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WEED MANAGEMENT STRATEGIES, BIOECONOMIC MODELS AND INFORMATION VALUE

Scott M. Swinton, Robert P. King, and Donald W. Lybecker[1]

Abstract. Bioeconomic weed management models offer farm managers a means to follow a flexible weed control strategy that responds to a predicted value of crop yield loss. The weed control thresholds embedded in these models can be flexible too, responding to environmental and health concerns, as well as changes in expected prices, costs, and weed-free yield. Users of bioeconomic models will need to gather new information on weed population pressure. The value of this information and the flexible management strategy it permits is illustrated with an example.
Additional index words: Decision aid, threshold, interference.

INTRODUCTION

Farmers and ranchers in the United States were projected to apply more that 406 million pounds active ingredients of herbicides on the major field crops in 1991. This is nearly 85% of the total pesticide active ingredient applied (Economic Research Service). Concerns have surfaced in recent years regarding the impact of this herbicide load on the environment, the health of those who apply these chemicals, and the safety of the food supply. In addressing these anxieties, advocates of "sustainable agriculture" have highlighted the desirability of developing reduced-chemical strategies and methods for controlling weeds.

An approach to weed management which is consistent with this goal is the use of computerized decision aids to assist farmers in choosing weed management strategies. Bioeconomic management models explicitly consider weed density and species composition, the efficacy of weed control tactics,

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crop losses due to weeds, weed control costs, and crop price. From estimates of weed density, they project likely crop yield losses. Model recommendations are driven by a comparison of weed control costs relative to the value of yield loss prevented. Because bioeconomic model recommendations stem directly from observed weed infestations, they have the potential to increase farm revenues by recommending the most appropriate control measures. At the same time, they may reduce chemical loading (and associated health risks) by recommending herbicide use only when and where it is economically justified.

The concept of a management *strategy* is key to understanding why bioeconomic models can be useful. As used here, the term "strategy" refers to a general approach to the goal of weed management. Three kinds of strategies are of particular interest: fixed, flexible, and mixed. Employing a predetermined schedule of actions (e.g., applying a postemergence herbicide every year to a field of corn (*Zea mays* L.) is a *fixed strategy*. Such a strategy is unresponsive to incoming information on the potential losses to be caused by emerging weeds that may interfere with the corn crop. When a farmer or crop scouting service inspects a field after emergence of the corn crop for the presence of weeds and bases the postemergence herbicide application decision upon the number, species, stage of growth, prices, and other factors, then a *flexible strategy* to weed control has been used. If only a few weed seedlings are present no herbicide will be applied. Another inspection can be made at a later date and the herbicide application decision reconsidered. If a farmer always uses a preemergence herbicide but evaluates the weed seedling situation before applying a postemergence herbicide a *mixed strategy* has been adopted.

The next section of the paper will present the concept of a threshold and develop the economic threshold for weed management. The subsequent section will define the concept information and develop its application in weed management. The final section will demonstrate the integration of these ideas in the bioeconomic model for weed management.

WEED MANAGEMENT THRESHOLDS

A key question in crop production is "how much of an input to apply?" In answering, agricultural production economists distinguish between inputs which can be applied in divisible quantities and inputs which can be applied only in fixed units. Examples of the first group are fertilizers, irrigation water and labor. The quantity of each of these can be tailored to the need. Examples of the second kind of input would include "lumpy" inputs such as machines. A field cannot be plowed lightly; it is either plowed or it isn't. With different tillage equipment it may be plowed differently, but the decision calls for choosing which equipment to use rather than how much to use a given implement.

When an input is divisible, the manager can maximize profit by using it up to the point where the value of the output that results from the last unit of input is equal to that unit's cost. At higher levels of input use, the value of the added output will be insufficient to cover its cost. At lower levels of input use, the marginal output is worth more than its cost of production, so there is an opportunity to earn more profit by using more input.

When an input is not divisible, highest profits are realized when the manager applies it only if it yields returns that equal or exceed its cost. The cost of the input constitutes a threshold of profitability: If returns exceed that threshold, the input should be used, otherwise not.

