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Economics of Herbicide Control of Leafy Spurge (*Euphorbia esula* L.)

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Leafy spurge (*Euphorbia esula* L.), a widely established exotic, noxious, perennial weed, is a major threat to the viability of commercial grazing and to beneficial outputs of wildlands in the Upper Great Plains. Herbicide treatments are often recommended based upon measures of physical control rather than on economic criteria. A deterministic, bioeconomic model was developed to evaluate the economic viability of current herbicide control strategies for leafy spurge. Control viability is highly site specific but falls into three categories. First, broadcast herbicide treatment may result in positive net returns for some grazing situations, especially small infestations on highly productive land, in the Upper Great Plains. Second, treating the perimeter to prevent patch expansion is viable in some situations when treating the entire infestation is not viable. Finally, for well-established infestations on less-productive land the best alternative, from an individual landowner's perspective, is to not treat leafy spurge with herbicide and bear the increasing productivity losses.

Key words: bioeconomic simulation, economics, herbicides, leafy spurge, range management

Introduction

Undesirable plants in grazing land often reduce forage production by competing with native plants and discouraging grazing near the plant, thereby directly affecting the land's usefulness for livestock grazing (Auld, Menz, and Tisdell; Huenneke). The most troublesome of these plants are usually fast-spreading, perennial, and difficult to control. These plant characteristics, combined with difficulty in assessing benefits of weed treatments in grazing land, often present complex control decisions for landowners and livestock producers.

The recognition of leafy spurge's persistent and aggressive nature, combined with current infestation rates in many areas of the Upper Great Plains, has led to attention-getting estimates of the impact of the weed on local, state, and regional economies. Leitch, Leistritz, and Bangsund estimated leafy spurge impacts on grazing land and wildland in Montana, North Dakota, South Dakota, and Wyoming to be nearly $130 million annually. About $3 to $5 million is spent annually treating leafy spurge in North Dakota alone. Public funds have been used to offset about 50 to 60% of these treatment costs.

Leafy spurge (*Euphorbia esula* L.), one of the most invasive, troublesome rangeland

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weeds, is found throughout the Great Plains. It is fast spreading, difficult to control, and directly reduces grazing land outputs. First reported in the Great Plains in 1909, the weed has expanded to infest large tracts of land throughout the Great Plains, despite efforts to prevent its spread. The nature of leafy spurge and the detrimental effects of the weed on untilled land have been well documented (Watson; Lajeunesse et al.; U.S. Department of Agriculture).

The recognizable detrimental effects of the weed, the apparent deficiencies of control methods, and widespread infestations have encouraged developing methods of controlling leafy spurge (Messersmith and Lym). In response to growing public recognition of the need to find control methods, several herbicide programs have been evaluated (Lym and Messersmith 1985, 1994; Messersmith). Leafy spurge has been considered a viable candidate for biological control (Carlson and Littlefield; Moran), although widespread use of biological agents is not imminent. Herbicides remain the mainstay of control.

Most of the emphasis in evaluating herbicides has focused on the degree and duration of physical damage to the plant. Some evaluations of the economics of control have been performed (Gylling and Arnold; Lym and Messersmith 1983); however, these studies did not include the value of preventing spread nor did they evaluate economics of control over extended periods. Few treatments were found to be economical in the short term (five-year horizon). Other efforts to evaluate the effectiveness of leafy spurge control have included the development of control models based on growth simulation and plant life cycles (Bowes and Thomas; Maxwell, Wilson, and Radosevich). These efforts did not incorporate trade-offs between treatment costs and benefits over time.

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. Considerations for a management strategy include the unique physical nature of leafy spurge, a host of economic variables confronting individual land managers, difficulty in quantifying benefits from control over time, the expensive nature of control treatments (relative to land values), and the potential economy-wide benefits from control. These factors demonstrate the need to identify economical control methods and to identify concerns regarding treatment options under a variety of economic situations.

The purpose of this study was to evaluate the long-term economic viability of conventional herbicide control of leafy spurge. Subobjectives included (*a*) estimating potential benefits of leafy spurge control, (*b*) estimating costs of leafy spurge control, and (*c*) identifying variables affecting the economic feasibility of leafy spurge control.

Procedures

Economic evaluation of long-term herbicide control of leafy spurge requires identifying treatment benefits and costs. First, a deterministic, bioeconomic model was developed to evaluate the economic feasibility of current herbicide control strategies. Second, recommended herbicide programs were identified, along with their costs and control characteristics. Finally, plausible treatment scenarios were selected to evaluate the economics of long-term control strategies and to assess the sensitivity of results to changes in magnitudes of control variables.

