Staff Paper

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Scott M. Swinton, Robert P. King, Donald W. Lybecker
Michigan State University, University of Minnesota
Colorado State University

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Department of Agricultural Economics
MICHIGAN STATE UNIVERSITY
East Lansing, Michigan

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Scott M. Swinton*
Donald W. Lybecker*
Robert P. King*

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Department of Agricultural Economics
Michigan State University
East Lansing, MI 48824-1039

* Scott M. Swinton is an assistant professor in the Department of Agricultural Economics, Michigan State University, E. Lansing, MI. Donald W. Lybecker is a professor in the Department of Agricultural and Resource Economics, Colorado State University, Ft. Collins, CO. Robert P. King is a professor in the Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, MN.

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Introduction

The potential health hazard posed by pesticides has raised public concern about their use. Herbicides are the most heavily used pesticides. While herbicide residues in food are negligible (as is the concomitant risk of cancer; Archibald and Winter), the same cannot be said of herbicidal contamination in rural groundwater. An estimated 46 million Americans drink water from groundwater supplies that may be contaminated by pesticides, herbicides especially (Nielsen and Lee). Although the extent of secondary human exposure to herbicides and their metabolites is increasingly well documented (Hallberg), the health effects are less well known. However, growing evidence points to a link between direct exposure of herbicide applicators and certain types of cancer (Hoar et al., Wigle et al.).

Over four-fifths of the herbicides used on U.S. crops are applied to corn and soybeans. Ninety-five percent of U.S. corn and soybean cropland surveyed by the U.S. Department of Agriculture (USDA) in 1991 was treated with herbicides. This amounts to roughly nine times as much active chemical ingredient as the total for both insecticides and fungicides on these crops (USDA).

As the most commonly encountered pesticide in groundwater, atrazine is especially troubling. Surveys have detected atrazine in U.S. groundwater 10 to 20 times more often than any other herbicide (Hallberg). It appears that atrazine metabolites may be equally toxic and equally common in groundwater. In midwestern corn production areas, concentrations in early summer sometimes exceed Environmental Protection Agency (EPA) tolerance levels for drinking water. Not coincidentally, atrazine is the herbicide most commonly used in U.S. corn and sorghum production (Belluck et al.).

Herbicides are more likely than other pesticides to enter the groundwater because 1) they are more heavily applied than other pesticides, 2) many are applied directly to the soil in pre-plant incorporated or pre-emergence treatments, and 3) even post-emergence treatments are usually applied when crops and weeds are small and much soil is exposed. Where spray rigs are dumped or washed out, herbicides can create point source contamination in addition to the non-point contamination associated with normal chemical treatment of crops.

There are two bases for thinking that herbicides may be "overused". First, there exists an economic externality problem in that farmers receive most of the social benefits of agricultural chemicals, while paying only some of the social costs. In particular, they avoid paying most of the social costs of water pollution. Second, it appears that most U.S. farmers possess little quantitative information on the weed populations in their fields and their likely economic effects. This may lead to weed control strategies that are suboptimal even from the private standpoint of the farm manager. It has been shown elsewhere that fuller information does, in fact, increase net revenues and may also reduce chemical loads (King et al., Swinton).

The public policy debate over reducing groundwater contamination starts from the premise that pesticides create economic externalities. This leads to the need to introduce incentives or regulations to insure that pesticide users realize the full social costs of chemical use (Segerson).

Unfortunately, the full social costs are not clear. Scientists disagree about the degree of risk; economists disagree about how to value that risk. While acute atrazine exposure has been reported to cause mammary cancer in rats (Belluck et al.), there is no scientific consensus on the threat posed to humans by chronic atrazine exposure in small amounts. Neither is there consensus on the threat to the quality of human life or that of other species' lives. In lieu of these, EPA benchmark toxicity thresholds for humans offer the best available point of reference. There is only limited consensus among economists on the value of reductions in human exposure to life-threatening risk and none at all on valuation of human health quality (Fisher et al.). This is even truer of other species, which tend to be appreciated by humans for the value of their species, rather than the value of an individual life (Norton). Without a measure of social cost, it is difficult to construct public policies that pass on these costs to pesticide users. Failing some acceptable valuation, Randall has recommended a safe minimum standard policy forbidding chemical exposure beyond some benchmark until society gains a better understanding of the toxicity threat (Randall; Harper and Zilberman).

While it is difficult to estimate the social costs of unrestricted pesticide use, estimating the private costs of herbicide restriction policies is more tractable. A first step is to identify a benchmark for comparison, such as the status quo. While eliminating all herbicide use (Knutson et al.) is unrealistic, eliminating a particular herbicide or class of herbicides constitutes a relevant extreme scenario. This can be accomplished by a regulatory ban on the herbicide or on resultant effluent, by a ban-equivalent tax, or by public purchase of herbicide usage rights. These policies will have markedly different effects on producer welfare, but will likely lead to similar substitutions in weed control strategy. Relevant policies between the no-change and total elimination extremes are harder to identify. One of interest would be a policy that eliminates "most" use of the target chemical, with "most" to be defined. A very different policy would examine how subsidies on public provision of pest information can affect use of a target pesticide.

Most previous studies of pesticide restriction policies have examined how total bans would affect the agricultural sector as a whole. The general equilibrium studies of Burton, Osteen and Kuchler, Hrubovcak et al., and Phillips et al. highlight the propensity of restrictions to raise crop prices, mitigating producer welfare loss. Non-users of the restricted chemicals realize major gains, causing important differences in regional impacts. Assuming static equilibrium prices, farm-level losses from bans have been estimated using enterprise budgets (Cox and Easter) and linear programming (Cashman et al.). The CEEPES atrazine ban study offers a mix of static equilibrium regional analyses which extends beyond strictly financial analysis to a more comprehensive environmental one.

Few investigators have looked into alternatives to bans for regulating herbicide use. Two studies have ventured to estimate the impacts of input taxes either in partial (Gianessi et al. 1989) or in general equilibrium (Hrubovcak et al.). Taff and Cox used Cox and Easter's results to estimate farmer willingness to accept payment for herbicide use rights. Although Gianessi et al. have proposed the use of marketable use permits for pesticides, no formal analysis has been attempted.

All of these studies have taken current agricultural technologies as their point of departure. A provocative exception is the nitrate leaching policy study by Johnson et al., based on marrying a linear programming optimization model to a nitrate leaching simulation model. That study found that information-intensive chemical management could increase farm profits while reducing nitrate leaching through better timing and more carefully calibrated application rates. Besides input reduction and taxes, their study also looked at a Pigovian tax on pollution. A Pigovian tax is one placed on the contaminating effluent. In order to maximize social welfare, the tax should be equal to the marginal social cost of the pollutant.

