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INTRODUCTION

Herbicides are an important production input for farmers in the United States and in Minnesota. Between 1965 and 1975, national sales of herbicides rose by 13% per year. By 1986, annual use of herbicides was over 579 million pounds in the United States (Swanson and Dahl, 1989). In Minnesota, the acres treated with herbicides doubled between 1972 and 1980. In 1980, 95% of all corn acres in Minnesota were treated with herbicides, and nearly 23 million pounds of herbicide active ingredients were applied to corn in Minnesota (Hanthorn, et al., 1982).

Concern for the environmental effects of herbicides and other agricultural chemicals has grown along with their use. Several pesticides have been banned, and restrictions have been placed on the use of many others. The adverse effects of herbicides on the health of farmers, farm workers and consumers of agricultural products has become increasingly controversial.

In the early 1980s, concern focused on the appearance of herbicides and other agricultural chemicals in ground water. In response to increasing concern over the potential for ground water contamination, the Minnesota Department of Agriculture and the Minnesota Department of Health tested private and public drinking water wells for the presence of herbicides and other pesticides.

Fifty-one percent of the private wells and 28% of the public wells tested positive. Fifteen pesticides were detected. Thirteen of the 15 were herbicides, 1 was an insecticide and 1 was a wood preservative. The herbicide, atrazine, was found in over 90% of the wells that tested positive for the presence of pesticides. Another herbicide, alachlor was found in 10% of the wells testing positive (MDA, 1988).

These studies were focused on wells with higher probabilities of contamination, and all the detections were below Recommended Allowable Limits. The frequency of contamination was, nevertheless, larger than expected.

These results stimulated concern and interest in alternative policies to control or prevent the continued contamination of ground water supplies with herbicides and other agricultural chemicals. One such policy, or rule, would be a regional ban of alachlor and atrazine in the ten counties of southeastern Minnesota. There are, at least, four reasons why such a policy is of particular interest.

First, atrazine and alachlor are by far the most common pesticides detected in Minnesota ground water. Both are important corn herbicides. Atrazine is particularly susceptible to leaching, and the health effects of alachlor are under debate.

Second, the well testing by the Minnesota Departments of Agriculture and Health has made it clear that certain regions are more susceptible than others to ground water contamination from herbicides. Southeastern Minnesota, with its karst geology, and central Minnesota with its coarse, drift aquifers are particularly sensitive to contamination from normal agricultural use of herbicides. Targeting herbicide restrictions to those areas most sensitive to contamination could dramatically reduce the cost of the restrictions, and hence increase net benefits from the policy.

Third, regional targeting of pesticide management is in keeping with recently promulgated policies of the Environmental Protection Agency (EPA). The EPA strategy for managing agricultural chemicals envisions a predominant role for state agencies. The strategy explicitly defines a "differential protection approach", that is, targeting protection efforts on sensitive or particularly valuable ground water supplies (EPA, 1987).

Finally, a regional ban of selected herbicides is the most restrictive of suggested policy options. An analysis of the economic, environmental and institutional effects of this most restrictive policy will serve as a baseline to compare other possible policy options.

Given this interest, we analyzed the effects of three hypothetical herbicide bans involving alachlor and atrazine in southeastern Minnesota. The hypothetical bans are: 1) banning atrazine, 2) banning alachlor, and 3) banning alachlor and atrazine together. The analysis is based on farm level economic impacts and the environmental impacts of the three regional herbicide bans.

LITERATURE REVIEW

Many studies have attempted to assess the economic impact of restricting the use of inputs for agricultural production. Relatively few of these studies focus on restricting of specific herbicides used in corn production, and even fewer focus on the farm level impacts of such restrictions.

Cashman, et al., 1980, analyzed the impacts on a representative 600 acre corn and soybean farm in Indiana of restrictions on herbicide use. Two herbicide restrictions were modeled: a ban of all acetanilide herbicides (alachlor, metolachlor, propachlor) and a ban of all triazine herbicides (atrazine, cyanazine, simazine). A linear programming (LP) model was used to simulate the production process of the representative farm. Likely substitutes to the banned herbicides were determined by consulting weed scientists and extension agents. The yield of specified substitutes was estimated based on plot trials. The optimal solution was constrained to one of the evaluated substitutes.

The acetanilide herbicide ban resulted in a yield loss of 4 bushels per acre (2.6%). Variable costs per acre declined by $5/acre (4%), but the drop in variable costs was not enough to offset lower yields, thus net returns per acre dropped by $4/acre (1.6%). Slightly greater impacts occurred with the triazine herbicide ban, as the yield loss was 5 bushels per acre (3.3%). Variable costs per acre declined after the ban by $4/acre (3.2%), while net returns per acre fell by $8/acre (3.2%).

Delvo, 1971, analyzed the farm level impacts of herbicide restrictions for three hypothetical scenarios. The base situation was weed control accomplished by pre-emergence herbicides and cultivation. The second scenario postulated a ban of all pre-emergence and pre-plant herbicides, leaving only post-emergence herbicides and cultivation for weed control. The third scenario postulated a ban of all herbicides, leaving only cultivation to accomplish weed control.

Delvo estimated the impacts of these restrictions on a 400 acre dryland farm, and a 600 acre irrigated farm in Nebraska. Yields were assumed to fall by 12% if all pre-emergence herbicides were banned, and by 23% if all herbicides were banned. Returns to labor and management were used as the metric of profitability.

The estimated returns to labor and management were between $1,900 and $7,700 before any bans. If pre-emergence and pre-plant herbicides were banned, returns fell to between $550 and $1.700. When all herbicides were banned, returns became negative.