Herbicides, fungicides and insecticides straddle the border between divisible and indivisible or "lumpy" inputs. In a strict sense, they are divisible (and some economists have advocated treating them as such (Pannell 1990)). A manager can apply as much or as little as he or she wishes (within legal limits). However, two factors favor treating pesticides as lumpy inputs. First, information on pesticide efficacy below recommended doses is generally not available. Second, pesticide manufacturers typically guarantee efficacy only when their chemical is applied at recommended rates. If a manager cares to have legal recourse to sue the chemical company for failure of the pesticide to control the pest population (nonperformance of the contract implicit in the pesticide label), then he or she is constrained to using recommended rates. Together these factors act to make the decision one not of "how much pesticide to apply," but rather of "whether to apply" at the recommended rate.

How pest population thresholds work.

Pest control treatments differ from many other agricultural inputs in that they do not increase production by acting directly on the crop. Rather, they curtail production losses to a pest. Since their effect is indirect, measuring their economic value is a two-step process. First, one needs to know how crop losses change with the size of the pest population. Second, one also needs to know how effectively pest control treatment does its job. When both are known, it becomes possible to estimate the amount of crop yield saved by controlling the pest. Of course, the value of crop yield saved depends upon the crop's price. This must be compared with the cost of the pest control input in order to determine whether control is worthwhile. For a given crop price and pest control cost, there exists an implicit pest population threshold above which control with a given agent will be cost effective.

Since this threshold depends upon control costs and the value of the yield saved, it is not a fixed weed density level. To see this, suppose that a certain herbicide, costing $25 per hectare to apply, could kill all green foxtails (*Setaria viridis* (L.) Beauv. #[2] SETVI). Suppose further that green foxtail is the only weed present in a corn field, that 100 green foxtails per square meter will reduce corn yield by 250 kg/ha, and that corn sells for 10 ¢/kg. This situation is illustrated by the upper curve in Figure 1. At this price, the threshold for weed control is 100 green foxtails per square meter, since the $25 worth of yield loss they cause is exactly offset by the $25 cost of control. At any density

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[2]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

greater than 100 foxtails per square meter, the farmer should control them. However, if the price of corn drops to 8 ¢/kg, as illustrated by the lower curve, it is no longer worthwhile to control the foxtails at a density of 100/m^2, since controlling them would cost $25 and they will only reduce net revenues by $20. When corn sells for 8 ¢/kg, the threshold for foxtail control is closer to 130 plants per square meter in this example. Similarly, if the foxtail control efficacy were to fall from 100% to a lower level, the threshold for control would rise, since the value of crop yield saved would be lower. Note also that if the cost of weed control drops below $25/ha, then the threshold drops with it. This can be seen by imagining how Figure 1 changes if the cost line is shifted below $25.

Types of thresholds.

The kind of weed control threshold discussed above is just one of many possible. It is a static economic weed population threshold "at which the cost of control measures equals the increased return on yield which would result" (Cousens, p. 15). Setting economics aside, one can imagine an "aesthetic threshold" at which a field begins to look shabby or a "biological threshold" at which crop loss becomes biologically detectable (Cussans et al.). Maxwell recently introduced a "resistance threshold" aimed at reducing genetic selection pressure for herbicide resistance.

More than one economic threshold exists as well. The static economic threshold described above focuses exclusively on yield losses in the current year. A more foresighted economic threshold is a dynamic one that takes into account the future yield losses that will result from weed seeds left in the current year, termed the "economic optimum threshold" by Cousens. Controlling weeds not only prevents them from competing with the crop in the current season, it also prevents them from setting seed that will sprout and cause yield losses in subsequent years. If long run profit maximization is the goal of the farm manager, then a dynamic economic threshold for weed control provides the best basis for weed management decisions. For the same crop price and weed control cost, a dynamic threshold occurs at a lower weed population than that illustrated in Figure 1, since it accounts for yield losses beyond the current year (e.g., Bauer and Mortensen).

