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Economic analysis of herbicide control of leafy spurge (*Euphorbia esula* L.) in rangeland

DEAN A. BANGSUND, JAY A. LEITCH, and F. LARRY LEISTRITZ

Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota, 58105.

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Editor's note: Appendices are not included.)

Agricultural Economics Report No. 342 January 1996

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Dean A. Bangsund
Jay A. Leitch
F. Larry Leistritz

Department of Agricultural Economics
Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota, 58105

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Drs. Rodney Lym and Calvin Messersmith, Department of Plant Sciences, North Dakota State University, for their assistance throughout the study.

Thanks are also extended to Carol Jensen for document preparation, Rita Hamm for editorial assistance, JoAnn Thompson for cover design, and to Roger Johnson, Bill Nelson, Larry Stearns, Tim Petry, Kevin Sedivac, Barry Brissman, and Steven Hirsch for manuscript review.

Financial support was provided by the Animal and Plant Health Inspection Service through the Cooperative State Research Service of the U.S. Department of Agriculture. We express our appreciation to these organizations for their support.

The authors assume responsibility for any errors of omission, logic, or otherwise.

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HIGHLIGHTS

*Leafy spurge (*Euphorbia esula *L.), a widely established exotic, noxious, perennial weed is a major threat to the viability of commercial grazing and to the beneficial outputs of wildlands in the Upper Great Plains. Herbicide treatments for leafy spurge are usually based on indicators of physical control, rather than economic criteria. The way leafy spurge spreads, the host of economic variables affecting individual land managers, the difficulty in quantifying benefits from control over time, the high cost of control treatments, and the potential economy-wide benefits from control, all support (1) the identification of economical control methods and (2) an understanding of the economic factors influencing long-term treatment decisions.*

A deterministic, simulation model was developed that included the benefits of recapturing grazing outputs from current infestations, the benefits of maintaining existing grazing outputs by preventing patch expansion, and the costs of herbicide treatment programs. The economic viability of various treatment programs was evaluated by comparing discounted annual costs to discounted annual returns over a 20-year period.

Herbicide control of leafy spurge was limited to two strategies: (1) treating the entire infestation or (2) treating only the perimeter of the infestation. Control strategies were evaluated by (1) comparing treatment costs with treatment returns (i.e., classic cost/returns approach) and (2) comparing losses with herbicides to losses without control (least-loss, cost minimization, or cost-effective approach).

Fifteen treatment programs, comprised of various herbicides (i.e., picloram, dicamba, 2,4-D ester and amine, and glyphosate), application rates, and frequencies were evaluated. Plausible scenarios were developed to (1) evaluate the long-term economic feasibility of herbicide treatments in a range of situations and (2) assess the influence of various economic and physical factors. All treatment scenarios were evaluated at carrying capacities that represented a likely range of productivity for most grazing land infested with leafy spurge in the Northern Plains.

A base scenario, developed as a typical treatment situation and used as a reference point for evaluating other treatment situations, was comprised of a one-acre leafy spurge infestation, grazing valued at $15.50/AUM, patch expanding at 2.0 radial feet/year, and patch cover had reached maximum leafy spurge density. Seven of the 15 treatments, evaluated for spraying the entire infestation, generated positive returns at carrying capacities greater than 0.65 AUMs/acre; however, the most economical treatment broke even at only 0.50 AUMs/acre. Four treatments had least-loss carrying capacities (minimum carrying capacity needed for the treatment to result in less loss than no treatment) at or near 0.30 AUMs/acre. Of the six perimeter treatment programs evaluated, two had positive returns at carrying capacities as low as 0.35 AUMs/acre and three had least-loss carrying capacities down to 0.20 AUMs/acre.

Economic and physical factors evaluated for treating entire infestations included infestation size, spread rate, herbicide cost, grazing value, control level, patch density, and treatment longevity. The physical factors having the greatest economic influence included infestation size, spread rate, land productivity, and structure (i.e., frequency and rates) of herbicide treatments. As could be expected, economic variables such as grazing values and herbicide costs also had direct impacts on the economic feasibility of control.

Generally, most treatment programs evaluated provided positive discounted net returns over 20 years when applied to small (one-half acre or less) infestations. However, few treatments, even under favorable conditions, provided positive returns as infestations approached 50 acres, although some treatments provided attractive economic alternatives to no control with large infestations. Perimeter treatments, however, were economical with large infestations, even in situations when broadcast treatments would not be recommended.

The confidence of results in this study could be improved with refined information on grazing recovery and spread characteristics. Current herbicide treatments cannot provide long-term positive returns from leafy spurge control in all rangeland conditions found in the Northern Plains. Although the results should be viewed with some caution, long-term control of leafy spurge with herbicides provides attractive economic alternatives to no treatment. As alternatives to using herbicides to control leafy spurge are sought, the long-term economic viability of those methods should be assessed.

Economic Analysis of Herbicide Control of Leafy Spurge in Rangeland

Dean A. Bangsund, Jay A. Leitch, and F. Larry Leistritz*

INTRODUCTION

Leafy spurge (*Euphorbia esula* L.) was first introduced in North America in the 19th century, was found in North Dakota in 1909, and was considered a threat to rangeland in the Great Plains as early as 1933 (Hanson and Rudd 1933). The weed currently infests large amounts of untilled land in the Plains and Mountain states. Cultivation will control leafy spurge, but is not a feasible control method in rangeland and other untilled land. Once established on untilled land, the weed spreads quickly, displacing native vegetation. Leafy spurge has unique characteristics that give it a competitive advantage over most native plants and provide it with natural defenses against cattle grazing. Leafy spurge can create serious economic losses for land owners and ranchers.

Current herbicide technologies are ineffective in eradicating established infestations. Control of the plant can be approached through chemical and/or biological strategies. However, long-term control of leafy spurge with herbicides is difficult because it resists chemical agents and sustains itself against repeated treatments, and biological controls, while showing promise, are still being developed and lack wide-spread adoption. Nonetheless, herbicide treatments remain the cornerstone of control efforts. Control with herbicides, by the very nature of the ineffectiveness of current agents, is a long-term management strategy. However, the most effective herbicides are expensive and the benefits of treatments are difficult to quantify, leaving many questions unanswered about the long-term economic feasibility of herbicide control.

Objectives

The purpose of this study is to provide an economic analysis of conventional herbicide control of leafy spurge. Specific objectives include

1) estimate benefits of leafy spurge control,
2) estimate costs of leafy spurge control,
3) identify factors affecting net returns from leafy spurge control, and
4) evaluate the long-term economic viability of control.

Background

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*Research associate, professor, and professor, respectively, Department of Agricultural Economics, North Dakota State University, Fargo.

Leafy spurge (*Euphorbia esula* L.), a perennial weed native to Europe and Asia, was introduced to North America in the 19th century. It first appeared in the Upper Midwest in North Dakota in 1909. By 1933, the weed was established in Minnesota, North Dakota, Montana, and several eastern states (Hanson and Rudd 1933); since then it has continued to spread to several midwestern states. Wide-spread infestations of leafy spurge can now be found in North Dakota, South Dakota, Montana, Minnesota, Nebraska, Colorado, Idaho, and Wyoming. The four-state region of Montana, North Dakota, South Dakota, and Wyoming alone is estimated to have 657,435 hectares (1,624,500 acres) of leafy spurge infested land. Leafy spurge infestations, until recently, were doubling about every ten years. However, the rate of infestation has slowed due largely to aggressive treatment efforts. About 6 percent of North Dakota's untilled land remains infested.

The plant is found primarily in nontilled agricultural land (pasture, rangeland, hayland, and idle cropland) and in other nontilled land (road ditches, shelterbelts, wildlife areas, around lakes and along rivers, and in parks). Because leafy spurge exhibits exceptional ability to spread and thrive in a variety of habitats, is hardy, and resists control, it has become a serious problem for farmers, ranchers, park operators, and other land managers. Leafy spurge competes with existing native vegetation for nutrients and moisture (Watson 1985; Belcher and Wilson 1989; Messersmith et al. 1985), eventually creating a near monoculture. This ability poses serious threats to the outputs of wildland and grazing land. Dense stands of leafy spurge are a less desirable habitat for indigenous wildlife and directly reduce grazing capacity for most domestic livestock.

Research has been conducted to examine the effectiveness of herbicide treatments in controlling leafy spurge (Lym and Messersmith 1994, Messersmith 1989, Lym and Messersmith 1985). Herbicide treatments vary in effectiveness depending on the agent, application rate, timing of application, and age and size of the leafy spurge plant. The effectiveness of herbicides in controlling leafy spurge growth, cost of treatment applications, and value of rangeland production using conventional economic analyses have indicated that the returns from most treatments are less than the costs (Thompson et al. 1990, Messersmith 1989, Lym and Messersmith 1983).

The recognition of this plant's persistent and aggressive nature, combined with current infestation rates in many areas of the Upper Great Plains, has prompted concern over the impact this weed has on area economies and the amount of resources that should be devoted to developing efficient leafy spurge control technologies. These concerns led to analyses of the impact the weed has on local, state, and regional economies.

Leitch et al. (1994) estimated leafy spurge impacts on grazing land and wildland in Montana, North Dakota, South Dakota, and Wyoming to be nearly $130 million annually. Thus, the economic losses from leafy spurge have heightened the awareness of the potentially serious effects of the weed, as well as demonstrating the potential benefits from effective long-term control.

As early as 1933, leafy spurge was recognized as a serious threat to cattle growers' incomes (Hanson and Rudd 1933). The "leafy spurge problem" has continued to be thought of as a range management concern, although the weed currently infests large amounts of nonagricultural land. However, most measurable economic losses from leafy spurge occur on grazing land (92 percent) as opposed to wildland (8 percent) (Leitch et al. 1994). Current impact estimates for leafy spurge infestations suggest the weed has substantial negative effects on local and regional economies.

Recent research efforts to control leafy spurge have focused on developing, expanding, and improving biological agents (insects and plant diseases), due in part to growing environmental concern over chemical use and the apparent ineffectiveness of herbicides to provide economical long-term control. Leafy spurge has been considered a potentially viable candidate for biological control since natural forces hold the plant in check in its native European habitat (Carlson and Littlefield 1983, Moran 1992).

Although biological control has shown promise in combating the weed, the efficacy of wide-spread use of biological control agents remains uncertain. Research is ongoing to answer the remaining questions (e.g., what are the most effective biological agents and the environmental variables most likely to insure their effectiveness?). Although private use of biological agents to control leafy spurge is currently practiced, access to and knowledge of biological control remains limited. In addition, biological control agents are expensive to introduce, raising some of the same long-term economical treatment questions currently surrounding herbicide control. Thus, even though biological control offers promise in the battle against the weed, the cornerstone of current control efforts is still herbicide control.

