.5	1.02192	9.48263	0.0088658	0.056669	40.2693	161.077
Atrazine<1.5	0.03753	0.27589	0.0002464	0.001934	2.1785	8.714
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0029	0.012
Dicamba	0.00025	0.04891	0.0000000	0.000004	0.8192	3.277
Cyanazine	0.00000	0.00018	0.0000000	0.000000	0.0755	0.302
Bromoxynil	0.00000	0.00001	0.0000000	0.000000	0.0150	0.060
Metolachlor	0.00096	0.06604	0.0000019	0.000143	14.5406	58.162
Alachlor	0.00000	0.00044	0.0000000	0.000000	1.1330	4.532
Simazine	0.15732	0.93788	0.0031730	0.014508	3.1891	12.756
Pendimethalin	0.00000	0.00000	0.0000000	0.000000	0.0000	0.000
2,4-D	0.00000	0.00006	0.0000000	0.000000	0.0121	0.048
SORGHUM						
Conventional-till						
Atrazine>1.5	4.226	5.39779	0.97685	0.44223	26.4553	105.821
Atrazine<1.5	1.073	0.99509	0.33211	0.10339	2.3066	9.226
Dicamba	0.005	0.03022	0.00088	0.00004	0.4684	1.873
Bromoxynil	0.000	0.00016	0.00000	0.00000	0.0435	0.174
Bentazon	0.001	0.00251	0.00003	0.00002	0.0574	0.230
Metolachlor	4.107	8.43260	1.07431	0.06637	26.7993	107.197
Alachlor	0.008	0.03858	0.00152	0.00017	4.9542	19.817
Pendimethalin	663.025	0.29293	0.00000	0.00005	0.4689	1.876
2,4-D	0.000	0.00191	0.00001	0.00000	0.1261	0.504

Table C.1. Continued

CHEMICAL	AVG12	PK12	AVG15	PK15	AVGSTRM	PKSTRM
Reduced-till						
Atrazine<1.5	0.055	0.22675	0.001124	0.0039034	2.23821	8.9528
Dicamba	0.036	0.19312	0.006106	0.0005137	0.60224	2.4089
Cyanazine	0.000	0.00000	0.000000	0.0000000	0.19185	0.7674
Bromoxynil	0.005	0.04181	0.000004	0.0000000	0.23289	0.9316
Bentazon	0.158	0.41046	0.016495	0.0031615	0.39190	1.5676
Metolachlor	0.000	0.00000	0.000000	0.0000000	0.05864	0.2346
Alachlor	0.000	0.00000	0.000000	0.0000000	0.07547	0.3019
Pendimethalin	172.305	0.48429	0.000001	0.0000231	3.41080	13.6432
Propachlor	0.000	0.00000	0.000000	0.0000000	0.34418	1.3767
2,4-D	0.020	0.15289	0.002243	0.0000716	0.69836	2.7935
No-till						
Atrazine>1.5	0.91694	2.96886	0.042231	0.069767	2.98330	11.9332
Atrazine<1.5	0.06780	0.11898	0.022303	0.001128	0.00988	0.0395
Pendimethalin	0.00004	0.00066	0.000000	0.000004	0.00302	0.0121

Table C.2. Atrazine post scenario herbicide concentrations in groundwater and surface water (ppb)

