Information Value in Weed Management

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Use of the economic threshold to improve the efficiency of preemergent-herbicide treatment decisions is limited by a lack of weed information. An economic model for assessing the expected value of weed information needed to implement a threshold decision rule is developed. Empirical results suggest that early season weed information can have value in cabbage weed management in Massachusetts.

The value of agricultural yield losses due to weed pests in the United States each year is generally thought to be large, perhaps an amount in the billions of dollars. Farmers also spend a considerable amount of money to control weeds. Environmental and health safety costs related to weed-control activities, particularly costs resulting from groundwater contamination by herbicides, are also receiving considerable attention and may be substantial (Nielsen and Lee).

Several studies have focused on the development of decision frameworks, usually involving the concept of the economic threshold, to promote more efficient postemergent-herbicide use in weed control (e.g., Marra and Carlson; Marra, Gould, and Porter). Much less attention has been given to preemergent herbicidal weed-control decisions, perhaps because key information needed to implement threshold-type decision rules is ordinarily unavailable for preemergent treatment decisions. For example, use of a threshold requires a measure of the pest population for implementation. Such a measure is typically unavailable in the preemergent case though there is apparently potential for and interest in its development among weed scientists (King, Lybecker, Schweizer, and Zimdahl).

A purpose of this paper is to present a method for assessing the expected value of pest information in preemergent herbicidal weed control. The method involves estimating information value conditional on optimal information utilization in the threshold decision-making context. Value estimates based on the method shed light on the magnitude of expenditures that could profitably be made by farmers to acquire such information. Estimates may also provide basic information for use by research and extension program administrators in establishing the priority that might be attached to development of pest-information models for preemergent use.

The first section discusses the use of information in preemergent weed management and elaborates on its valuation. Next, a model for calculating the expected value of information and empirical results for cabbage weed management in Massachusetts are presented. Concluding remarks are given in the final section.

Conceptual Framework

Preemergent treatments with herbicide are typically made assuming, at least implicitly, that the weed problem during the growing season will have sufficiently serious economic consequences to warrant control. If this assumption turns out to be incorrect, then a pest-control expense and a potential risk to environmental resources are incurred unnecessarily. A possible improvement over such a "schedule spray" use of preemergent material may be based on utilization of pest information and implementation of a threshold-type decision rule.

To use a threshold decision rule, information on the weed population is needed to compare to the threshold population; however, for a preemergent application of herbicide, a weed population does not exist and cannot be monitored in a straightforward manner at the time the treatment decision must be made. To circumvent this dilemma re-

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quires development of some type of weed-prediction model based on start-of-season information. Such a weed predictor might depend on a number of factors including weather forecasts, viable weed seeds in the seed bank, cropping history, herbicidal control history, and previous seasons' weed weights. At present, there is apparently a considerable amount of interest among weed scientists in improving the efficiency of preemergent-herbicide use and, in fact, some efforts are underway to develop early season forecasting tools for weed pests (King et al.). An interesting related economic issue is the potential value that might be expected to accrue to development of such pest-information models.

To shed light on the value that pest information might have for preemergent herbicidal treatment decisions requires assessment of the change in expected profit resulting from optimal utilization, in a threshold decision-making context, of perfect information (Moffitt, Farnsworth, Zavaleta, and Kogan). The value estimate obtained in this manner is therefore interpreted as a potential value: It is an upper bound on the value that early season weed information might have for preemergent herbicidal treatment decisions and will differ from actual value to the extent that sample rather than perfect information and risk aversion rather than risk neutrality prevail. An upper-bound value estimate, as provided by the method developed in the next section, provides basic information for use in determining the appropriateness of committing resources to improving decision-making efficiency in preemergent weed control.

The Model

Consider the following crop-weed pest model:

(1) $\Pi = p_y Y - vh - f,$

(2) $Y = Y_0 - \alpha W,$

(3) $W = W_0 \exp(-\beta h),$

(4) $W_0 \sim N(\mu, \sigma^2),$

where Π is profit, p_y is cabbage price (\$/kg), Y is yield (kg/ha), v is herbicide price (\$/kg ai), h is herbicide dose (kg ai/ha), f is fixed herbicide application cost (\$/ha), W is the controlled weed population (kg/ha), Y_0 is the potential yield with all other inputs fixed except weed population (kg/ha), α is the unit effect of weeds on yield (kg/ha), W_0 is the uncontrolled weed population (kg/ha) with expected value μ and variance σ^2, and β is a kill-efficiency parameter of herbicide.

The model, equations (1)–(4), depicts profit resulting from weed management in a crop-pest system characterized by linear pest damage and an exponential relationship between the weed population and preemergent herbicidal control. Common functional forms and stochastic specification are employed as useful simplifications of perhaps more complicated relationships to facilitate analytical tractability. After estimating parameters, expected profit can be calculated for a "schedule spray" strategy in which a preemergent-herbicide treatment is made routinely at a recommended rate, h^r, and no other weed control is employed. Expected profit for a threshold-type weed-control strategy can also be evaluated.