Because of leafy spurge's growth and spread characteristics and the ineffectiveness of current control technologies, leafy spurge control must be approached as a long-term management problem. Questions remain unanswered about the economic viability of many control treatments. Several factors combine to accentuate the need to identify economically advantageous control methods and to identify economic concerns regarding treatment options under a variety of economic situations. These components include the rate of spread and difficulty in controlling leafy spurge, the number of economic factors affecting individual land managers, the high cost of herbicide treatments, the quantification of control benefits over time, and the potential economy-wide benefits from control.

PROCEDURES

A deterministic, simulation model was developed to evaluate the economics of using herbicides to control leafy spurge. The model was also used to analyze the effects of changes in general inputs, as well as to determine which variables influence the economic feasibility of various control strategies. Economic feasibility compares long-term costs with long-term benefits. Financial feasibility, which generally addresses cash flow issues and financial constraints, was not addressed.

Given an initial leafy spurge infestation, the model predicts leafy spurge spread and the corresponding annual losses in grazing output from that infestation (Figure 1). The effects of herbicide treatments on patch density and spread rates were incorporated. The dynamics of control (i.e., the interaction of changes in density and rate of spread) were based on secondary information and consultation with weed control scientists. The annual difference between treatment expenses and the value of grazing outputs recovered and retained through treatment were discounted over time to provide a long-term perspective for each treatment scenario.

Discounting future costs and benefits facilitates comparisons of events occurring over time. A 4 percent discount rate was used because it represents a reasonable rate for long-term planning, given 1995 conditions. A lower rate would improve the returns relative to the costs of herbicide control, conversely a higher rate would reduce returns relative to costs.

Model Development

Leafy spurge control is a long-term management problem since (1) the weed cannot be eradicated economically with current technology,[1] (2) uncontrolled infestations have detrimental long-term consequences for grazing land, and (3) time lags often exist between treatments and results. The overall framework for the economic analysis was based on evaluating control in near-real situations.

[1]Leafy spurge has been eradicated using tillage activities in combination with fertilization in cropland (Lym and Messersmith 1993). However, the techniques used are not feasible in grazing land situations.

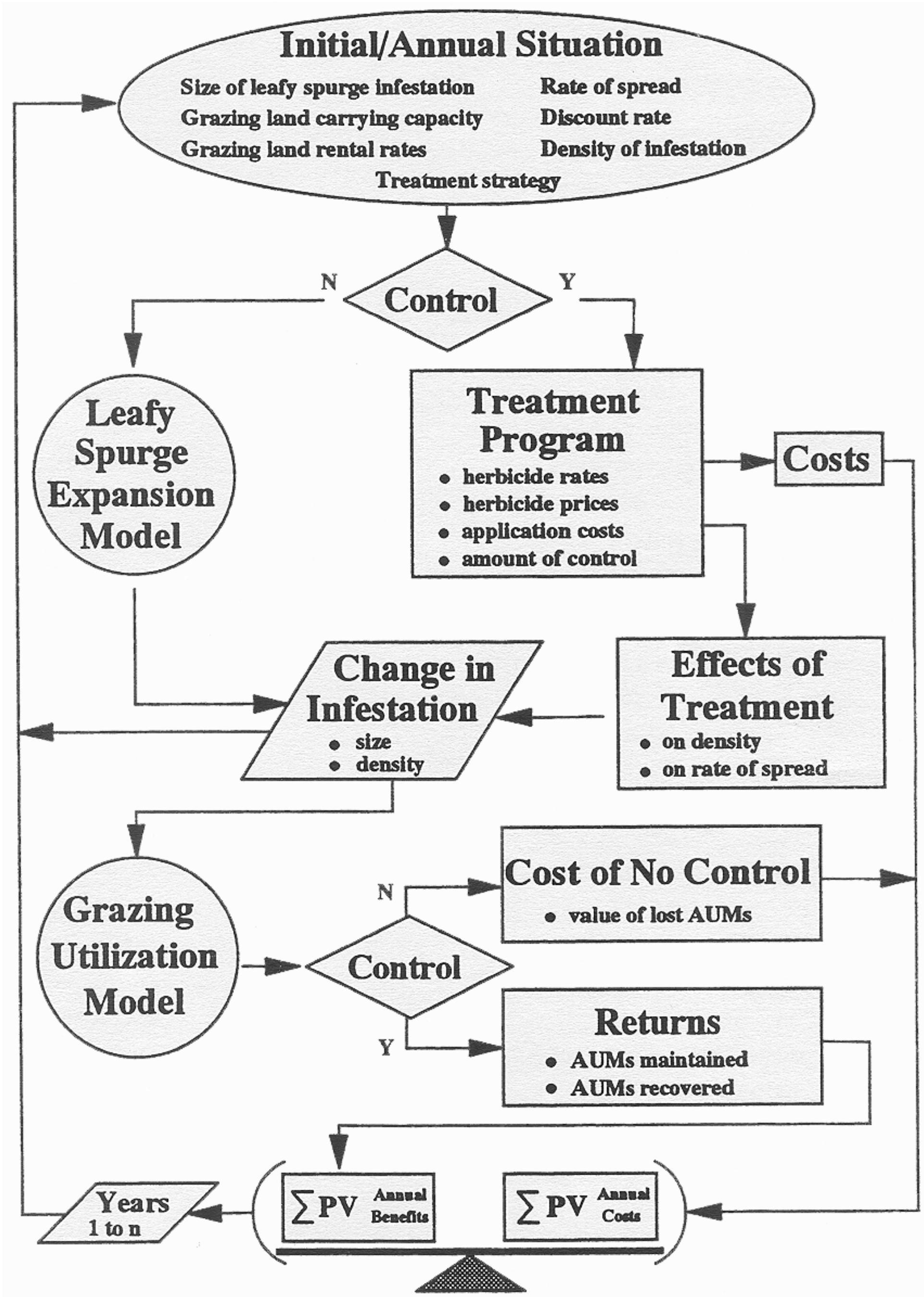

Figure 1. Economic Evaluation Model of Herbicide Control of Leafy Spurge in Rangeland

The model starts with initial values describing the physical and economic characteristics of an infestation. The opportunity cost of no control is measured by estimating the loss of grazing from the initial infestation and the subsequent losses from expansion. The benefits of control include (1) recapturing grazing outputs from current infestations and (2) maintaining existing grazing outputs by preventing patch expansion. The costs of control include material, labor, and equipment expenses. The model estimates the economic viability of control, given information on control effectiveness and costs, by comparing discounted annual costs and returns for up to 20 years.

Leafy spurge control is a multi-year effort due to the plant s biophysical characteristics. Most treatment programs provide control for several years (some up to eight years). Also, since some of the benefits of leafy spurge control include preventing future damage, many control programs do not break even until several years into the future. This study assumed programs that did not break even by the 20th year would not be attractive to landowners.

Many of the model components were adapted from previous work. A leafy spurge growth model was used to estimate infestation sizes over time given various expansion rates (Bangsund et al. 1993). The interaction between lost grazing capacity and infestation densities was estimated from Lym et al. (1993) and Thompson (1990). The functions of control, rate of spread, and density reduction over time, given initial treatment effectiveness, were estimated from Lym et al. (1993) and from consultation with weed scientists.

Two control strategies were considered: (1) treat the entire infestation, or (2) treat only the perimeter of the infestation to prevent expansion. Under the first strategy, the entire infestation is treated to reduce existing infestation densities and also prevent plant spread. The second strategy of preventing patch expansion is an option when the first strategy proves uneconomical. Under this strategy, only the infestation periphery is treated to prevent expansion from lateral root growth (patch expansion results almost entirely from lateral root spread [Best et al. 1980]).

The model was structured to assess control strategies by (1) comparing only treatment costs with treatment returns (i.e., classic economic cost/returns approach) and (2) determining potential overall losses of control versus losses without control (least-loss or cost-effective approach). The first economic analysis considers only treatment benefits and costs. Treatments where cumulative discounted annual returns are greater than cumulative discounted annual costs are economically feasible. In the second approach, treatments that are not economical (i.e., costs greater than returns) may still result in less economic loss than incurred without control. Under those conditions, treatments would be economically advisable, provided better control programs were not available. In the event that current herbicide programs (regardless of the strategy) result in more loss than without control, a "do nothing" strategy or one employing other methods might be optimal.

Model Outputs and Assumptions

Leafy spurge expansion was based on a model adapted from Bangsund et al. (1993). Established leafy spurge patches in the Upper Midwest expand at a rate of about two radial feet annually. However, the rate of annual spread was allowed to change, accounting for possible variations in growth environments. Unless the growth rate was modified, expansion was assumed uninterrupted without constraints from other weed patches, cropland boundaries, water boundaries, roadways, or other natural or man-made obstacles. The area of leafy spurge infestation was used to estimate grazing losses and the size of the treatment area.

Grazing land output is typically measured by livestock carrying capacity. Carrying capacity was assumed to be the highest sustainable stocking rate possible without incurring damage to vegetation or related resources. Carrying capacities are generally measured in animal unit months (AUMs). An AUM is an average amount of forage needed to feed one animal unit (AU) for one month. An AU is typically considered a mature cow weighing approximately 1,000 pounds or an equivalent grazing animal(s) based on an average feed consumption of 26 pounds of dry matter per day (Shaver 1977). Carrying capacities of uninfested land were assumed to remain unchanged during the treatment period.

AUM values were estimated using grazing land rental rates and county-wide carrying capacities (Appendix A). Cash rents represent an analytically attractive measure of the value of grazing since (1) they should closely approximate the contribution of a unit of grazing to a rancher's income under conditions of a competitive market, (2) variations among land tracts or areas should reflect differences in productivity, and (3) they should reflect differences in profitability of livestock production. Rental rates divided by carrying capacities provide market values for AUMs.

Long-term control of leafy spurge with herbicides is difficult because the plant generates regrowth after treatments and can rapidly return to pre-treatment densities. Herbicide rates and prices and application costs were input variables. Treatment area was equivalent to the size of the infestation, except with 'perimeter only' strategies. Annual control costs were based on treatment area and herbicide and application costs.