Several authors used larger LP models to estimate the welfare changes if herbicides were banned nationally. Osteen and Kuchler, 1986 and 1987, used a national model of crop prices, production acreage, crop rent and economic surpluses to estimate the effect of national bans on corn herbicides. Four scenarios were evaluated: ban alachlor, ban all acetanilide, ban atrazine, and ban all triazines. The effect of the bans on yield, and the probable substitutes for the banned chemicals were derived from questionnaires sent to representative weed scientists across the country.

The higher production costs and lower yields resulting from the bans were offset by increased commodity prices induced by lower national production of corn. Consequently, the bans brought about increases in net returns per acre. Both users and non-users of the restricted herbicides gained from herbicide restrictions on corn. However, the authors stressed the need to assess the order in which herbicides were restricted, and suggested that evaluating possible restrictions one chemical at a time might lead to undesirable effects as more and more chemicals were banned.

Similar results were reported by Burton and Martin, 1987, who evaluated the impact of national bans on corn and soybean herbicides. Corn yields were assumed to drop by 2% if atrazine was banned and by 25% if all herbicides were banned. Production costs were expected to rise by $4.61/acre if atrazine was banned, and by $14.61/acre if all herbicides were banned. They found that changes in consumer and producer surpluses were small if atrazine was banned alone, but that producer surplus increased by 5.7%, and consumer surplus decreased by 0.3% if all herbicides were banned.

Kania and Johnson, 1981, simulated the effect on the national market of national bans on selected pesticides, and used a regional linear programming model of a crop production area in Nebraska to assess the impact of such restrictions on a local production region. They assumed no yield decreases in Nebraska, if atrazine was banned, and a decline in production costs. Product prices were estimated to increase due to national reductions in corn production. The combination of no yield loss, decreased production costs and price increases resulted in 2.5% increase in producer surplus if atrazine was banned. The authors cautioned that their results were very sensitive to estimated yield effects.

Taylor and Frohberg, 1977, estimated the welfare effects of erosion controls and input restrictions on a national level. They estimated yield losses of 19% if all herbicides were banned in corn production, consumer surplus reductions of over $3.5 billion, and increased producer surplus of $1.8 billion.

Finally, Gianessi, et al., 1988, evaluated the effects of a regional ban of all triazines in the Chesapeake Bay area. They found there was no effect on market prices of corn or other commodities, so that the effects of the regional ban were restricted to changes in producer surplus. Costs were estimated to increase by $7.50 to $12.50/ac, and yield losses were between 0 and 16.8%, depending on local practices. Yield and cost estimates were based on discussions with local extension and experiment station personnel. These changes in costs and yields cause regional producer surplus to drop by $4 to $70 million. No farm level impacts were reported.

THEORY

The effect of herbicide restrictions is illustrated in Figure 1. The y-axis represents yield, and the x-axis the expenditure on weed control. The yield response to weed control involves a pair of response functions such as F_{gw} and F_{bw} in the figure. A pair of response functions is needed to represent each weed control treatment since weed control is affected by weather. The function F_{gw} represents yield response to weed control if the weather is good for weed control, while F_{bw} represents the yield response in weather not suitable for weed control.[1] Larger expenditures on weed control are required in weather not suitable for weed control to achieve the same yield as in good weather.

The effect of an herbicide ban is to shift the pair of response functions from F_{gw} to F^1_{gw}, and from F_{bw} to F^1_{bw}. This shift down and to the right reflects the use of weed control substitutes that are less effective, or more expensive, or both. The vertical distance between F^1_{gw} and F_{gw} reflects lower yields at the same expenditure for weed control in good weather following the ban. The horizontal distance reflects the increased cost required to maintain yields at the same level as before the

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[1] Good weather for chemical weed control is defined as more than .5 inches of rain in the week after the herbicide application, so there is sufficient water to move the herbicide into the soil. Good weather for mechanical weed control is defined as less than .75 inches of rain in each of the two weeks following planting so that the soil is dry enough to allow cultivation.

