Alternatives to Triazine Herbicides in Iowa Corn Production

Paul E. Rosenberry and Jason F. Shogren

Staff Report 91-SR 53
May 1991

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and Jason F. Shogren

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Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011

Paul E. Rosenberry is an affiliate professor of economics with CARD; and Jason F. Shogren is assistant professor of economics and head of the Resource and Environmental Policy Division of CARD.

Prepared under a cooperative agreement between the Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C., and the Center for Agricultural and Rural Development, Iowa State University.

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ABSTRACT

This report explores triazine herbicide alternatives in corn production given the possibility of restricted atrazine use. We identify three key results:

- Restricting atrazine application rate to 1.5 pounds of active ingredient per acre would generally not reduce weed control or corn yield.
- An atrazine ban might not decrease weed control or lower yields provided farmers can manage alternative strategies efficiently.
- A triazine ban would likely increase costs, labor, and total pounds of active ingredients of substitute herbicides, but would not necessarily decrease weed control.

ACKNOWLEDGMENTS

Material presented in this report has been compiled and summarized from various weed management guides including the *Weed Management Guide for 1990*, Pm-601 (revised), Iowa State University Extension; and the *1990 Crop Protection Guide*, published by CENEX Land O'Lakes. This report would not have been possible without the patient tutorial help of Dr. Robert Hartzler, extension agronomist in weed science with the agronomy department, Iowa State University. To a large extent, all that is correct in this report is a result of Dr. Hartzler's assistance. The authors assume full responsibility for everything that is inaccurate or misleading in this report.

ALTERNATIVES TO TRIAZINE HERBICIDES IN IOWA CORN PRODUCTION

Farmers apply triazines and other herbicides to corn to prevent yield losses from weed competition for sunlight, nutrients, and water. Due to their efficacy, triazines have become popular with corn producers and have widespread use (Wintersteen and Hartzler 1987). Some individuals and groups argue, however, that herbicide use may create environmental and health risks. For example, atrazine has been detected in the groundwater of 23 Iowa counties (National Governors' Association 1990). As public pressure increases, the U.S. Environmental Protection Agency (EPA) must examine the risks, benefits, and weed control alternatives of pesticides like atrazine, and then decide whether or not the chemical's registration should be canceled or renewed. To effectively support their decision, the EPA needs detailed information on the risk-benefit tradeoff. The Comprehensive Environmental Economic Policy Evaluation System (CEEPES) being developed by the Center for Agricultural and Rural Development (CARD) at Iowa State University in cooperation with the EPA is designed to provide this information (Johnson, Rosenberry, and Shogren 1990).

The chief goal of this report is to answer or provide the methodology to answer specific questions raised by Dr. G. W. Keitt, Jr. of the EPA (see Appendix A). Dr. Keitt has raised several questions regarding triazine herbicide alternatives in corn production, given the possibility that the registration of atrazine, or all triazines, might be canceled after the EPA's special review process. This report sets forth physical facts, expert opinion, and plans for an additional economic analysis of the potential producer response to a cancellation of atrazine or all triazines.

Current Use of Triazines

The primary triazines used in Iowa's corn production are atrazine, cyanazine, and simazine. Table 1 presents the 1990 Iowa corn acreage treated with triazines alone or with other products. Alone, atrazine is used on 8 percent and cyanazine on 7 percent of the corn acreage. Simazine is a distant third with only 1 percent being applied to corn acreage. More triazines are being applied in tank mixes than as individual chemicals to provide a broader spectrum of weed control than that achieved from applying individual chemicals. Tank mixtures of triazine herbicides are applied to about 27 percent of corn acres. When tank mixes of triazines and other herbicides are included, the corn acres treated increase to 73 percent. Atrazine is included in 56 percent of these corn acres treated with all herbicides. If the acreage where atrazine is applied alone is added to the acreage treated with tank mixes, the total corn acres receiving atrazine increases to 64 percent. Similarly, cyanazine is applied to 35 percent of corn acreage.