Regrowth was based on the level of control (Lym et al. 1993). The amount of control from each treatment was an input variable. More effective control (70 percent or greater) results in less regrowth; however, as control drops below 50 percent, regrowth approaches 100 percent. Density of the infestation each year was estimated from initial density, amount of control, and regrowth. The rate of spread (patch expansion) following treatments was based upon the amount of control. Expansion rates were assumed to be unrelated to infestation densities. Spread after treatment, expressed as a percentage of the pretreatment rate, became zero with greater than 50 percent control. Conversely, as control approached zero, the rate of spread increased to 100 percent of the pretreatment rate.

A Grazing Reduction Model (GRM) (Figure 2) was used to estimate grazing use by cattle (percent of uninfested land) within leafy spurge infestations based upon infestation density (Lym et al. 1993). The percentage of grazing use, the land's carrying capacity, and the area of infestation were used to estimate the number of lost AUMs. Correspondingly, the increase in available AUMs resulting from reductions in infestation densities were estimated using the GRM. Additional benefits of control were estimated from the difference in infestation spread following treatment and infestation spread without control. The difference in infestation areas was used with carrying capacity rates and AUM values to estimate the benefit from preventing expansion. The values of AUM retention (preventing spread) and AUM recovery (gain in grazing from reducing infestation density) were summed annually to estimate total returns from control. Benefits less control costs were estimated annually and discounted back to the present to assess the economic viability of a control program.

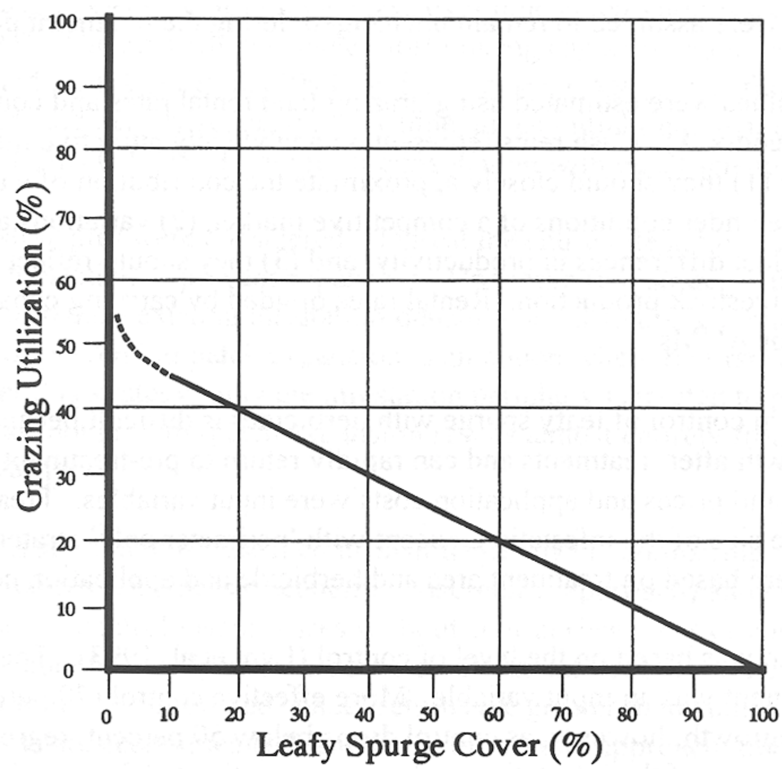

Figure 2. Grazing Reduction Model for Cattle Grazing Within Leafy Spurge Infestations

Source: Lym et al. (1993).

Considering current herbicide control technologies, 100 percent grazing recovery from leafy spurge infestations is unlikely. Thus, even with effective herbicide control some grazing capacity would likely be lost. The difference between uninfested grazing capacity (i.e., 100 percent of the highest sustainable rate) and grazing use after treatment, represented the loss of grazing output with control. The value of this lost grazing capacity was combined with the net value (+/-) of the treatment and compared to the loss of grazing under no control. If the combination of grazing losses/gains from control and uncontrollable losses during treatment were greater than losses under no control, the use of that treatment option would result in greater loss than if no control was adopted.

RESULTS

The factors involved in leafy spurge control decisions can be complex. A host of economic and environmental variables are involved with each treatment decision. The treatment programs analyzed followed commonly accepted recommendations for leafy spurge control in grazing land and followed other general guidelines (i.e., timing of application, environmental restrictions). Not only will actual control and treatment conditions differ from the simulations used in this study, but economic variables specific to individual situations are likely to vary as well. Thus, economic evaluation of general treatment options was conducted across a wide range of environmental and economic values.

Potential Returns to Control

The first step in evaluating the economic feasibility of long-term herbicide treatments was to estimate the potential returns of leafy spurge control (forgone benefits of no treatment). The cost of no control includes lost grazing outputs from the current infestation plus lost outputs from patch expansion. Losses from decreased land values were not included. The present value (PV) of lost grazing outputs from an initial infestation and subsequent expansion was estimated for various carrying capacities, AUM values, and expansion rates (Table 1).

The value of lost grazing outputs from leafy spurge infestations increases with more productive land, higher AUM values, and greater rates of spread. The PV of grazing losses from a one-acre leafy spurge infestation spreading 2 radial feet/year for 20 years on grazing land with a carrying capacity of 0.50 AUMs/acre and a $12 AUM value is $107 (Table 1). The loss increases to $136 when spread changes from 2 to 4 radial feet/year. Likewise, the PV of lost grazing outputs increases from $107 to $169 when AUM values increase from $12 to $19, holding other variables constant. Similarly, if carrying capacity increases from 0.50 to 0.75 AUMs/acre and other factors remain constant, the PV of lost grazing outputs increases from $107 to $160.

Changes in carrying capacities result in proportional changes in losses. Changes in AUM values also result in proportional changes in lost grazing values; however, AUM values fluctuate much less than carrying capacities (Bangsund and Leistritz 1991). Doubling the rate of leafy spurge spread from 2 radial feet per year to 4 feet increases losses only 28 percent over 20 years

(Table 1). Grazing losses from leafy spurge increase as grazing land increases in productivity, as AUMs become more valuable, and as leafy spurge spreads more quickly.

Table 1. Present Value of Forgone Grazing Benefits From a One-Acre Leafy Spurge Infestation Expanding at Various Rates Over 20 Years

	$12 per AUM			$15.50 per AUM			$19 per AUM		
Carrying	Radial Spread ft/yr			Radial Spread ft/yr			Radial Spread ft/yr		
Capacity	2	3	4	2	3	4	2	3	4
AUMs/acre	dollars[a]								
0.20	43	48	55	55	62	70	68	77	86
0.25	53	60	68	69	78	88	84	96	108
0.30	64	73	82	83	94	106	101	115	130
0.35	75	85	95	96	109	123	118	134	151
0.40	85	97	109	110	125	141	135	153	173
0.45	96	109	123	124	141	159	152	172	194
0.50	107	121	136	138	156	176	169	191	216
0.55	117	133	150	152	172	194	186	211	238
0.60	128	145	164	165	187	211	203	230	259
0.65	139	157	177	179	203	229	219	249	281
0.70	149	169	191	193	219	247	236	268	302
0.75	160	181	205	207	234	264	253	287	324
0.80	171	193	218	220	250	282	270	306	346
0.85	181	206	232	234	266	300	287	326	367
0.90	192	218	246	248	281	317	304	345	389
0.95	203	230	259	262	297	335	321	364	410
1.0	213	242	273	275	312	352	338	383	432

[a] Present value of lost benefits discounted at 4 percent.

Herbicide Treatment Costs

The degree of effectiveness of a herbicide depends upon application rate, timing of application, combination with other agents, and age and size of the leafy spurge plant. Herbicides (alone and in combination with others), application rates, and timing of applications have been identified that result in the most effective physical control of leafy spurge (Lym et al. 1993, Messersmith 1989). While average measures of control were used for the herbicide treatments in this analysis, the ability to change control effectiveness was incorporated into the model. Thus, since actual control will likely vary from site to site for any given treatment and vary over time at any given site, reductions from average control were included in the economic evaluation.

The most common herbicides providing effective physical control of leafy spurge include picloram (trade name Tordon®), dicamba (trade name Banvel®), 2,4-D ester and amine, and glyphosate (trade name Landmaster®). Although the number of herbicides most commonly used to control leafy spurge is limited, the possible combinations of agents, rates, and applications are numerous. To more succinctly discuss assessments of treatment programs, several combinations were identified (Table 2).

The cost of controlling leafy spurge with herbicides varies with herbicide prices, application rates, additional tank mixes (surfactants), number of applications per year, and application costs (e.g., fuel, repairs, equipment depreciation, labor). Herbicide prices were reflective of 1995 retail prices in North Dakota (Zollinger 1995). Although some applications may include a surfactant (i.e., an agent to enhance effect of herbicide), treatments evaluated in this study did not contain surfactants or other tank additives. Application costs vary depending upon method of application (e.g., rope wick vs. aerial spray), terrain of infestation, machinery costs (e.g., rented vs. owned equipment, pull sprayer vs. spray coupe), and labor charges. Other factors influencing spray costs include travel to and from treatment areas, equipment efficiency, setup requirements, cleanup, and any additional fencing or livestock handling requirements resulting from treatments.

Swenson (1995) estimated spray application costs average $1.85 to $2.20 per acre, assuming an owned 25-foot pull-type sprayer operating at 70 percent efficiency using 0.13 hours of labor per acre. Estimates of other labor requirements were not available. North Dakota Agricultural Statistics Service (1995) reported an overall average custom rate for broadcast liquid herbicide (cropland and grazing land) with surface vehicles to be $2.48 per acre, while the most common rate was $2.00 per acre. Separate rates for cropland and grazing land applications were not available. An application cost of $2.25 per acre was used in this study.