The CEEPES atrazine study also links a series of biophysical process models to a linear programming core. It includes a broad range of herbicide formulations and tillage methods, over a wide range of soils. It is limited by assuming perfect herbicide efficacy and only two species of weed. Within those assumptions, it provides comprehensive estimates of the financial and environmental impacts of bans on atrazine and the triazine herbicides (Bouzaher et al. 1992a and 1992b, CEEPES).

Two elements are lacking in these studies. While they all provide estimates of the financial impact of herbicide restrictions, even the farm-level analyses cannot say how the weed species composition causes differential policy impacts. Yet historically, weeds have spread in direct response to the difficulty of controlling them. Second, none has examined how regulatory policies might affect the proliferation of information-based decision support models.

This paper examines the farm-level impacts of policies restricting the use of atrazine and the triazine family of herbicides. Of particular interest are the effects on net farm revenue, total chemical load, and the nature of substitute weed control practices likely to take place. Substitute practices are examined as a function of weed species and population density. In order to capture the effects of herbicide restrictions in distinct farming environments, the study examines two representative cash grain farms: one, a rainfed corn and soybean farm in southwestern Minnesota and the other, an irrigated continuous corn farm in northeast Colorado.

<u>Analytical Methods</u>

The two models applied here generate weed management recommendations from estimates of weed density by simulating crop yield response to weed competition. The recommended weed management tactics maximize expected net revenue per acre over a one-year time horizon. The WEEDSIM-Minnesota model (Swinton and King 1992) is applied to weed management in southwestern Minnesota rainfed corn and soybean. The Lybecker et al. model is applied to weed management in northeast Colorado irrigated corn. The two models are used here to recommend soil-applied (pre-plant incorporated, PPI, or pre-emergence, PRE) and post-emergence (POST) weed treatments that maximize expected net revenues over a one-year planning horizon. Recommendations are based upon estimates of weed seed and/or emerged seedling density in the target field. The models simulate weed seed germination, weed mortality from control measures, and crop yield loss due to weeds. They screen all PPI/PRE and POST treatment combinations in their databases to identify that pair which maximizes expected net revenue per acre. Like the bioeconomic weed control threshold model of Wilkerson et al., they use a yield equation to estimate the economic impact of weed control practices. Unlike the CEEPES policy analysis model, recommendations from these models depend upon weed species composition and density.

The WEEDSIM-Minnesota model was supplied with weed and crop data typical of southwest Minnesota rainfed corn-soybean farming conditions. The weed species included were green and yellow foxtails (<u>Setaria glauca</u> and <u>S. viridis</u>), common lambsquarters (<u>Chenopodium album</u>), and redroot pigweed (<u>Amaranthus retroflexus</u>). Seeds of the two broadleaf species were assumed to occur in a 2:1 ratio, following the data of Forcella and Lindstrom. The predominant chemical treatments encountered in a 1988 survey of Minnesota farms (Gianessi and Puffer) were updated to delete those no longer legal (chloramben) and add new arrivals of importance (e.g., sethoxydim, nicosulfuron). Mechanical control in the form of rotary hoeing was also added. Ten weed control treatments were available for corn and nine for soybean, as shown in Table 1a. Defining treatment pairs by application time as combinations of PPI or PRE treatments with POST treatments, there were 80 weed treatment pairs for corn and 42 for soybeans. Doses modeled were the average of the high and low label rates.

Since the two recommendations models are driven by the composition and severity of the weed infestation, they were run repeatedly in a grid search over the range of grass and broadleaf weed densities where recommendations were sensitive to changes. Weed seed densities (based on cores 10 cm. deep) ranged from 0 to 1000 seeds/m^2 for broadleaf weeds (pigweed and lambsquarters) and from 0 to 1500 seeds/m^2 for grass weeds, with step sizes of 100 seeds/m^2. Based upon the emergence functions estimated for southwest Minnesota (Forcella), 100 seeds/m^2 density of weed seeds of a given species translates into full-season average emergence of 27 mixed foxtails, 17 common lambsquarters, and 10 redroot pigweeds. Note, however, that on average 40% of the lambsquarters and 18% of the foxtail seedlings emerge early enough to be killed in conventional planting operations.

Based on a set of 16 northeast Colorado farms, the Colorado model assumes a more diverse mix of weed seed species. The broadleaf weed seed population is dominated by redroot pigweed (59.1%) and kochia (Kochia scoparia (L.) Schrad.) (28.8%), but also includes nightshade (Solanum spp.) (5.1%), common purslane (Portulaca oleracea L.) (3.8%), common lambsquarter (1.2%), common sunflower (Helianthus annuus L.) (0.1%), wild buckwheat (Polygonum convolvulus L.) (0.1%), and other unidentifiable broadleafs (1.8%).

The grass weed seed population is dominated by foxtails (41.3%), but also include sandbur (Cenchrus longspinus L.) (4.2%), barnyardgrass (Echinochloa crusgalli (L.) Beauv.) (2.7%), wild proso millet (Panicum miliaceum L.) (2.1%), and a substantial number of unidentifiable grasses (49.7%). Based on an alternative seed count and emergence function methodology (Schweizer and Zimdahl; Lybecker et al.), seed numbers are considerably higher and emergence percentages lower than in the Minnesota WEEDSIM model. Weed seed counts are based upon cores ten inches deep (roughly 2.5 times the depth used for the Minnesota data). Twenty-three different weed control treatments were available in the Colorado model, all of them tailored for use on corn (Table 1b).

Both models assume expected prices of $2.50 per bushel for corn and $6.00 per bushel for soybeans, and 1991 prices for herbicides (Durgan et al. and Lybecker) and mechanical control options. Both assume use of conventional tillage and broadcast herbicides. WEEDSIM-Minnesota was run using target weed-free yields for corn and soybeans of 108 and 39 bushels/acre. The Lybecker et al. model was run for a sandy clay loam soil and an expected weed-free corn yield of 160 bushels/acre.

The first step of the analysis was to run a search over weed densities and input tax levels to determine what level of tax on atrazine and the triazine herbicide family (including atrazine, cyanazine, and metribuzin) would be sufficiently high to eliminate them from all recommendations. Since carryover problems preclude atrazine use in Minnesota corn-soybean rotations, the atrazine ban analysis was done only for the continuous corn rotation.

As a second step, recommendations were generated over the ranges of weed densities cited above to determine how dominant strategies change under the following herbicide restriction policies: 1) no change (3 lbs/acre atrazine limit), 2) atrazine ban, and 3) triazine ban. Mean "load" of active chemical ingredients as well as expected net returns to labor, land, management and fixed capital were predicted for each recommended treatment.