Preplant, Preemergence, and Postemergence

Atrazine and cyanazine are applied preplant, preemergence, or postemergence (Table 1). Simazine is not effective for postemergence weed control and is either applied preplant or preemergence. Atrazine and cyanazine, when used alone, are fairly evenly divided among preplant, preemergence, and postemergence timings. This timing of application changes significantly when tank mixtures are considered. The mixture of atrazine and cyanazine is predominantly used either preplant or preemergence. This is also true when metolachlor, alachlor, butylate, and EPTC are mixed with either atrazine or cyanazine. In contrast, the tank mixes of atrazine and bentazon, dicamba salt, and bromoxynil are all applied postemergence.

Table 1. Corn acres treated with triazines alone or with other products, Iowa 1990

Chemical	Trade Name	Ingredients Per Acre	Target Weeds Name	Target Weeds Control	Corn acreage Preplant	Corn acreage Emergence Pre	Corn acreage Emergence Post	Corn acreage Total
				percent				
Triazines								
Atrazine	Aatrex, Atrazine[a]	1-3	Foxtails/broadleafs	90-95	3	2	3	8
Cyanazine	Bladex	2-3	Grasses/broadleafs	90-95	3	2	2	7
Simazine	Princep	1.5	Grasses	90-95	<1	<1	0	1
Triazine tank mixes								
Preemergence								
Metolachlor-atrazine	Bicep	2 + 1.6	Broadleafs/grasses	90-95	6	3	0	9
Alachlor atrazine	Bullet/Lariat	2.5 + 1.5	Broadleafs/grasses	90-95	4	5	0	9
Cyanazine-atrazine	Extrazine II	3 + 1	Broadleafs/grasses	90-95	6	5	0	11
Cyanazine-alachlor, metolachlor, Butylate, EPTC	Bladex, Lasso, Dual	3, 2.5, 3 Sutan, or Eradicane	Broadleafs/grasses	90-95 or 3	7	10	0	17
Postemergence								
Bantazon-atrazine	Laddock, Basagran, Atrazine	1 + 1	Broadleafs/grasses		0	0	4	4
Dicamba salt-atrazine	Marksman, Banvel, Atrazine	0.5 + 1.1	Velvetleaf	90-95	0	0	15	15
Bromoxynil-atrazine	Buctril, Atrazine	0.5 + 1.0	Broadleafs	90-95	0	0	8	8

SOURCE: Wintersteen and Hartzler 1987.

Note: See Appendix C.

[a]Trade names "Aatrex" and "Atrazine" are assumed to be interchangable.

Target Weeds

Preplant and preemergence tank mixes generally target both grasses and broadleafs. Postemergence tank mixes, when applied to corn, are generally for broadleaf weed control. Atrazine is most effective when used to control annual broadleaf weeds that are small or have not emerged. Although at higher application rates atrazine may also be used to control preemerged or very small grasses (less than 2 inches), a tank mix containing other triazines generally provides more effective control. Cyanazine has activity on both grasses and broadleafs, but is usually combined with atrazine to improve broadleaf control. Postemergence applications of atrazine have increased in recent years due to premix products that provide broad spectrum broadleaf control while keeping atrazine rates low enough to minimize carryover risks to susceptible crops.

Other Herbicide Treatments

Metolachlor is applied prior to atrazine application on about one-half of the corn acreage treated with atrazine alone. The purpose of the metolachlor treatment is to increase control of grasses. Cyanazine and simazine corn applications are not usually preceded by other herbicide treatments.

Preemergence tank mixes listed in Table 1 are not preceded by applications of other herbicides. Table 2 presents the chemicals applied to corn before using triazines alone. Postemergence tank mixes are generally preceded by herbicides to control grass, probably either preplant or preemergence.

Posttriazine herbicide applications are generally for broadleafs. Table 3 lists the chemicals applied to corn after triazines are applied alone. After grasses have reached the 2-inch height and corn has reached the 6-inch height, effectiveness of grass control decreases significantly and, except for atrazine, corn herbicide tolerance also decreases significantly. Therefore, early posttriazine applications may include alachlor, but later applications of the leading posttriazine herbicides include