Table 2. Selected Herbicide Treatments for Leafy Spurge in Grazing Land

Treatment	Herbicides	Application Rate				Control in Years After Last Treatment[a]				
Label		Used Yr 1	Yr 2	Yr 3	Yr 4	First	Second	Third	Fourth	Fifth
-------------		lbs/ac				%				
Pic.25	Picloram	0.25	0.25	0.25	0.25	60	40	20	0	0
Pic.5	Picloram	0.5	0.5	0.5	0.5	95	85	78	60	20
Pic1	Picloram	1.0	0	0	0	75	20	0	0	0
Pic2	Picloram	2.0	0	0	0	95	80	75	25	0
Pic.25+24D	Picloram & 2,4-D	0.25,1	0.25,1	0.25,1	0.25,1	90	85	70	20	0
Pic.5+24D	Picloram & 2,4-D	0.5,1	0.5,1	0.5,1	0.5,1	95	85	70	20	0
Pic.5+24Ds	Picloram & 2,4-D	0.5,1	0.5,1	0.5,1	0,0	90	80	70	20	0
Dic2	Dicamba	2.0	2.0	2.0	2.0	95	85	70	20	0
Dic8	Dicamba	8.0	0	0	0	80	35	0	0	0
Dic2s	Dicamba	2.0	2.0	2.0	0	95	85	70	20	0
24D1[b]	2,4-D	1.0 annually				na				
24D2[b]	2,4-D	2.0 annually				na				
Glph.75	Glyphosate	0.75	0	0	0	80	10	0	0	0
GlPic+24D[c]	Glyphosate & 2,4-D and Picloram & 2,4-D	0.4,0.6	0.25,1	0.25,1	0.25,1	90	85	75	30	0
GlPic+24Ds[c]	Glyphosate & 2,4-D and Picloram & 2,4-D	0.4,0.6	0.25,1	0,0	0,0	90	78	50	20	0

[a] Control in year of application is generally 100 percent of top growth. Control for herbicide treatments is usually stated as the amount of control received in years following treatment.

[b] 24D1 and 24D2 treatments were applied annually.

[c] Glyphosate and 2,4-D applied in year 1 with picloram and 2,4-D applied in years 2 through 4.

SOURCE: Adapted from Lym et al. (1993).

Annualized costs were estimated for several recommended herbicide treatments (Table 3). Herbicide costs ranged from 74 to 99 percent of total treatment expenses. With the exception of annual treatments, overall costs are most sensitive to fluctuations in herbicide application rates and prices. Annualized treatment costs ranged from $4.24 per acre (GlPic+24Ds) to $110.75 per acre (Dic2) (Table 3).

Table 3. Costs of Herbicide Treatments for Control of Leafy Spurge, 1995

Treatment Label	Annualized Costs[a] Herbicides[b]	Application[c]	Total	Years of Effective Control in Treatment
	------------------ dollars per acre	--------------------		
Pic.25	5.71	1.29	7.00	7
Pic.5	8.89	1.00	9.89	9
Pic1	13.33	0.75	14.08	3
Pic2	16.00	0.45	16.45	5
Pic.25+24D	6.63	1.13	7.75	8
Pic.5+24D	11.63	1.13	12.75	8
Pic.5+24Ds	9.96	0.96	10.93	7
Dic2	41.25	1.13	42.38	8
Dic8	110.00	0.75	110.75	3
Dic2s	35.36	0.96	36.32	7
24D1	3.25	2.25	5.50	1
24D2	6.50	2.25	8.75	1
Glph.75	3.58	0.75	4.33	3
GlPic+24D	5.93	1.13	7.05	8
GlPic+24Ds	3.49	0.75	4.24	6

[a] Costs divided by years of control for the treatment. Most treatments incur costs in fewer years than the effective control period.
[b] Herbicide prices based on 1995 retail prices in North Dakota (Zollinger 1995).
[c] Application cost was $2.25 per acre.

Feasibility of Long-term Control

Treatments were approached from two control perspectives and evaluated from two economic perspectives. Control strategies were limited to treating the entire infestation to recover lost grazing or to treating the perimeter to prevent future losses. Economic evaluations were based on cost/return analysis (revenues compared to expenses) and least-loss analysis (treatments result in less loss than without treatment). Within each framework, a baseline scenario was used to analyze the various treatment programs. Environmental and economic variables were changed systematically, creating scenarios from which comparisons against the baseline were made.

Economic and environmental variables for all treatment scenarios were fixed for carrying capacities ranging from 0.20 to 1.0 AUMs/acre, which represents a likely range of productivity for most grazing land infested with leafy spurge in the Northern Plains. Treatment programs were repeated over 20 years each time control reached zero. The base scenario used the following values:

- $15.50 per AUM (the average value of grazing in North Dakota from 1992 through 1994),
- spread at 2.0 radial feet/year (the average rate of leafy spurge spread in the Upper Midwest [Stroh et al. 1990]),
- infestation size of one acre
- dense stands (leafy spurge within patch reached maximum density).

Control Entire Infestation

A common approach to leafy spurge control in rangeland is to treat the entire infestation to reduce stand density and inhibit seed development, thereby simultaneously recovering grazing capacity and stopping the infestation's ability to spread. Considering the multitude of possible treatment scenarios, several assumptions were made as a reasonable situation for treatment comparisons (base scenario). A base scenario provided initial evaluation of each treatment (Table 4). Break-even carrying capacities, the level of land productivity where returns from treatments become positive, ranged from 0.50 AUMs/acre (Glph.75) to 11 AUMs/acre (Dic2). Least-loss carrying capacities, the level of land productivity needed for treatments to result in less loss than without control, were as low as 0.25 AUMs/acre.

Six of 15 treatment programs evaluated showed positive returns at carrying capacities at or above 0.65 AUMs/acre. Initial returns from the dicamba treatments (Dic2, Dic8, Dic2s) suggested there is no economic justification for using those treatments to control leafy spurge at current herbicide prices, and as such, they were not evaluated beyond the base scenario. The most economical treatments were Glph.75 and GlPic+24Ds, both providing positive returns at carrying capacities as low as 0.55 AUMs/acre and generating the greatest returns at higher carrying capacities. No herbicide treatment, under conditions of the base scenario, provided positive returns for carrying capacities under 0.50 AUMs/acre; however, four treatments would result in less loss than no treatment if applied to land with carrying capacities as low as 0.30 AUMs/acre.

Table 4. Long-term Net Returns From Herbicide Control of Leafy Spurge in Rangeland[a]

Carrying Capacity	Herbicide Treatments														
	Pic.25	Pic.5	Pic1	Pic2	Pic.25 +24D	Pic.5 +24D	Pic.5 +24Ds	Dic2	Dic8	Dic2s	24D1	24D2	Glph.75	GlPic +24D	GlPic +24Ds
AUMs/acre	dollars/acre[b]														
0.20	(70)	(125)	(191)	(219)	(91)	(175)	(134)	(672)	(1,613)	(526)	(48)	(85)	(39)	(81)	(46)
0.25	(60)	(116)	(184)	(212)	(81)	(165)	(125)	(662)	(1,606)	(517)	(41)	(76)	(32)	(71)	(38)
0.30	(51)	(107)	(177)	(205)	(72)	(155)	(116)	(652)	(1,598)	(508)	(34)	(68)	(25)	(61)	(31)
0.35	(42)	(98)	(170)	(198)	(62)	(145)	(108)	(642)	(1,591)	(499)	(28)	(59)	(18)	(51)	(23)
0.40	(32)	(88)	(163)	(191)	(52)	(136)	(99)	(633)	(1,583)	(490)	(21)	(51)	(10)	(42)	(16)
0.45	(23)	(79)	(156)	(184)	(42)	(126)	(90)	(623)	(1,576)	(481)	(14)	(42)	(3)	(32)	(8)
0.50	(14)	(70)	(149)	(177)	(33)	(116)	(81)	(613)	(1,568)	(472)	(7)	(34)	4	(22)	(0)
0.55	(5)	(61)	(142)	(170)	(23)	(106)	(73)	(603)	(1,561)	(463)	(1)	(25)	11	(12)	7
0.60	5	(52)	(135)	(163)	(13)	(96)	(64)	(593)	(1,553)	(454)	6	(17)	19	(2)	15
0.65	14	(43)	(128)	(156)	(3)	(87)	(55)	(584)	(1,546)	(445)	13	(8)	26	8	22
0.70	23	(34)	(121)	(149)	6	(77)	(46)	(574)	(1,538)	(436)	20	0	33	17	30
0.75	33	(25)	(113)	(142)	16	(67)	(38)	(564)	(1,531)	(428)	26	9	40	27	38
0.80	42	(16)	(106)	(135)	26	(57)	(29)	(554)	(1,523)	(419)	33	17	48	37	45
0.85	51	(7)	(99)	(128)	35	(47)	(20)	(544)	(1,516)	(410)	40	26	55	47	53
0.90	60	2	(92)	(121)	45	(38)	(12)	(535)	(1,508)	(401)	47	34	62	57	60
0.95	70	11	(85)	(114)	55	(28)	(3)	(525)	(1,501)	(392)	53	43	69	67	68
1.00	79	20	(78)	(107)	65	(18)	6	(515)	(1,493)	(383)	60	51	77	76	76
	Least-loss Carrying Capacity[c]														
	0.30	0.45	0.80	0.90	0.35	0.55	0.55	>1.0	>1.0	>1.0	0.30	0.35	0.25	0.35	0.30

[a] Treatment scenario: $15.50 per AUM, patch spread at 2.0 radial feet/year, 1-acre infestation, and maximum leafy spurge density.

[b] Present value of returns from herbicide treatments, 20-year period, 4 percent discount rate.

[c] Minimum carrying capacity needed for the treatment to result in less loss than without treatment.

Physical Factors

Several treatment scenarios were used to assess the effects on returns from long-term herbicide control (Appendix B). Under conditions of faster-than-normal spread (3.0 to 4.0 radial feet/year), break-even carrying capacities decreased by 0.10 to 0.15 AUMs/acre and net returns increased at each carrying capacity when compared to normal spread rates (Table 5). Two treatments (Glph.75 and GlPic+24Ds) under scenarios of rapid spread, provided positive net benefits down to carrying capacities of 0.35 AUMs/acre and had least-loss carrying capacities of 0.20 AUMs/acre.

Initial leafy spurge densities were set at 50 and 20 percent of total cover for 1-acre, 25-acre, and 50-acre infestations. Lower initial densities resulted in small increases in net returns for all-sized infestations; however, break-even and least-loss carrying capacities remained unchanged from scenarios with maximum leafy spurge density (Table 5).

The effect of restarting treatments in years when control dropped to 20 percent or less was evaluated. For example, in year seven of the Pic.25 treatment, predicted control drops to 20 percent, with treatment restarting in year eight; however, treatment was restarted in year seven. Results were mixed. For Pic.25, Pic.5, and Pic.5+24Ds, returns decreased, while for Pic.25+24D, Pic.5+24D, Glph.75, GlPic+24D, and GlPic+24Ds returns improved. Changes in returns, whether positive or negative, were about $10 or less per acre and resulted in 0.05 AUMs/acre change in break-even carrying capacities.

In another scenario, effective control for the most economical treatments was reduced by 10 percent in treatment years and reduced 20 percent in years following applications. The effect of reduced control decreased returns slightly, but did not change break-even carrying capacities.