RESULTS

Ban-equivalent taxes

The ban-equivalent tax for a herbicide is equal to the percentage increase in its cost that will induce substitution of alternative weed controls at all weed seed bank densities. Ban-equivalent taxes were estimated in this analysis by successively raising the herbicide price level and identifying optimal weed control strategies for each allowable set of weed seed levels. The ban-equivalent tax on atrazine in the WEEDSIM-Minnesota model was highest at low weed seed densities. At seed densities for foxtails, lambsquarters and pigweed of 200-33-66, the ban-equivalent tax reached a maximum of 210%. At this level, the atrazine POST treatment is eliminated. Because of its low cost and broad-spectrum efficacy, atrazine is recommended by the model at low weed densities, when the next best alternative is no control.

In the Colorado model, a tax of 94% was sufficient to eliminate atrazine and atrazine combinations. As in the WEEDSIM-Minnesota case, the post-emergence atrazine treatment was the one offering the highest gross margin over the next best weed control alternative. The 94% atrazine tax was necessary to remove the POST atrazine treatment for high broadleaf weed seed bank levels and low to moderate (20,000 to 50,000 seeds/m^2) grass weed seed bank levels. The lower level of tax needed for the Colorado model reflects the broader range of treatments included, the lower rate of yield loss at low weed densities under irrigated conditions, and the fact that the Colorado model imposes some chemical weed control even at very low weed seed densities.

The ban-equivalent tax for the three triazines in the WEEDSIM-Minnesota model (atrazine, cyanazine, and metribuzin) was 232% for the continuous corn rotation. This value is higher than that for a straight atrazine ban because cyanazine is the next best alternative to atrazine over a wide range of weed densities. As with the atrazine ban, the 200-33-66 foxtail-lambsquarters-pigweed seed density level is the one at which the ban-equivalent tax is highest. For corn in rotation with soybeans, the ban-equivalent tax is only 30%. This is the level required to eliminate cyanazine from the recommendations at the 200-0-0 weed seed density level. No tax is needed to eliminate the triazine from recommended weed control for soybeans, as metribuzin was never a best choice under the conditions examined.

Weed management responses to bans on triazine herbicides

The recommendations analysis by herbicide restriction policy highlights the importance of atrazine for weed control in continuous corn. In the absence of herbicide use restrictions (other than the current 3 lbs/acre limit on atrazine, which precludes both PPI/PRE and POST treatments), atrazine appears in virtually every treatment pair when grass weed pressure exceeds 100 seeds/m^2 in the Minnesota model or 5000 seeds/m^2 in the Colorado model. These results are presented in Figures 1a and 1b. For the sake of two-dimensional graphic illustration, the weed species included were pooled into broadleaf and grass classes.

When atrazine is banned, Figure 2a shows that in the Minnesota model, its place is largely taken by cyanazine, with dicamba entering the solution at low grass weed densities.

In the Colorado model, EPTC and nicosulfuron as well as cyanazine tend to supplant atrazine (Figure 2b).

When all triazines are banned from the Minnesota continuous corn rotation, EPTC plus safener (Eradicane) and alachlor take the place of cyanazine as the preferred soil-applied grass killer, as shown in Figure 3a. The Colorado model, which relied more heavily on EPTC to begin with, substitutes EPTC for cyanazine when triazines are banned (Figure 3b). The Colorado result conforms in part with that of CEEPES, which predicts that nicosulfuron and primosulfuron will replace the triazines. The Minnesota analysis found those to be too costly to be recommended for most mixtures of the weed species examined.

Farm-level cost of herbicide bans

As has been discussed elsewhere, restrictions induce two revenue-reducing effects: increased control costs and increased crop yield loss (Swinton and King, 1990). With each addition to the list of banned herbicides, the threshold for chemical treatment rises. For the status quo, no control is optimal only for seed densities below 100 seeds/m^2 in the Minnesota model. With the atrazine ban, that threshold rises to 200 seeds/m^2 of foxtails. With the triazine ban, it rises again up to 300 seeds/m^2 for foxtails. The low cost, broad-spectrum efficacy of 2,4-D against broadleaf weeds keeps the threshold for weed control of mixed lambsquarters and pigweed at 100 seeds/m^2. Since the Colorado model predicts some weeds even with no observed seeds, there is no weed density at which it recommends no post-emergence control.

Thus the farm-level effect of a ban on atrazine or the entire triazine family depends upon the density of the weed infestation on the farm. While the Minnesota results are based upon expected net revenue and those for Colorado upon expected gross margin, both methods give directly comparable estimates of changes in farm revenues due to banning a herbicide. Results from the WEEDSIM-Minnesota model indicate that an atrazine ban would reduce farm net revenue per acre of continuous corn due by $0 to $8.53. For a triazine ban, the range is $0 - $9.43. Nearly identical results were obtained using the Colorado model. The atrazine ban would reduce gross margin per acre by $0 - $8.25 while the triazine ban would reduce it by $0 - $ 9.98.

Since atrazine and the other triazines constitute the minimum-cost weed control for a wide range of weed densities and species mixes, their elimination tends to raise the weed density threshold above which control is recommended. This means increased weed populations and resulting crop loss under profit-maximizing management. This is especially apparent in the WEEDSIM-Minnesota results, as the more conservative Colorado model recommends POST herbicide control even at the lowest weed populations.

The reduction in potential net revenue depends upon the degree and species composition of the weed infestation. Where only broadleaf weeds are present, triazine herbicides are not recommended so their loss costs nothing. On the other hand, when a small, mixed weed population is present, such that the next best alternative to atrazine control is EPTC, alachlor, or dicamba, the cost may be quite high. This case represents the maximum loss figure, which is directly related to the ban-equivalent tax estimate. The estimates of lost revenue from bans on atrazine and all triazines presented here conform with Cox and Easter's estimate of $7.93/acre in southesatern Minnesota continuous corn (based on a weed-free yield assumption of 152 bushels and a corn price of $2.43). Comparison with the CEEPES result of 2.9% and 3.7% reductions in Minnesota net farm income is difficult, since the CEEPES study is based on only two weeds and the report does not reveal assumptions concerning farm size, enterprise mix, costs, prices or weed-free yields.

The change in load of herbicide active chemical ingredient introduced into the environment depends upon the weed pressure and the recommended alternative. At weed densities low enough that the second best alternative to the banned substance is no control, herbicide loads obviously decline. At higher weed densities, the change in herbicide load depends upon the substitute. Since cyanazine typically replaces atrazine under a ban on the latter, herbicide loads at the average label rate tend to rise from 2.5 lbs/acre to 2.675 lbs/acre for soil-applied herbicide and 1.5 to 1.6 lbs/acre POST control. The EPA chronic toxicity benchmarks for humans are 3 parts per billion (ppb) for atrazine and 8 ppb for cyanazine (CEEPES), suggesting that even if both substances are equally leachable (which may be the case, Belluck et al.), this increase in chemical load may reduce human health risks. As a substitute for soil-applied triazine, EPTC significantly increases herbicide loads to 4.5 lbs/acre. The increase is smaller for an alternative like alachlor (2.75 lbs/acre).