Table 2. Chemicals applied to corn before triazines listed in Table 1, Iowa 1990

Triazine List from Table 1			Pretriazine Application			
Chemical	Trade Name	Name	Actual Ingredient Per Acre	Use	Target	Control
			pounds			percent
Triazines						
Atrazine	Aatrex, Atrazine[a]	Dual/Lasso	2-4	4	grass	90-95
Cyanazine	Bladex	Sutan/Eradicane		--	--	--
Simazine	Princep	None	--	--	--	--
Triazine tank mixes						
Preemergence						
Metolachlor-atrazine	Bicep	None	--	--	--	--
Extrazine II	Extrazine II	None	--	--	--	--
Cyanazine-alachlor, metolachlor,	Bladex, Lasso, Dual	None	--	--	--	--
Butylate-atrazine	Sutan, Aatrex	None	--	--	--	--
Postemergence						
Bantazon-atrazine	Laddock, Basagran, Atrazine	Lasso/Dual/ Sutan/Eradicane	2	2	grass	90-95
Dicamba-atrazine	Marksman	Sutan/Eradicane	5	3	grass	90-95
Bromoxynil-atrazine	Buctril, Atrazine	Sutan/Eradicane	3	2	grass	90-95

SOURCE: Conversation with Robert Hartzler and Micheal Owen, Agronomy Extension, Iowa State University.

[a]Trade names "Aatrex" and "Atrazine" are assumed to be interchangable.

Table 3. Chemicals applied to corn after triazines, Iowa 1990

	Postatrazine application				
				Target Weed	
Chemical	Name	Active Ingredient Per Acre	Use	Name	Control
		pints	percent		percent
2, 4-D	2, 4-D	.25	6	Broadleafs	90-95
Bromoxynil Ester	Buctril	.38	2	Broadleafs	90-95
Dicamba Sol. Salt	Banvel	.5	8	Broadleafs	90-95

SOURCE: Conversation with Robert Hartzler and Micheal Owen, Agronomy Extension, Iowa State University.

dicamba and 2, 4-D with 8 and 6 percent application of corn acreage. The use of bromoxynil is increasing, especially where velvetleaf populations are high.

Reasons for Preferring Triazines

There are several reasons for the widespread use of triazine herbicide, the most important being effectiveness, versatility, relative cost, and risk aversion. Although there are several alternative products that (when used appropriately) can provide equally effective control, triazines' overall advantages have helped to keep them popular with corn growers.

Atrazine has a broad spectrum of effectiveness that controls most broadleaf weeds growing in Iowa. Atrazine has both soil and foliar activity. This allows atrazine to be used preplant or preemergence to control weed seedlings after emergence. The long soil residual of atrazine normally provides full-season weed control. Because of these characteristics, atrazine may be used in most tillage systems.

Cyanazine is commonly used in combination with atrazine to improve atrazine annual grass control. This tank mix also allows reduced rates of both products, thus reducing the carryover potential from atrazine and crop injury from cyanazine. The additive action of cyanazine and atrazine tends to reverse the reduced rates, and slightly improves the control of certain broadleaf weeds over atrazine used in combination with other nontriazine grass herbicides.

The major alternatives to atrazine for broadleaf control are primarily postemergence herbicides. These chemicals require additional application trips across the field and tend to increase production costs (including labor). Alternative triazine products also have little or no residual activity in the soil, so late-emerging weeds may increase the number of weed seeds in the soil. Postemergence chemicals often have a narrow window for application that can result in poor weed control if weather conditions prevent timely application. Finally, many of the alternatives to atrazine have a lower margin of safety when applied to corn and may under certain weather conditions reduce crop yields. Effective weed control programs that do not rely on triazine herbicides can be developed. However, these programs may require more management skills and timely herbicide applications to maintain effective weed control. The long residual activity of atrazine provides a larger window for herbicide application, and also makes the product especially well suited for conservation tillage systems.

The cost per acre of individual triazine products relative to other herbicide alternatives is also a significant factor in their popularity (Table 4). Atrazine is the least-cost herbicide when both grass and broadleaf weeds need to be controlled. There are several good triazine substitutes for preemergence control of most grasses. But after grasses and corn have emerged, the number of grass control alternatives decreases significantly. There are some weeds that can be controlled only with high application rates of triazines (e.g., quackgrass). In these cases, nicosulfuran and primisulfuron appear to be effective alternatives, but incur a significantly higher cost per acre treated.

Atrazine, and to a lesser degree cyanazine, reduces the risk from herbicide failures. Herbicide effectiveness in controlling weeds can be reduced by unfavorable weather. For example, too much or too little rain during planting season can reduce weed control. In such instances, atrazine and cyanazine can be used to control emerged grasses and broadleafs. Unfavorable corn growing weather can delay corn emergence, growth, and canopy establishment (shading) and allow a longer time for weeds to become established. The full season persistence of atrazine can be advantageous in these cases as its half-life (resistance to decay) is relatively longer than cyanazine and other nontriazine corn herbicides. Even for the weeds triazines do not control, they can cause plant stress that improves the efficiency of the other herbicides used in the weed control strategy.