CHEMICAL	AVG12	PK12	AVG15	PK15	AVGSTRM	PKSTRM
CORN						
Conventional-till						
Atrazine>1.5	0.03074	0.28503	0.0002035	0.001175	2.0226	8.0904
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0015	0.0059
Dicamba	0.00025	0.05531	0.0000000	0.000001	2.3869	9.5475
Cyanazine	0.00011	0.02222	0.0000000	0.000006	12.7996	51.1985
Bromoxynil	0.00000	0.00000	0.0000000	0.000000	0.0156	0.0626
Bentazon	0.01110	0.22689	0.0000121	0.000141	1.0818	4.3272
Metolachlor	0.00024	0.01804	0.0000004	0.000026	3.3459	13.3834
Alachlor	0.00016	0.02618	0.0000001	0.000010	6.7022	26.8089
Simazine	0.62861	5.31337	0.0057957	0.041976	16.7955	67.1821
Butylate	0.00520	1.34644	0.0000000	0.000002	4.1527	16.6108
2,4-D	0.00011	0.04431	0.0000000	0.000000	10.6845	42.7379
Reduced-till						
Nicosulfuron	0.0000000	0.00000	0.00000000	0.00000000	0.01846	0.0738
Dicamba	0.0010401	0.25853	0.00000010	0.00001181	6.62268	26.4907
Cyanazine	0.0000387	0.00615	0.00000000	0.00000026	7.39370	29.5748
Bromoxynil	0.0000008	0.00006	0.00000000	0.00000000	0.08187	0.3275
Bentazon	0.0001713	0.00381	0.00000012	0.00000214	0.01309	0.0523
Metolachlor	0.0000987	0.00633	0.00000003	0.00000386	2.96305	11.8522
Alachlor	0.0000358	0.00514	0.00000000	0.00000041	3.84700	15.3880
Simazine	0.0081867	0.05130	0.00018692	0.00083688	0.21976	0.8790
2,4-D	0.0000034	0.00168	0.00000000	0.00000000	0.66784	2.6714
No-till						
Atrazine>1.5	0.63524	6.48862	0.0055177	0.046906	14.0737	56.2948
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0018	0.0070
Dicamba	0.00017	0.03186	0.0000000	0.000002	0.6665	2.6658
Cyanazine	0.00003	0.00520	0.0000000	0.000003	1.1872	4.7489
Bromoxynil	0.00000	0.00001	0.0000000	0.000000	0.0069	0.0276
Metolachlor	0.00058	0.04060	0.0000010	0.000083	11.0451	44.1802
Alachlor	0.00010	0.01580	0.0000000	0.000007	6.3742	25.4967
Simazine	0.43220	2.56962	0.0072905	0.033936	15.3529	61.4116
2,4-D	0.00001	0.00351	0.0000000	0.000000	0.6498	2.5991
SORGHUM						
Conventional-till						
Atrazine<1.5	1.89464	3.03584	0.37927	0.028766	3.2270	12.9078
Dicamba	0.00140	0.01357	0.00006	0.000025	1.2452	4.9808
Metolachlor	0.97261	2.37975	0.14984	0.028546	19.0628	76.2511
Alachlor	0.01198	0.05785	0.00196	0.000239	10.6092	42.4367
2,4-D	0.00120	0.01936	0.00001	0.000004	1.1502	4.6006
Reduced-till						
Atrazine<1.5	0.15097	0.42500	0.008522	0.0060632	3.00470	12.0188
Dicamba	0.02729	0.14772	0.004573	0.0003919	0.52070	2.0828
Cyanazine	0.00000	0.00000	0.000000	0.0000000	0.40793	1.6317
Bromoxynil	0.00484	0.04181	0.000004	0.0000000	0.23289	0.9316
Bentazon	0.15821	0.41046	0.016495	0.0031615	0.39190	1.5676
Metolachlor	0.00000	0.00000	0.000000	0.0000000	0.05667	0.2267
Alachlor	0.00000	0.00000	0.000000	0.0000000	0.07547	0.3019
Propachlor	0.00000	0.00000	0.000000	0.0000000	0.62677	2.5071
2,4-D	0.01469	0.11390	0.001656	0.0000533	0.59130	2.3652
No-till						
Atrazine<1.5	4.77038	3.82004	0.046825	0.046290	4.7055	18.822

Table C.3. Atrazine ban scenario herbicide concentrations in groundwater and surface water (ppb)

