Proceedings of the 1992 Winter Simulation Conference
ed. J. J. Swain, D. Goldsman, R. C. Crain, and J. R. Wilson

SIMULATING WEED SCOUTING AND WEED CONTROL DECISION MAKING TO EVALUATE SCOUTING PLANS

Lori J. Wiles

Agricultural Engineering Research Center
USDA-ARS
Colorado State University
Fort Collins, Colorado 80523, U.S.A.

Gail G. Wilkerson
Harvey J. Gold

Department of Crop Science
Biomathematics Program-Department of Statistics
North Carolina State University
Raleigh, North Carolina 27695, U.S.A.

ABSTRACT

The weed seedling population in a field must be scouted or sampled to choose the most appropriate postemergence control treatment. The cost-effectiveness of a scouting plan must be evaluated to confidently recommend its use. We conducted simulation experiments to evaluate scouting plans for use with a microcomputer postemergence weed control decision model for soybeans. The following were simulated: the process of scouting, use of the decision model with the scouting information, and the resulting profit from the decision model's recommendation. Simulations were based on data from 14 North Carolina soybean fields. While scouting is recognized as valuable for determining if control is required, our results highlight the value of scouting for choosing among treatments when the need for control is obvious. Our results also indicate that the scouting plan recommended for use with the decision model is cost-effective. However, some risk averse decision makers may wish to scout more intensively. Use of simulation to evaluate weed scouting plans is currently constrained by the lack of data on the cost of scouting and the distribution of weeds within fields.

1 INTRODUCTION

This paper describes simulation experiments to evaluate scouting plans for use with a decision model for postemergence weed control in soybeans. Use of postemergence herbicides in place of preemergence, soil-applied treatments is being encouraged as a strategy to reduce the risk of contamination of groundwater and surface water. Preemergence treatments are applied to the soil before weeds emerge while postemergence treatments are applied to emerged weed seedlings. Consequently, the population may be observed before postemergence treatment to determine if fields, or portions of fields, may be left untreated and to match treatment to the mix of weeds present. Since postemergence treatments are applied to emerged weeds rather than the soil, less chemical may reach the soil. Overall herbicide use may be reduced as well because many of the new postemergence chemicals are very active and adequate control may be achieved with small amounts.

Microcomputer decision software is available for on-farm help in choosing postemergence weed control for some crops and more models are being developed (Mortensen and Coble, 1991). To use most of these decision models, the density of each weed species present in a field must be estimated by "scouting" or sampling the weed population. Since counting and identifying weeds can be time consuming and expensive, just a small portion of the field is examined. The procedure used to obtain these density estimates will influence their accuracy and, ultimately, the quality of the recommendation generated by the decision model (Ives and Moon, 1987). A robust, cost-effective procedure or scouting plan for obtaining these density estimates is needed.

A scouting plan outlines how to collect information about a pest population in a field in order to make a control decision (Ives and Moon, 1987; Southwood, 1976). When weed density by species must be estimated to choose a postemergence weed control strategy, the scouting plan specifies the size and shape of the quadrats (sample units) in which weeds are to be identified and counted, the number of quadrats to be examined (sampling intensity) and the method for selecting the location of the quadrats within the field (sampling strategy).

A scouting plan is designed to achieve a balance between the cost of scouting and the value of the information obtained (Ives and Moon, 1987; Southwood, 1976). The information is valuable from the perspective of preventing mistakes in selecting the most appropriate control treatment and thereby preventing unnecessary herbicide use or yield loss. The scouting plan should specify the most cost-effective method of collecting the required information and the amount of information that should be collected. Just enough information should be collected so that the cost of collecting any additional information would exceed the value of that information. The optimal design for a scouting plan is influenced by the cost of scouting, the sensitivity of the recommendation to the scouting information, and the characteristic spatial distribution of the pest (Ives and Moon, 1987; Southwood, 1976).

Our objectives for this paper are to 1) discuss the advantages of using simulation to design weed scouting plans, 2) summarize our simulation experiments for evaluating weed scouting plans for a particular postemergence weed control decision model, and 3) highlight some challenges in evaluating weed scouting plans with simulation.