Table 4. Iowa prices of triazine alternatives, Iowa 1990

Herbicide	Rate per Acre	$ per Acre
Grass and broadleafs		
Atrazine 90DF	1.6-2.2 lb.	4.00-5.25
Bladex 90DF	2.2-4.3 lb.	9.40-18.80
Grass		
Metolachlor	2-2.5	13.50-16.90
Alachlor	2.5-3.0	14.50-17.43
Cyanazine	2-3	9.40-14.10
Butylate	3-5	9.40-13.15
EPTC	3-5	10.15-16.95
Broadleafs		
Banvel 4S	0.5-1.0 pt.	4.75-9.50
Basagran 4S	.75-1.0 qt.	11.00-14.75
Buctril 2E	1.0-1.5 pt.	5.20-7.79
2, 4-D LVE	0.5-1.0 pt.	0.93-1.86

Note: These are 1990 suggested retail prices, which vary with time, location, and quantity.

Agriculture Producers' Expected Adjustments to Regulation

A discussion of possible alternatives and adjustments triazine users might choose when faced with policy scenarios like those listed in Appendix B is explored in this section. Adaptations might include the use of alternative herbicides, tillage practices, rotations, or land use variations. Rotation and land use changes are assumed for this report to be small under either a ban or limitations on the quantity of triazines applied. Alternative herbicide substitutes appear to be generally available. These alternatives usually cost more per treated acre, but are assumed to be considerably smaller than the profit advantage of the corn enterprise over other competing land uses. This hypothesis will be tested in a companion report using a linear program framework (Bouzaher et al. 1991). A loss of all triazines in combination with soybean herbicides (grass-Treflon) may cause a significant rotation change because soybean herbicides are highly effective in controlling grass problems from the corn-rotation years.

Herbicide Alternatives to an Atrazine Ban

Table 5 presents alternative herbicide adjustments following an atrazine ban. Cyanazine use would be expected to increase to 20 percent from 7 percent of corn acreage. The majority of this increase would occur on preemergence applications. Cyanazine would also be substituted for atrazine in tank mixes. Preemergence dicamba use would increase to 3 percent and postemergence per acre. applications would be expected to increase from 6 to 20 percent of the corn acreage. Bromoxynil, 2,4-D, and bentazon would also be expected to increase significantly as postemergence applications. All of these herbicides, except for cyanazine, would be expected to follow preemergence applications of alachlor, metolachlor, EPTC, or butylate to improve grass control (Table 5).

Table 5. Expected herbicide adjustments to withdrawal of atrazine and triazine, Iowa 1990

			Corn Acres					
			No Atrazine			No Triazines		
Alternatives	Trade Name	Actual Ingredients Per Acre	Pre-plant	Pre-emerge	Post-emerge	Pre-plant	Pre-emerge	Post-emerge
		pounds	percent					
Dicamba	Banvel	.50	0	3	40	0	3	50
2, 4-D	2, 4-D	.25	0	0	25	0	0	35
Bromoxynil	Buctril	.38	0	0	10	0	0	20
Bentazon	Basagran	.75	8	0	10	0	0	15
Cynanazine	Bladex	2.00	3	40	10	--	--	--
Metolachlor	Dual	2.00	2	40	0	3	45	0
Alachlor	Lasso	2.50	2	35	0	2	40	0
EPTC	Eradicane	3.00	11	0	0	2	0	0
Butylate	Sutan	3.00	0	0	0	11	0	0
	Accent	.03.	0	0	8	0	0	10
	Beacon	05	0	0	4	0	0	5
					0			

SOURCE: Conversation with Robert Hartzler and Micheal Owen, Agronomy Extension, Iowa State University

Herbicide Adjustments to a Triazine Ban

In the case of a total triazine ban, the use of EPTC, metolachlor, butylate, and alachlor would increase due to the additional loss of cyanazine (Table 5). Applications of these herbicides would be either preplant or preemergence. Most broadleafs are somewhat tolerant to these products, so additional postemergence herbicides would be required to provide broad spectrum control. The major impact would be to require most corn producers to make two separate applications. The recent registration of nicosulfuron could reduce this requirement. A ban on all triazines, the worst possible scenario, could cause an increase in both the number of herbicide applications required and the total pounds of active ingredient of all herbicides used. A companion report (Bouzaher et al. 1991) will discuss a framework for studying this possibility.