CHEMICAL	AVG12	PK12	AVG15	PK15	AVGSTRM	PKSTRM
CORN						
Conventional-till						
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0021	0.0084
Dicamba	0.00024	0.05428	0.0000000	0.000001	2.2279	8.9114
Cyanazine	0.00012	0.02314	0.0000000	0.000005	11.5153	46.0613
Bromoxynil	0.00000	0.00000	0.0000000	0.000000	0.0150	0.0599
Bentazon	0.01054	0.21598	0.0000114	0.000134	1.0301	4.1205
Metolachlor	0.00027	0.02028	0.0000004	0.000030	3.6423	14.5693
Alachlor	0.00017	0.02848	0.0000001	0.000011	6.9946	27.9782
Simazine	0.61531	5.19380	0.0056870	0.041430	16.5356	66.1422
Butylate	0.00520	1.34705	0.0000000	0.000002	4.1576	16.6305
2,4-D	0.00011	0.04442	0.0000000	0.000000	10.7630	43.0519
Reduced-till						
Nicosulfuron	0.0000000	0.00000	0.00000000	0.00000000	0.01202	0.0481
Dicamba	0.0005670	0.13912	0.00000004	0.00000481	4.34485	17.3794
Cyanazine	0.0000377	0.00611	0.00000000	0.00000066	6.91843	27.6737
Bromoxynil	0.0000003	0.00003	0.00000000	0.00000000	0.05881	0.2352
Bentazon	0.0001923	0.00428	0.00000013	0.00000241	0.01470	0.0588
Metolachlor	0.0001365	0.00905	0.00000005	0.00000623	3.60400	14.4160
Alachlor	0.0000519	0.00772	0.00000000	0.00000087	4.77068	19.0827
Simazine	0.0081867	0.05130	0.00018692	0.00083688	0.21976	0.8790
2,4-D	0.0000030	0.00154	0.00000000	0.00000000	0.70535	2.8214
No-till						
Nicosulfuron	0.00000	0.00000	0.0000000	0.000000	0.0020	0.0079
Dicamba	0.00024	0.04568	0.0000000	0.000003	0.9577	3.8307
Cyanazine	0.00003	0.00569	0.0000000	0.000003	1.3282	5.3130
Bromoxynil	0.00000	0.00001	0.0000000	0.000000	0.0086	0.0342
Bentazon	0.00201	0.03851	0.0000037	0.000031	0.0673	0.2693
Metolachlor	0.00035	0.02415	0.0000006	0.000049	6.7043	26.8172
Alachlor	0.00006	0.00940	0.0000000	0.000004	3.8798	15.5191
Simazine	0.44349	2.65130	0.0076768	0.036839	15.8103	63.2410
2,4-D	0.00005	0.02716	0.0000000	0.000000	2.8498	11.3992
SORGHUM						
Conventional-till						
Dicamba	0.00858	0.0574	0.00115	0.000092	1.8427	7.371
Bromoxynil	0.00001	0.0001	0.00000	0.000000	0.0692	0.277
Bentazon	0.00110	0.0042	0.00008	0.000039	0.0936	0.374
Metolachlor	4.84107	10.1778	1.18962	0.089056	37.0718	148.287
Alachlor	0.01198	0.0579	0.00196	0.000239	10.6092	42.437
2,4-D	0.00111	0.0158	0.00002	0.000003	0.5258	2.103
Reduced-till						
Dicamba	0.02713	0.14692	0.004553	0.0003896	0.60745	2.42978
Cyanazine	0.00000	0.00000	0.000000	0.0000000	0.57559	2.30237
Bromoxynil	0.00484	0.04181	0.000004	0.0000000	0.23289	0.93157
Bentazon	0.15821	0.41046	0.016495	0.0031615	0.39190	1.56760
Metolachlor	0.00000	0.00000	0.000000	0.0000000	0.05584	0.22335
Alachlor	0.00000	0.00000	0.000000	0.0000000	0.07547	0.30188
Propachlor	0.00000	0.00000	0.000000	0.0000000	0.85482	3.41926
2,4-D	0.01474	0.11454	0.001659	0.0000536	0.81497	3.25987

APPENDIX D. RELATIVE ECONOMIC AND ENVIRONMENTAL IMPACTS OF ATRAZINE POST AND ATRAZINE BAN POLICIES

Table D.1. Crop acreages

Crop	Baseline	Atrazine Post Restriction	Atrazine Ban
	million acres	percent change	
Barley	5.22	0.00	0.00
Corn	72.46	-2.60	-2.35
Cotton	1.23	0.00	0.00
Hay	52.71	0.70	0.60
Oats	4.88	1.23	1.10
Sorghum	5.41	-0.52	-3.72
Soybeans	43.87	3.47	3.51
Summer fallow	6.15	-2.33	-2.04
Sunflowers	1.05	0.00	-0.01
Wheat	23.52	0.44	0.51

Table D.2. Yields by crop

Crop	Units	Baseline	Atrazine Post Restriction	Atrazine Ban
		units per acre	percent change	
Barley	bu.	48.2	0.00	0.00
Corn	bu.	109.1	-1.15	-1.19
Corn silage	tons	10.6	1.67	1.01
Cotton	bales	1.5	0.00	0.00
Legume hay	tons	4.4	0.52	0.13
Nonlegume hay	tons	1.0	-1.84	-1.01
Oats	bu.	52.6	-0.01	0.12
Sorghum	bu.	79.9	0.42	-3.43
Sorghum silage	tons	11.4	0.01	-0.50
Soybeans	bu.	36.3	0.21	0.19
Sunflowers	cwt.	13.2	0.00	0.01
Spring wheat	bu.	32.0	0.18	0.17
Winter wheat	bu.	56.1	0.05	0.02

Table D.3. Cost per treated acre

	Baseline	Atrazine Post Restriction	Atrazine Ban
		Absolute change	
Corn	10.80	0.61	1.08
Sorghum	8.55	0.61	3.10