CONCLUSIONS

The impact of herbicide restrictions on recommended weed management practices varies importantly with the severity of the weed problem. Both the expected loss in farm net revenue and the likely substitute treatments in response to a herbicide ban depend upon the density and species composition of the weed infestation.

This suggests that one way to reduce the negative farm-level effect of herbicide restrictions is to allow them to be flexible. Several options exist for doing this. One is to apply an input tax that is less than the ban-equivalent. This would allow farmers to use the restricted herbicide in situations where it is far more remunerative than the alternatives. If enforceable at low cost--which it is not--a Pigovian tax on herbicide effluent reaching the groundwater might be yet more efficient (Johnson et al.). For one thing, it would be flexible geographically. Farmers in warm regions could take advantage of more rapid chemical degradation. Where local soils are relatively impermeable, leachable chemicals such as atrazine are less likely to reach the water table before breaking down, again leaving farmers more options. Regional bans or taxes offer one way to achieve a comparable level of geographic flexibility. Some transfer of regulatory responsibility from the federal government to the states could facilitate this, although the resultant environmental policies would certainly differ across states for political reasons as well as biophysical ones.

All of these approaches presuppose the government's right unilaterally to restrict chemical use. If that right resides with the landowner, a policy of purchasing chemical use rights might achieve a similar goal, albeit at higher cost to taxpayers (Taff and Cox). Again, rights could be purchased selectively so as to minimize the likelihood of significant groundwater contamination. Farmer willingness to accept payment for such rights can be computed as the perpetually discounted opportunity cost of using the next best weed control treatment over a relevant range of expected weed densities.

The maps of alternative weed management tactics indicate that weed control substitutes for atrazine or the triazines might reach levels that are as environmentally threatening as atrazine. In the Minnesota results, cyanazine is recommended over a wide range of weed species densities as an atrazine alternative. Yet Hallberg indicates that it too has a record of groundwater detections. This may be acceptable given the higher human tolerances for cyanazine under EPA guidelines. Similarly, while triazine alternatives, such as

EPTC, could dramatically increase herbicide loading, EPA benchmarks allow much higher chronic human exposure to EPTC than to atrazine or cyanazine.

A final policy consideration is the potential for weeds to develop resistance to herbicides. In spite of the heavy use of triazine herbicides, few weeds have developed resistance. This is thought to be due to their multiple sites of biochemical action. Some of the new, low-dose POST herbicides (e.g., sulfonyl ureas, such as nicosulfuron and primosulfuron) have a single site of action. This has already led to the development of genetically resistant weed varieties when these herbicides were used repeatedly. Interestingly, these herbicides were developed to control grass weeds, a task which these results suggest is an important area for future research and development.

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Table 1a: Efficacy rates, application times, and costs of weed control treatments included in the WEEDSIM-Minnesota model, by crop.

Treatment	Application time[3]	Efficacy Rate (%)[1] Fox-tail	Lambs-quarter	Pig-weed	Materials cost per acre[2] PPI/PRE	POST
		- - - - - - - - % - - - - - - - -			- - - - $ - - - -	
Corn						
No control	0,1,2	0	0	0	--	--
Alachlor 4E	0,1	90	30	90	16.25	--
Atrazine 4F[t]	0,1,2	90	90	90	6.78	4.07
Bromoxynil 2E	2	0	90	70	--	6.89
Cyanazine 4F[t]	0,1,2	90	90	50	14.71	8.80
Dicamba 4S	1,2	10	90	90	6.05	6.05
Eradicane (EPTC) 6.7E	0	90	70	5	15.48	--
Nicosulfuron	2	90	30	90	--	17.98
Rotary hoe	1	30	50	50	--	--[4]
2,4-D Amine 4S	2	0	90	90	--	1.49
Soybean						
No control	0,1,2	0	0	0	--	--
Acifluorfen 2S	2	10	10	90	--	15.03
Alachlor 4 MT	0,1	90	30	90	16.99	--

Bentazon 4S	2	0	10	90	--	11.22
Imazethapyr 2L	2	90	10	90	--	18.11
Metribuzin DF[t]	0,1	50	90	90	16.62	--
Rotary hoe	1	30	50	50	--	--[4]
Sethoxydim 1.5EC	2	90	0	0	--	16.72
Trifluralin 4E	0	90	70	90	5.25	--

[t] Denotes triazine herbicide.

1. Efficacy rate are a linear transformation of the qualitative ratings published in Durgan et al. where "good" efficacy is interpreted as 90% efficacious and "poor" as 10% efficacious.

2. Applied at the average of the recommended rates in Durgan et al. Application costs per acre (Fuller et al., 1991), omitting labor, are:

PPI (sprayer & cultivator)	$4.82
PRE (sprayer)	$1.40
POST (sprayer)	$1.40
Rotary hoe	$2.04

3. Codes are as follows: 0=pre-plant incorporated, 1=pre-weed emergence, 2=post-weed emergence.

4. Rotary hoe causes 3-5% stand loss (Jeffrey L. Gunsolus, personal communication), leading to an average loss of 1.5% of yield.

Table 1b. Soil applied and postemergence treatment costs and efficacy rates included in the Colorado model.