Denote a population threshold by W_T, and the preemergent-herbicide control level by h_T. Following Moffitt, Hall, and Osteen, expected profit is given by

$$
\begin{aligned}
(5) \qquad E[\Pi] &= p_y Y_0 \Phi [(W_T - \mu)/\sigma] \\
&+ p_y \alpha [(\sigma/\sqrt{2\pi}) \exp((-1/(2\sigma^2)) (W_T - \mu)^2) \\
&- \mu \Phi ((W_T - \mu)/\sigma)] + (p_y Y_0 - vh_T - f) \\
&\cdot [1 - \Phi((W_T - \mu)/\sigma)] - p_y \alpha \exp \\
&(-\beta h_T)\{(\sigma/\sqrt{2\pi})\exp((-1/(2\sigma^2))(W_T \\
&- \mu)^2) + \mu[1 - \Phi((W_T - \mu)/\sigma)]\},
\end{aligned}
$$

where Φ is the standard normal cumulative probability distribution (see Appendix). Expected profit corresponding to the "schedule spray" management strategy at a recommended rate follows from evaluation of (5) with $h_T = h^r$. Equation (5) can also be used to calculate the expected profit for a threshold-type strategy in conjunction with early season weed information.

Threshold-type strategies have been particularly popular in pest-management decisions. Maximization of (5) with respect to W_T and h_T results in the largest expected profit among management strategies of the type: If a population threshold is exceeded, then apply a preemergent-herbicide treatment at the rate h_T; otherwise do not use preemergent control. Necessary derivations for the optimal threshold and level of control associated with (5) are considered in an empirical example in the next section. Given the optimal strategy, expected profit can be evaluated and used to obtain the value of weed information corresponding to information use in a threshold-type strategy. Results indicate the expected value of early season weed information and provide an upper bound on maximum willingness to pay when information is utilized in the context of a threshold decision strategy.

Value of Cabbage Weed Information in Massachusetts

Weed pests, mainly grasses such as crab grass and fall panicum, and broadleaf weeds such as redroot pigweed and lamb's-quarters, are a serious problem in cabbage production in Massachusetts and can significantly reduce yield if uncontrolled. Postemergent-herbicide use is not commonly used for cabbage weed control in Massachusetts; only recently has a suitable herbicide become available to growers. Since an early planting date is regarded as critical, growers are advised to use early transplant varieties of cabbage and to apply preemergent treatment with herbicide at a recommended rate (Gillmeister, Moffitt, Bhowmik, and Allen).

Because of a number of concerns related to herbicide use, multiplot-multiyear testing was conducted at the University of Massachusetts to investigate the relative effectiveness of different preemergent-herbicide treatments (Bhowmik 1982, 1983, 1984). Experiments involving control strategies based on preemergent herbicidal treatment provided observations on cabbage yield and weed weight corresponding to the different strategies. A total of eighty observations were obtained for use in estimation (Gillmeister).

The parameters in equations (2) and (3) were estimated by the method of maximum likelihood using the experimental data described above. Parameter estimates are $\hat{Y}_0 = 20{,}598$ (18.84), $\hat{\alpha} = 20.651$ (5.93), and $\hat{\beta} = 2.68$ (3.32), where numbers in parentheses are estimated asymptotic t-statistics. An average cabbage price of \$0.20/kg (U.S. Department of Agriculture), trifluralin price of \$14.20/kg ai (Agsystems Research), and fixed application cost of \$22.05/ha (University of Massachusetts Cooperative Extension) were used along with the estimated technical parameters. Time-series cross-section observations involving no weed control were used to obtain estimates for μ and σ^2 of 563.15 kg/ha and 175,710 kg/ha, respectively. Currently, a treatment rate of 1.12 kg/ha is recommended for trifluralin.

Parameter estimates were used to maximize (5) to determine the threshold and level of control for the preemergent-herbicide trifluralin. The necessary conditions for determining the threshold and level of control for trifluralin are determined in a straightforward manner (see Appendix) and are

$$(6)\quad 0 = \sigma\beta p_y\alpha(1/\sqrt{2\pi})\, exp\{(-1/2\ \sigma^2) * ((vh_T + f - \mu p_y\alpha[1 - \exp(-\beta h_T)])/p_y\alpha[1 - \exp(-\beta h_T)])^2 - \beta h_T\} + (\mu\beta p_y\alpha \exp(-\beta h_T) - v) * \{1 - \Phi[(vh_T + f - \mu p_y\alpha * [1 - \exp(-\beta h_T)])/\sigma p_y\alpha[1 - \exp(-\beta h_T)]]\},$$

$$(7)\quad 0 = W_T - (vh_T + f)/p_y\alpha[1 - \exp(-\beta h_T)].$$

Table 1 shows the level of control, threshold, and expected profit for "schedule spray" preemergent herbicidal treatment and the threshold treatment strategy defined earlier. The expected value of cabbage weed information corresponding to the latter is also shown in the table. As is evident, early season weed information can have substantial value, perhaps as much as \$175 per hectare.

