The Effects of Environmental Policy on Trade-offs in Weed Control Management

Aziz Bouzaher,
David Archer, Richard Cabe,
Alicia Carriquiry, and Jason F. Shogren

Working Paper 91-WP 81
November 1991

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

Aziz Bouzaher is a visiting associate professor of economics, CARD; David Archer is a CARD graduate assistant; Richard Cabe is an assistant professor of economics, New Mexico State University; Alicia Carriquiry is an assistant professor of statistics and economics, Iowa State University; and Jason F. Shogren is an assistant professor of economics and head of the Resource and Environmental Policy Division, CARD.

This paper was presented at the 1991 AAEA Annual Meeting, August 4-7, Manhattan, Kansas. This work has been supported in part by the U.S. Environmental Protection Agency (CR-816099-01-0). We also acknowledge the help of Bob Hartzler, Paul Rosenberry, and Phil Gassman. All errors remaining are ours.

Abstract

This paper presents a novel approach for generating information for regulatory and policy analysis, based on farmers' adoption of weed control technology. A simulation model, WISH, is used to generate cost and risk information on 258 weed control strategies. The environmental policies simulated are bans on triazines and broadcast application technology.

1. Introduction

Weeds represent production constraints that reduce profits in agricultural activity. Traditionally, profits have been maintained by controlling weeds through intensive chemical use. Perceived health risks associated with herbicide use, however, are forcing regulators to consider new restrictions on the herbicides used in weed control management (NGA 1989, Abt 1987). Yet little is known about how farmers will respond to the alternative restrictions that are currently being proposed. Acquiring this information is vital if we are to understand the impact of environmental policies on trade-offs in weed control management.

This paper presents a novel approach to evaluate the trade-offs given alternative herbicide use restrictions. Specifically, we simulate various weed control strategies given environmental policy in the form of quantity and technology constraints. Our model simulates the impact of weather and soil characteristics on the efficacy of 258 weed control strategies.[1] The model computes the probabilities of yield loss when farmers use the various strategies. The output will contribute to our understanding of the impact of alternative herbicide restrictions (i) on farmers' weed control decisions and adoption of different technologies, and (ii) for aggregate economic and environmental consequences on a regional or national basis.

The paper is organized as follows. Section 2 presents the background information and analytical framework. We focus on weed control strategies for corn and sorghum production. Given that atrazine and triazine herbicides have been targeted for restriction, we consider three different restrictions on atrazine and triazine use.[2] Section 3 defines the structure and content of a weed

---

[1] At this point it is helpful to note that, in general, a weed control strategy is uniquely defined by a set of herbicides with associated application rates and costs, application technology, timings of application for each herbicide, and windows of effectiveness for both grasses and broadleafs.

[2] Atrazine accounts for 12 percent of all herbicides used in the U.S, and is the most detected pesticide in groundwater and surface water (Cabe et al. 1991).

control strategy. We then present the simulation model used to assess the effectiveness and cost of 258 different weed control strategies. Section 4 presents the empirical results and the final section summarizes the findings.

2. Background and Analytical Framework

Our overall objective is to develop a flexible methodology to estimate the economically efficient set of weed control strategies under various policies of herbicide restriction. We focus on short-term adjustments in farmers' adoption of currently available weed control technology given herbicide bans or restrictions on atrazine and triazine use in corn and sorghum, and the banning of broadcast application technology. These policies are currently under review by the U.S. Environmental Protection Agency. The resulting efficient weed control strategies can then be used in a firm model (e.g., profit maximization farm model) to determine shifts in input use and optimal production patterns, in conjunction with other agricultural policy restrictions. Market and longer term consequences can then be evaluated in a general equilibrium context.

We assume farmers trade off expected risk for expected application cost when deciding to adopt a weed control strategy.[3] Weed control requires important management decisions in terms of trade-offs between amount and timing of control and expected benefits. About 80 percent of the farmers (ERS 1989) apply herbicides before planting (early pre-plant, pre-plant incorporated) or after planting (pre-emergent); in either case, weather conditions can be too wet for farmers to get into the field to apply herbicides or cultivate, or weather conditions can be too dry during the critical times for herbicides to be effective, implying additional application cost or important yield losses or both.

---

[3] The setting of this study is that of a typical Corn Belt farmer using herbicides for weed control management in corn and sorghum. Major weeds are grasses, such as Giant Foxtail, and broadleafs, such as Cocklebur.

The expectation is computed over an optimal simulation period,[4] and risk is defined as the probability of noneffectiveness of a given herbicide strategy (which can also be interpreted as the probability of yield loss, or the percentage of acreage on which weed control was not effective, or the percentage of time a given strategy fails to achieve full control[5]). Trading cost for risk can be expressed in traditional trade-offs between expected net return and variance of net return.

A weed control strategy is efficient if: (i) it is the least expected cost among all strategies with the same expected risk level, and (ii) it is the least risky among all strategies with the same expected cost. This concept of efficiency is illustrated in Figure 1, together with the concept of ϵ-efficiency, which allows treating all strategies in a same small neighborhood as equally efficient. In addition, the set of efficient strategies make up the "efficient frontier" that contains all the necessary trade-off information for a farmer to choose one or several strategies. Individual constraints on application cost and/or risk attitudes can further narrow the efficient subset.

The effect of an environmental policy[6] (ban of a herbicide or an application technology) is to shift the efficient frontier up and to the right, reflecting the use of substitute weed control strategies that are either less effective (vertical shift AB in Figure 1-b), or more expensive (horizontal Shift CB in Figure 1-b), or both. Since we take the perspective of an individual farmer, weed control is treated as another input decision and herbicide as another input in the farmer's crop production process, in which case, the optimal amount of control will have the property that its marginal cost equals its marginal product (measured as additional yield or reduction in production risk). Total weed

---

[4] Appropriate tests were performed to determine an optimal simulation from steady state conditions.