Returns from treating infestations of less than one acre in size were substantially more attractive than results from treating patches larger than one acre in size (Table 5). When infestation area was increased beyond one acre, returns diminished quickly; however, as infestation areas increased beyond 5 acres, returns diminished much less. For example, moving from one acre to 5-acre infestations, returns diminished $15 to $25 per acre and returns decreased $20 to $30 per acre when treatment area moved from one acre to 10 acres. However, returns only decreased $3 to $10 per acre when infestations went from 10- to 25- and 50-acre infestations. Returns across all treatments decreased $30 to $55 per acre when infestation area increased from 0.25 to 50 acres. Changes in break-even and least-loss carrying capacities were substantial.

For example, the Pic.25+24D treatment on a 0.25-acre infestation broke even at 0.50 AUMs/acre, whereas, using the same treatment on a 50-acre infestation resulted in a 0.95 AUMs/acre break-even carrying capacity. Least-loss carrying capacities, when treating 50-acre infestations as compared to one-acre infestations, generally increased 0.10 to 0.15 AUMs/acre.

Table 5. Effects of Physical and Economic Factors on the Economics of Long-term Herbicide Control of Leafy Spurge Infestations in Rangeland

Factors[a]	Returns[b]	Break-even Carrying Capacity[c]	Least-loss Carrying Capacity[d]
	-- $/acre --	------------------- AUMs/acre -------------------	
Spread Rates (radial ft/yr)			
3.0	15 to 30	decrease 0.10 to 0.15	decrease 0.05
4.0	30 to 50	decrease 0.10 to 0.25	decrease 0.10
Infestation Size			
10, 25, 50 acres	-20 to -30	increase 0.15 to 0.25	increase 0.10
0.25 acre	40 to 50	decrease 0.10 to 0.25	decrease 0.10
0.50 acre	15 to 20	decrease 0.05 to 0.10	decrease 0.05
from 0.25 acre to 0.50 acre	-25 to -30	increase 0.05 to 0.15	increase 0.05
from 25 acres to 50 acres	-5	no change	no change
Restart Treatments Early[e]	mixed	mixed	mixed
Reduced Control[f]	-10 to -20	increase 0.05 to 0.10	increase 0.05
Reduced Herbicide Cost[g]	15 to 25	decrease 0.05 to 0.15	decrease 0.05
Value of Grazing			
AUM valued at $19	15 to 30	decrease 0.10 to 0.20	decrease 0.10
AUM valued at $12	-20 to -30	increase 0.15 to 0.25	increase 0.10

[a] Most comparisons made to results from treatments under base scenario conditions. Base scenario consisted of $15.50 per AUM, patch spread at 2.0 radial feet/year, 1-acre infestation, and maximum leafy spurge density.

[b] Present value of returns from herbicide treatments, 20-year period, 4 percent discount rate.

[c] The level of land productivity where returns from the treatment become positive.

[d] The level of land productivity needed for the treatment to result in less loss than without treatment.

[e] Multiple-year treatments were restarted when control reached 20 percent or less. Returns increased slightly for some treatments and decreased slightly for others.

[f] Control of leafy spurge was set at 90 percent in years of herbicide application and normal control was reduced 20 percent in years following herbicide applications. Also, grazing recovery in years 3 and 4 of multiple-year treatments was reduced from 98 to 90 percent; in other treatments grazing recovery was reduced by about 10 percent.

[g] Herbicide prices were reduced 20 percent.

The relationship between infestation size and break-even carrying capacities (i.e., the point where net returns become positive) was averaged for the six most economical treatments (Pic.25, Pic.25+24D, 24D1, 24D2, GlPic+24D, and GlPic+24Ds). As infestation size changed from small patches (0.05 acres) to large areas (50 acres), the average break-even point moved from 0.20 AUMs/acre to about 0.90 AUMs/acre (Figure 3).

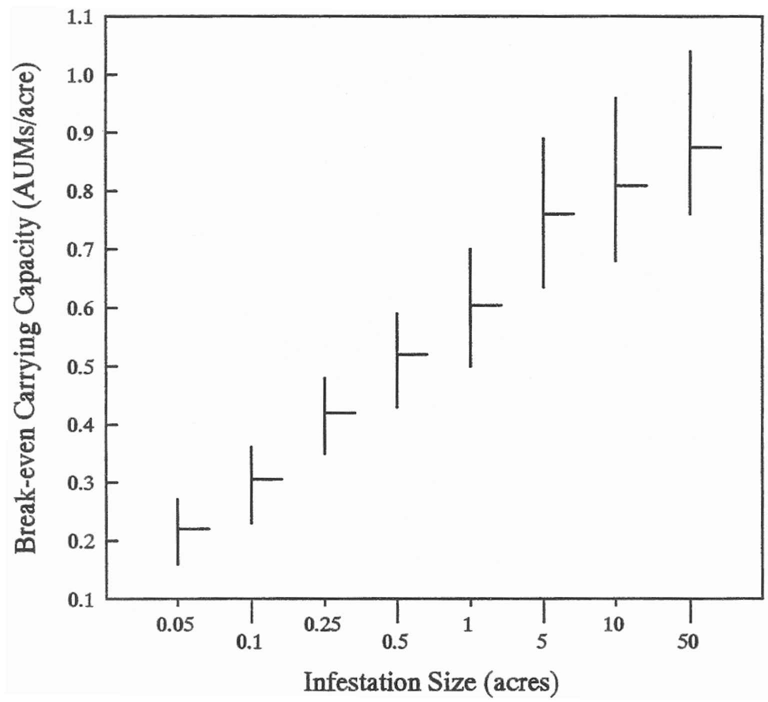

Figure 3. High, Low, and Average Break-even Carrying Capacities for the Six Most Economical Treatment Programs, 20 Years of Leafy Spurge Control in Rangeland Small infestations, with normal and faster-than-normal spread rates, provided the most attractive returns of any of the physical situations examined. Under scenarios of 0.25 acre infestations doubling in size every ten years (2.8 radial ft/yr), net returns at break-even carrying capacities across all treatments increased about $85 per acre from scenarios with one-acre infestations having baseline expansion rates and resulted in break-even carrying capacities as low as 0.30 AUMs/acre for some treatments. Least-loss carrying capacities for six treatments dropped to 0.20 AUMs/acre. Returns were greatest for infestations of 0.022 acres in size (about 35 feet in diameter). Seven treatments generated positive returns at 0.20 AUMs/acre with 0.022 acre infestations. Returns from 0.022-acre infestations increased $350 per acre, averaged across all treatments, when compared to returns at break-even carrying capacities from one-acre infestations. (See Appendix B for a complete listing of all treatments and results.)

Economic Variables

Economic values were adjusted to assess the effect on returns from long-term herbicide control (Appendix B). AUM values were changed to $19 and $12, reflecting average high and low regional grazing values in North Dakota from 1992 to 1994. Regional grazing values were estimated from information obtained from North Dakota Agricultural Statistics Service (various years) and Sedivec (1993) (Appendix A). At $19 per AUM, returns increased across most treatments about $10 per acre at low carrying capacities to nearly $50 per acre at high carrying capacities, depending upon treatment and infestation size. The break-even carrying capacities declined about 0.10 to 0.20 AUMs/acre for treatments having break-even capacities of 0.70 AUMs/acre or higher, but declined less (0.05 to 0.10 AUMs/acre) when previous break-even capacities were at 0.50 AUMs/acre or lower. Raising AUM values essentially made returns greater at all carrying capacities, thereby lowering break-even and least-loss carrying capacities. Returns decreased proportionately and break-even and least-loss carrying capacities increased when grazing was valued at $12 per AUM. Lowering the AUM value essentially decreased returns at all carrying capacities.

Herbicide prices were reduced 20 percent to evaluate the effect of reduced herbicide costs on long-term returns. Increases in per acre returns varied by treatment, but typically ranged from $10 to $25 per acre. The largest decreases in break-even carrying capacities (0.05 to 0.15 AUMs/acre) came from treatments with high herbicide costs and high break-even carrying capacities (Pic1, Pic2, Pic.5+24D, and Pic.5+24Ds). Three treatments (24D1, Glph.75, and GlPic+24Ds), with 20 percent lower herbicide costs, had least-loss carrying capacities down to 0.25 AUMs/acre with one-acre infestations. (See Appendix B for a complete listing of all treatments and results.)

Perimeter Control

An alternative to controlling the entire infestation would be to treat only the perimeter of an infestation, preventing the infestation from expanding. The herbicide treatments used for controlling entire infestations, in most cases, were developed to reduce stand density and provide long-term control. Although those treatment programs would be physiologically acceptable for perimeter control, they generally are much more intensive (and expensive) than required to only suppress the weed's spread. Treatments appropriate for preventing spread were developed by adjusting the application frequency of long-term treatments.

Six treatment programs were developed to prevent spread and minimize treatment costs. The Pic.25 treatment was reduced to a three-year program (Pic.25-pc); herbicide applied for two years, skipping every third year. The 24D1 treatment was used for perimeter control (24D1-pc), but not modified from its previous structure. The Pic.5 (Pic.5-pc), Pic.25+24D (Pic.25+24D-pc), Glph.75 (Glph.75-pc), and GlPic+24D (GlPic+24D-pc) programs were converted to biennial treatments.

Values for physical and economic variables were varied from a base scenario to determine the factors affecting perimeter treatments. The base scenario for perimeter control remained unchanged from that used for treating the entire infestation. Under baseline conditions, break-even carrying capacities ranged from 0.35 AUMs/acre (24D1-pc and GlPic+24D-pc) to 0.65 AUMs/acre (Pic.5-pc) (Table 6). Least-loss carrying capacities were generally 0.35 AUMs/acre or less. Discounted returns for perimeter treatments were reported as totals for the treatment. The magnitude of total returns varied little (about $3) from one carrying capacity to another under baseline conditions (Table 6).

