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Basic mathematical programming applications to weed control in forestry

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BASIC MATHEMATICAL PROGRAMMING APPLICATIONS IN WEED CONTROL IN FORESTS.

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ABSTRACT

Many studies document herbicide performance for weed and hardwood control in forestry. Few studies, however, attempt to develop optimal application strategies. Stand-level optimization is presently limited due to lack of growth and yield information. Forest-level optimization is possible, however, and has great potential to aid in planning forestry weed control programs.

INTRODUCTION

Forest weed control involves interrelated decisions over time. Forest managers must decide what herbicides to use, and how, when and where they should be applied. Weed control costs that occur early in the life of a stand are not recovered until timber is sold. Early weed control must therefore be planned and performed efficiently to maximize returns or minimize costs to forest landowners.

Forest management tools currently exist that can aid in planning herbicide treatments. Mathematical programming techniques are widely known and have been used to solve many types of complex forestry problems. Applications to harvest scheduling, thinning and log bucking, for example, are among those reviewed by Dykstra (1984). Weed control in forests is an area with great potential benefit from mathematical programming. While numerous studies have reported the effects of herbicides in forestry (e.g., Nelson et al. 1981, 1985, and Zutter et al. 1986), few studies have optimized herbicide application decisions.

OPTIMAL WEED CONTROL PROGRAMS

Mathematical programming and other optimization methods involve two distinct steps, model formulation and model solution. Formulation involves stating a specific problem or type of problem in a format that can be analyzed. Solution methods, of course, are applied to models after they have been formulated.

We formulate two types of herbicide application problems, stand-level and forest-level. Forestry questions and management techniques for answering them were summarized at stand and forest levels by Hann and Brodie (1980). Stand-level decisions involve how herbicide or other silvicultural treatments are applied to individual stands, e.g., "What application rate of herbicide XYZ will yield the highest rate of return per acre for weed control in loblolly pine plantations?" The question does not consider the entire forest, merely what is best for one stand. Forest-level models are designed for decisions concerning all stands in a forest, e.g., "What herbicide application program is best for all stands in the forest under a total cost budget?"

Weed Control at the Stand-Level

Weed control options for individual stands may be evaluated in several ways. One approach is to formulate herbicide decisions as a dynamic programming problem. For various site/species/age conditions in the South, what weed control strategy will maximize per acre yields or returns? The question should be considered in combination with other stand management decisions, since herbicide applications at a young age influence yields from thinning and final harvest. Dynamic programming is an optimization technique that considers interrelationships simultaneously. A general forward recursion formulation for thinning and final harvest decisions was presented by Brodie and Haight (1985):

$$f_t(S_1,\ldots,S_n) = \max_{\{s_1,\ldots,s_n\}} \frac{P_d T - L_{d,v} T - C}{(1+i)^t} + f_{t-x}(s_1,\ldots,s_n)$$

Where the optimal value function $f_t(S_1,\ldots,S_n)$ is the best present net worth decision set from regeneration to age t and state $(S_1,\ldots,S_n)$. State variables $(S_1,\ldots S_n)$ characterize the stand at each age, P_d is the per unit value of harvested material of average diameter d, T is the volume removed in thinning or final harvest, $L_{d,v}$ is the per unit logging cost for a harvest of volume v and diameter d, C is any fixed harvest cost, i is the discount rate, and $s_1,\ldots,s_n$ is the set of all feasible states at age t-x from which current levels of the states $S_1,\ldots S_n$ can be achieved. Brodie and Haight (1985) also define t as the dynamic programming stage variable, to be incremented by x, the number of years between harvests. Although they did not discuss herbicide applications, Brodie and Haight incorporated planting density and precommercial density control, fertilization intensity, and type of thinning. Decision models for stand-level herbicide optimization are therefore not limited by potential decision methods, but are limited at present by lack of stand development growth and yield models that include potential herbicide use.

Weed Control at the Forest-Level

Forest-level weed control options may be evaluated with linear programming and extensions such as goal or separable programming. An example might involve a timber industry with thousands of acres comprised of hundreds of different stands. In any given year or planning period, the company has weed control options on some of the stands, and must choose the best policy to treat the areas subject to budget, time, environmental or other constraints.

$$\underset{\{X_{ij}\}}{\text{Minimize}}\ C = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

> Choose the X_{ij}, numbers of acres treated with different herbicides (i=1,...,m) and methods of application (j=1,...,n), that minimizes total costs (C). C_{ij} is the per acre cost of using herbicide i and method j. Another index could be used to distinguish different stands.

Subject to:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} X_{ij} \leq T$$

Where t_{ij} is the time necessary to treat one acre with herbicide i, method j, and T is the application time available. Such constraints may also reflect different time limits for different herbicides and application methods.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} k_{ij} X_{ij} \leq K$$

Where k_{ij} is new capital expenditures to treat one acre and K is total capital available.

$$\sum_{j=1}^{n} X_{ij} \geq A_i \quad (i=1,\ldots,m)$$

At least A_i acres are to be treated with herbicide i.

$$\sum_{i=1}^{m} X_{ij} \geq A_j$$

At least A_j acres are to be treated with application method j.

Other objectives and constraints, of course, may be formulated. The general linear programming model is adaptable to nearly any forest-level weed control situation. Once formulated, solutions may be obtained from any one of several linear programming computer packages.

DISCUSSION

Computers and recent growth and yield models have allowed relatively sophisticated analyses of thinning and final harvest decisions. One growth and yield model, HDWD (Burkhart 1984), allows hardwood competition to be specified, and has promise for herbicide evaluation. Herbicide applications in general, however, have not been incorporated in growth and yield models since most application studies began fairly recently. Stand-level analyses of weed control are therefore limited to discrete evaluation. Limits are due to information needs, however, rather than appropriate optimization methods.

At the forest level, there is great potential for planning weed control programs. Mathematical programming methods are adaptable, and formulations are very straightforward. Linear programming is a natural point of beginning for such analyses. Computer packages are widely available, and models can be solved on microcomputers at very little cost. Other mathematical programming methods are also frequently applied in forestry, and may be adapted to weed control planning. Model formulations may thus involve nonlinear relationships or integer variables, for example.

Forest-level analyses are most appropriate for public agencies or private corporations with annual or periodic weed control needs. Because of their scale, such programs may involve very large expenditures. Optimization methods are available which can help ensure that weed control programs accomplish corporate or agency goals as efficiently as possible.

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