[5] Full control is aimed at achieving between 80 and 100 percent effectiveness; this area of control defines a "free zone" where very low densities of weeds have very little yield impact.

[6] Cox and Easter 1990 present a farm level approach to evaluating regional herbicide bans. Their approach uses an artificial characterization of weather impact on herbicide through two states of nature, good and bad weather. In addition, weather only impacts the herbicide effectiveness and not all the elements of a weed control strategy.

control cost includes the cost of chemicals, labor, machinery, and energy; it does not explicitly include any cost of off-farm damages stemming from weed control. If we consider uncertainty explicitly, due to weather or other unpredictable factors, then a stochastic approach is required for assessing the amount of expected risk farmers face.

We note that this approach of assessing risk associated with weed control can be useful when the perspective is that of policy or regulatory analysis, either for controlling entire weed species or assessing the effect of chemical use on the environment. A regional agricultural model would be built around only those strategies on the efficient frontier. One of the main objectives of the CEEPES/Atrazine study (Johnson et al. 1990; Cabe et al. 1990) is to assess the economic value of various government policies affecting weed control, including the associated externalities. The model presented in this paper is part of the system of models comprising the agricultural decision component of CEEPES.

3. WISH: A Model of Weather Impact Simulation on Herbicide

Researchers are turning to process simulation models to predict yield effects of weed infestations. ALMANAC[7] is one model that has been incorporated into the CEEPES (Comprehensive Environmental Economic Policy Evaluation System) framework (Johnson et al. 1990). ALMANAC is a process model that simulates crop growth, weed competition, and the interaction of management factors for a variety of soil properties and climatic conditions. An important limitation of ALMANAC is that it does not explicitly recognize specific herbicides and differences in weed control strategies: herbicides used alone or in tank mixes; residual effects; target weeds; timing of application; application mode; weather impact on field day availability, timing and

[7] ALMANAC stands for: Agricultural Land Management Alternatives with Numerical Assessment Criteria. The model is being developed by Agricultural Research Service at the Grassland, Soil, and Water Research Laboratory at Temple, Texas (Jones and O'Toole 1986; Williams and Kiniry 1990).

application mode, effectiveness of individual chemicals, and effectiveness of overall strategy; tillage system; and farmer's risk behavior (see Bouzaher 1991). Although ALMANAC reflects the impact of environmental conditions on the various physical processes involved in crop growth and weed competition, it does not reflect the impact of environmental conditions on the input and management factors comprising a weed control strategy.

To use ALMANAC, weed control strategies are mapped into weed densities that are then simulated for yield effect. This implies all weed control strategies aimed at achieving the same control level are considered equivalent; clearly this can be misleading, as illustrated by the three examples in Table 1. Weather can have significant and differentiated effects on different weed control strategies; weather can also affect total cost of application since a failed first application may require additional treatment of the same acreage.

Weed competition models need to be used in conjunction with other models, like WISH, capable of predicting the effectiveness (measured by cost and risk) of various weed control strategies. Farmers typically use weed control strategies to achieve full control. These strategies either work or fail when environmental conditions prevent the application of herbicide or impair its effectiveness (these conditions are usually associated with extreme variability in weather conditions, too dry or too wet). Hence yield loss refers to the maximum potential loss when weed control fails and a weed infestation (of grasses, broadleafs, or both) is not prevented.

We now briefly present the process of structuring weed control strategies and the model of simulating weather and soil properties for each of these strategies. Starting with a list of 16 available herbicides and their ordinarily rated performance on grasses and broadleafs, we ran a cluster analysis to determine groupings of herbicides based on similarity in rating. After consultation with a weed scientist and a translation of the ratings into a cardinal scale, we derived five groups of herbicides: (i) triazines, (ii) nontriazines for grasses, (iii) nontriazines for broadleafs, (iv) tank mixes of triazines and nontriazines for grasses, and (v) tank mixes of nontriazines for both grasses and broadleafs. The numerical ratings are translated into weed densities.

Based on herbicide timing, mode of application, targeted weeds, and observed farming practices, we construct a herbicide decision flow chart to represent the average farmer's most likely management approach to weed control. The farmer's herbicide decision tree and the results of the cluster analysis are combined to define:

(i) The structure of a herbicide strategy. This is assumed to be made up of a **primary** herbicide treatment (to be applied on an early pre-plant, pre-plant, pre-emergence, or even post emergence basis), and a **secondary** herbicide treatment (mainly post emergence) that would be applied only if the primary substrategy fails for reasons mainly related to weather. Note that a strategy rests on the key assumption that, under "normal" weather conditions,[8] it will achieve a full level of weed control (both grasses and broadleafs). Finally, a herbicide strategy structure is completed by specifying a "**time window of application**" and a "**time window of effectiveness**" for each of its primary and secondary components, and for each weed group (an example is given in Table 1).

(ii) The content and list of all feasible herbicide strategies. This strategy list (containing 258 uniquely defined strategies like the three shown in Table 1) is established by tillage practice and by timing of application and scope of control of each herbicide in the strategy. The list is also built with the policy specifications in mind, thereby distinguishing between strategies using atrazine alone, at rates lower or higher than 1.5 pounds, strategies using triazine substitutes for atrazine (bladex and princep), and strategies using nontriazines, in various combinations. These feasible strategies are individually simulated to determine their yearly cost, labor requirements, and application rates, and percent effectiveness for each weed group and for two soil characteristics (sand and clay).

---

[8] These are the "optimal" weather conditions under which application rates are recommended by chemical manufacturers.