Table D.4. Average per acre herbicide use

Chemical	Crop	Baseline	Atrazine Post Restriction	Atrazine Ban
		lb. a.i. per acre	percent change	
Atrazine >1.5 lb/a	Corn	0.83	-75.47	-100.00
	Sorghum	2.14	-100.00	-100.00
Atrazine <1.5 lb/a	Corn	0.66	-100.00	-100.00
	Sorghum	0.82	-19.05	-100.00
Nicosulfuron	Corn	0.01	33.20	10.27
	Sorghum	0.00	0.00	0.00
Dicamba	Corn	0.04	15.64	1.93
	Sorghum	0.06	41.18	57.68
Cyanazine	Corn	0.54	56.18	48.53
	Sorghum	0.76	-9.36	-2.11
Bromoxynil	Corn	0.01	19.12	6.26
	Sorghum	0.06	11.81	-28.70
Bentazon	Corn	0.04	-12.54	-6.21
	Sorghum	0.05	13.70	-31.64
Metolachlor	Corn	0.72	-24.41	-22.06
	Sorghum	1.14	3.89	12.87
EPTC	Corn	0.00	0.00	0.00
	Sorghum	0.00	0.00	0.00
Alachlor	Corn	0.72	-16.26	-15.45
	Sorghum	0.89	26.75	35.31
Simazine	Corn	1.52	16.16	14.58
	Sorghum	0.00	0.00	0.00
Pendimethalin	Corn	0.06	383.81	213.80
	Sorghum	0.70	4.40	-100.00
Propachlor	Corn	2.12	-100.00	-100.00
	Sorghum	1.93	-27.69	-26.51
Glyphosate	Corn	0.00	0.00	0.00
	Sorghum	0.85	0.00	0.00
Butylate	Corn	2.04	-6.85	-5.68
	Sorghum	0.00	0.00	0.00
2,4-D	Corn	0.06	320.78	132.21
	Sorghum	0.08	129.55	88.60

Table D.5. Acres treated in study region

Chemical	Crop	Baseline	Atrazine Post Restriction	Atrazine Ban
		million acres	percent change	
Atrazine >1.5 lb/a	Corn	11.09	54.08	-100.00
	Sorghum	0.97	-100.00	-100.00
Atrazine <1.5 lb/a	Corn	43.25	-100.00	-100.00
	Sorghum	2.50	39.98	-100.00
Nicosulfuron	Corn	50.04	-20.52	0.38
	Sorghum	0.00	0.00	0.00
Dicamba	Corn	65.19	-19.31	6.46
	Sorghum	3.08	-21.78	68.81
Cyanazine	Corn	38.05	-1.71	9.64
	Sorghum	0.06	1209.10	3272.90
Bromoxynil	Corn	52.39	-4.79	10.98
	Sorghum	0.86	-17.98	77.05
Bentazon	Corn	2.36	329.40	236.04
	Sorghum	0.86	-17.98	77.05
Metolachlor	Corn	29.82	2.80	20.90
	Sorghum	1.27	-8.78	92.67
EPTC	Corn	0.00	0.00	0.00
	Sorghum	0.00	0.00	0.00
Alachlor	Corn	26.03	17.41	37.01
	Sorghum	0.51	20.45	86.81
Simazine	Corn	7.82	68.82	63.72
	Sorghum	0.00	0.00	0.00
Pendimethalin	Corn	2.16	-52.80	-10.21
	Sorghum	2.50	39.98	-100.00
Propachlor	Corn	0.16	-100.00	-100.00
	Sorghum	0.21	316.87	876.04
Glyphosate	Corn	0.00	0.00	0.00
	Sorghum	0.00	1000.00	1000.00
Butylate	Corn	2.33	306.14	202.97
	Sorghum	0.00	0.00	0.00
2,4-D	Corn	13.62	-10.70	28.46
	Sorghum	2.04	-23.58	80.46

Table D.6. Herbicide use in study region

Chemical	Crop	Baseline	Atrazine Post Restriction	Atrazine Ban
		mil. lb. a.i.	percent change	
Atrazine	Corn	37.6	-90.72	-100.00
	Sorghum	4.1	-43.95	-100.00
All Triazines	Corn	70.2	-16.50	-20.16
	Sorghum	4.2	-32.16	-65.57
Non-triazines	Corn	50.2	21.15	25.56
	Sorghum	4.5	42.66	85.61
All Herbicides	Corn	120.4	-0.81	-1.11
	Sorghum	8.7	6.73	13.02

Table D.7. Aggregate economic effects of atrazine post restriction

Welfare Effects	Atrazine Post Restriction		Atrazine Ban	
	Short-term	Long-term	Short-term	Long-term
	million $			
Producer income	-204	-50	-269	-207
Domestic consumer effect	-19	-193	-188	-412
Foreign consumer effect	-1	-52	-70	-87
Government outlays	(-65)	(-1)	(-287)	(-248)
Total economic effect	-159	-294	-240	-458