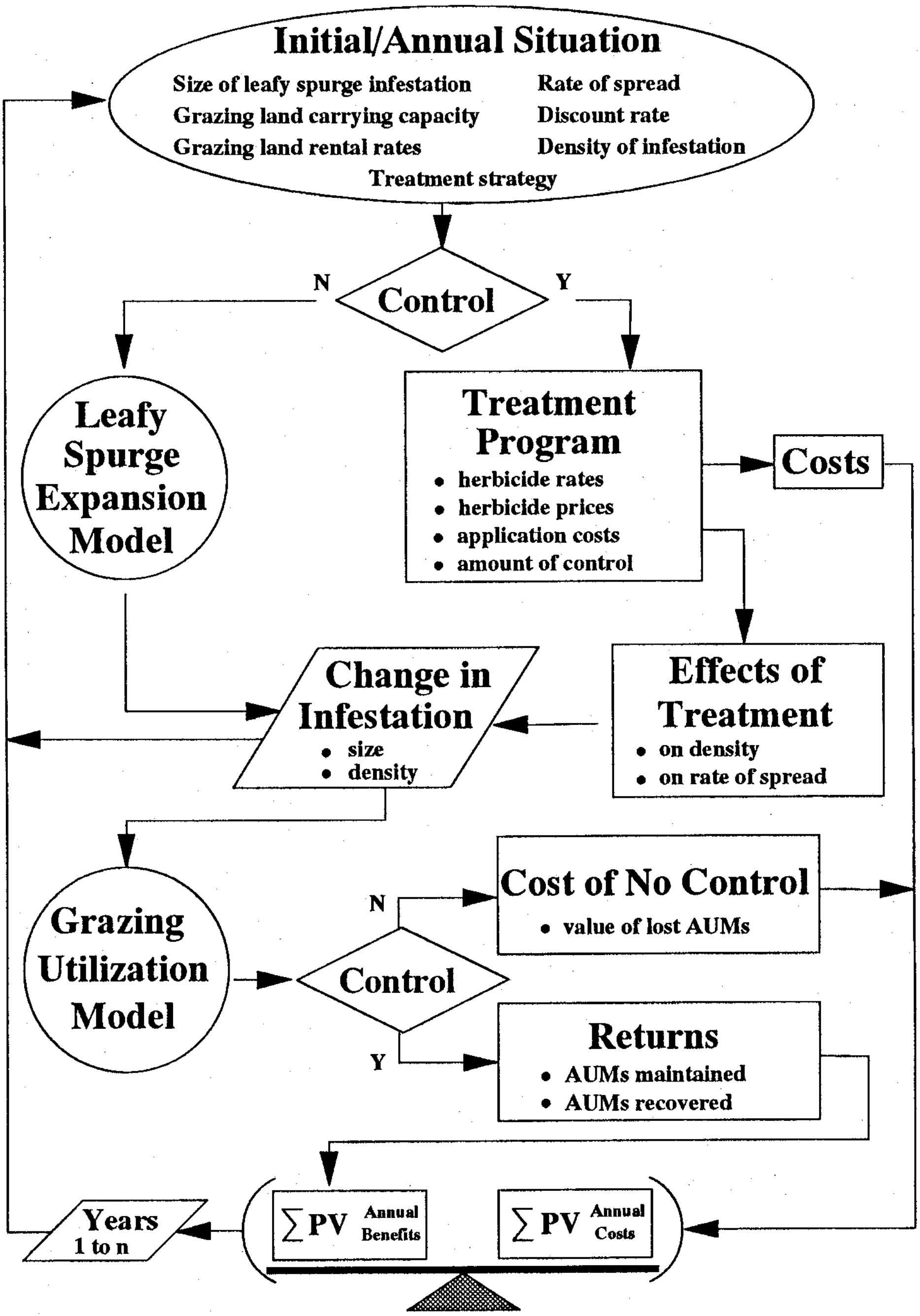

Figure 1. Economic evaluation model for control of leafy spurge with herbicides

Model Development

A deterministic simulation model was developed to evaluate the economics of controlling leafy spurge with herbicides. Although many of the variables involve risk, their probability distributions are not known so expected mean values were used rather than incorporating stochastic behavior in the model. Given an initial leafy spurge infestation, the model predicts leafy spurge spread and the corresponding annual reductions in grazing output from that infestation (fig. 1). Potential returns were estimated from the value of grazing outputs lost from the infestation, assuming no control and no effect on livestock prices. Control costs included material and application expenses. The annual difference between treatment expenses and the value of grazing outputs recovered through treatment was discounted over time to provide a long-term (20 years) perspective of each treatment scenario. Twenty years was long enough to (*a*) realize the benefits of controlling infestations that would expand in the absence of control and (*b*) adequately consider treatment programs varying from one to several years in duration.