WISH reads the herbicide strategy table and a weather file that contains daily average information on temperature, rainfall, and wind. For each herbicide strategy over a period of 50 years, starting with the primary application, the model considers rainfall and wind and records the percentage of acres treated during the window of application; it also records the application rate and cost for each chemical used, and any cultivation requirements. Time advances and weather conditions are checked during the window of effectiveness. An indicator variable cumulatively records the percentage effectiveness of the primary strategy for each weed group. If this variable is less then one, the secondary application is triggered and the same information is recorded. It is important to note that the main objective of this simulation is to capture the effect of those special years (too dry or too wet) where a farmer may have to apply herbicide more than once and still sustain some yield loss (in addition to higher cost), or does not have time to apply herbicide and sustains a major yield loss. The model assumes that three days are enough for a farmer to treat all his acres, and provides for handling of special cases where strategies involve split applications (part pre-emerge and part post-emerge) or entirely post-emerge applications. A flow chart of the main steps of WISH is given in Figure 5.

4. Empirical Results

The results of the simulation model can be examined on an individual year basis, if one is interested in extreme weather years, or in terms of an expectation over the 50-year simulation period. Figures 2 (for sandy soils) and 3 (for clay soils) illustrate efficient frontiers, which represent trade-offs between expected application cost and expected risk, as defined in Section 2. In every case, efficient strategies are represented by small squares and inferior strategies are represented by bold dots. These frontiers are distinguished by whether the soils are assumed to be predominantly sand or clay. In addition, four policy cases are presented: status quo, ban atrazine, ban all triazines, and ban broadcasting as an application technology.

We find four key results that are illustrated by superimposing the efficient frontiers from all policy scenarios in Figure 4. First, strategies that are actually used by farmers are on the efficient frontier of the base case (e.g., A1-BL.ppi with 24-BA.post, A2-BL.ppi with A1.post, A1-PR.pre with 24-BA.post, A1-PR.ppi with PRL-BL.post).[9] This result gives credence to our approach and adds weight to the argument that farmer's week control decisions reflect trade-offs between risk and cost,[10] it also serves as a validation of the simulation model.

Second, the shifts in the efficient frontier as policy restrictions are imposed, whether on sand or clay, can be summarized as follows: (i) an atrazine ban results in substitutions of strategies that are slightly more costly ($0.81 to $1.50 per acre) but with a higher risk potential (1.3 to 38 percent), (ii) a ban of all triazines dramatically reduces the substitution alternatives and results in higher risk (5.3 to 25.3 percent) and higher cost ($5.60 to $13.80 per acre), and (iii) a ban on broadcasting results in moving to an application technology using banding, and substituting week control strategies involving relatively higher risk (0 to 12 percent) and slightly higher application costs. On the basis of increase in risk for each extra dollar increase in cost, an atrazine ban would rank last, followed by a ban on broadcast technology, and a ban on all triazines.[11]

Third, with respect to soil properties, we observe a shift in all efficient frontiers upward and to the right as we move from sand to clay. This implies that weed control on predominantly clay soils costs more and may be less effective; both results are not surprising, since herbicide application

---

[9]A1(2): Atrazine >(<) 1.5 lb per acre; PR: Princep; BL: Bladex; 24: 2,4-D; BA: Banvel; PRL: Prowl; ppi: pre-plant; post: post-emergent.

[10]We note that we have only considered total cost of application and implicitly assumed constant costs for tillage and labor across all strategies. This assumption, however, does not affect the fundamental approach of information generation and substitution alternatives presented in this paper.

[11]We note that a ban on all triazines is probably unlikely to occur since atrazine (aatrex) is the only chemical in the group associated with water quality problems. The other two chemicals in the group are bladex (cyanazine) and princep (simazine); the first one is very effective and has a two-week half life, the second one has a very long half life (more than a year) and thus can only be effectively used on continuous corn, because of severe carryover problems.

rates are higher and weather (wetness of fields) has more effect on windows of application on clay soils.

Finally, in Table 2 we present a sample of efficient strategies from each of the four cases discussed. Each strategy carries a numerical label that is also shown on the graphs in Figures 1 and 2. Table 2 also demonstrates that when atrazine is banned, other triazines (bladex and princep) are still superior. In addition, when all triazines are banned, some of the most well-known and currently used herbicides appear in the efficient strategies: Lasso, Dual, and Sutan for grass control, and Banvel, 2,4-D, and Basagran for broadleaf control.

5. Concluding Remarks

We developed a framework to examine weed control management decisions based on the hypothesis that farmers trade off expected risk and expected cost of treatment. The framework rests on the concept of a weed control strategy that views weed control as a system of several herbicides applied in a primary or a secondary mode, and linked together by several parameters including scope of control, tillage, windows of application and effectiveness, application technology, and environmental conditions. By simulating the effects of three policies--a ban on atrazine, a ban on all triazines, and a ban on broadcasting as an application technology--the empirical results clearly confirm the economic importance of all triazines. In particular, atrazine, a versatile and low-cost herbicide, is present in all efficient strategies in the base case. An atrazine ban would result in substitution to more expensive triazines. However, the results show that a complete triazine ban would have a more significant impact on both application costs and weed control effectiveness. Banning broadcast application results in higher risk due to the switch to banding, a technology used within a much more restricted time frame.

Table 1. Examples of weed control strategies aimed at full control

Weed Control Strategy	Al.epp + Al.post		LA.ppi + 24.post	DU.pre + BA.post
Application Window (B)	4/5-4/25	5/17-6/7	5/17-6/1	6/1-6/14
Application Window (G)	4/5-4/25	5/17-5/31	5/1-5/10	5/10-5/17
Effectiveness Window (days)	B: 77 G: 47	5/17-6/7 5/17-5/31	5/17-6/1 50	6/1-6/14 50
Tillage System	No Till		Conventional Till	Reduced Till
Application Technology	Broadcast		Incorporated/ Banded	Broadcast/ Banded
Chemical Cost/acre($)	6.81		16.61	22.52

Note: Al: Atrazine > 1.5 lb per acre; LA: Lasso; 24: 2,4-D; BA: Banvel; DU: Dual epp: early preplant; ppi: preplant incorporated; pre: preplant; post: post-emergent; B: Broadleafs; G: Grasses.