Soil Applied Treatments	Cost[1] ($/Ac.)	Efficacy Rates: Broadleafs: Redroot Pigweed	Kochia	Common Lambs-quarters	Night-shade	Common Sun-flower	Common Purslane	Wild Buck-wheat	Unknown Broad-leafs	Grasses: Barn-yard Grass	Foxtail	Wild Proso-Millet	Sand-bur	Unknown Grasses
None	0.00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Butylate	18.46	62%	35%	72%	82%	49%	35%	62%	56%	95%	95%	62%	82%	83%
EPTC & Cyanazine	25.94	82%	76%	87%	88%	65%	62%	76%	75%	95%	95%	69%	82%	85%
EPTC	19.77	75%	62%	82%	88%	49%	62%	62%	61%	95%	95%	69%	82%	85%
Atrazine	11.85	95%	95%	95%	95%	91%	82%	95%	91%	75%	78%	0%	62%	46%
Alachlor & Atrazine	16.22	95%	91%	95%	95%	82%	35%	82%	80%	92%	91%	55%	69%	70%
Alachlor & Cyanazine	26.09	86%	91%	86%	92%	72%	35%	82%	75%	92%	92%	55%	72%	70%
Alachlor	22.56	82%	49%	75%	82%	49%	35%	59%	59%	95%	95%	55%	65%	73%
Metolachlor + Atrazine	19.25	95%	95%	95%	92%	78%	50%	82%	80%	95%	91%	55%	65%	70%
Metolachlor & Cyanazine	27.33	86%	91%	86%	92%	72%	25%	91%	70%	95%	95%	55%	72%	61%
Metolachlor	20.34	78%	35%	82%	82%	35%	25%	27%	47%	95%	95%	55%	65%	69%
Postemergence Treatments:														
None	0.00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2,4-D	2.86	91%	82%	91%	75%	86%	35%	35%	72%	0%	0%	0%	0%	0%
Dicamba	5.76	88%	86%	86%	62%	82%	62%	95%	77%	0%	0%	0%	0%	0%
Dicamba & 2,4-D	6.15	88%	86%	88%	82%	84%	82%	95%	84%	0%	0%	0%	0%	0%
Bromoxynil	7.66	72%	82%	82%	88%	95%	35%	89%	79%	0%	0%	0%	0%	0%
Cyanazine	13.26	75%	88%	87%	95%	75%	82%	82%	83%	75%	78%	10%	62%	54%
Cyanazine & Dicamba	38.49	84%	87%	87%	95%	78%	82%	95%	86%	75%	78%	10%	62%	54%

Cyanazine & Tridiphane	33.98	82%	85%	85%	85%	82%	82%	72%	83%	75%	78%	46%	62%	65%
Pendimethalin & Cyanazine	21.67	78%	86%	86%	82%	62%	82%	72%	78%	92%	91%	62%	75%	70%
Dicamba + Atrazine	11.99	95%	88%	95%	95%	95%	82%	95%	91%	25%	25%	0%	25%	20%
Atrazine	10.07	95%	95%	95%	93%	91%	82%	95%	92%	69%	82%	0%	62%	52%
Alachlor + Atrazine	21.27	95%	91%	95%	95%	82%	35%	82%	80%	92%	91%	55%	69%	70%
Metolachlor + Atrazine	16.10	95%	95%	95%	92%	78%	50%	82%	80%	95%	91%	55%	65%	70%
Nicosulfuron	23.03	90%	62%	25%	35%	62%	0%	0%	34%	91%	87%	85%	89%	74%
Nicosulfuron & Dicamba	26.15	90%	86%	86%	62%	82%	62%	95%	77%	91%	87%	85%	89%	74%
Primosulfuron	19.71	82%	78%	62%	82%	82%	0%	0%	48%	60%	63%	63%	73%	59%
Primosulfuron & Dicamba	22.54	88%	86%	86%	82%	82%	62%	95%	79%	60%	63%	63%	73%	59%

[1] Includes materials and cost of application.

Figure 1a: Weed control recommendations map from WEEDSIM-Minnesota for continuous corn with no herbicide restrictions.