An important caution related to the value estimate should be noted. The optimal treatment rate associated with the threshold-type management strategy is larger than the currently recommended treatment rate. Possible phytotoxic (Ellis and Ilnicki) and/or environmental concerns may place constraints on treatment rates, thereby reducing the value of weed information in implementing a control strategy. To investigate information value in this circumstance, (5) was maximized constraining the treatment rate to not exceed the recommended rate. As shown in Table 1, expected profit in this case is \$4,037 per hectare with expected weed information value of \$71 per hectare. Hence, early season weed information appears to have potential value even if the preemergent treatment rate is confined to the current recommendation.

Concluding Remarks

Because of concerns about both groundwater quality and food safety, reducing the routine use of preemergent herbicides may become an increasingly important component of weed-management strategies in the years ahead. Economists can participate in this process by assisting in the development of environmentally sound weed-management strategies that are based on knowledge of and sensitivity to implications for the farm economy. The

Table 1. Management Strategy, Expected Profit, and Expected Value of Information for Cabbage Weed Control in Massachusetts

Management Strategy	Expected Profit ($/ha)	Expected Value of Weed Information ($/ha)
Apply a preemergent trifluralin treatment at 1.12 kg/ha.	3,966	—
If weed weight exceeds 13.07 kg/ha, then apply a preemergent trifluralin treatment at 2.32 kg/ha; else do not control.	4,141	175
If weed weight exceeds 9.67 kg/ha, then apply a preemergent trifluralin treatment at 1.12 kg/ha; else do not control.	4,037	71

economic potential of early season weed information was explored in this paper as a herbicide substitute in cabbage weed control with promising results. However, much more empirical work is needed to provide a basis for focusing research activities and developing weed-management alternatives.

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Appendix

Derivation of equations (5), (6), and (7) in the text is indicated below. Notation is the same as in the text.

$$
\begin{aligned}
E[\Pi] &= E[\Pi \mid W_0 \leq W_T] \cdot Pr[W_0 \leq W_T] \\
&\quad + E[\Pi \mid W_0 > W_T] \cdot Pr[W_0 > W_T] \\
&= \int_{-\infty}^{W_T} (p_y Y_0 - p_y \alpha W_0)(1/(\sqrt{2\pi}\,\sigma)) \\
&\quad \exp((-1/(2\sigma^2))(W_0 - \mu)^2) d W_0 \\
&\quad + \int_{W_T}^{\infty} (p_y Y_0 - p_y \alpha W_0 \exp(-\beta h_T) - v h_T - f) \\
&\quad (1/(\sqrt{2\pi}\,\sigma)) \exp((-1/(2\sigma^2))(W_0 - \mu)^2) d W_0 \\
&= p_y Y_0 \Phi\left(\frac{W_T - \mu}{\sigma}\right) - p_y \alpha \\
&\quad \int_{-\infty}^{W_T} W_0 (1/(\sqrt{2\pi}\,\sigma)) \exp((-1/(2\sigma^2))(W_0 - \mu)^2) d W_0 \\
&\quad + (p_y Y_0 - v h_T - f) \left[1 - \Phi\left(\frac{W_T - \mu}{\sigma}\right)\right] \\
&\quad - p_y \alpha \exp(-\beta h_T) \int_{W_T}^{\infty} W_0 (1/(\sqrt{2\pi}\,\sigma)) \\
&\quad \exp((-1/(2\sigma^2))(W_0 - \mu)^2) d W_0,
\end{aligned}
$$

which reduces to equation (5) in the text. Differentiation with respect to h_T and W_T gives

$$
\begin{aligned}
\frac{\partial E[\Pi]}{\partial h_T} &= -v\left[1 - \Phi\left(\frac{W_T - \mu}{\sigma}\right)\right. \\
&\quad + \beta p_y \alpha \exp(-\beta h_T)\{(\sigma/\sqrt{2\pi}) \exp((-1/(2\sigma^2)) \\
&\quad (W_T - \mu)^2) + \mu \left[1 - \Phi\left(\frac{W_T - \mu}{\sigma}\right)\right]
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{\partial E[\Pi]}{\partial W_T} &= (p_y Y_0 - p_y \alpha W_T)(1/(\sqrt{2\pi}\,\sigma)) \\
&\quad \exp(-(1/(2\sigma^2))(W_T - \mu)^2) \\
&\quad - (p_y Y_0 - p_y \alpha W_T \exp(-\beta h_T) - v h_T - f) \\
&\quad \cdot (1/(\sqrt{2\pi}\,\sigma)) \exp(-(1/(2\sigma^2))(W_T - \mu)^2).
\end{aligned}
$$

Setting derivatives to zero and solving simultaneously gives equations (6) and (7), respectively, in the text.