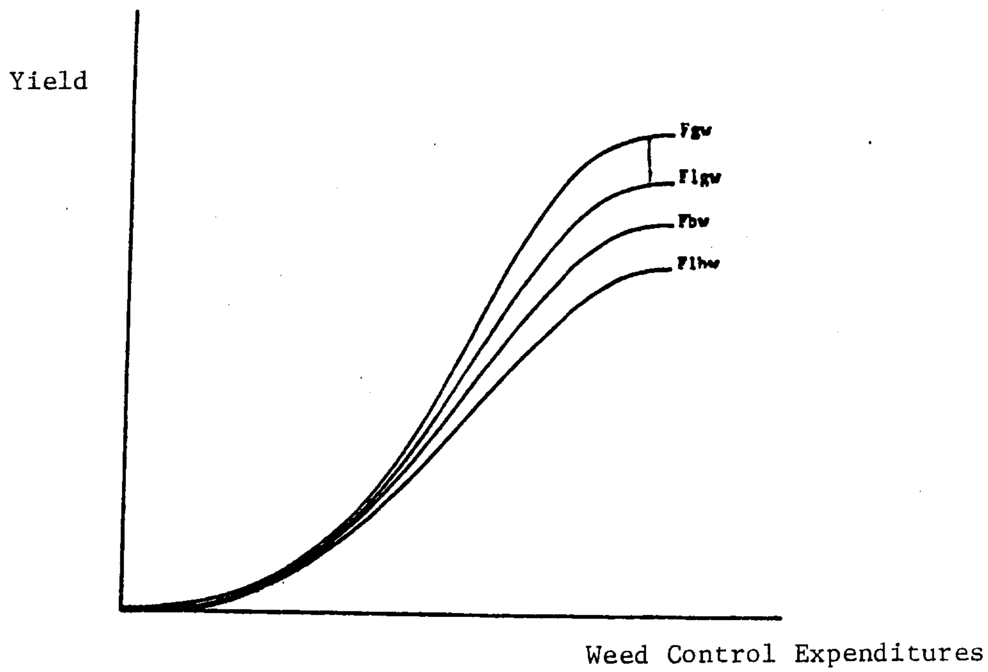

Figure 1
Response Functions for a Herbicide Ban

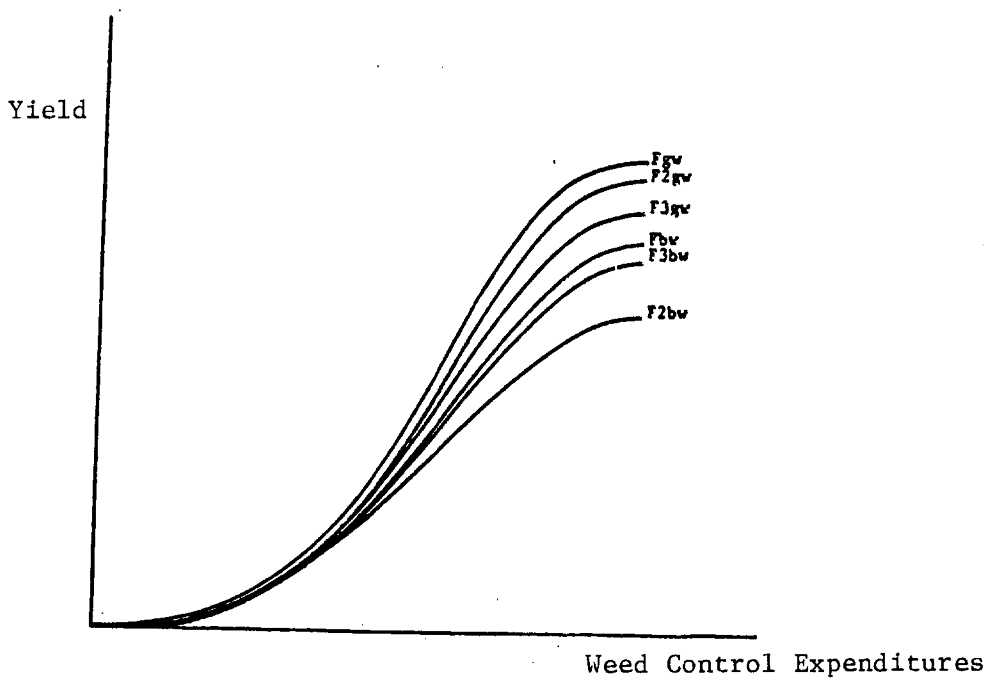

Figure 2
Response Functions of Three Weed Control Options

ban. The vertical distance between response functions under good and bad weather, i.e., F_{gw} and F_{bw}, for a given treatment is a suggestion of the risk involved in using that treatment.

In Figure 1, $F^1{}_{gw}$ shifts down and to the right the same distance from F_{gw} as $F^1{}_{bw}$ shifts from F_{bw}. That is, the vertical distance between the pair of functions before the ban is the same as the distance between the pair of functions after the ban. This means the risk of yield losses due to weather is the same both before and after the ban. Clearly, this does not have to be the case.

Figure 2 illustrates other possible shifts. The substitute, F^2, performs nearly as well in good weather as the original treatment, F, used before the ban, but its performance is very poor in bad weather. The risk of yield losses during bad weather is much greater for this treatment than for the treatment used before the ban.

The substitute F^3 performs about as well in bad weather as the treatment used before the ban, but performs less well in good weather. The risk of yield losses in bad weather, as measured by the difference between yield in good and bad weather, is actually smaller for this alternative than for the treatment before the ban.

It is also possible to imagine an average response function. This response function would lie somewhere between the response functions for good or bad weather, and would represent the weighted average yield expected for any weed control expenditure, with the weights being the probabilities of a good or bad weather event. Such weighted average response functions are not shown in Figures 1 and 2.

Large losses in weighted average yields suggests that the weed control substitute performs poorly in weather bad for weed control, and that there is a high probability of weather induced failure of weed control. If the probability of weather induced failure for the substitute is high, the difference in weighted average yields between the substitute and the banned chemical will be larger than the difference in yields between the two alternatives in bad weather. The converse will be true if the probability of weather induced failure for the substitute is quite small. Such results were, in fact, found in the analysis of weed control alternatives described below.

One can imagine many different hypothetical pairs of response functions, each pair representing a possible substitute to the weed control treatment used before the ban. The important thing to note is the producer must consider yield, cost and risk when choosing a substitute.

MODEL

The producer is assumed to maximize profits represented by the following function:

$$\text{MAX} \quad P[F(X,W)] - C(X)$$

where X is a vector of inputs, W is a vector of weather variables, F is the response function for the farm firm, and C is the cost function. All inputs except those relating to weed control are fixed.

If all inputs except those used for weed control are fixed, then F becomes a model relating weed control to yield. This model has three parts. The first part relates weed control inputs to a weed density in the field while the second part relates weed density to yield. A full account of the construction of these two parts of the model can be found in Cox, 1989.

The third part of the model relates weather to weed control, and it is the most difficult part to estimate. The amount and timing of rainfall alters the effectiveness of both chemical and non-chemical weed control, and therefore alters yield. To estimate F, a vector of states of nature, defined in terms of precipitation, and the yield expected in each of these states of nature is needed. In addition, the probability of occurrence of each state of nature is needed. Then given some assumptions on the risk preferences of the producer, an optimal solution to the problem might be found.