Table 2. Efficient substitution strategies
Base case: no restrictions

Label	Soil	Strategy Primary	Strategy Secondary	Risk (%)	Cost/acre ($)
6	c	PR.ppi	Al-post	2.1	8.82
5	c	Al-PR.ppi	BL.post/PRL-BL.post	8.8	8.62
2	c	Al-PR.pre	24.post/BA-24.post	38.7	6.48
1	c		Al-post	42.7	4.17

Note: Al(2): Atrazine >(<) 1.5 lb per acre; LA: Lasso; 24: 2,4-D; BA: Banvel; DU: Dual; AC: Accent; BE: Beacon; BL: Bladex; PR: Princep; SU: Sutan; PRL: Prowl; ppi: preplant incorporated; pre: preplant; post: post-emergent; s: sand; c: clay.

Table 3. Efficient substitution strategies
Case 2: Atrazine ban

Label	Soil	Strategy: Primary	Strategy: Secondary	Risk (%)	Cost/acre ($)
6	c	PR.ppi	AC.post/BE.post	3.4	10.12
5	c	PR.ppi	BL.post/PRL-BL.post	8.8	9.02
2	c	PR.pre	24.post/BA-24.post	66.0	5.22
1	c		BL.post/PRL-BL.post	80.7	4.97

Note: A1(2): Atrazine >(<) 1.5 lb per acre; LA: Lasso; 24: 2,4-D; BA: Banvel; DU: Dual; AC: Accent; BE: Beacon; BL: Bladex; PR: Princep; SU: Sutan; PRL: Prowl; ppi: preplant incorporated; pre: preplant; post: post-emergent; s: sand; c: clay.

Table 4. Efficient substitution strategies
Case 3 : Triazine ban

Label	Soil	Strategy: Primary	Strategy: Secondary	Risk (%)	Cost/acre ($)
4	c	SU.ppi & 24.post/ LA.ppi & 24.post/ DU.ppi & 24.post	ACpost/ BE.post	7.4	22.58
1	c	LA.pre & BA.post/ DU.pre & BA.post	24.post/ BA-24.post	68.0	9.80

Note: A1(2): Atrazine >(<) 1.5 lb per acre; LA: Lasso; 24: 2,4-D; BA: Banvel; DU: Dual; AC: Accent; BE: Beacon; BL: Bladex; PR: Princep; SU: Sutan; PRL: Prowl; ppi: preplant incorporated; pre: preplant; post: post-emergent; s: sand; c: clay.

Table 5. Efficient substitution strategies
Case 4: Broadcast ban

Label	Soil	Strategy		Risk	Cost/acre
		Primary	Secondary	(%)	($)
4	c	A1-PR.pre	AC.post/BE.post	14.1	11.53
3	c	PR-pre	A1.post	24.1	6.63
2	c	A1-PR.pre	24.post/BA-24.post	38.7	6.48

Note: A1(2): Atrazine >(<) 1.5 lb per acre; LA: Lasso; 24: 2,4-D; BA: Banvel; DU: Dual; AC: Accent; BE: Beacon; BL: Bladex; PR: Princep; SU: Sutan; PRL: Prowl; ppi: preplant incorporated; pre: preplant; post: post-emergent; s: sand; c: clay.