2 THE ADVANTAGES OF SIMULATION EXPERIMENTS FOR EVALUATING WEED SCOUTING PLANS

Currently, most weed scouting is intuitive and unstructured. In contrast, there are numerous examples of insect scouting plans in use which have been evaluated in simulation experiments or analytically derived from a statistical description of the insect's characteristic spatial distribution. Unfortunately, weed scouting involves problems which are not encountered with insects. Insect control decisions are usually a choice between one or two potential treatments for control of a single species. The spatial distribution of the insect may be fairly consistent and easy to describe. Postemergence weed control decisions commonly involve choosing among many potential treatments for control of a mix of weed species. The spatial distribution of these mixed weed populations may be difficult to characterize (Wiles et al., 1992a). The complexities preclude analytical and statistical approaches to designing scouting plans but can be readily included in a simulation.

Simulation has several advantages over testing weed scouting plans in actual fields. In the field, there is a limited period of time during which plans can be tested in a single field if the weeds are to be controlled. With simulation, the field is always available; candidate scouting plans do not have to be identified before going to the field and results with one plan can guide development of additional plans. In addition, there is more complete information about simulated fields than real fields. The information obtained according to different plans can be compared against "perfect knowledge" of the weed population rather than just the information obtained using other scouting plans. The profit and/or yield with the recommendation from each scouting plan can be simulated and compared. A real field may be treated only once.

3 SIMULATION EXPERIMENTS TO EVALUATE SCOUTING PLANS FOR HERB DECISIONS

HERB is a commercially available decision model for postemergence weed control in soybeans (Wilkerson, Modena, and Coble, 1991). To use the program, the average density of each weed species present in the field must be estimated. A scouting plan for obtaining these estimates is outlined in the user's guide for the model (Wilkerson, Modena, and Coble, 1988). The quadrat size is 100 square feet. The sampling intensity is one randomly selected quadrat per acre with a minimum of ten quadrats observed in any field. The weed seedlings within a quadrat should be identified and counted by species. We evaluated this recommended scouting plan and variations of it in our simulation experiments.

A realistic model of the spatial distribution of weeds within a field is needed to accurately simulate the information obtained by scouting and the yield loss from uncontrolled weeds. The weed populations in our simulation experiments were based on extensive sampling of the populations in 14 North Carolina soybean fields (Wiles et al., 1992a). An empirical joint distribution for quadrat counts by species was constructed from the field observations (Law and Kelton, 1982). This empirical joint distribution was assumed to accurately represent the composition and distribution of the population in the field.

Each simulation tested a plan in a specified field and involved four steps (Figure 1): 1) identifying the optimal action for the field (**OPTACT**), 2) scouting, 3) generating the HERB recommendation based on the scouting information (**SCTACT**), and 4) evaluating the quality of the generated recommendation. The optimal decision (**OPTACT**, step 1) is the treatment that would be recommended with "perfect knowledge" of the weed population. For this step, a model of treatment efficacy in response to environmental conditions and the yield loss from remaining weeds was constructed using the logic of HERB. The use of all treatments in a field was simulated using this model and the treatment which maximized profit was selected as **OPTACT**. Scouting (step 2) was simulated by sampling with replacement from the empirical joint distribution constructed for that field (Efron, 1982). The number of samples drawn varied with the sampling intensity of the scouting plan. The average density of each species in the sample was calculated and these densities were used to generate a recommendation with the decision model (SCTACT, step 3).

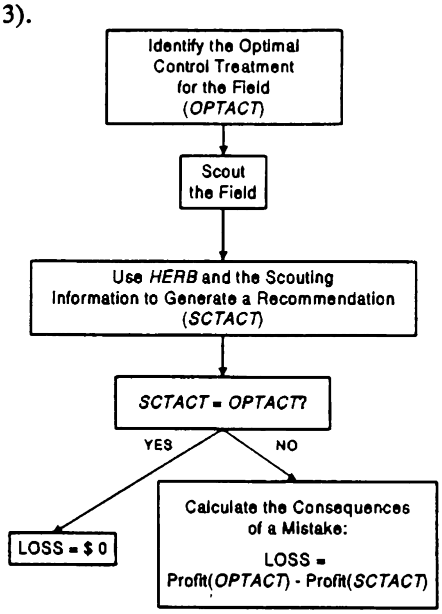

Figure 1: Flow Chart of the Steps in a Simulation

The decision analytic concept of *loss* was our measure of the quality of the generated recommendation (step 4) (Anderson, Dillon, and Hardaker, 1977; Gold, 1989). The *loss* was calculated as the profit expected with OPTACT, the optimal treatment, minus the profit expected with SCTACT. The model constructed for step 1 was used to determine both profits. *Loss* reflects the decision maker's perspective on the accuracy of scouting: inaccurate density estimates are a concern only if the inaccuracy leads to a mistake in choosing the optimal treatment. If the recommendation based on the scouting information was the optimal action (SCTACT = OPTACT), then the loss was \$0. If the recommendation was another treatment (SCTACT ≠ OPTACT), then the loss was a value greater than \$0 with larger values indicating more serious mistakes.