Empirically, only two states of nature are defined given present data. These are estimates of yield in good and bad weather for weed control. Yields in any intermediate state of nature are not known. Thus the response function is evaluated at only two points.

The weighted average yields are calculated based on yields in good and bad weather, and the probabilities of good and bad weather occurring. Such weighted average yields, however, should not be interpreted as the yield expected in average weather. The characteristics of the response function at such intermediate points are not known.

The cost function is estimated by constructing a representative farm and evaluating enterprise budgets for that farm using alternative weed control treatments. The representative farm is assumed to contain 300 acres of continuous corn. Three tillage systems are analyzed: conventional, reduced and ridge tillage. Ridge tillage has the highest returns over variable costs of the three systems, but is not as yet widely used in the study area. Conventional and reduced tillage systems are quite similar in their responses to herbicide bans, consequently only the results for the conventional system are reported here. A full account of all three tillage systems analyzed can be found in Cox, 1989.

Enterprise budgets are constructed for each tillage system. All costs except those relating to weed control are held fixed. The representative farm uses a pre-emergent application of atrazine and alachlor before any hypothetical herbicide bans are imposed. No change in tillage system, or rotation is allowed, since the physical data needed to model the effect of rotation changes on weed control are not available. Because of this restriction in the flexibility of a producer's response, the results must be interpreted as worst case estimates.

Four decision rules are used in this study to simulate producer's decisions:

1) The producer decides to maintain the same yield in both good and bad weather as before the ban, and pays the extra cost of weed control required to maintain yields.
2) The producer decides to maximize profit assuming good weather and ignores the possibility of bad weather losses.
3) The producer decides to maximize profit assuming bad weather.
4) The producer decides to maximize weighted average profit, with the weights being the probabilities of good and bad weather.

These decision rules are used to choose substitutes to alachlor and atrazine following a hypothetical ban of either or both herbicides, with returns over operating costs used as the measure of profit.

FARM LEVEL EFFECTS OF BANS

A pre-emergent application of atrazine and alachlor is the optimal choice for the representative farm before any hypothetical bans are imposed. This choice is optimal since it produces larger profits in both good and bad weather than any other weed control alternative and has a smaller risk, as measured by the difference between yield in good and bad weather. If either atrazine or alachlor is banned, there is no other alternative that maximizes profit in good and bad weather, and minimizes risk.

This means the farmer must trade off yield, cost and risk when choosing an alternative to either atrazine or alachlor. The magnitude of the effects of the ban on any particular producer will depend on how he/she makes these trade offs, that is, which decision rule is used to choose a weed control substitute.

Effects of an Atrazine Ban

Returns over operating costs fall if atrazine is banned regardless of which decision rule producers use to respond to the loss of atrazine (Table 1). Returns fall by $7.73/ac in both good and bad weather if producers decide to maintain the same yields as before the ban, or if they decide to maximize profit in bad weather. In both cases, producers substitute cyanazine for atrazine, and add a second cultivation to maintain weed control. The losses in returns are due solely to the increased cost of the substitute herbicide and the increased tillage cost of the added cultivation since yield is unchanged.

TABLE 1

LOSSES IN PER ACRE RETURNS
OVER OPERATING COSTS DUE TO HERBICIDE BANS

TYPES OF BAN AND DECISION RULE	LOSSES IN GOOD WEATHER	LOSSES IN BAD WEATHER	LOSSES IN WEIGHTED AVG. RETURNS
	-------------per acre	---------------	
I. Ban Atrazine			
1. Same yield	$ 7.73(3%)	$ 7.73(4%)	$ 7.73(4%)
2. Max. Prof. Good Weather	0.51(0%)	20.56(10%)	27.18(11%)
3. Max. Prof. Bad Weather	7.73(3%)	7.73(4%)	7.73(4%)
4. Max. Average Profit	7.73(3%)	7.73(4%)	7.73(4%)
II. Ban Alachlor			
1. Same yield	2.64(1%)	2.64(1%)	2.64(1%)
2. Max. Prof. Good Weather	0.10(0%)	20.14(10%)	7.71(3%)
3. Max. Prof. Bad Weather	2.64(1%)	2.64(1%)	2.64(1%)
4. Max. Average Profit	2.64(1%)	2.64(1%)	2.64(1%)
III. Ban Both			
1. Same yield	9.53(3%)	9.53(5%)	9.53(4%)
2. Max. Prof. Good Weather	0.51(0%)	20.56(10%)	27.18(11%)
3. Max. Prof. Bad Weather	9.53(3%)	9.53(5%)	9.53(4%)
4. Max. Average Profit	11.62(4%)	71.76(35%)	7.81(3%)

Producers can reduce these losses by choosing to maximize profit in good weather by substituting pendimethalin for atrazine and substantially increasing mechanical weed control. Losses in good weather are then only $0.51/ac. Again, the losses with good weather are due only to increased weed control costs. However, producers using this decision rule are exposed to losses of $20.56/ac or a 10% drop in returns if the weather is unsuited for weed control. Yields drop with bad weather by 8 bus/ac due to inadequate weed control. Losses in average returns are even larger if producers use this decision rule to choose a substitute since the probability of unfavorable weather is high.

Losses to producers are very similar if they use either reduced or ridge tillage instead of conventional tillage. The atrazine ban does not change the relative profitability of alternative tillage systems; ridge tillage remains the most profitable system, followed by reduced and conventional tillage.