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, Stroh, and Leitch). The interaction between lost grazing capacity and infestation densities was estimated from secondary sources (Lym, Messersmith, and Zollinger; Thompson). The functions of control, rate of spread, and density reduction over time, given initial treatment effectiveness, were estimated from Lym, Messersmith, and Zollinger.

Although weed control generally falls into four categories: prevention, eradication, reduction, and containment (Auld, Menz, and Tisdell; Westbrooks and Eplee), only reduction and containment goals were evaluated. With widespread infestations throughout the Upper Great Plains, continued spread and introduction of the plant to new areas are likely, if not inevitable (Asher). Although prevention can be difficult, it remains a high priority in unaffected areas; however, due to widespread infestations, it is not a relevant option for many producers and land managers. Likewise, eradication of established leafy spurge infestations in grazing land is unlikely. The only documented case of eradicating established leafy spurge infestations has involved cultivation (Lym and Messersmith 1993), not a recommended or feasible control method in most rangeland. Thus, the most salient leafy spurge control options are population reduction and containment.

Under the strategy of population reduction, an entire infestation would be treated to reduce infestation densities and to prevent patch spread. The containment-only strategy involves treating the infestation periphery to prevent expansion from lateral root growth [patch expansion results almost entirely from lateral root spread (Best et al.)].

Two economic perspectives were considered for each control strategy: (*a*) compare treatment costs with treatment returns (i.e., classic cost/returns approach) and (*b*) determine potential losses with control compared to losses without control (least loss, loss minimization, or cost-effective approach). The first analysis considered only treatment benefits and costs. Treatment situations where cumulative discounted annual returns are greater than cumulative discounted annual costs are economically feasible.[1] In the second analysis, treatment situations that are not economically feasible may still result in less economic loss over time than incurred without control. Under those conditions, herbicide treatments would be economically advisable, as long as better control strategies were not available. When a no-control strategy resulted in less loss than with control, a "do nothing" strategy or one employing other methods might be optimal.

[1] The concept of financial feasibility (i.e., constraints on or availability of resources needed for herbicide purchases) was not examined.

Table 1. Selected Herbicide Treatments for Leafy Spurge Control in Rangeland

Treat-ment	Herbicides Used	Application Rate Yr. 1	Yr. 2	Yr. 3	Yr. 4	Control after Last Treatment[a] Yr. 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5
		(lbs./ac.)				(%)				
Pic1	Picloram	0.25	0.25	0.25	0.25	60	40	20	0	0
Pic2	Picloram	0.5	0.5	0.5	0.5	95	85	78	60	20
Pic3	Picloram	1.0	0	0	0	75	20	0	0	0
Pic4	Picloram	2.0	0	0	0	95	80	75	25	0
Pic5	Picloram and 2,4-D	0.25, 1	0.25, 1	0.25, 1	0.25, 1	90	85	70	20	0
Pic6	Picloram and 2,4-D	0.5, 1	0.5, 1	0.5 1	0.5, 1	95	85	70	20	0
Pic7	Picloram and 2,4-D	0.5, 1	0.5, 1	0.5, 1	0, 0	90	80	70	20	0
Dic1	Dicamba	2.0	2.0	2.0	2.0	95	85	70	20	0
Dic2	Dicamba	8.0	0	0	0	80	35	0	0	0
Dic3	Dicamba	2.0	2.0	2.0	0	95	85	70	20	0
TFD1[b]	2,4-D	1.0				na				
TFD2[b]	2,4-D	2.0				na				
Glph1	Glyphosate	0.75	0	0	0	80	10	0	0	0
Glph2[c]	Glyphosate and 2,4-D and Picloram and 2,4-D	0.4, 0.6	0.25, 1	0.25, 1	0.25, 1	90	85	75	30	0
Glph3[c]	Glyphosate and 2,4-D and Picloram and 2,4-D	0.4, 0.6	0.25, 1	0, 0	0, 0	90	78	50	20	0

Source: Adopted from Lym, Messersmith, and Zollinger.
[a] Control in year of application is generally 100% of top growth. When treating leafy spurge, control from herbicides is usually stated as the amount of control received in years following treatment.
[b] TFD1 and TFD2 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.