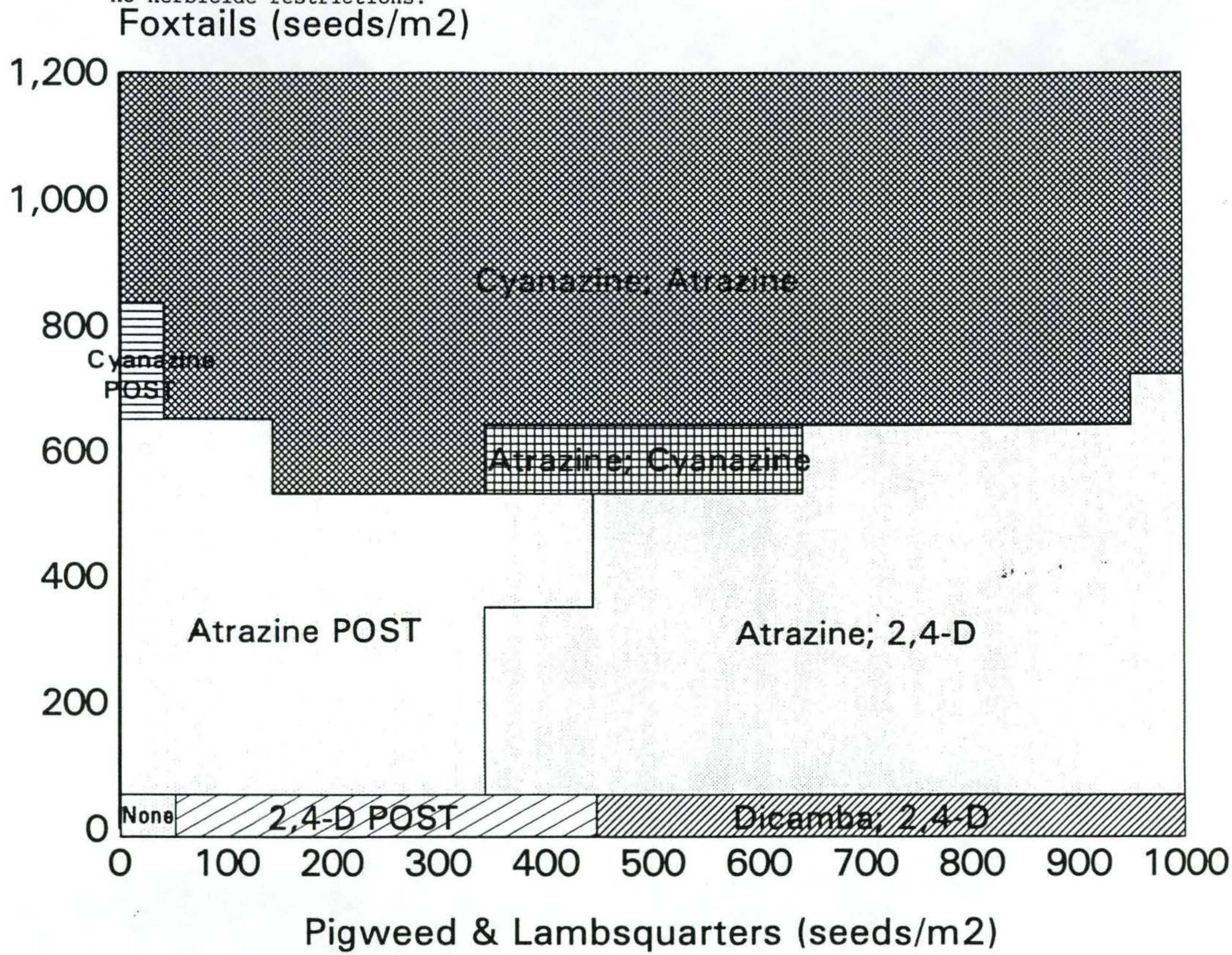
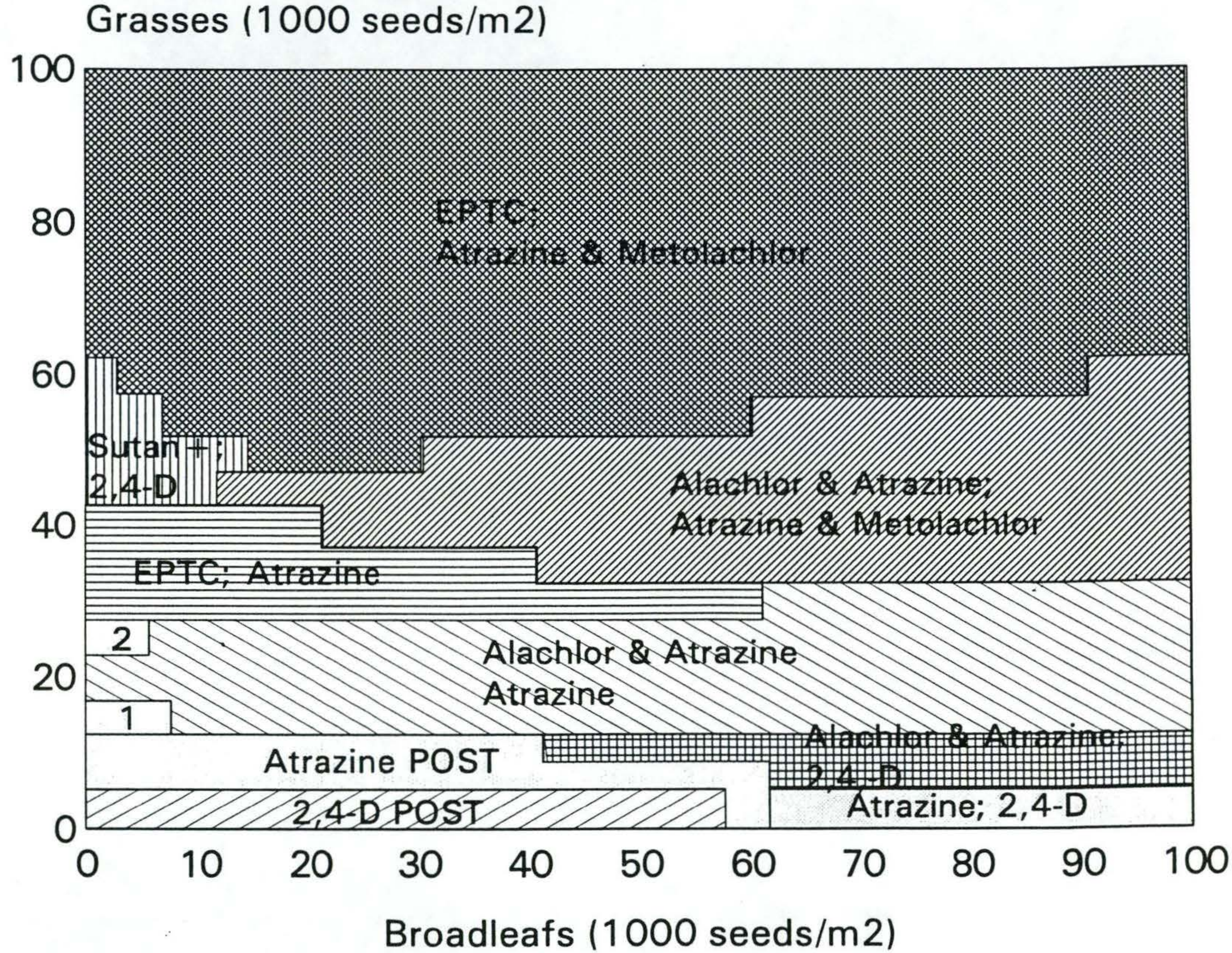


Figure 1b: Weed cpontrol recommendations map from the Colorado model for continuous corn with no herbicide restrictions.



[1] Sutan+; 2,4-D

[2] Sutan+; Atrazine

Figure 2a: Weed control recommendations map from WEEDSIM-Minnesota for continuous corn with atrazine banned.