Table 6. Long-term Returns From Perimeter Treatment of Leafy Spurge Infestations Using Herbicides[a]

Carrying Capacity	Herbicide Treatment Programs					
	Pic.25-pc	Pic.5-pc	Pic.25+24D-pc	24D1-pc	Glph.75-pc	GlPic+24D-pc
AUMs/acre ------	------ total dollars[b] ------					
0.20	(19)	(29)	(16)	(7)	(11)	(8)
0.25	(15)	(26)	(13)	(4)	(8)	(5)
0.30	(12)	(22)	(10)	(1)	(5)	(2)
0.35	(9)	(19)	(6)	2	(2)	1
0.40	(6)	(16)	(3)	6	2	4
0.45	(2)	(13)	0	9	5	8
0.50	1	(9)	3	12	8	11
0.55	4	(6)	7	15	11	14
0.60	7	(3)	10	19	14	17
0.65	10	0	13	22	18	21
0.70	14	4	16	25	21	24
0.75	17	7	19	28	24	27
0.80	20	10	23	32	27	30
0.85	23	13	26	35	31	34
0.90	27	17	29	38	34	37
0.95	30	20	32	41	37	40
1.00	33	23	36	45	40	43
	------ Least-loss Carrying Capacity[c] ------					
	0.25	0.35	0.25	0.20	0.20	0.20

[a] Treatment situation: $15.50 per AUM, patch spread at 2.0 radial feet/year, 1-acre infestation, maximum leafy spurge density, and 15 feet of periphery treated.
[b] Present value of total returns, 20-year period, 4 percent discount rate.
[c] Minimum carrying capacity needed for the treatment to result in less loss than without treatment.

Physical Factors

A variety of environmental situations were assessed to estimate the effect on returns from long-term perimeter control (Appendix B). Under conditions of faster-than-baseline spread (3.0 and 4.0 radial feet/year), break-even carrying capacities decreased by 0.10 to 0.25 AUMs/acre and net returns increased at each carrying capacity when compared to baseline spread rates. Three treatments, 24D1-pc, Glph.75-pc, and GlPic+24D-pc, under scenarios of rapid spread (4.0 radial feet/year), provided positive net returns down to carrying capacities of 0.20 AUMs/acre and had least-loss carrying capacities of 0.20 AUMs/acre. Returns from perimeter treatments were much more sensitive to slower-than-normal spread (1.0 radial foot/year) rates. Spread rates of 1.0 radial foot/year generally decreased returns by $45 when compared at break-even carrying capacities under baseline spread rates (Table 7). Slower-than-baseline spread rates increased break-even carrying capacities by 0.45 AUMs/acre and increased least-loss carrying capacities by 0.20 AUMs/acre.

Size of the infestation did not materially affect returns from long-term perimeter control (Table 7). Perimeter treatments for infestations of 1, 5, 10, 25, and 50 acres were evaluated. Total returns from treating the perimeters of infestations of 1 to 50 acres changed only $5 to $15 at break-even carrying capacities. Break-even carrying capacities and least-loss carrying capacities changed little as infestation size increased.

The amount of periphery treated was reduced from 15 radial feet to 12.5 and 10 radial feet. For each 2.5 radial feet reduction in periphery treated, break-even carrying capacities decreased 0.05 AUMs/acre. Returns increased about $10 per every 0.05 AUMs/acre carrying capacity for each 2.5 feet of reduced periphery treated (Table 7). (See Appendix B for all perimeter treatment returns.)

Economic Variables

Economic values were adjusted to assess the effect on returns from long-term perimeter control (Appendix B). AUM values were changed from $15.50 to $19 and $12, reflecting high and low extremes in grazing values. Compared to baseline conditions, break-even carrying capacities decreased only 0.05 AUMs/acre with high grazing values. Most least-loss carrying capacities did not change (most were already at 0.20 AUMs/acre). Returns from increased grazing values, compared to baseline values at break-even carrying capacities, increased about $6 across all treatments. When compared to returns from 50-acre infestations under baseline AUM values, returns with higher grazing values increased about $45 across all treatments. Returns from high and low AUM values, when compared to baseline conditions at break-even carrying capacities and averaged across all infestation sizes, increased most ($30) with the Pic.5-pc treatment and increased least ($15) with the 24D1-pc and GlPic+24D-pc treatments.

Reduced grazing values ($12/AUM) increased break-even carrying capacities about 0.10 AUMs/acre and increased least-loss carrying capacities about 0.05 AUMs/acre. Reducing herbicide prices by 20 percent resulted in similar changes in returns and break-even carrying capacities as observed with increased grazing values. (See Appendix B for all perimeter treatment returns.)

Table 7. Effects of Physical and Economic Factors on the Economics of Long-term Perimeter Treatments of Leafy Spurge Infestations

Factors[a]	Returns[b]	Break-even Carrying Capacity[c]	Least-loss Carrying Capacity[d]
	-- total $ --	---------- AUMs/acre ----------	
Spread Rates (radial ft/yr)			
1.0	-35 to -50	increase 0.35 to 0.55	increase 0.20
3.0	10 to 20	decrease 0.10	no change
4.0	30 to 40	decrease 0.15	decrease 0.05
Infestation Size (acres)			
5	<= 5	no change	no change
10	2 to 7	no change	no change
25	5 to 10	no change	no change
50	10 to 15	no change	no change
Reduced Periphery (ft)[e]			
12.5	7 to 12	decrease 0.05	no change
10.0	10 to 15	decrease 0.10	decrease 0.05
Reduced Herbicide Cost[f]	4 to 8	decrease 0.05	no change
Value of Grazing			
1-acre infestation			
AUM valued at $19	5 to 10	decrease 0.05 to 0.10	no change
AUM valued at $12	-5 to -10	increase 0.10 to 0.15	increase 0.05
50-acre infestation			
AUM valued at $19	35 to 55	decrease 0.05 to 0.10	no change
AUM valued at $12	-35 to -55	increase 0.10 to 0.15	increase 0.05

[a] Most comparisons made to results from treatments under base scenario conditions. Base scenario consisted of $15.50 per AUM, patch spread at 2.0 radial feet/year, 1-acre infestation, maximum leafy spurge density, and 15 feet of periphery beyond patch perimeter treated.
[b] Present value of typical returns from herbicide treatments, 20-year period, 4 percent discount rate.
[c] The level of land productivity where returns from the treatment become positive.
[d] The level of land productivity needed for the treatment to result in less loss than without treatment.
[e] Perimeter of infestation treated to control spread.
[f] Herbicide prices were reduced 20 percent.

Case Study

Two counties in North Dakota with wide-spread leafy spurge infestations and contrasting grazing land productivities and AUM values, Slope and Ransom, were chosen to illustrate potential differences in the economics of long-term herbicide control of leafy spurge. Ransom County, in the southeast corner of the state, has relatively productive grazing land (i.e., high carrying capacities) and moderate AUM values (i.e., $12 to $14/AUM). Slope County, in the western part of North Dakota, has less productive grazing land with relatively low carrying capacities and higher AUM values. No evidence was found that other treatment characteristics (e.g., percent control, rates of spread, etc.) in each of the counties differed from the values used in the general analysis. Thus, values for input parameters remained unchanged from previous treatment situations, except for grazing values.

Slope County

The county-wide carrying capacity for grazing land in Slope County is 0.45 AUMs/acre (Sedivec 1993). AUMs were valued at $19.23 (average from 1992 through 1994). Based on a base scenario using $19.23/AUM and a desired break-even carrying capacity of at least 0.45 AUMs/acre, only four of the 10 treatment programs evaluated resulted in positive returns (Appendix C). Across all treatment programs, net returns were negative for infestation sizes over 5 acres. Although the least-loss carrying capacities for some treatments applied to large infestations were higher than the county average carrying capacity, under all scenarios at least one or more treatments would provide a least-loss option to no control. Thus, even though the most economical treatment programs may result in negative net returns depending upon the treatment scenario, herbicide treatments should result in less loss than no control. Perimeter control was not evaluated for Slope County since earlier results (see Table 6) indicated that some perimeter treatments would be economical in Slope County.

Ransom County

The average carrying capacity for grazing land in Ransom County is about 0.95 AUMs/acre (Sedivec 1993). AUMs were valued at $13.93 (average from 1992 through 1994). Based on a base scenario using $13.93/AUM and a desired break-even carrying capacity of 0.95 AUMs/acre, 7 of the 11 treatment programs evaluated resulted in positive returns (Appendix C). Positive net returns could be realized across all treatment scenarios, even for infestations as large as 50 acres. Under all scenarios, at least one or more treatments would provide positive net returns at the county average carrying capacity. Thus, given the productive nature of grazing land in Ransom County, the use of herbicides to control leafy spurge could result in positive returns for a variety of treatment situations.

The economic conditions found in Slope and Ransom Counties help demonstrate that long-term net returns from chemical treatments are largely influenced by land productivity and grazing values. Some treatments may be more economical than others for any particular situation; however, a treatment that is not economical in one situation may be economical in another. Thus, site-specific economic criteria play an equally important part (i.e., compared to physical treatment relationships) in assessing the economics of long-term chemical control of leafy spurge.

DISCUSSION

Assessing the benefits of leafy spurge control requires consideration of a variety of issues and concerns. Issues surrounding public assistance for leafy spurge control may arise now that additional information is available to policymakers and managers regarding the long-term viability of herbicide control. These issues and some general interpretations and recommendations are discussed in the following sections.

Implications

The results in this study were based on repeating treatment programs over 20 years, which is a long time to wage war on any weed infestation. However, considering the current effectiveness of control methods, 5, 10, or 15 years of treatments are not likely going to produce a change in the weed's ability to reduce grazing outputs. Thus, leafy spurge, given current technology, is truly a long-term problem and 20 years appears to be a reasonable period to evaluate current control methods. Even though the time frame for this analysis may be appropriate, it does raise some important considerations.

First, if many treatment programs require roughly 20 years to generate positive net returns, landowners and producers must recognize the long-term commitment required to combat the weed. Granted, more effective controls may appear within that time frame, however, no guarantees exist that adopting those controls at that time would be preferable to no treatment today. Also, some treatments may generate positive net returns in time periods shorter than 20 years; however, whether treatments produce positive net returns in 6, 12, or 16 years is not entirely relevant. In the absence of superior control methods, treatments should continue since the weed will likely continue to thrive. Current herbicide control technology stresses the importance of long-term commitments to leafy spurge control. Similarly, economics of control suggest that long time periods may be required to recapture the initial investment in herbicide treatments. Treatments may appear to be a bad investment after 10 years, but may ultimately be a good investment after 20 years.

Since herbicide treatments require long time periods to generate positive returns, a need exists to find control methods that can produce positive returns in shorter time periods. Some treatments evaluated in this study will produce positive net returns in less than 20 years. However, the exact nature of the benefit stream for each treatment under a variety of situations was not evaluated. The time frames, along with all of the other commitments required for long-term herbicide control, may deter individuals from pursuing such intensive treatment programs. Thus, even though herbicide treatments can be economically attractive alternatives to no control, the small margins involved and the time required may not justify the effort.