Table D.8. Price effects of atrazine post restriction on selected commodities

Crop[a]	Atrazine Post Restriction Short-term	Atrazine Post Restriction Long-term	Atrazine Ban Short-term	Atrazine Ban Long-term
		percent change		
Corn	+0.4	+1.1	+1.83	+2.25
Sorghum	-0.2	+0.1	+2.42	+3.16
Soybeans	-0.2	+0.5	-0.26	-0.26
Oats	+0.1	-0.2	-0.23	+0.10
All hay	-0.6	-0.6	+0.37	+0.57
Wheat	-0.2	-0.2	-0.07	-0.09
Barley	~0.0	-1.0	-0.01	-0.86
Cotton	~0.0	+0.1	-0.06	+0.01

[a] Price effects on livestock and livestock products in the short run are close to zero.

Table D.9. Estimated proportion of acreage under different tillage practices

Tillage	Crop	Baseline	Atrazine Post Restriction	Atrazine Ban
Conventional	Corn	0.5774	0.5721	0.5657
	Sorghum	0.4516	0.4491	0.4444
	All crops	0.6941	0.6933	0.6940
Reduced	Corn	0.3686	0.3837	0.3918
	Sorghum	0.5468	0.5489	0.5556
	All crops	0.2797	0.2805	0.2799
No-till	Corn	0.0540	0.0442	0.0425
	Sorghum	0.0016	0.0020	0.0000
	All crops	0.0262	0.0262	0.0261

Table D.10. Percentage of at-risk corn acres treated with herbicides

Chemical	Conventional Tillage	Reduced Tillage	No-till	Weighted Sum
Baseline				
Atrazine >1.5	5.44	3.76	61.24	7.83
Atrazine <1.5	38.44	3.26	5.14	23.67
Cyanazine	19.41	3.39	0.00	12.46
Bentazon	1.76	7.06	0.00	3.62
Metolachlor	0.17	0.30	30.63	1.86
Alachlor	11.69	4.22	2.58	8.44
Simazine	58.50	1.63	11.38	34.99
Propachlor	0.00	2.43	0.00	0.90
Atrazine Post				
Atrazine >1.5	2.33	0.00	23.48	2.37
Cyanazine	21.89	13.65	0.00	17.76
Bentazon	10.50	0.00	30.00	6.01
Metolachlor	0.01	0.74	24.61	1.38
Alachlor	2.13	2.91	12.79	2.90
Simazine	64.37	0.41	34.37	38.50
Atrazine Ban				
Cyanazine	19.47	9.28	0.00	14.65
Bentazon	8.97	0.00	0.00	5.07
Metolachlor	0.01	0.84	12.36	0.86
Alachlor	2.90	4.51	8.54	3.77
Simazine	64.75	0.41	39.37	38.46

Notes: Risk measured as acute surface water concentration exceeding the 10-day HA benchmark. Chemicals not shown in the baseline imply zero at-risk acres, while if a chemical appears in the baseline but does not show up in the policy scenario implies disappearance of at-risk acres.

Table D.11. Relative impacts of policies on soil erosion, ground and surface water quality, and ecosystem

Medium	Ref. Benchmark	Baseline	Atrazine post	Atrazine ban
Soil erosion	Change (baseline)	1.00	0.9978[a]	0.9974[a]
Groundwater, 1.2m	10-day HA	0.1122/0.0554	0.0717/0.0610	0.667/0.0609
	Long-term MCL	0.3633/0.2591	0.0489/0.0415	0.0125/0117
Groundwater, 15m	10-day HA	0.0008/0.0005	0.0005/0.0005	0.0005/0.0005
	Long-term MCL	0.0161/0.0118	0.0047/0.0045	0.0006/0.0005
Surface water	10-day HA	2.2218/0.8893	1.7715/0.8975	1.6756/0.8950
Ecosystem risk	Aquatic	32.47/8.84	27.95/9.16	26.87/8.86

[a] This policy run is performed with conservation compliance enforced in the economic model.

Note: The first number in a cell represents the weighted sum (weighted across tillage and crop—corn and sorghum) of the pesticide exposure values for a given medium and the second is the highest weighted exposure value for any pesticide predicted in a medium.

Table D.12. Impacts of tillage on soil erosion

Tillage	Baseline	Atrazine Post	Change	Atrazine Ban	Change
	million tons		percent	million tons	percent
Conventional Tillage	754	751	-0.4	750	-0.5
Reduced Tillage	219	221	0.9	222	1.4
No-till	6	5	-16.7	5	-16.7

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