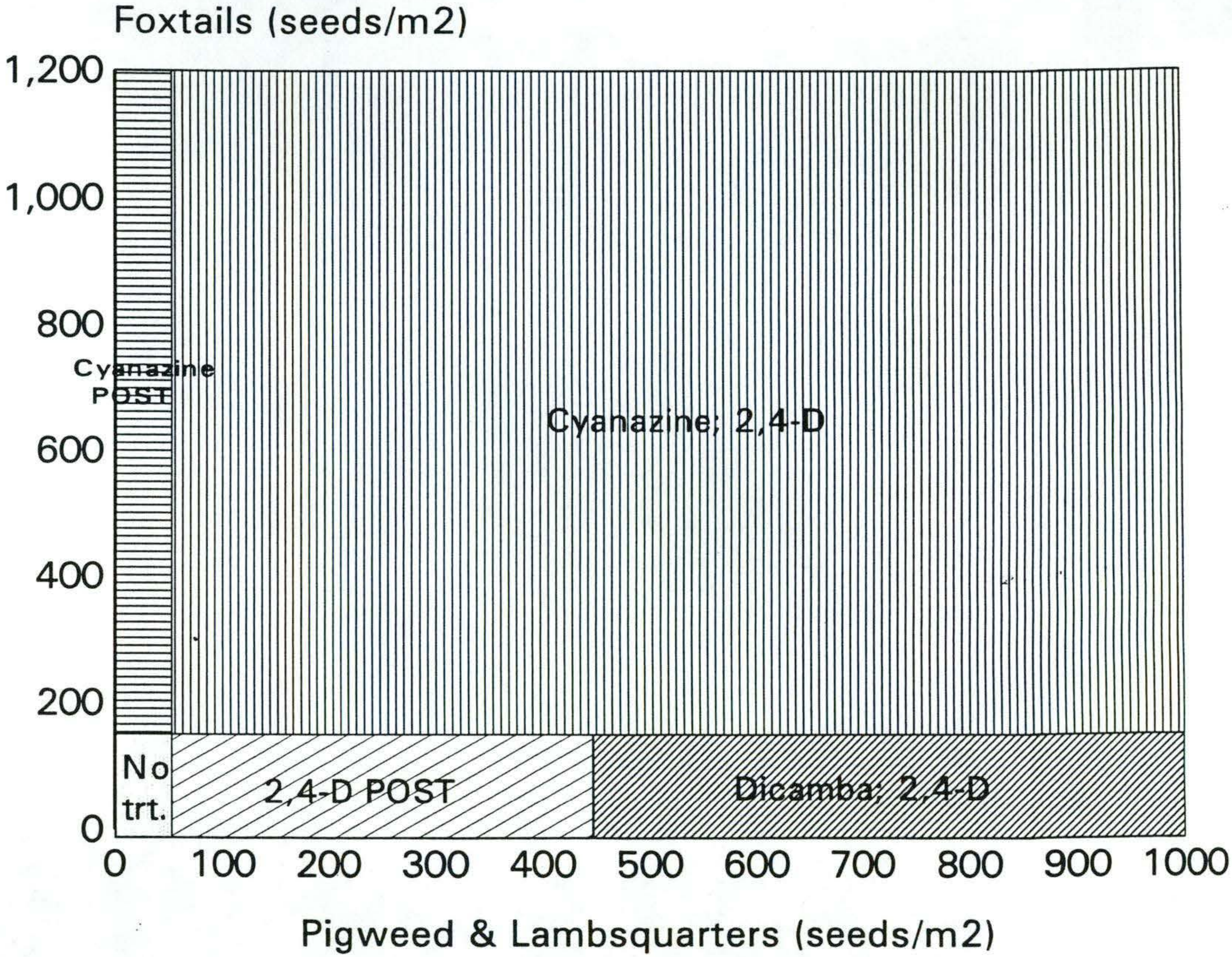
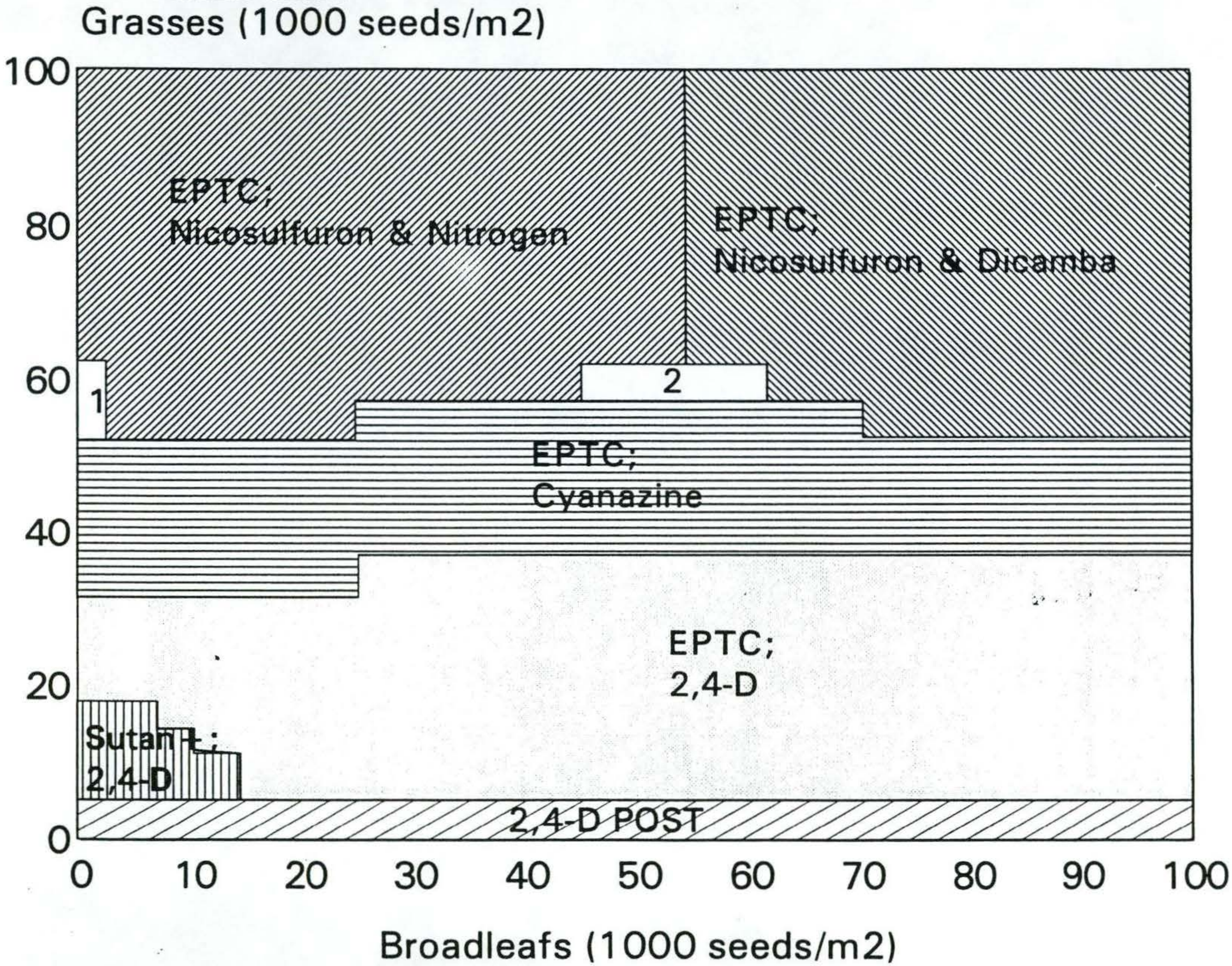


Figure 2b: Weed control recommendations map from Colorado model for continous corn with atrazine banned.



[1] Sutan+; Nicosulfuron & Nitrogen

[2] Sutan+; Pendimethalin & Cyanazine

Figure 3a: Weed control recommendations map from WEEDSIM-Minnesota for continuous corn with triazines banned.