Results of this study provide a useful first approximation of the grazing conditions under which the use of herbicides to control leafy spurge would be economical. Knowing (1) the approximate break-even range of treatments, (2) the approximate amount of grazing land that meets those requirements, and (3) the distribution of leafy spurge on those lands may have important implications in addressing state-wide efforts to combat the weed.

About two-thirds of the privately-owned grazing land in North Dakota is less productive than the most common break-even point (0.60 AUMs/acre) for long-term herbicide treatments of leafy spurge (Appendix D). However, only about 40 percent of all leafy spurge infestations are found on grazing land with carrying capacities less than 0.60 AUMs/acre. The remaining one-third of private grazing land in North Dakota, having carrying capacities over 0.60 AUMs/acre, contains about 60 percent of the state's leafy spurge infestations (on grazing land).

A substantial number of the leafy spurge infestations on private grazing land may not meet minimum economic thresholds for economical treatment. Without additional economic incentives, wide-scale efforts to combat the weed may not succeed. This raises implications for continued public support of noxious weed control, such as cost-share and landowner assistance programs throughout the state. Issues not clearly resolved include the legitimacy of public funded support for leafy spurge control, such as whether or not public funds should be used to combat the weed, and if so;

1) the amount of public resources needed;
2) the manner in which those resources should be collected and distributed;
3) the appropriate roles for various governmental units; and
4) the potential long-term returns from the use of public funds for leafy spurge control.

Results from this study demonstrate that a need exists to find economical long-term control programs for leafy spurge. Additional research is needed to pursue (1) more economical long-term herbicide treatments and/or (2) develop alternative treatment methods that can substitute or complement existing programs. This raises implications for developing and determining if other methods, such as cultural (grazing, plant competition) or biological control (insects and plant diseases), used independently or cooperatively, would be economical. Additional information on grazing recovery rates and on the characteristics of spreading infestations would help narrow the confidence limits of the estimates. Field observations over time would add validity to key relationships that are currently "best guesses" or based on unquantified assumptions.

Economic Relationships

Results from this study are presented as point estimates; however, they should be used only as general guides to assist in control decisions. Weed control specialists should be consulted when developing a long-term weed management program.

Probably the most pronounced finding in this study is the inverse relationship between infestation area and treatment payoff, which indicates early detection and control are best (Figure 4). Results for the most economical treatments show that average net returns become negative between 1- to 2-acre infestations (carrying capacities ranging from 0.40 to 0.60 AUMs/acre). As carrying capacity increases for any treatment situation, net returns increase and the maximum treatment area that can produce positive returns increases (Figure 4).

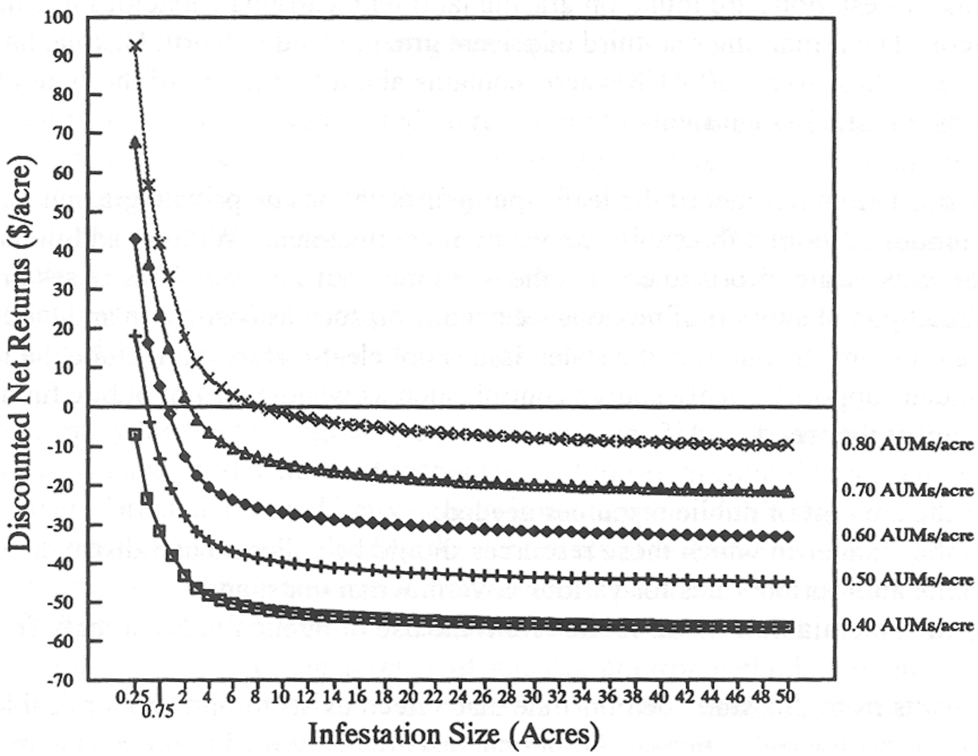

Figure 4. Net Returns Averaged From the Six Most Economical Leafy Spurge Treatment Programs Across Various Infestation Sizes, 20 Years of Control

The economic relationship between infestation area and treatment returns can be understood by considering patch expansion dynamics (Appendix E). Small (less than an acre in size) patches spread much faster, as a percent of original area, than do large infestations. A patch of leafy spurge 75 feet in diameter spreading at 2.0 radial feet/year will increase in size 330 percent over 20 years, whereas, a 10-acre infestation spreading at the same radial rate will increase in size only 23 percent. As such, small patches of leafy spurge generate proportionally more grazing loss from expansion than from the original infestation.

The relationship between grazing loss from the original patch and from expansion becomes dominated by original patch area as infestations become larger. Large patches consume more area as they expand than small patches, but treating small infestations captures relatively more returns through maintaining existing grazing outputs (grazing retention) than from recapturing grazing outputs from the infestation (grazing recovery). However, as the dynamics of patch expansion change when moving from small to large infestations, returns become more sensitive to the amount of grazing recovery and less sensitive to the amount of grazing retention.

A critical aspect of herbicide treatment is being able to get cattle to graze within or near infestations. Treating large infestations is more risky than treating small patches since a relatively large cash outlay is incurred in an attempt to recover grazing potential from the infestation. Grazing recovery rates are uncertain since (1) most treatment programs will not eliminate all plants and as such, will not totally remove the aversion cattle may have for grazing in the patch and (2) less than expected control could cause cattle to avoid the infestation area altogether.

Given current economic criteria, treatment involving large infestations, particularly in less productive land (lower AUMs/acre), will likely be more risky than those for small patches. A less risky alternative to treating the entire (large) infestation is perimeter control. A perimeter control strategy should incur less time and money than other treatment approaches.

More frequent treatments at lower herbicide rates (e.g., Pic.25 and Pic.25+24D) appear more economical than less frequent treatments using higher herbicide rates (e.g., Pic1 and Pic2). Typically, in order to achieve leafy spurge control for two or more years following a single treatment, relatively high rates of herbicide are required per application. Whereas, treatments applied at lower rates for several years appear more economical. Multiple-year treatments are generally more effective in reducing stand density over time, thereby increasing chances for grazing recovery. Multiple-year treatments are less risky than high-rate, single-year treatments since stand reduction and control are less responsive to a single application. Also, generally multiple-year treatments are less expensive in terms of cumulative treatment costs.

Break-even points are sensitive to spread rates. Thus, spread differing from the assumed 2.0 radial feet/year rate used in this study will likely affect long-term returns and influence long-term treatment strategies. When treating small infestations, faster-than-normal spread rates enhance an already economical situation, whereas, with acre-sized infestations, faster spread rates push break-even carrying capacities down to levels equal to the less productive grazing land in North Dakota. Faster-than-normal spread rates in large infestations (five acres and larger) do little to improve the long-term returns from treating the entire infestation; however, those rates influence returns from "control only" approaches to large infestations. Likewise, slower-than-normal spread rates have negative effects on treatment returns. The best way to determine the effect on individual situations is to estimate the rate of leafy spurge spread, perhaps through observation.

Method and Data Shortcomings

Leafy spurge infestation spread rates were simplified to patches with distinct boundaries, consistent expansion rates, and no constraints to continue expanding. In reality, leafy spurge infestations often start out as small patches, expanding and becoming more dense over time and wide-spread infestations do not necessarily have convenient boundaries or homogenous densities. Densities vary from solid leafy spurge stands to a few plants per area. Also, not all leafy spurge expansion is constant and unlimited. Patches within large infested areas will converge over time, while others run into man-made and natural boundaries, and still others may expand at various/inconsistent rates.

Leafy spurge spread rates used in this study may not be consistent with what takes place in the field. Infestations of varying sizes and/or densities next to each other or other barriers, will likely expand into each other or expand in limited directions. Under these conditions the benefits from expansion used in this study will likely be overstated from those realized in the field. A benefit of control not quantified is prevention of seed development--a major source of new infestations. No documentation could be found to quantify the influence of established infestations creating new infestations through seed dispersal.

Herbicide prices and the amount of herbicide use assumed in this study will differ from actual treatment programs. Factors influencing the amount of herbicide used include sprayer calibration, rate of travel, overlap and skips, terrain of the infestation, "using up extra chemical," and so on. Buying practices, shifting market prices over time, cost-share programs, and other factors can influence herbicide prices. Application costs are likely to vary from those used in this study. Thus, individual herbicide application practices and changing herbicide prices will influence overall costs of treatments.

An important assumption used in this study was the amount of grazing recovery received from treatments and stocking rates for infested land. First, grazing recovery for many of the years in all of the treatment programs was explicitly defined (i.e., predetermined based upon control measures received from treatments). These grazing recovery rates were based upon (1) top growth or density of infestations being sufficiently reduced so that cattle will graze within the infestations, (2) the pasture being stocked at a rate sufficient that cattle graze within the treated infestations, and (3) other factors. The first assumption is straightforward--leafy spurge must be sufficiently controlled as to remove the avoidance factor cattle have for it, since cattle are basically intolerant of the plant. If control is ineffective, it would be unreasonable to expect cattle to graze in or near infestations.

The second factor influencing grazing recovery can be affected by several things. First, a pasture that is under stocked may not entice cattle to graze in treated areas. Cattle may find less intrusive forage in other areas of the pasture, due largely to forage that goes ungrazed, and also, even the most effective treatments will not remove all leafy spurge plants, thereby still generating some avoidance for cattle. Second, timing of herbicide applications must be conducive to producing available forage. Only allowing forage in the infestations to be grazed for short time periods (e.g., one month) will result in lower returns from treatment. Fall treatments that provide little long-term control will unlikely, even with acceptable short-term control, produce the grazing recovery rates used in this study. Third, the effects of rainfall on herbicide effectiveness and grass production were not included. Finally, the amount of herbicide applied, timing of herbicide applications, and choice of herbicide can affect grass injury, which was not addressed in this study, but could directly affect grazing recovery.