Tillage Adjustments to Triazine Regulations

Tillage impacts would tend to be largest for corn producers growing continuous corn or using a conservation tillage or no-till farming system. Producers planting continuous corn can apply relatively large quantities of atrazine without being concerned about injury to susceptible crops in the next cropping year. The likely need for timely and separate applications of triazine substitutes may increase costs, time, and perhaps the need for extra cultivations when weed problems occur. The risk of a build-up in weed seeds in the soil over time may also increase the need for more tillage in future years. Increased tillage will increase soil erosion risks and potential pollution of air and surface water. Increased production costs for conservation tillage and no-till would decrease their competitiveness with conventional tillage. This would increase the costs of farmers needing to employ conservation tillage to comply with government conservation programs. Also, large commercial farms may not have the time to increase the number of tillage operations because of limitations in the number of days tillage can be performed due to weather and soil. Therefore, if increased tillage becomes necessary because of triazine regulations, it would likely be rotary hoeing and/or an extra row cultivation after the corn has emerged rather than more preplant tillage when time is an important factor. These factors are discussed in a companion report (Bouzaher et al. 1991).

Production Costs

A triazine ban would increase the number of times herbicides would need to be applied. A grass herbicide would need to be applied before corn emergence. Metolachlor, EPTC, alachlor, and butylate require incorporation and would have to be applied before planting. Since the currently available grass herbicides do not effectively control broadleafs, a broadleaf herbicide would also need to be applied postemergence. This requires a minimum of two herbicide applications (postemergence broadleaf control may require more than one application), increasing labor and machinery expenses. A subsequent paper will describe these cost differences in weed control strategies.

The added tillage (mostly rotary hoeing or row cultivation) of corn also includes the additional expenses of labor and machinery operation costs. Some corn growers may have to acquire additional tillage equipment to control weeds.

Most growers who use triazine herbicides would face increased production costs due to loss of these products. Alternative products for broadleaf control would increase grower outlays by $2 to $7 per acre. In addition to increased herbicide costs, many growers would need to split applications of herbicides, increase primary tillage, and increase rotary hoe and row cultivator use.

Yield Impacts from Triazine Regulation

A reduction in atrazine application rates should not reduce corn yields. The reduced rates would reduce the effectiveness of atrazine on quackgrass, Canada thistle, cocklebur, velvetleaf, and certain other broadleafs. Even an atrazine ban would not likely have an impact on yields because there are alternative control strategies (Table 5).

A triazine ban should not generally decrease yields but would significantly increase the risks already discussed. Yield impacts from triazine regulations would occur most directly to the continuous corn producers using either conservation tillage or no-till.

The question of exactly how much corn yields will decrease when weed control strategies fail will be left to future reports. However, the characteristics of the relationship between corn yields and weed populations can be discussed at this time. The response curve has three distinct zones, as shown in Figure 1. The first zone is named the "free zone," and is characterized by very low weed competition. Intuitively there is a threshold below which weed numbers have little impact on yields. There is the intermediate zone where weeds begin to compete with the corn plant for sunlight, moisture, and nutrients. But in the third zone, one more weed does not reduce corn yields any further.

Preliminary experimental data seem to indicate that the maximum decrease in corn yields from weed competition is about one-third in a wet year and one-half in a dry year, assuming adequate nitrogen availability.