Effects of an Alachlor Ban

Producers also suffer losses in returns over operating costs if alachlor is banned regardless of which decision rule they use to respond to the ban. If producers choose to maintain the same yields in good and bad weather as before the ban, they lose $2.64/ac in both good and bad weather. The losses in returns over operating costs are the same if producers respond to the ban by maximizing profits in bad weather. These losses are due solely to increased cost of weed control and are much smaller than those if atrazine is banned, because of a very close substitute for alachlor. Producers can simply substitute metolaclor for alachlor with no added cultivation or other tillage changes. The added cost of metolachlor is minimal, but could go up substantially due to price increases once alachlor is banned. This happened when Canada banned alachlor.

Metolachlor is very similar chemically to alachlor and it is possible that metolachlor would be banned along with alachlor. If both chemicals are banned, the effect on costs is greater. For example, the losses in returns for producers deciding to maintain the same yields in good and bad weather as before the ban are $5.18/ac. The greater cost is due both to the substitution of a more expensive herbicide, and the need to shift from pre-emergent applications to pre-plant applications with added tillage costs.

As with the atrazine ban, producers can substantially reduce per acre losses in good weather if alachlor is banned by using a substitute that maximizes profit in good weather and ignore the possibility of bad weather. Losses in returns for producers using this decision rule are only $0.10/ac when the weather is good for weed control but during bad weather, losses jump to $20.15/ac.

The losses in returns due to an alachlor ban are very similar if producers use reduced or ridge rather than conventional tillage. An alachlor ban does not affect the relative profitability of tillage systems. If both alachlor and metolachlor are banned, however, there is no substitute that will maintain the same yields in both good and bad weather as before the ban with ridge tillage. The relative profitability of tillage systems then depends on which decision rule producers use to respond to the loss of alachlor and metolachlor. Banning both alachlor and metolachlor might induce shifts in tillage systems from ridge to reduced or conventional tillage.

Effects of an Atrazine and Alachlor Ban

The losses in returns over operating costs are larger if atrazine and alachlor are banned together than if they are banned individually. Producers suffer losses regardless of which decision rule they use to respond to the ban.

When the same yields are maintained in good and bad weather as before the ban, losses in returns over operating costs are $9.53/ac. The losses are the same if the decision rule is to minimize losses in bad weather. Producers using either of these two decision rules substitute cyanazine for atrazine and metolachlor for alachlor and add a second cultivation to maintain weed control. The losses are due solely to increased cost.

If producers decide to respond to the ban by maximizing profits in good weather and ignores the possibility of bad weather, they can reduce losses in good weather to $0.51/ac, but only by being exposed to losses of $20.56/ac during bad weather for weed control. Again, losses in average returns are even larger for the producer using this decision rule, since the probability of bad weather is relatively high.

If producers decide to respond to the atrazine and alachlor ban by maximizing weighted average profits, they will shift to a weed control regime using no herbicides. Losses in average returns are then only $7.81/ac. The losses to a producer using only mechanical weed control are very large if the weather is bad, but the probability of bad weather events for mechanical weed control is quite small relative to bad weather for chemical control, and hence losses on average returns are relatively small.

The representative farm constructed for this study is constrained to continuous corn. The producer is not allowed to change rotations in response to the herbicide bans. In addition, the weed control and yield model used overestimates yield losses when weed densities are high, meaning that the estimated yield losses for a non-herbicide weed control regime in bad weather are over-stated. This suggests that the no herbicide option may be a more viable alternative than estimated here for a producer with the financial stability to accept occasionally large losses during bad weather for weed control.

The losses from an atrazine and alachlor ban for conventional tillage are similar to those for either reduced or ridge tillage. An atrazine and alachlor ban does not produce any incentive to shift tillage systems. Ridge tillage remains the most profitable system, followed by reduced and conventional tillage.

If metolachlor should be banned along with alachlor and atrazine, the losses a producer suffers are larger than the atrazine and alachlor ban. Producers lose $12.91/ac if they try to maintain the same yields as before the ban. Again these larger losses are due to more expensive herbicide alternatives and the need to shift to pre-plant incorporation with its greater tillage costs. The relative profitability of tillage systems depends on the decision rule producers use to respond to the ban, and on the weather. In some cases producers may be better off shifting from ridge tillage to reduced or conventional tillage.

Comparison of Bans

The hypothetical herbicide bans studied differ from one another in their effects on the representative farm in systematic ways. Bans involving atrazine have the largest effect on costs. There are no patent restrictions on atrazine, and generic products are available. This means atrazine is the least expensive pre-emergent broadleaf herbicide available. Substitutes for atrazine require more expensive chemicals, more mechanical weed control, or a shift to both pre-emerge and post-emerge applications. All of these changes in tillage and application increase costs.

Bans involving alachlor are less costly. There is a perfect substitute, in terms of yield impacts, which is only slightly higher in cost. This substitute requires no change in application and no increased mechanical weed control.

The relative effect of a ban on profit, measured by returns over operating costs per acre, is complicated by the fact that returns depend on both cost and yield changes, and yield depends on both the decision rule used and the weather experienced.

Still, the herbicide bans can be ranked for conventional and reduced tillage by increasing losses as follows:

1. ban alachlor
2. ban alachlor and metolachlor
3. ban atrazine
4. ban atrazine and alachlor
5. ban atrazine, alachlor and metolachlor

In ridge tillage, the picture is not as simple. If the acetanilides are banned, all substitutes available to producers in ridge tillage have lower yields in bad weather than before the ban. This means that the relative effect of herbicide bans on producers using ridge tillage depends on weather. In good weather, the ranking of the bans is the same as that for conventional and reduced tillage given above. In bad weather, a ban on acetanilides creates larger losses than bans of atrazine, alachlor or atrazine and alachlor together.