Many farm managers have broader goals than even long run profit maximization. Some are concerned about the risks associated with correctly predicting crop yields, weed control efficacy, weed populations, or the availability of workable field days to control weeds. The risk of mistakenly failing to control weeds may be particularly important if financial loss endangers the survival of the farm. For these managers, the threshold rule needs to be adjusted to compensate for that risk. Typically, this will entail a decision rule that more readily recommends weed control than one appropriate for a manager indifferent to income risk.[3]

Worker safety or environmental protection may be other management objectives. While most herbicides have low levels of acute toxicity to humans, direct contact with them still constitutes a health risk. A related objective is reduction of environmental contamination on the farmstead or the surrounding community. Certain herbicides are prone to leach into the groundwater. The economic thresholds discussed so far are *privately* optimal: they ignore the external effects of the farmer's weed control decision. While bioeconomic models may often lead to lower levels of herbicide use (King et al., Lybecker et al., Swinton), this is not assured unless minimizing chemical loading is an objective of the model. Including such externalities as worker safety and environmental contamination will lead managers to follow a decision rule that is less prone to recommended dangerous or leachable herbicides than a straight profit-maximizing dynamic economic threshold. For example, if herbicides are assigned an implicit environmental cost in addition to their financial cost, a higher "environmental threshold" results (Higley and Wintersteen).

With minor modifications to the dynamic economic threshold rule, it is possible to design suitable decision rules for farm managers with broader objectives than profit maximization. Alternatively,

[3]Although for certain classes of risk, this need not be so (Pannell 1991).

recommendations from garden-variety economic threshold models can be subjectively modified by a decision maker. Bioeconomic models make it possible to evaluate the expected cost in profitability of choosing a weed control tactic other than the profit-maximizing one. These advantages come at a cost. Decisions based on weed population levels require information to assess and predict those populations.

THE VALUE OF INFORMATION

"Information" is a term that is widely used but often poorly understood. Davis and Olson (p. 200) define information as

> "... data that has been processed into a form that is meaningful to the recipient and is of real or perceived value in current or prospective actions or decisions."

This definition makes a distinction between data and information. Data is the "raw material" for information, but it does not become information until it is placed in the context of particular decisions. The definition also emphasizes that data becomes information only when it has value to the recipient. That value may be derived from the sense of reassurance that comes when current beliefs are confirmed, but the more important basis for the value of information is a change in behavior.

For farmers, the information derived from weed population data and knowledge of weed population thresholds has greatest value when it leads to crop management decisions that are different from and more profitable than those that would have been made in the absence of that information. The following example will help illustrate why weed population information has value and how that value can be measured.

A Minnesota corn producer is trying to decide whether to use a standard prophylactic postemergence weed control treatment or to base postemergence weed control decisions on weed seedling counts. The field in question was planted on May 15. EPTC (S-ethyl dipropyl carbamothioate) plus safener was applied pre-plant incorporated.

Given these early season weed control decisions, five possible "states of nature" describe the range of weed population conditions that could hold just prior to the application of postemergence weed control treatments. The states of nature are equally likely. Therefore, each has a 0.2 probability of occurring. Each state of nature is defined by early season weed population levels for three weed species: green foxtail, common lambsquarters (*Chenopodium album* L. # CHEAL), and redroot pigweed (*Amaranthus retroflexus* L. # AMARE). These are shown in Table 1.

Three possible postemergence weed control treatments are being considered: no control, dicamba (3,6-dichloro-2-methoxybenzoic acid), and cyanazine (2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile). End of season weed counts and crop yields associated with each of these treatments are also shown for each state of nature in Table 1. Note that dicamba controls lambsquarters and pigweed effectively but has little effect on green foxtail. Cyanazine provides good control for green foxtail and lambsquarters but is less effective in controlling pigweed. Therefore the overall effectiveness of these herbicide treatments depends on the mixture of weeds present.