Needed Research

A remaining task is to determine the impact of triazine regulations on weeds in the remaining major corn-growing states. This will be accomplished by two efforts. First, we will circulate this document among weed experts in major corn-growing states and ask for reviews and applicability of the data to their states. Second, a general agricultural management model, ALMANAC (Williams 1990), has been calibrated to known experimental plot data designed to measure yield impacts from

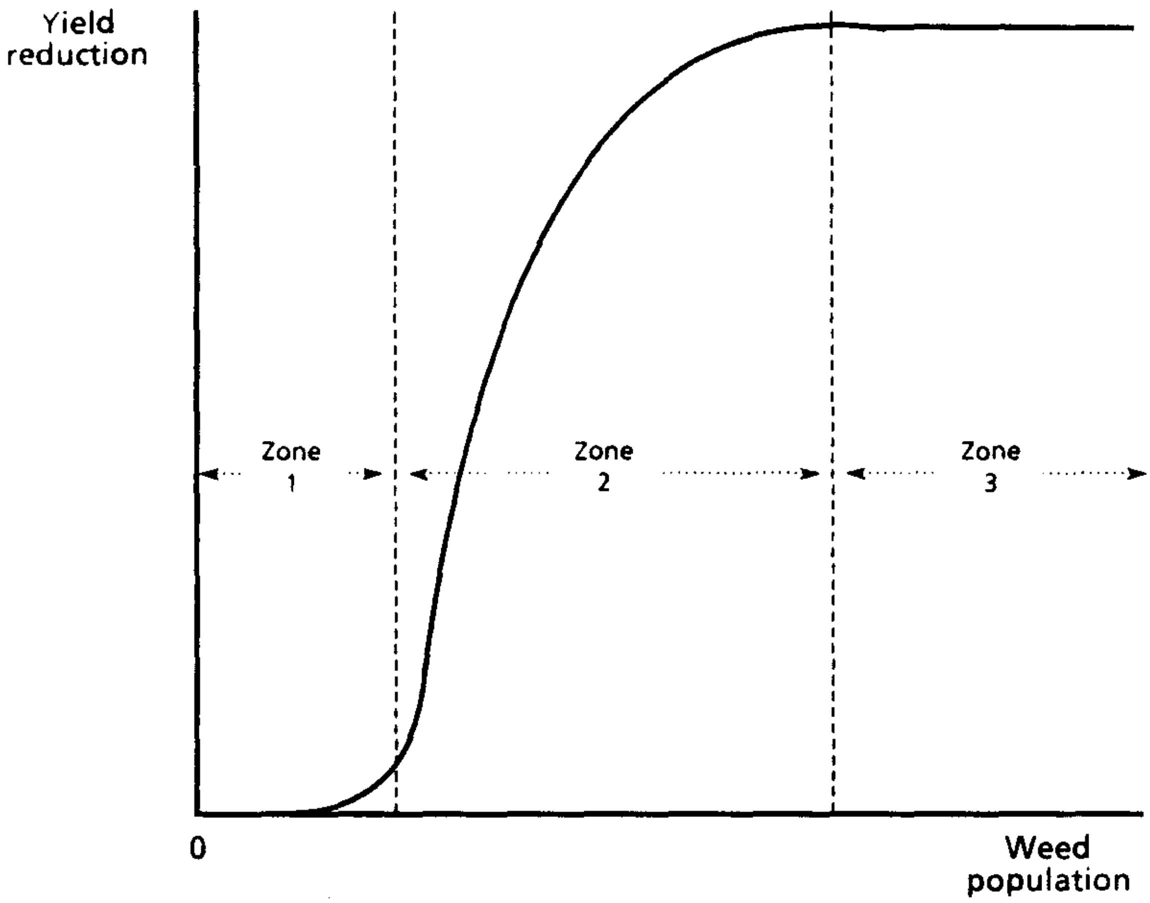

Figure 1. Decrease in corn yields as weed population is increased

weed pressure. ALMANAC runs will be prepared to cover weather, soils, and other agronomic practices not included in experimental plot data. Results of the ALMANAC runs will be published in a technical report. A response surface for important pollution and cost indicators will be derived and published. These tasks will be undertaken by the agricultural decision and biogeophysical work groups of the CEEPES research team.

Another goal, to compute the impact to the costs of producing corn under triazine regulations, also will be undertaken by the CEEPES agriculture decision work group in CARD.

The final evaluation will be a study of the risk impact (yields and costs) of triazine regulations. Corn producers are often forced to take risks, but many of these risks cannot be insured for or avoided. As a result, many producers tend to eliminate or take steps to self-insure against risk and potential loss whenever possible. Triazine regulations may increase a corn producer's exposure to risk. Although some of the risks have been noted in this paper, risk impacts will be explored in more depth in subsequent phases of the project. A survey of producer behavior, given various triazine regulation scenarios, is needed and will be proposed. First- and second-order impacts will be quantified with respect to triazine regulation and the substitutability of possible alternatives and their impact on potential risks.