The hypothetical bans do not change the relative profitability of tillage systems if atrazine, alachlor or atrazine and alachlor are banned. Ridge tillage remains the most profitable system, followed by reduced and conventional tillage. If the metolachlor is banned along with alachlor or in combination with atrazine, the relative ranking of tillage systems depends on weather and the substitute selected. This reflects again the fact that banning alachlor and metolachlor exposes the ridge till producer to greater risk of losses in bad weather no matter what substitute is selected.

Sensitivity of Results

Profit, and hence the effects of herbicide bans on farmers, are much more sensitive to changes in yield and corn price, than to changes in weed control costs. A five percent change in costs of the representative farm results in only a 3% change in the estimated effects of herbicide bans on returns. A five percent change in yield or price of corn, however, results in a nearly ten percent change in the estimated effects of an herbicide ban on returns.

The estimation of yield losses due to herbicide bans is the most uncertain factor in the model used to estimate the effect of herbicide bans on producer profits. It is quite possible that the estimated yields may be in error by more than 5%. This means the loss estimates may well be in error by more than 10%.

Losses in bad weather due to herbicide bans are the most important effect of herbicide bans. Since the representative farm is constrained in its response to herbicide bans to simple substitutions of herbicides and tillage, and since the weed control and yield model tends to overestimate losses in bad weather, the results should be viewed as worst case losses.

Changes in average returns over operating costs are sensitive to the assigned weights; in this study, the weights are the probabilities of good and bad weather events. Any changes in the estimated probabilities of good and bad weather events will have important effects on the estimated effects of a herbicide ban on average returns.

Herbicide Bans in General

This study reveals several important characteristics of estimations of the effects of herbicide bans on producers. First, most weed control regimes perform similarly if the weather is favorable for weed control. It is performance of weed control regimes when the weather is unfavorable that distinguishes one weed control regime from another. The major effect of the herbicide bans analyzed is to increase the risk of losses in yield, and/or increases in the costs of weed control when the weather is unfavorable for weed control. If producers can get into their fields at the appropriate time, they can successfully substitute mechanical for chemical weed control. When there is adequate rainfall to move herbicides into the soil before weeds germinate, the substitution of one herbicide for another has little effect on yield. However, if the weather is unfavorable, then particular herbicides perform better than others, and the substitution of mechanical for chemical weed control is much more uncertain. It is under these conditions that the loss of one or more herbicide options is most clearly felt by producers.

Second, as mentioned above, weed control cost increases are dwarfed by losses due to declines in per acre yields. It is the estimation of these yield losses that is most critical to the estimation of the impact of herbicide restrictions. Surprisingly, the technical information available to estimate such yield losses is poor. Most agronomic studies have focused on the relative performance of one herbicide compared to another as measured by percent weed control. The effect of different levels of weed control on yield has not been estimated. Much more agronomic research focusing on the effect of weed density on yield, and on the relative performance or alternative weed control regimes on yield needs to be conducted before better estimates of the impact of herbicide restrictions can be made.

Third, the more flexible the response to weed infestations, and the more flexible the response to herbicide restrictions, the smaller is the impact of any herbicide restriction. Producers who can change their rotations and cropping patterns in response to weed problems or herbicide restrictions can substantially mitigate the effect of a restriction on the use of a particular herbicide. Additionally, a producer who can make weed control decisions in stages during the season, that is, can respond in a timely fashion to any particular weed problem, can respond more flexibly to an herbicide restriction. A producer who is prepared to make split applications of grass and broadleaf herbicides, and to make timely substitution of mechanical for chemical weed control, when the weather reduces the herbicide effectiveness, can reduce the losses due to any herbicide restriction. Modeling this kind of flexible response is difficult, and requires more detailed information about the relationship between weather, weed control and yield than is presently available.

Finally, it is clear that the number of herbicides restricted at any one time has dramatic effects on the magnitude of the impacts on producers. This is particularly important when restrictions eliminate most of the available herbicides for a particular weed problem. For example, banning both alachlor and metolachlor greatly reduces the herbicide options available for grass weed control in corn and, therefore requires a shift from pre-emerge to pre-plant incorporation with concomitantly increased costs.

ENVIRONMENTAL EFFECTS

The probability of a particular herbicide leaching into the ground water depends on the nature of the soil on which it is applied and on the chemical properties of the herbicide. Substitutes may be more, less or likely to leach as the herbicides they replace. In this study, the soil type to which these herbicides are applied is assumed to be constant; that is, the bans are assumed not to change the fields used to produce corn, no land is taken out of production, and there is no crop substitution. Thus, the environmental effect of the herbicide ban will be dependent on the relative leaching potential of the weed control substitutes for atrazine and alachlor.

Leaching Potential

The propensity of a particular herbicide to leach is determined by its solubility in water, its persistence, and the strength with which it adheres to soil particles. The greater the solubility of the herbicide in water, the greater the probability that the herbicide will be carried by percolating water out of the root zone and into ground water. The greater the persistence of the herbicide, measured by its half-life in the soil, the greater the probability that the herbicide will end up in ground or surface water. Herbicides that break down quickly have much less chance of moving into the subsoil. Finally, herbicides that become strongly attached to soil particles are much less likely to move with percolating water. Soil sorption is measured by the Koc value. The higher the Koc value, the greater the attachment to soil particles.

These three herbicide characteristics (solubility, half-life and adherence) have been integrated to rate the leaching potential of each herbicide (SCS, unpublished). The leaching potential is "the tendency of a pesticide to move in solution with water and leach below the root zone into deep percolation," (SCS, unpublished). Herbicides are ranked as having a small, medium or large potential to leach. These rankings are used to compare the probability of substitutes for atrazine and alachlor leaching into ground water.