Suppose the price of corn is 8.9 cents/kg ($2.25/bu) and the cost of all inputs except those used for postemergence weed control is $370.70 per hectare. Materials and application costs for the dicamba and cyanazine weed control treatments are $18.40 per hectare and $25.20 per hectare respectively. There are, of course, no materials or application costs associated with the no control alternative. Under these assumptions, net returns per hectare are defined by the following expression:

$$(1)\quad (0.089 * Y) - 370.70 - WCC$$

where Y is crop yield and WCC is weed control cost.

Net returns per hectare for the three postemergence weed control strategies are shown in Table 2. The cyanazine treatment has the highest average net return per hectare. In three of the five states of nature, however, one or both of the other two treatments performs better than cyanazine. Given data on early season weed densities, knowledge of the relative efficacy of the alternative weed control treatments, and an understanding of potential yield reductions due to weed pressure, weed control actions could be tailored to actual field conditions. In the absence of that information, cyanazine would be the best fixed weed control strategy.

With perfect knowledge of what weed population conditions would prevail, the farmer would use dicamba in States of Nature 1 and 5, cyanazine in States of Nature 3 and 4, and no control in State of Nature 2. As shown in Table 2, the average net return per hectare for this flexible strategy is $186.20 per hectare, $8.00 higher than the average net return for the cyanazine treatment. This $8.00 difference in net returns is a measure of the value per hectare of the information that allows the farmer to tailor weed control actions to specific field conditions.

In this case, information is derived from early season weed seedling counts and from knowledge of how alternative treatments perform under a wide range of conditions. Weed seedlings cannot be counted prior to the application of soil applied herbicides or the use of early season cultivation tools such as a rotary hoe. Weed seed counts from soil samples can be used, however, to make the weed population forecasts required to tailor early season weed control decisions to field conditions.

In this example, weed seedling counts are assumed to be the basis for perfect predictions of which postemergence weed control treatment will be best. In reality, of course, the performance of biological systems is difficult to forecast with perfect accuracy. As the predictive power of procedures used to process weed population data into weed control recommendations declines, the value of weed population information will also decline. Therefore, the value of weed population information is sensitive to our knowledge of weed population dynamics and weed-crop competition, and the value of that information can be enhanced by research that improves our understanding of these biological processes.

Measures of the value of information are also sensitive to biological conditions at the field level. Had the analysis in Tables 1 and 2 been done for a field with strong weed pressure and especially high levels of green foxtail, the cyanazine treatment (which is especially effective against green foxtail) might have been best in nearly all possible states of nature. Under these conditions, information derived from weed seedling counts would be of little value because the recommended action would almost always be the same. Similarly, if weed pressures were low and postemergence treatments were rarely needed, the value of information derived from weed seedling counts would be low.

Changes in product price or weed control costs can also affect the value of weed population information. For example, an increase in the price of corn coupled with an increase in weed control costs could make the selection of an appropriate weed control action more important, thereby increasing the value of information used for weed management decisions.

Finally, it is important to remember that there are costs as well as benefits associated with the use of weed population information. The costs can be divided into two broad categories: the costs of collecting weed seed or weed seedling counts for a particular field and the costs of processing field level data into specific weed control recommendations.

The cost of collecting weed population data depends on sampling intensity and measurement methods. As the number of samples collected per field increases, the accuracy of weed seed or weed seedling counts should increase, but at a decreasing rate. Labor costs for data collection, on the other hand, would increase at a fairly constant rate. Therefore, there will be some point at which the increased cost of collecting another sample will outweigh the increased benefit from greater accuracy. Measurement methods also affect the cost of weed population data. A range of methods have been used to count weed seeds in soil samples. These differ in both cost and accuracy. Similarly, weed seedling densities can be assessed by direct counts or by less precise and less costly visual scoring methods. At present, our knowledge of the cost/accuracy tradeoffs for both sampling intensity and alternative measurement methods is limited. This is an area where further research is needed.