Summary

The primary goal of this report is to answer specific questions concerning triazine regulations raised by Dr. G. W. Keitt, Jr. of the EPA. This report presents physical facts, expert opinions, and needed research.

The primary triazines used in Iowa's production of corn are atrazine, cyanazine, and simazine (Table 1). Alone, atrazine is applied on 8 percent of corn acreage, while cyanazine and simazine are used on 7 and 1 percent of corn acres. More triazines are being applied as tank mixes with other herbicides than as individual chemicals. Specifically, about 49 percent of corn acres receive triazines in tank mixes with other herbicides, compared to only 16 percent of corn acres treated with individual triazines.

The major findings of this report are:

- Limiting atrazine application rate to 1.5 pounds of active ingredient per acre would not cause lower weed control rates or yield reductions. Exceptions would be farmers in Northeast Iowa experiencing quackgrass pressure.

- An atrazine ban would not necessarily decrease weed control or lower corn yields. The ban would likely increase costs, labor requirements, and total pounds of active ingredients of allherbicides applied to corn. Further detailed analyses of these suggestions and incidence of impacts will be examined and reported in forthcoming publications.

APPENDIX A. ENVIRONMENTAL PROTECTION AGENCY QUESTIONS

Dr. George Keitt, Jr. of the U.S. EPA (Biological Analysis Branch) requested information from Dr. Peter Kuch in the following areas in regard to current research related to atrazine.

I. Find out first how triazines are most commonly used, and why.

   a. What is the respective percentage of use preplant, preemergence, and postemergence?

   b. With what other herbicides are they tank mixed or used in sequence? Note the most popular combinations. Our sense is that a relatively small number of combinations are much more common than others, but this needs verification.

   c. What weeds are the major targets in each case? That is, what is controlled by the triazine that other herbicides in the treatment program do not?

   d. What other reason may there be for preferring a triazine?

II. Then, for each regulatory scenario and popular use pattern, ask what growers would do instead of using triazines (to deal with the problems identified in c and d above).

III. Then, for each alternative situation determined in II, ask what the expected effects would be on yield (this includes both weed control and phytotoxicity aspects). Include cultivation among the options but note the limitations thereon in the case of tillage practices that feature erosion control.

Dr. Keitt seems to believe that most triazines are used preemergence, and that without them, more use will be made of postemergence herbicides to control what escapes preplant and preemergence herbicides. He is not aware of an alternative preemergence herbicide that is as useful on broadleaf weeds. He does not know what may possibly be available soon for registration requests.

APPENDIX B. LIST OF POLICY SCENARIOS

1. Cancel atrazine everywhere.

2. Cancel the triazines everywhere.

3. Cancel the triazines and sulfonylureas everywhere.

4. Selectively cancel atrazine where it has been found or is predicted to contaminate water.

5. Selectively cancel the triazines where they have been found or are predicted to contaminate water.

6. Selectively cancel the triazines and sulfonylureas where they have been found or they are predicted to contaminate water.

7. Restrict the application of atrazine to 1.5 lb/ac. or half the current legal rate and prohibit applications within 50 feet, and mixing and loading within 100 feet of water bodies.

8. Restrict application of triazines to half their legal rate and prohibit application within 50 feet, and mixing and loading within 100 feet of water bodies.

9. Prohibit broadcast applications of atrazine.

10. Prohibit broadcast application of triazines.

11. Restrict atrazine use to alternative years and limit total application per year to no more than 4 lb/ac.

12. Prohibit the preplant and preemergent use of atrazine.

13. Prohibit mixing and loading on the farm. Require dealers to install diked containments for mixing and loading.

APPENDIX C. IOWA PESTICIDE SURVEY

Much of the data in Table 1 initially came from a sample of 5,000 Iowa farm operators located in the nine crop-reporting districts (Figure C.1). The survey was conducted in 1985 and published in 1987 (Wintersteen and Hartzler). Some of the data were adjusted to reflect trends after 1985.

Farm operators were selected by arranging their names in ascending order based on the total number of acres in their operation. A systematic sample was drawn, which ensured a sufficient representation of all sizes of farm operations.