Since environmental conditions influence the control expected with a herbicide treatment, each plan was simulated for every combination of a field and six sets of environmental conditions. Since all the scouting plans involved random selection of sample units, simulation of a scouting plan for a field/environmental conditions combination was replicated. Crop selling price and herbicide and application costs were not varied in the simulations. In all, a plan was simulated 6300 times (14 fields x 75 replications x 6 sets of environmental conditions).

4 RESULTS

Our results for the recommended scouting plan, shown as box plots (Tukey, 1977) by field, indicate that scouting according to the recommended plan is cost-effective (Figure 2). For all fields except 6 and 9, the median of the distribution of losses was zero. That is, in at least 50% of the simulations for all fields except 6 and 9, the optimal action was selected based on the information obtained by scouting (OPTACT = SCTACT). Further, the optimal action was selected based on the scouting information in at least 75% of the simulations for fields 10 and 14. The average loss in profit with this plan was \$7.78 field^{-1}. However, the largest loss was nearly \$200 (field 7). Decision makers vary in their attitude towards risk-taking (Anderson, Dillon, and Hardaker, 1977). Consequently, some risk averse decision makers might prefer a more intensive scouting plan than the recommended plan. Observing additional quadrats would be insurance against the rare, but expensive mistakes.

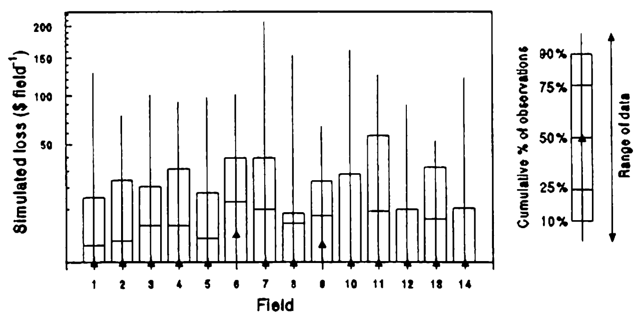

Figure 2: Box Plots by Field for the Distribution of Losses Simulated for Scouting According to the Recommended Plan

Growers are customarily advised to carefully scout when the population in the field is so low that it is not obvious whether the benefit from treatment will exceed the cost. Less emphasis is generally placed on scouting when the need for control is obvious. In our simulations, however, scouting was also shown to be important for matching treatment to the composition of the population (moderate to high total weed density), not just for deciding if control is needed (low total weed density) (Figure 3). In fact, the most expensive mistake was the result of choosing an inappropriate treatment. Choosing the wrong herbicide can be expensive and scouting may help prevent this type of mistake.

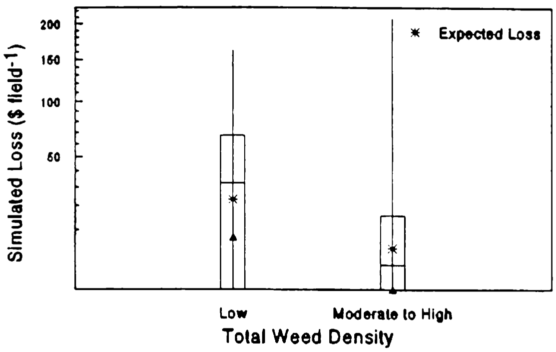

Figure 3: Box Plots by Total Weed Density for the Distribution of Losses Simulated for Scouting According to the Recommended Plan

Besides the recommended scouting plan, we simulated plans with different sampling intensities (the number of quadrats observed per acre). Lack of data on the costs of scouting prevented us from recommending a sampling intensity based on our simulation results. However, using a rough cost estimate we can illustrate one approach for identifying the appropriate sampling intensity. More intensive scouting is only worthwhile if the value of the additional information is expected to be greater than its cost. Loss, as a measure of the quality of decision making, quantifies the value of scouting. When additional sampling is valuable, the average or expected loss should decrease. Increasing the sampling intensity should be recommended only if the decrease in loss is greater than the cost of the additional scouting. Assuming that the average cost of counting and identifying weeds in a quadrat is $0.40 (G. Oliver and A. York, Department of Crop Science, North Carolina State University, personal communication), observation of two quadrats per acre would be recommended. (Table 1).