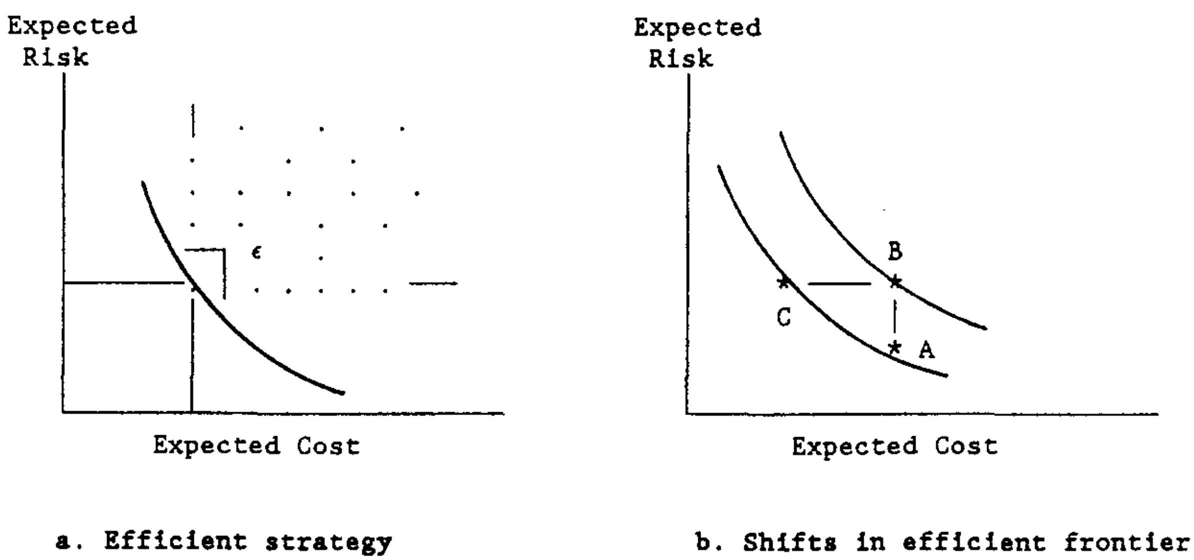
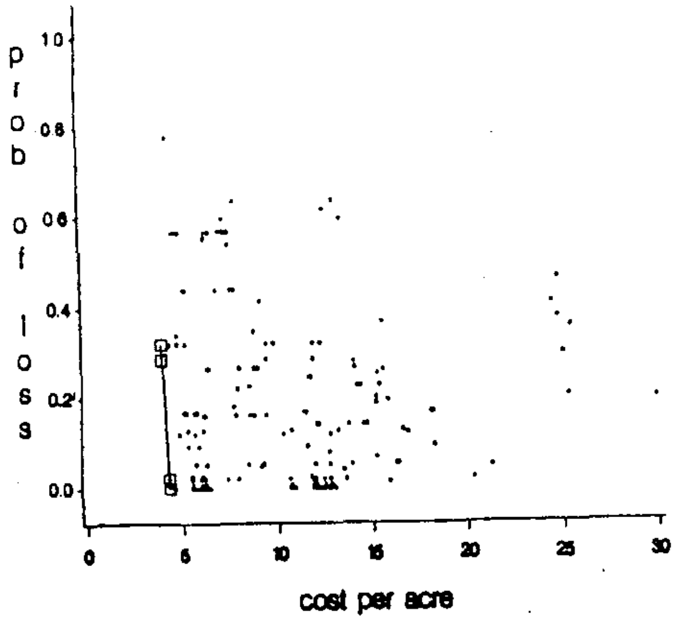
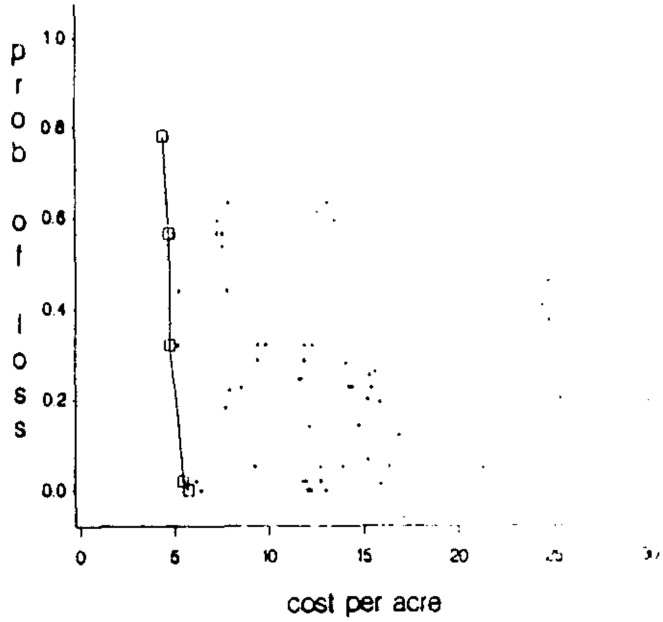


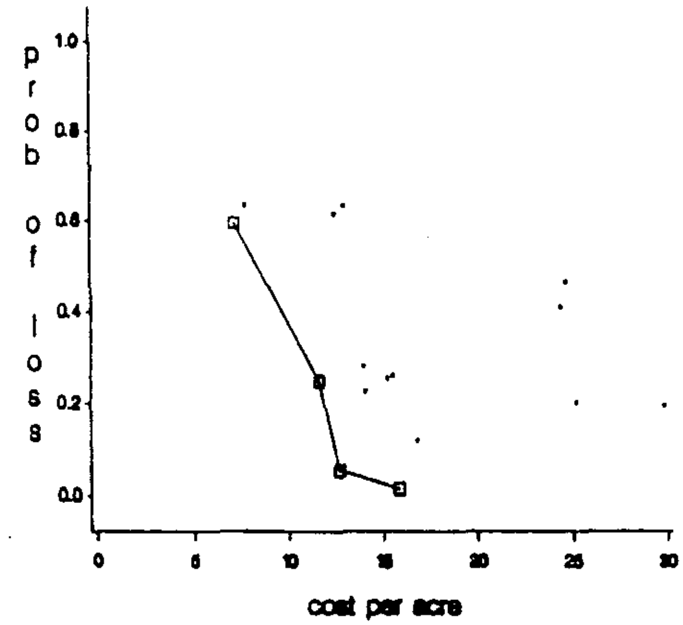
Figure 1. Illustration of Efficiency Concept