BIOECONOMIC MODELS FOR WEED MANAGEMENT

Bioeconomic models (such as those developed by Lybecker, Schweizer, and Westra; Wilkerson, Modena, and Coble; and Swinton and King[4]) are one kind of tool that can be used to process weed population data into weed control recommendations. These models include economic thresholds by weed species or weed groups which reflect the value of expected yield losses and costs of weed management treatments. Other data integrated into these models include absolute and relative status of the crop and the weeds (height and number of leaves), herbicide label restrictions, and constraints to herbicide use that are internal to the farm.

Development and maintenance costs for such models are high and are generally borne by the public sector. Relative to the benefits, the costs of using an existing model to generate recommendations for a field are relatively low, at least for postemergence weed counts (Swinton). After sampling, it takes only a few minutes to enter weed population data, analyze alternative strategies, and print recommendations. Weed population data can also be processed into weed control recommendations by experts who, through training and experience, have developed skills in making weed control recommendations. Experts can take unusual conditions into account that could never be

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[4]Swinton, Scott M. and Robert P. King. "A Bioeconomic Model for Weed Management in Corn and Soybean." Staff Paper 92-44. Department of Agricultural Economics, Michigan State University, East Lansing, MI, July 1992.

included in a bioeconomic model. They may also be able to adapt more quickly to changing conditions.

On the other hand, expert reasoning may not be consistent from one field to the next and, when time is limited, experts may not consider the full range of weed control alternatives. Furthermore, while the expertise embodied in a computerized bioeconomic model can be copied and distributed at low cost, training a new expert can be both costly and time consuming. As in the case of weed population data collection, the relative costs and benefits of alternative approaches for processing that data are poorly understood.

Finally, multiple decision criteria may be used for weed management decisions. The net margin or relative profit of alternative treatments is not the only criterion that farmers may consider. One approach, noted above, is to modify the threshold decision rules that drive bioeconomic models to reflect objectives other than maximizing net financial returns. An alternative is to use a standard net revenue maximization decision rule, but bar certain treatments from consideration. For example, the number of weed escapes from the most favorable net margin alternative may be unacceptably high to a farmer who takes pride in "perfectly weed clean fields." Applicator health concerns or groundwater pollution may require that feasible treatments be eliminated. The cost of selecting the second or third most profitable treatment may be large or small. The advantage of a bioeconomic model is that it can make that cost explicit, allowing the individual operator to weigh the financial sacrifice against other decision criteria of importance.

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Table 1. Weed Populations and Crop Yields in Five States of Nature Under Three Postemergence Weed Control Treatments.

State of nature	Unit of measure	Early season weed counts	End of season weed counts and crop yield		
			No control	Dicamba	Cyanazine
1					
Green foxtail	no./m^2	23	26	23	5
Lambsquarters	no./m^2	4	4	1	1
Pigweed	no./m^2	12	13	2	7
Corn yield	kg/ha		5200	6400	6400
2					
Green foxtail	no./m^2	7	8	7	1
Lambsquarters	no./m^2	0	0	0	0
Pigweed	no./m^2	2	2	0	1
Corn yield	kg/ha		6700	6800	6800
3					
Green foxtail	no./m^2	36	40	36	8
Lambsquarters	no./m^2	3	3	0	0
Pigweed	no./m^2	7	8	1	4
Corn yield	kg/ha		5500	6200	6500
4					
Green foxtail	no./m^2	55	61	56	12
Lambsquarters	no./m^2	5	5	1	1
Pigweed	no./m^2	14	15	3	8
Corn yield	kg/ha		4000	5800	6200
5					
Green foxtail	no./m^2	7	8	7	1
Lambsquarters	no./m^2	2	2	0	0
Pigweed	no./m^2	9	10	2	5
Corn yield	kg/ha		6000	6700	6500

Table 2. Net Returns in Five States of Nature Under Four Weed Control Strategies.