Expected loss as a criterion for evaluating sampling intensity is consistent with a risk neutral attitude of the decision maker. There are other approaches for examining the simulation results when the risk attitude of the decision maker may be a concern. For example, the cost of scouting may be added to the loss from a simulation to create a distribution of "total loss." Then that distribution may be analyzed by stochastic dominance techniques (Anderson, Dillon, and Hardaker, 1977) to suggest an optimal sampling intensity consistent with specified risk attitudes.

Table 1. Expected losses simulated with different sampling intensities.

Sampling Intensity (quadrats acre^{-1})	Expected Loss ($ field^{-1})	Value of Increase in Sampling Intensity ($ field^{-1})	Cost of Increase in Sampling Intensity ($ field^{-1})
1*	$7.78	-	-
2	4.19	3.59	2.80
3	2.81	4.97	5.60

*Sampling intensity of scouting plan recommended for use with HERB.

5 SUMMARY, CONCLUSIONS, AND CHALLENGES

Concern for the profitability and environmental impacts of crop production makes avoiding mistakes in herbicide use imperative. We expect that well-designed scouting plans will become an important type of tool for making appropriate weed control decisions, whether or not a decision model is used. We have demonstrated a simulation methodology for evaluating weed scouting plans. This methodology has advantages over testing of weed scouting plans in actual fields and it may be more feasible than theoretical development of scouting plans for mixed populations. However, we need more data and more sophisticated models of weed distribution within fields to fully use this methodology.

Meaningful simulation output relies on realistic inputs. We know little about the costs of weed scouting or the spatial distribution of weeds within fields. The limited data indicates that spatial distribution is apparently highly variable between fields and weed species (Wiles et al., 1992a). Because of this natural variability, many fields will have to be studied to characterize weed distribution. This lack of data is being addressed by several research groups.

We need a more sophisticated, two dimensional model of weed distribution within a field. When weed distribution within a field is described with a statistical distribution, only scouting plans which use random selection of the quadrats can be simulated. The distribution of weeds within fields is best characterized with a negative binomial distribution; apparently weeds occur in patches (Marshall, 1988; Wiles et al., 1992a). In this case, more structured selection of quadrats, such as stratified random sampling, may lead to better density estimates than random sampling (Southwood, 1976). It may soon be possible to accurately map the weed population in a field using geostatistical analysis (Johnson et al., 1991; Halstead, Gross, and Renner, 1990). More structured selection of quadrats can be simulated if weed distribution is characterized with a geostatistical map instead of an empirical joint distribution.

Proposed scouting plans must be evaluated against actual scouting practices. Currently, a scout may randomly walk through a field until a patch is observed and then carefully examine or randomly sample the patch to estimate its composition. Simulating this type of scouting will be challenging and a map of the weed distribution will be needed. Combining simulation and field experimentation is an alternative. In place of simulating current scouting practices, we may have growers or consultants scout an actual field and recommend treatment. Then the weed population in that field would be accurately mapped to conduct the usual simulation of proposed scouting plans along with simulation of the results of the recommended treatment. With an estimate of the cost of the actual scouting practices, the practices may then be compared to the plans which are only simulated.

The methodology we have outlined should prove useful in exploring other aspects of weed management decision making. It may be adapted to scouting for postemergence decisions in other crops if a decision model exists or if the usual decision process can be modeled. Decision models for soil-applied treatments are being developed and tested (Mortensen and Coble, 1991). These models generate recommendations from weed seed bank samples which are assumed to reasonably represent the seed bank in the field. The methodology may be used to determine the best plan for sampling the seed bank. Finally, the methodology may be adapted to evaluate alternative decision models. In this case, one scouting plan would be used in step 2, but different models could be substituted in step 3. This approach has been used to evaluate decision models with alternative assumptions about the yield loss caused by weeds (Wiles et al., 1992b) and a decision model which accounts for the uncertainty of weed density because density estimates are obtained by scouting (Wiles, Wilkerson, and Gold, 1992).