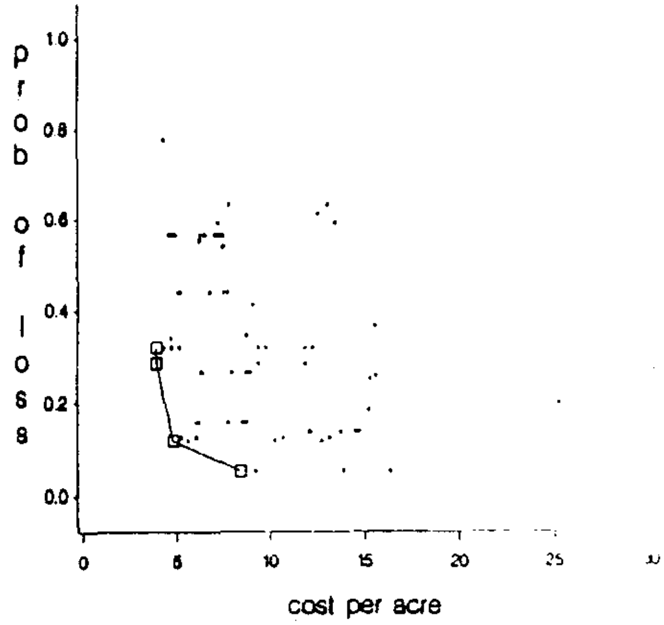
Case 1: All herbicides



Case 2: Atrazine ban



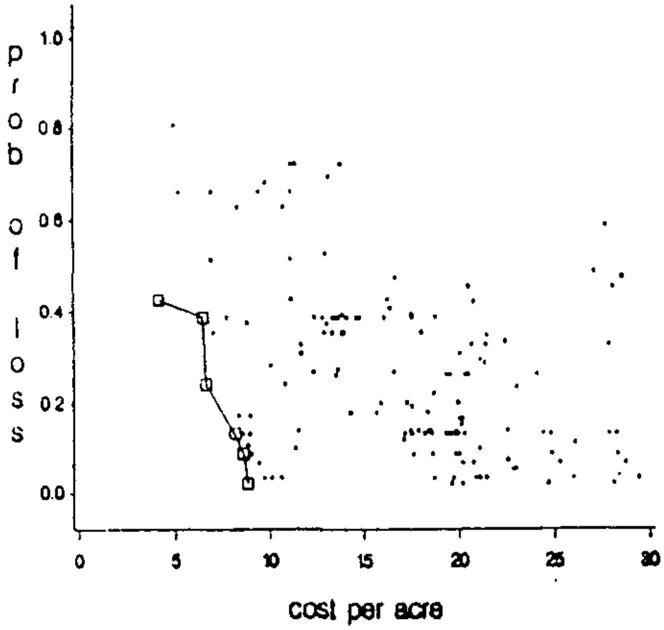
Case 3: All triazine ban



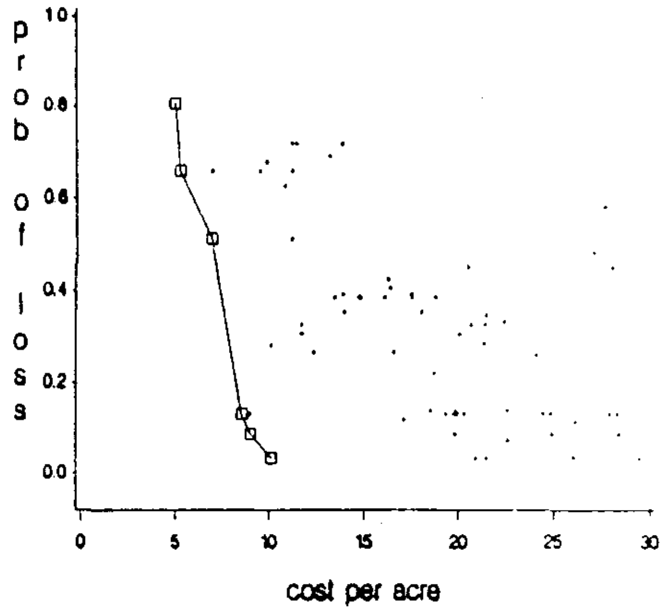
Case 4: Broadcast ban

Soil type: Sand

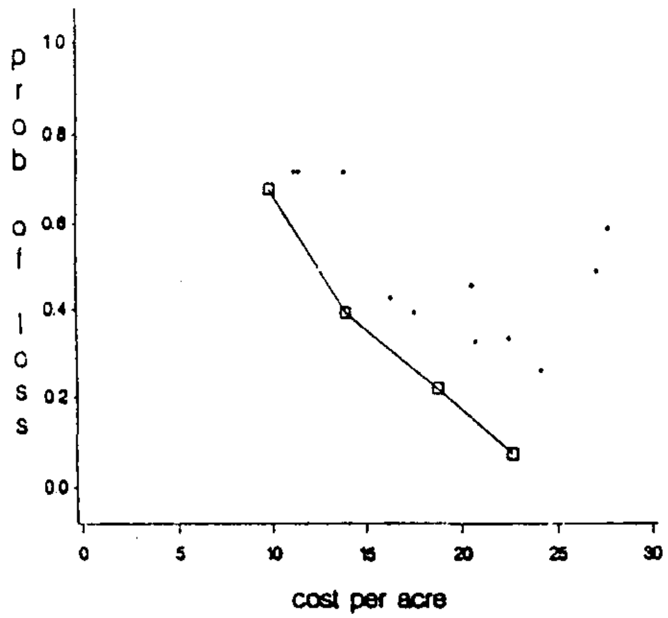
Figure 2. Risk-Cost Trade-offs Under Herbicide Policy Restrictions