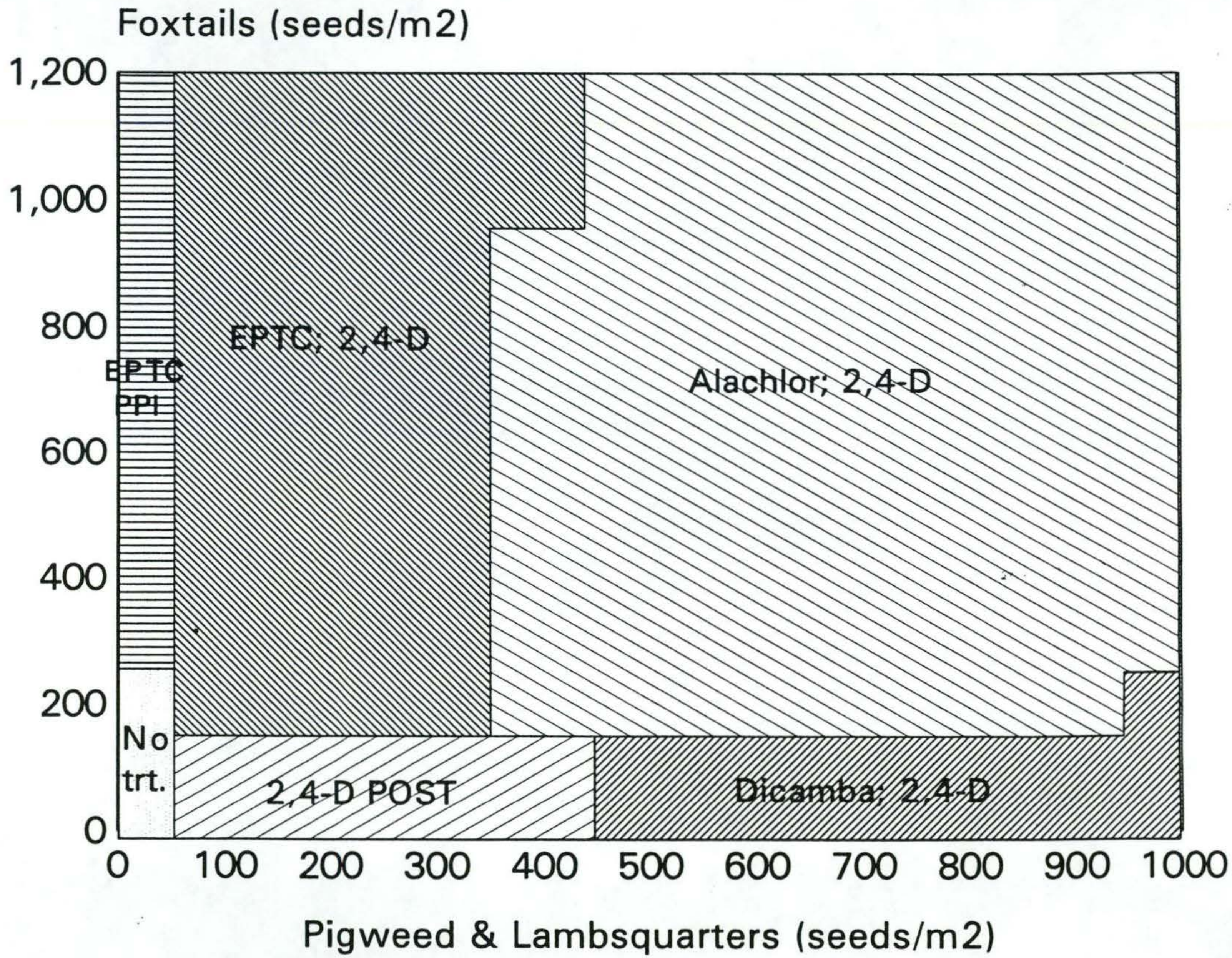
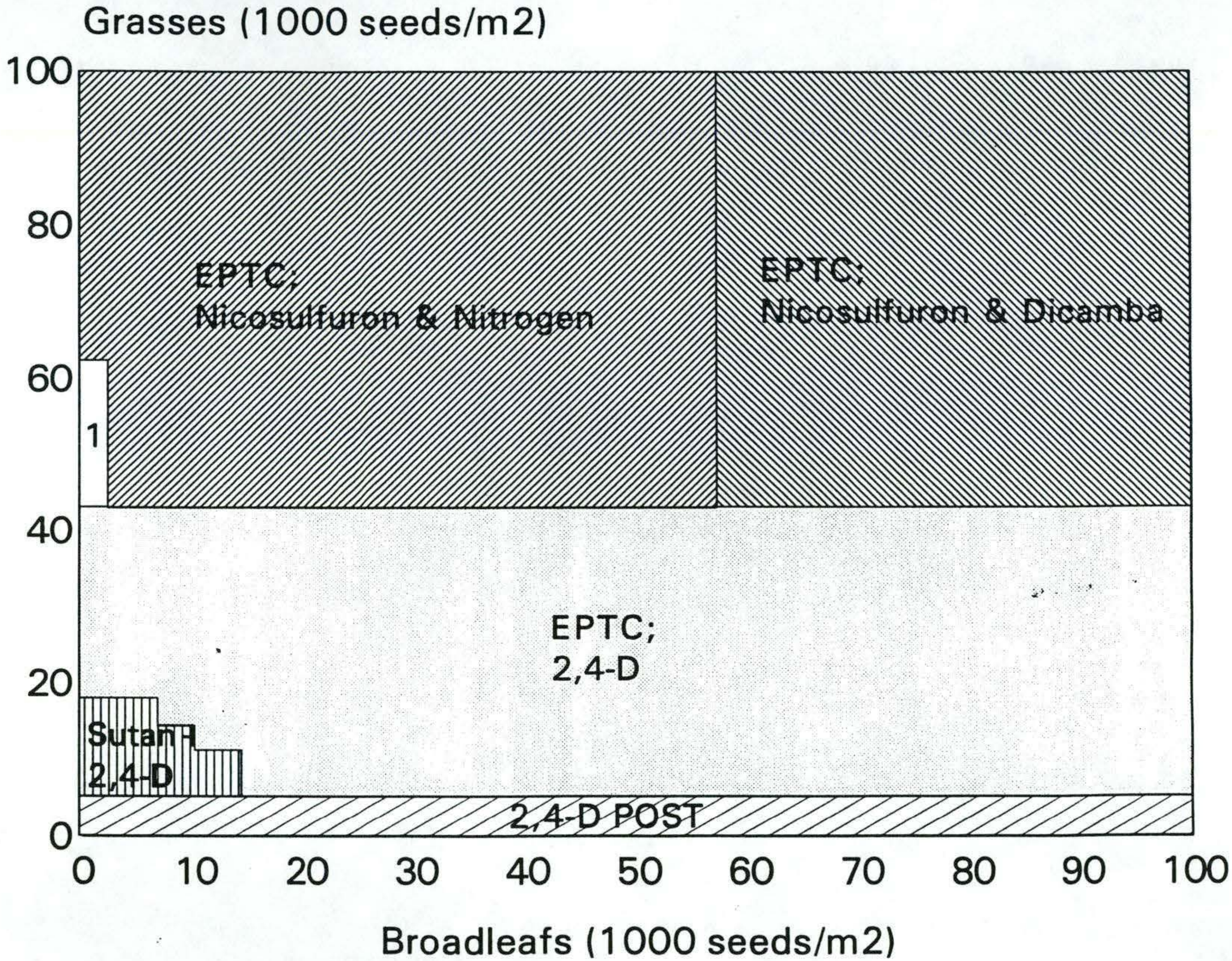


Figure 3b: Weed control recommendations map from the Colorado model for continuous corn with triazines banned.



[1] Sutan+; Nicosulfuron & Nitrogen.