Table 2 lists the weed control alternatives that are within the likely set of substitutes if atrazine is banned alone, or in combination with alachlor or the acetanilide. Since atrazine has a large potential to

TABLE 2
LEACHING POTENTIAL OF LIKELY SUBSTITUTES TO ATRAZINE

Herbicide	LEACHING POTENTIAL
atrazine	large
cyanazine	medium
2,4-D	small-medium

leach because of its high solubility and long half life, all of the likely substitutes have lower leaching potentials than atrazine. Therefore, banning atrazine should reduce the probability of herbicides reaching ground water.

Environmental effects are more equivocal if alachlor is banned. Table 3 lists the leaching potential of alachlor and its likely

TABLE 3
LEACHING POTENTIAL OF LIKELY SUBSTITUTES FOR ALACHLOR

Herbicide	LEACHING POTENTIAL
alachlor	medium
metolachlor	medium
pendimethalin	small
EPTC	medium

substitutes. Of these substitutes, only pendimethalin has a smaller leaching potential than alachlor itself. Pendimethalin enters the set of likely substitutes as the alternative that maximizes profit in good weather. However, it carries with it risk of much greater losses in bad weather. It becomes a more prominent substitute only if all the acetanilide are banned, that is if metolachlor and propachlor are banned along with alachlor. Even then, the producer would have to be willing to accept much larger losses in bad weather to choose pendimethalin over EPTC.

Herbicide Bans and Soil Erosion

Efforts to control soil loss have focused on adopting tillage practices that leave substantial amounts of crop residue on the soil surface. The residue reduces the effect of raindrop impact on loosening soil particles, and impedes the flow of water over the field. It is possible that measures to restrict herbicides could cause substitutions that reduce the amount of residue left on the soil surface, and thereby increase the risk of soil loss.

There are two ways the herbicide restrictions might influence the amount of crop residue left on the field. First, the restrictions might induce a shift from conservation tillage practices to more conventional tillage practices. Second, the restrictions might induce a substitution of mechanical for chemical weed control within a particular tillage system.

The shift from a conservation tillage system to a more conventional system will have the most dramatic impact on soil losses. Allmaras, et al., 1985, estimated the residue remaining on the soil surface under various tillage practices. They reported that 84% of crop residue remained under no-till tillage, 32% under reduced tillage, and only 8% under conventional tillage. Since crop residue is critical to the reduction in soil erosion, any herbicide ban that results in shifts from ridge to reduced tillage, or from reduced to conventional tillage would be expected to exacerbate soil losses.

Such shifts in tillage system are likely only if all the acetanilide are banned as a group. The results of this study indicate that a ban of acetanilides or of acetanilides plus atrazine may well induce producers to shift to more conventional tillage practices in order to take advantage of pre-plant incorporated grass herbicides. Bans of atrazine, alachlor, or atrazine and alachlor together, do not change the relative profitability of tillage systems. It appears that bans have to encompass most of the herbicides available for a particular weed control function, in our case, for grass weed control, before shifts in tillage systems become likely.

In contrast, all of the bans studied are likely to induce some substitution of mechanical for chemical weed control. Bans of atrazine alone or alachlor alone are likely to result in an added cultivation to maintain weed control at pre-ban levels. The addition of a single cultivation, however, would be expected to have minimal effects on soil losses. Substitutions relying primarily on mechanical weed control could have significant effects on the risk of soil loss.

Increased risk of soil loss does not necessarily mean increased damage from soil loss. The actual soil loss is closely linked to many site factors, including slope, slope length, and position in the watershed. Other management factors including rotation, strip cropping, contouring and terracing have important effects on whether soil is lost or not, regardless of the tillage system used.

Interactions with Conservation Compliance

Conservation Compliance regulations may constrain the tillage practice choice set of producers responding to herbicide restrictions when the regulations go into effect. The interaction between Conservation Compliance and herbicide bans are difficult to predict because of the complexity of the factors involved in determining whether a producer is in compliance on any particular field.

Conservation Compliance regulations are not tied solely to tillage practices. Changes in rotation, strip cropping and contouring will also satisfy the regulations. However, two points seem clear. In southeastern Minnesota, continuous row crops with no hay rotation will probably require some form of conservation tillage to comply (Breitbach, 1989). This means that producers will be constrained from shifting out of conservation tillage, in response to a ban on all acetanilide, on fields subject to Conservation Compliance.

Second, farmers using pre-plant incorporated herbicides may have trouble complying with Conservation Compliance, especially in continuous row crop systems (Breitbach, 1989). Again, this will constrain the substitutions available to producers on land subject to Conservation Compliance if all acetanilide are banned. A pre-plant incorporated application of EPTC becomes a likely substitute under such a ban. This treatment is the only treatment with the same yields in bad weather as before the ban. Yet because of Conservation Compliance, producers may not be able to use this substitute without changing their rotation.

Conservation Compliance regulations should not seriously constrain the choice of substitutes if alachlor or atrazine are banned alone, or if alachlor and atrazine are banned together.

SUMMARY

The major effect of herbicide bans on producers is to increase the risk of yield losses when the weather is unsuitable for weed control. This means that financially stable producers, that is, those able to absorb a year of lower yields, have much more flexibility in responding to the ban, and can reduce the overall impact of the ban on their profits. Financially unstable producers have less choice in responding to the ban. If they must reduce the risk of low yields when the weather is unsuitable for weed control, then they will have to settle for lower average returns due to the herbicide ban.

The dollar impact on producers depends on both weather and the decision rule the producer uses to respond to the ban. Cost increases range from $2 to $10 per acre if the producers try to maintain the same yields in both good and bad weather for weed control as before the bans. Banning alachlor has the smallest effect on cost; banning atrazine and alachlor has the largest effect on cost.