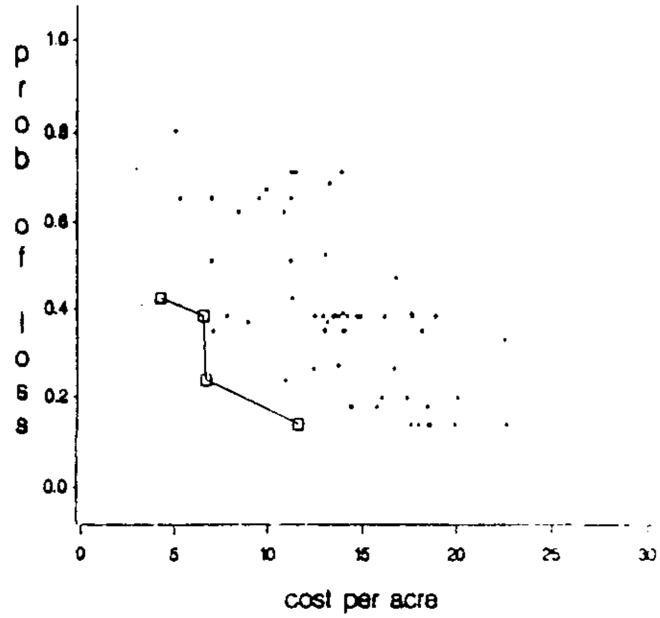
Case 1: All herbicides



Case 2: Atrazine ban



Case 3: All triazine ban



Case 4: Broadcast ban

Soil type: Clay

Figure 3. Risk-Cost Trade-offs Under Additional Herbicide Policy Restrictions

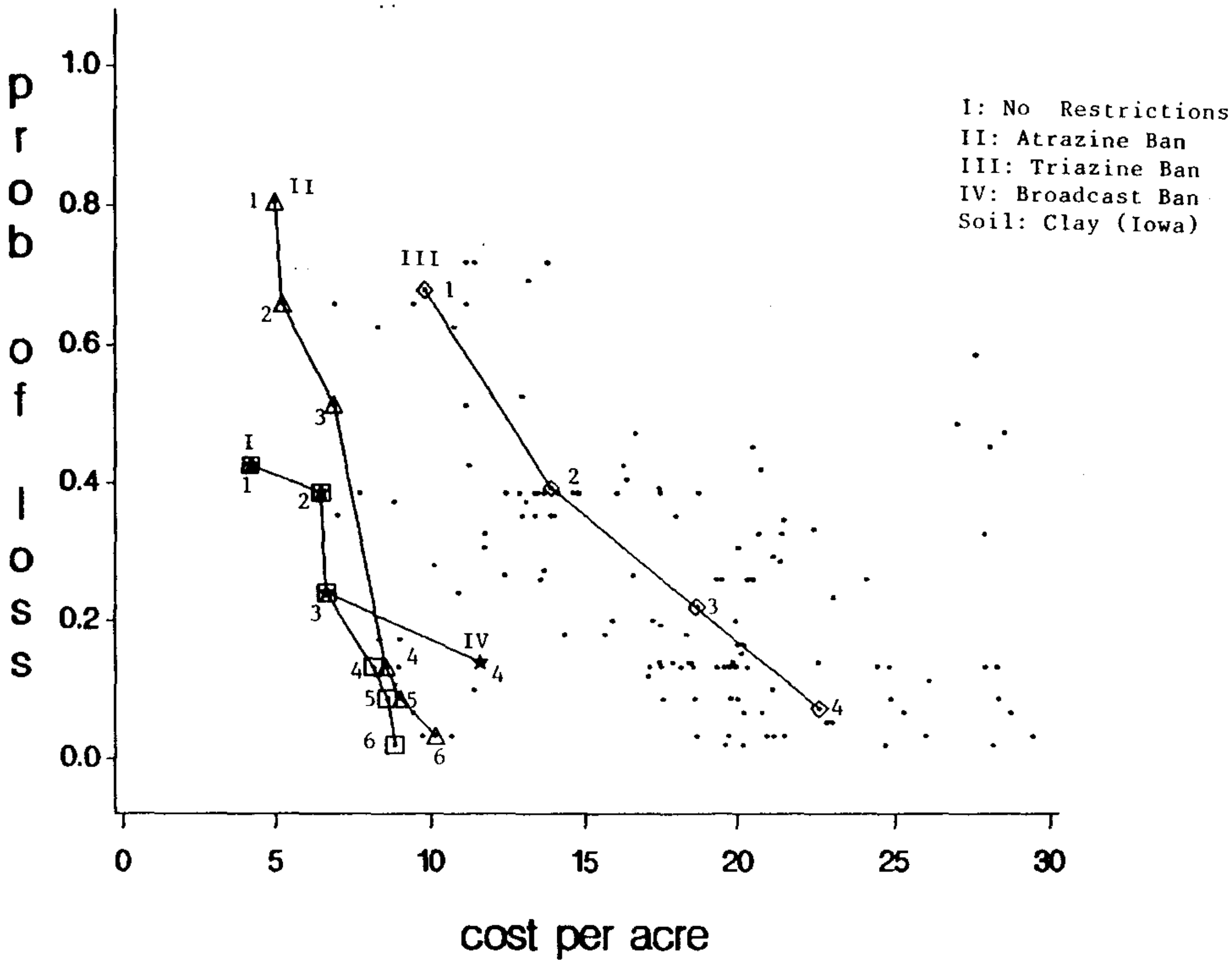


Figure 4. Comparative Agrichemical Policies

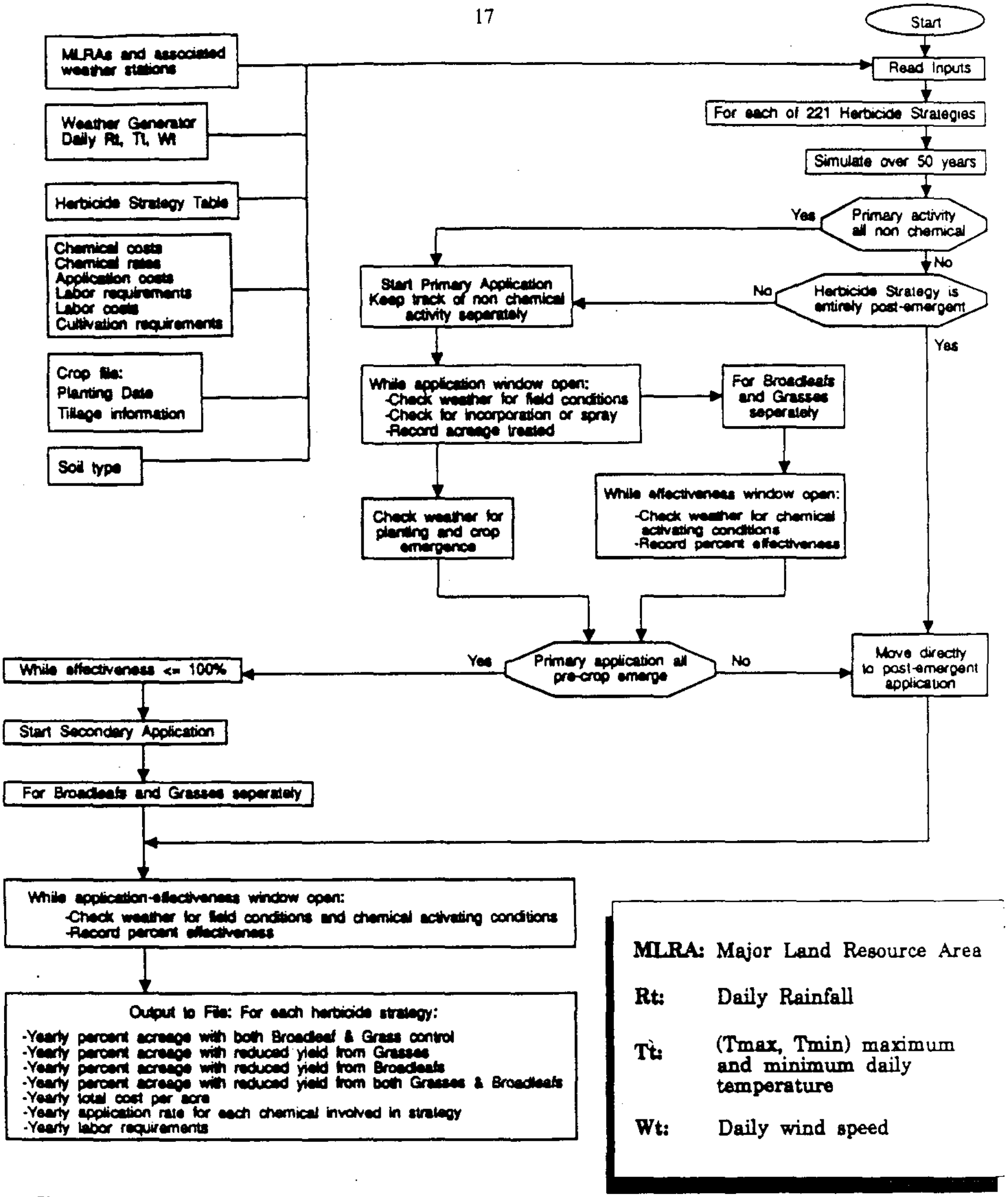


Figure 5. WISH Macro Flow Chart

References

Abt Associates Inc (1987). Pesticide Drinking Water Exposure/Risk Methodology. Washington, D.C.

ARS (1990a). EPIC-Erosion/Productivity Impact Calculator: 1. Model Documentation. Technical Bulletin Number 1768.

ARS (1990b). EPIC-Erosion/Productivity Impact Calculator: 2. User Manual. Technical Bulletin Number 1768.

Auld, B. A., K.M. Menz, and C. A. Tisdell (1987). Weed Control Economics. New York, London: Academic Press.

Bouzaher, Aziz (1991). "Simulation of Weed Control Management in CEEPES with ALMANAC." Unpublished manuscript. Center for Agricultural and Rural Development, Iowa State University. January.

Cabe, Richard, Peter J. Kuch, and Jason Shogren (1990). "Integrating Economic and Environmental Process Models: An Application of CEEPES to Atrazine." Draft report. Center for Agricultural and Rural Development, Iowa State University

Cabe, Richard, Alicia Carriquiry, Jason F. Shogren, Aziz Bouzaher, and Charles Hintermeister (1991). "Agri-Ecological Economics, Response Surfaces, and Research Efficiency." Paper submitted for presentation at the 1991 AAEA Annual Meeting, August 4-7, Manhattan, Kansas.

Cox, Graig, and K.W. Easter (1990). "A Regional Ban of Alachlor and Atrazine in Southeastern Minnesota: The Economic and Environmental Effects." Staff Paper P90-58. September. Department of Agriculture and Applied Economics, University of Minnesota.