One of the problems with projecting returns and costs 20 years into the future is the amount of uncertainty in the analysis. Twenty years represents a long time to assume constant technology and static economic values. The effect of changing technology (changes in herbicide control or the development/discovery of other methods), environmental regulations, societal preferences, and other intangible factors are unknown. As key constants in the analysis change, the economics of long-term control should be reassessed.

Individual results from management programs that skip years, switch treatment programs, or include activities that change costs and returns during the period will likely differ from those reported in this study. The results presented in this study represent only *an attempt* to provide insight on the economics of long-term control of leafy spurge using herbicides. They are first approximations of average conditions.

CONCLUSIONS

Leafy spurge, a troublesome weed in untilled land, spreads rapidly, resists control, and reduces land outputs, presenting long-term problems to land managers in the Upper Midwest. A variety of intensive herbicide treatment programs, currently the mainstay of combating the weed, has been effective in controlling, but not eradicating, the weed. Thus, efforts to control and restrict the spread of leafy spurge require long-term commitments; however, tradeoffs between control costs and returns from control have until now remained unquantified.

Under rangeland conditions found in North Dakota (i.e., grazing values, land carrying capacities, spread rates, herbicide effectiveness, and treatment costs), long-term (20 years) herbicide control of leafy spurge can provide positive returns. Discounted present returns, however, vary across a variety of physical, environmental, and economic factors.

Annual applications of 2,4-D at moderate rates, picloram alone or picloram with 2,4-D at light rates repeated for several years, and glyphosate with 2,4-D combinations applied annually or biennially at moderate rates provided the most economically attractive returns from long-term treatments of leafy spurge. Individual strategies to combat leafy spurge will vary depending upon a host of factors. However, an overall recommendation would be to intensively treat small infestations and at the very least, attempt to control the spread of large infestations.

The physical/environmental conditions having the greatest influence on returns from long-term herbicide control included treatment size, spread rates, land productivity, and structure (i.e., frequency and rate) of herbicide applications. As could be expected, grazing values and herbicide costs had direct impacts on the economic feasibility of control.

Treatment area was a major factor influencing returns from long-term herbicide control of leafy spurge. Generally, most treatment programs evaluated provided positive discounted returns when applied to small (one-half acre or less) infestations over 20 years. However, even under favorable physical, and optimistic economic conditions, few treatments provided acceptable returns as infestation area approached 50 acres. As treatment area moved from infestations of less than an acre to over five acres, returns diminished quickly, implying a sensitive relationship between treatment size and returns. Treatments across a wide range of infestation sizes provided attractive economic alternatives to no treatment.

In all situations, faster-than-baseline rates of spread made treatments more economical and correspondingly, slower-than-baseline rates made treatments less economical. When treating the entire infestation, returns from large infestations improved the least from more rapid spread, whereas, the rate of spread affected returns substantially when only treating to control the spread of large infestations.

An obvious direct relationship was noticed between land productivity, value of grazing, and returns from treatment. As land productivity ranged from low to high capacity with fixed grazing values, returns improved noticeably for all treatments. In relatively unproductive land, few treatments were economical, in contrast to highly productive land, where most treatments provided positive returns. In many cases, the change in returns from the most valuable grazing scenario to the least valuable scenario would be sufficient to influence decisions regarding the implementation and/or continuation of specific treatment programs.

Other factors affecting returns included treatment costs, grazing recovery, and level of control. Grazing recovery was more important to single-year treatment programs than to multiple-year programs, due largely to the structure of the treatment programs and the way grazing recovery was handled in treatment years versus years after herbicide applications. Multiple-year treatments using low-to-moderate rates of herbicide fared better than single-year treatments using high rates of herbicide. Reductions in infestation densities increased returns negligibly. Similarly, small reductions in control reduced returns only slightly.

The level of productivity at which most herbicide treatment programs break even is higher than the levels of productivity found in much of North Dakota's grazing land. Substantial amounts of leafy spurge infested grazing land exist that may not produce sufficient economic incentives for individuals to commit to long-term herbicide control, raising questions about public support for control and the impacts of cost-share and landowner assistance programs.

Confidence with the results in this study could be improved with refined information on key relationships and assumptions, particularly grazing recovery and spread characteristics. Current herbicide technologies cannot provide long-term positive returns from leafy spurge control in all rangeland conditions found in North Dakota. As alternatives to controlling leafy spurge with herbicides are sought, the long-term economic viability of those methods also needs to be assessed.

Although the results should be viewed with some caution, in general, long-term herbicide control of leafy spurge provides attractive economic alternatives to no treatment.

REFERENCES

Bangsund, Dean A. and F. Larry Leistritz. 1991. Economic Impact of Leafy Spurge in Montana, South Dakota, and Wyoming. Agricultural Economics Report No. 275. Department of Agricultural Economics, North Dakota State University, Fargo.

Bangsund, Dean A. and Frayne E. Olson. 1993. North Dakota Value-Added Agriculture Regional Assessment Model--Version 1--Documentation and Technical Guide. Agricultural Economics Software Series No. 7. Department of Agricultural Economics, North Dakota State University, Fargo.

Bangsund, Dean A., Rodney K. Stroh, and Jay A. Leitch. 1993. "Leafy Spurge Patch Expansion." Natural Areas Journal 13(2):131-132.

Belcher, Joyce W. and Scott D. Wilson. 1989. "Leafy Spurge and the Species Composition of a Mixed-Grass Prairie." Journal of Range Management 42(2):172-175.

Best, K. F., G. G. Bowes, A. G. Thomas, and M. G. Maw. 1980. "The Biology of Canadian Weeds. Euphorbia esula L." Canadian Journal of Plant Science 60:651-663.

Carlson, R. B. and L. J. Littlefield. 1983. "The Potential for Biological Control of Leafy Spurge." North Dakota Farm Research 40(5):14-16.

Hanson, H. C. and V. E. Rudd. 1933. Leafy Spurge Life History and Habits. Agricultural Experiment Station Bulletin 226. North Dakota Agriculture College, Fargo.

Leitch, Jay A., Dean A. Bangsund, and F. Larry Leistritz. 1995. Economic Impact of Leafy Spurge in North Dakota--Executive Summary and County-level Impact Estimates. Paper prepared for the 11th North Dakota Weed Control Association Annual Conference. Department of Agricultural Economics, North Dakota State University, Fargo.

Leitch, Jay A., F. Larry Leistritz, and Dean A. Bangsund. 1994. Economic Effect of Leafy Spurge in the Upper Great Plains: Methods, Models, and Results. Agricultural Economics Report No. 316. Department of Agricultural Economics, North Dakota State University, Fargo.

Lym, Rodney G. and Calvin G. Messersmith. 1983. "Control of Leafy Spurge with Herbicides." North Dakota Farm Research 40(5):16-19,26.

Lym, Rodney G. and Calvin G. Messersmith. 1985. "A Summary of Leafy Spurge Control with Herbicides in North Dakota Since 1963." North Dakota Farm Research 43(1):3-6.

Lym, Rodney G. and Calvin G. Messersmith. 1993. "Fall Cultivation and Fertilization to Reduce Winterhardiness of Leafy Spurge (*Euphorbia esula*)." Weed Science 41:441-446.

Lym, Rodney G. and Calvin G. Messersmith. 1994. "A Decade of Herbicide Treatments Controlled Leafy Spurge." North Dakota Farm Research 50(3):9-12.

Lym, Rodney G., Calvin G. Messersmith, and Richard Zollinger. 1993. Leafy Spurge Identification and Control. Extension Publication W-765. North Dakota State University Extension Service, North Dakota State University, Fargo.

Messersmith, Calvin G. 1989. "Leafy Spurge Control: Reflections on 17 Years of Research," in Proceedings of the 1989 Leafy Spurge Symposium, Robert M. Nowierski, ed., Montana Agricultural Experiment Station, Montana State University, Bozeman.

Messersmith, Calvin G., Rodney G. Lym, and Donald S. Galitz. 1985. "Biology of Leafy Spurge." pp. 42-56 in Leafy Spurge, A.K. Watson, ed., Weed Science Society of America, Champaign, IL.

Moran, Gary. 1992. "Leafy Spurge A Candidate For Biological Control." North Dakota Farm Research 49(5):3-6.

North Dakota Agricultural Statistics Service. 1995. North Dakota Agricultural Statistics 1995. Agricultural Statistics Report No. 64. North Dakota Agricultural Statistics Service, North Dakota State University, and U.S. Department of Agriculture, Fargo.

North Dakota Agricultural Statistics Service. *various years*. North Dakota County Rents and Values. North Dakota Agricultural Statistics Service, North Dakota State University, and U.S. Department of Agriculture, Fargo.

Sedivec, Kevin. 1993. Personal Communication. Rangeland Management Specialist, North Dakota State University Extension Service, Department of Animal and Range Sciences, North Dakota State University, Fargo.

Shaver, J. C. 1977. North Dakota Rangeland Resources 1977. Society for Range Management and the Old West Regional Range Program. Denver, CO.

Stroh, Rodney K., Dean A. Bangsund, and Jay A. Leitch. 1990. Leafy Spurge Patch Expansion. Agricultural Economics Staff Paper No. AE90001. Department of Agricultural Economics, North Dakota State University, Fargo.

Swenson, Andrew. 1995. Personal Communication. Extension Farm Management Specialist, Extension Agricultural Economics, North Dakota State University, Fargo.

Thompson, Flint. 1990. Economic Impact of Leafy Spurge on North Dakota Grazing Lands. M.S. thesis. North Dakota State University, Fargo.

Thompson, Flint, F. Larry Leistritz, and Jay A. Leitch. 1990. Economic Impact of Leafy Spurge in North Dakota. Agricultural Economics Report No. 257. Department of Agricultural Economics, North Dakota State University, Fargo.

U.S. Department of Commerce. *various years*. Survey of Current Business. Bureau of Economic Analysis, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C.

Watson, A. K. 1985. "Integrated Management of Leafy Spurge." pp. 93-103 in Leafy Spurge, A.K. Watson, ed., Weed Science Society of America, Champaign, IL.

Zollinger, R. K. 1995. 1995 North Dakota Herbicide Price List. Department of Plant Sciences Fact Sheet. Department of Plant Sciences, North Dakota State University, Fargo.

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