Cost increases can be substantially reduced if farmers are willing to accept a risk of larger yield losses when the weather is unsuitable for weed control. Cost increases of less than $1 per acre can maintain the same yields in good weather, but result in losses of 6 to 8 bushels per acre if the weather is unfavorable for weed control. This translates into losses of $20 per acre when the weather is unfavorable.

If producers respond to the ban by focusing on weighted average profits, then losses range from $3 to $8 per acre.

Banning groups of herbicides always has a larger impact than banning single herbicides. This is especially true if the ban includes most of the herbicides available for a specific function. For example, a ban of all the acetanilide herbicides, alachlor, metolachlor and propachlor, eliminates most of the herbicides available for grass control in corn. Such a ban will require producers to change from a pre-emerge to a pre-plant incorporated herbicide, and increase mechanical weed control, with attendant cost increases.

Banning atrazine or alachlor alone or in combination does not change the relative profitability of tillage systems. Ridge tillage remains the most profitable, followed by reduced and conventional tillage. Such bans, therefore, would not be expected to dramatically increase soil erosion by shifting producers out of conservation tillage strategies. If all the acetanilide are banned, the ranking of tillage systems then depends on both the weather and the decision rule used by the producer. Such a ban might create an incentive to shift from conservation tillage systems to more conventional tillage systems.

Finally, the more flexibility producers have to respond to an herbicide ban, the more they can reduce the impact of those bans on costs and yield. If producers can augment chemical weed control with timely mechanical weed control, if weed control activities can be sequenced through the crop year with decisions based on weather and weed populations, and if the producer can accept a risk of larger losses in a bad weed control year, then they can blunt many of the effects of a herbicide ban.

CONCLUSION

The intent of an exercise in policy analysis such as this one is to help determine whether regional herbicide bans are good or bad policy. There are at least three criteria that can be used to help answer that question. First, will the herbicide bans effectively reduce ground water contamination, second, do the benefits of such bans outweigh their costs, and third, do the bans result in an equitable distribution of costs and benefits? The results of this study shed some light on all of these questions, but unfortunately, on none of them conclusively.

Effectiveness

The effectiveness of the regional bans in reducing ground water contamination can be looked at in two ways. First, do the bans result in herbicide substitutions that are less likely to pollute ground water, and second, will producers actually abide by the bans?

Banning atrazine results in substitutions that are all less likely to pollute ground water, as measured by their leaching potential. The results are more equivocal if alachlor is banned. Two of the three likely chemical substitutes for alachlor have the same leaching potential as alachlor. The other likely substitute has a smaller leaching potential, but exposes the producer to risk of greater losses in yields if the weather is bad. This substitute is not likely to be chosen unless atrazine is banned along with alachlor, or if metolachlor is banned with alachlor. Banning alachlor alone would most likely result in more widespread use of a chemical substitute with the same leaching potential as alachlor.

The second issue regarding the effectiveness of herbicide bans is whether producers will abide by the bans. This issue is complex and can only be summarized here.

Regional herbicide bans have some advantages over other possible responses to herbicide pollution of ground water. First, the bans could be enforced by focusing on herbicide dealers. Dealers could be made responsible for verifying sales to producers within the affected region. Such an approach would be similar to the restricted use herbicide regulations already in place. Such an approach means that the set of agents requiring monitoring is much reduced, since enforcement can focus on dealers rather than users of the banned herbicide.

A ban is also simple to understand; one can either use or not use the herbicide. This is an advantage over best management practices, changes in labelling, or restrictions by soil type which require more information to implement.

Regional bans may also be more credible in the eyes of both agricultural producers and consumers of ground water. It is important that producers perceive the ban as credibly enforceable since the incentive to defect from the ban is much greater if producers expect others to defect. It is also important that consumers of ground water find the policy response credible. Consumers can opt for private solutions by deepening their wells, installing filtration equipment or using bottled water. The aggregate cost of these private solutions may be much larger than the cost of a ban. The worst case would be if consumers expect the policy to be unworkable after it is imposed and still opt for private solutions. This would mean that costs would be imposed on agricultural producers without avoiding costs of private solutions imposed on consumers of ground water.

Benefits and Costs

The list of agents potentially affected by a regional herbicide ban includes: producers that use the banned herbicide, producers that do not use the banned herbicide, herbicide manufacturers, herbicide dealers, custom herbicide applicators, consumers of ground water, consumers of surface water, and consumers of corn. It is clear that the largest losers are producers that use the banned herbicide, and the largest gainers are the regional consumers of ground water. Since this study focused on estimating the losses to users of the banned herbicides the gains and losses to others are purely speculative. Additional research is needed to provide estimates of benefits from a regional ban on selected herbicides.

Equity

The distribution of costs and benefits resulting from a regional herbicide ban depends upon the underlying structure of rights. Presently, producers have the right to use the offending herbicide without concern for contamination of ground water and can impose the costs of contamination on consumers of ground water. The effect of a ban is to reverse the structure of rights, giving consumers the right to impose costs on producers. The decision on whether the distribution of costs and benefits, after a ban is imposed, is equitable, is a decision on which structure of rights is equitable.

It is often proposed that the most equitable solution is to adopt a mechanism that allows both producers and consumers, that is, both gainers and losers, to share the costs and benefits of the policy change. Since the major effect of an herbicide ban is on risk, one is tempted to suggest an insurance scheme to compensate producers for losses incurred because of the ban. Contributors to the insurance pool could include both producers and consumers. The moral hazard problem looms large in such a proposal, but such a scheme would provide a mechanism for consumers and producers to share the costs of a regional herbicide ban.

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