Davidson, J.I., Williams, J.R., J.G. Arnold (1989). "Water Models Save Resources." Agricultural Research (August):4-9.

Doyle , C.J., A.K. Oswald, R.J. Haggar, and F.W. Kirkham (1984). "A Mathematical Modeling Approach to the Study of the Economics of Controlling Rumex Obtusifolius in Grassland." Weed Research 24:183-183.

Edwards, C.A (1987). "The Concept of Integrated Systems in Lower Input/Sustainable Agriculture." American Journal of Alternative Agriculture 2:148-152.

ERS (1989). Agricultural Resources--Inputs: Situation and Outlook. USDA/ERS, AR-15. August. Washington, D.C.

Hazell, Peter B.R., and Roger D. Norton (1986). Mathematical Programming for Economic Analysis in Agriculture. New York: Macmillan.

Johnson, S.R., P.E. Rosenberry, J.F. Shogren, and P.J.Kuch (1990). CEEPES: An Overview of the Comprehensive Economic Environmental Policy Evaluation System. CARD Staff Report 90-SR 47. Ames: Center for Agricultural and Rural Development, Iowa State University.

Jones, C.A., and J.C. O'Toole (1986). "Application of Crop Production Models in Agro-Ecological Characterization." Agrotechnology Transfer 4 (October).

MacRae, R.J., S.B. Hill, J. Henning, and A.J. Bentley (1990). "Policies, Programs, and Regulations, to Support the Transition to Sustainable Agriculture in Canada." American Journal of Alternative Agriculture 5(2):76-92.

National Governors' Association (NGA) (1989). Agriculture and Water Quality. Washington, D.C.: NGA.

Wu Nesa, and Richard Coppins (1981). Linear Programming and Extensions. New York: McGraw Hill.