ACKNOWLEDGMENTS

G. W. Oliver and Dr. A. C. York, Department of Crop Science, North Carolina State University, supplied the weed distribution data which was used in the simulation experiments.

REFERENCES

Anderson, J. R., J. L. Dillon, and J. B. Hardaker. 1977. *Agricultural Decision Analysis.* Iowa State University Press, Ames, IA.

Efron, B. 1982. *The jackknife, the bootstrap and Other Resampling Plans.* Philadelphia: Society for Industrial and Applied Mathematics.

Gold, H. J. 1989. Decision analytic modeling for plant disease control. In *Plant Disease Epidemiology, 2,* ed. K. J. Leonard and W. E. Fry, 84-124. New York: Macmillan Company.

Halstead, S. A., K. L. Gross, and K. A. Renner. 1990. Geostatistical analysis of the weed seed bank. *Proceedings of the North Central Weed Science Society* 45:123-124.

Ives, P. M. and R. D. Moon. 1987. Sampling theory and protocol for insects. In *Crop Loss Assessment and Pest Management,* ed. P. S. Teng, 49-75. St. Paul: APS Press.

Johnson, G. A., D. A. Mortensen, L. J. Young, and A. R. Martin. 1991. Preliminary results of weed distribution studies in Nebraska. *Proceedings of the North Central Weed Science Society* 46:111-112.

Law, A. M. and W. D. Kelton. 1982. *Simulation Modeling and Analysis.* New York: McGraw-Hill Book Co.

Marshall, E. J. P. 1988. Field-scale estimates of grass weed populations in arable land. *Weed Research* 28:191-198.

Mortensen, D. A. and H. D. Coble. 1991. Two approaches to weed control decision-aid software. *Weed Technology* 5:445-452.

Southwood, T. R. E. 1976. *Ecological methods with particular reference to the study of insect populations.* 2nd ed. New York: John Wiley and Sons.

Tukey, J. W. 1977. *Exploratory Data Analysis.* Reading, Massachusetts: Addison-Wesley Publishing Company.

Wiles, L. J., G. G. Wilkerson, and H. J. Gold. 1992. The value of information about weed distribution for improving postemergence control decisions. *Crop Protection* (in press).

Wiles, L. J., G. W. Oliver, A. C. York, H. J. Gold, and G. G. Wilkerson. 1992a. The spatial distribution of broadleaf weeds in North Carolina Soybean (*Glycine max*) fields. *Weed Science* (in press).

Wiles, L. J., G. G. Wilkerson, H. J. Gold, and H. D. Coble. 1992b. Modeling weed distribution for improved postemergence control decisions. *Weed*

Science (in press).

Wilkerson, G. G., S. A. Modena, and H. D. Coble. 1988. *HERB V2.0 Herbicide decision model for postemergence weed control in soybean user's manual.* Bulletin 113, Crop Science Department, North Carolina State University, Raleigh, North Carolina.

Wilkerson, G. G., S. A. Modena, and H. D. Coble. 1991. HERB: Decision model for postemergence weed control in soybeans. *Agronomy Journal* 83:413-417.

AUTHOR BIOGRAPHIES

LORI J. WILES is a weed scientist with the Water Management Research Unit, USDA-ARS at Fort Collins, Colorado, and faculty affiliate of the Department of Plant Pathology and Weed Science, Colorado State University. Her research focuses on modeling the biology and economics of weed control to identify environmentally sound and economically efficient weed management systems. Her current projects include developing a decision model for weed control in dry beans and designing scouting plans for use with a weed management decision aid for irrigated corn production.

GAIL G. WILKERSON is an Associate Professor of Crop Science and Statistics (Biomathematics Program) at North Carolina State University. Her research interests include development of crop and pest simulation models and computerized decision aids for crop management. She is an associate editor for *Agronomy Journal.*

HARVEY J. GOLD is a Professor in the Biomathematics Graduate Program, Department of Statistics, at North Carolina State University, and is also a member of the Operations Research Faculty. He is an active member of the Decision Analysis interest group of ORSA. His research interests deal with applications of decision analysis to management of environmental and agricultural systems.