State of nature	Net return ($/ha)			
	No control	Dicamba	Cyanazine	Flexible strategy
1	94.10	176.30	167.90	176.30
2	220.00	211.80	207.6	220.00
3	116.10	163.50	181.50	181.50
4	- 16.10	122.20	149.90	149.90
5	163.60	203.40	184.30	203.40
Mean	115.50	175.40	178.20	186.20

FIGURE CAPTIONS

Figure 1:

The threshold weed density for control depends upon the price of the crop and the cost of control.

FIGURES

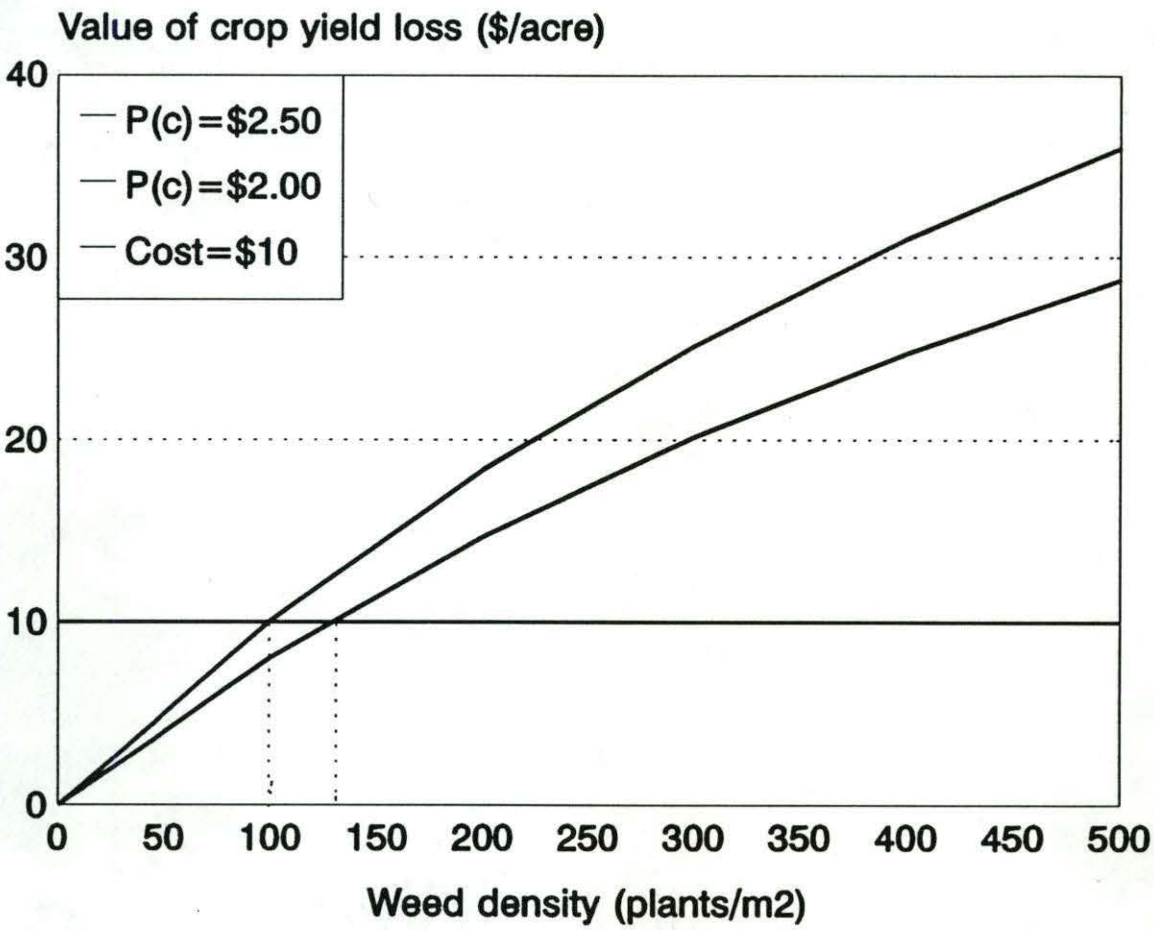

Figure 1: The threshold weed density for control depends upon the price of the crop and the cost of control.