The survey was carried out during February and March 1986. A presurvey letter was mailed to each operator in the sample explaining the purpose of the survey and providing a brief outline of questions that would be asked during the interview. Farm operators were then interviewed either by telephone or in person. The data from each completed questionnaire were processed through a computerized data validation edit prior to summarization. A total of 2,262 farm operations was summarized.

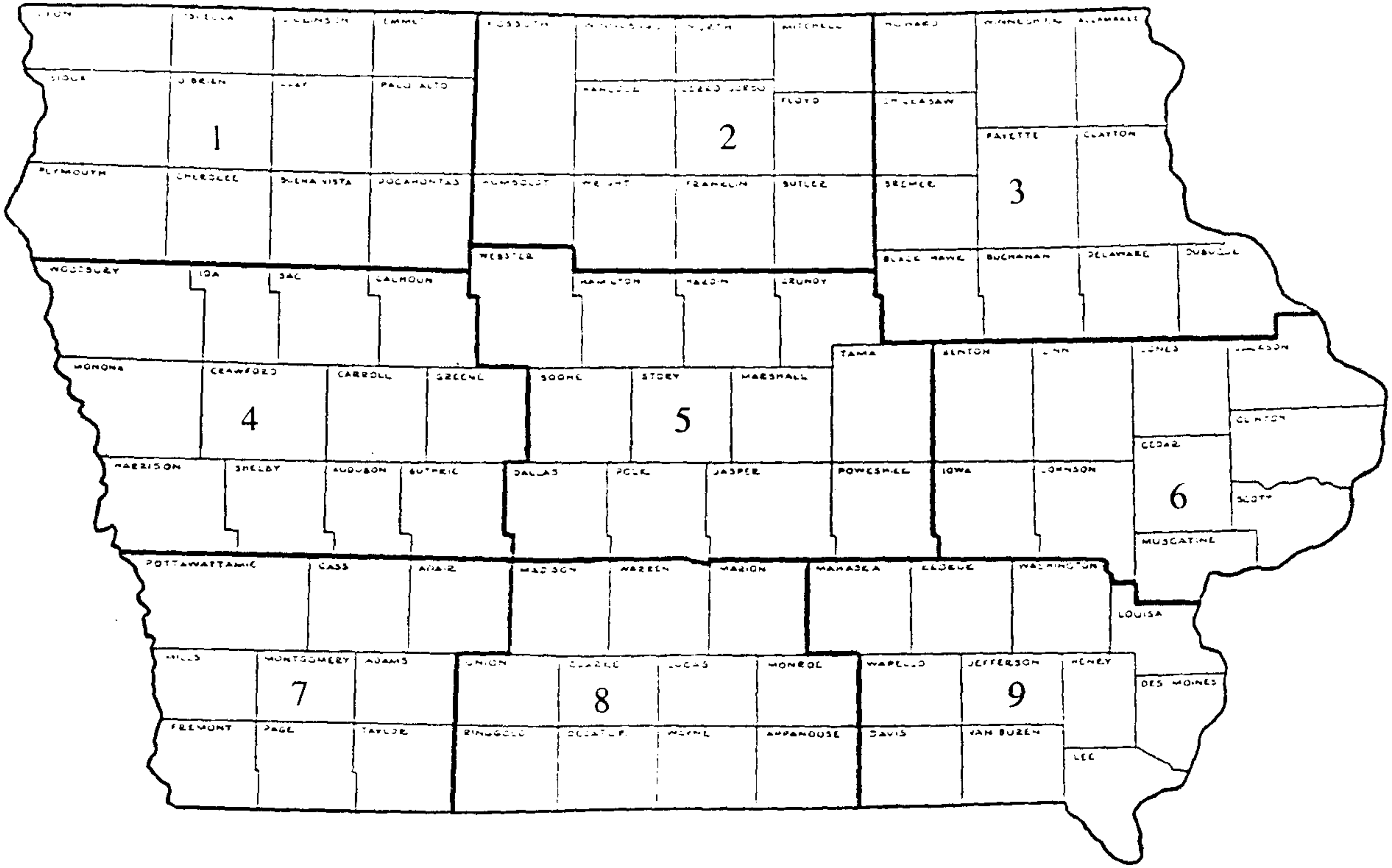

Figure C.1. Crop-reporting districts

SOURCE: Wintersteen and Hartzler 1987

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