Treatment Programs

Herbicide agents and combinations thereof, application rates, and timing of applications that result in the most effective physical control (population reduction) of leafy spurge have been identified (Lym, Messersmith, and Zollinger; Messersmith). The most common herbicides providing effective physical control of leafy spurge include picloram (Tordon); dicamba (Banvel); 2,4-D ester and amine; and glyphosate plus 2,4-D (Landmaster). Fifteen treatment programs were evaluated for density reduction of leafy spurge infestations (table 1). All treatment programs evaluated are recommended for use on leafy spurge in grazing land and adhere to labeling guidelines and environmental regulations (Lym, Messersmith, and Zollinger).

Although herbicide treatment programs designed for reducing stand density would be physiologically acceptable for containment-only strategies, they are more intensive and expensive than required to simply suppress the weed's spread. Six treatment programs were developed to prevent spread and minimize treatment costs by adjusting the application frequency of treatments used for density reduction. The Pic1 treatment (table 1) was reduced to a three-year program (Pic1-pc): herbicide applied for two consecutive years, skipping every third year. The annual TFD1 treatment also was used for perimeter treatments (TFD1-pc). The Pic2 (Pic2-pc), Pic5 (Pic5-pc), Glph1 (Glph1-pc), and Glph2 (Glph2-pc) programs were converted to biennial treatments.

Treatment program costs vary with herbicide prices, application rates, additional surfactants or herbicide adjuvants, number of applications per year, and application costs (e.g., fuel, repairs, depreciation, labor). We assumed that there were no resource (e.g., working capital, labor) constraints to implementing the leafy spurge control programs in the model. Herbicide prices used were 1995 retail prices in North Dakota (Zollinger). Treatments evaluated in this study did not contain surfactants or other herbicide adjuvants because they seldom are used by producers or landowners. Annualized treatment costs ranged from $4.24 per acre (Glph3) to $110.75 per acre (Dic2).

Application costs vary depending upon method of application, terrain of infestation, machinery expenses, labor requirements, equipment efficiency, setup time, cleanup requirements, and other considerations. An application cost of $2.25 per acre was used which represented an average of two published application costs (Swenson; North Dakota Agricultural Statistics Service).

Control Scenarios

A base scenario was developed to compare initial evaluations of each treatment program. Subsequently, values of economic and physical variables were changed, creating alternative scenarios from which to compare the economic feasibility of various situations and assess the effect of changes in input values.

Values of economic and physical variables for all treatment scenarios were fixed for carrying capacities ranging from 0.20 to 1.0 animal unit months (AUM) per acre, which represents the range of productivity for most grazing land infested with leafy spurge in the Northern Plains.[2] Multiyear treatment programs were restarted each time control reached zero over the 20-year simulation. The base scenario was based on the following values:

1. $15.50 per AUM (the average value of grazing in North Dakota from 1992 through 1994, in 1994 dollars),
2. Spread at 2.0 radial feet per year [the average rate of leafy spurge spread in the Upper Midwest (Stroh, Bangsund, and Leitch)],
3. Leafy spurge patches were at maximum density, and
4. Infestation area of one acre.

Several alternative scenarios were developed. Grazing values were changed to $12 and $19 per AUM, representing the lowest and highest regional grazing values in North Dakota from 1992 through 1994. Infestations ranging from 0.022 to 50 acres were examined. Growth rates of 1, 3, and 4 radial feet per year were included in separate scenarios and combined with various infestation sizes in other treatment situations. Infestation densities of 25 and 50% of total cover were examined with various patch sizes. Prices were arbitrarily set lower in one scenario to test sensitivity to input price. Almost no control programs resulted in a positive net return with current prices; therefore, there was no interest in simulating a higher price. Other scenarios included restarting treatment programs earlier than normal and included reduced control and grazing recovery.

[2] An animal unit month is an average figure of the 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 equivalent grazing animal(s) based on an average feed consumption of 26 pounds of dry matter per day (Shaver).

Table 2. Present Value of Foregone Grazing Outputs from a One-Acre Leafy Spurge Infestation Expanding at Various Rates over Twenty Years

Carrying Capacity (AUMs/ acre)	$12 per AUM			$15.5 per AUM			$19 per AUM		
	Radial Spread (ft./yr.)			Radial Spread (ft./yr.)			Radial Spread (ft./yr.)		
	2	3	4	2	3	4	2	3	4
	(dollars)								
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

Note: Losses discounted at 4%.

Model Output

Results from the model provided a quantitative look at the long-term economic feasibility of common control strategies under a variety of plausible treatment situations facing landowners in the Upper Great Plains. The model also was used to assess the influence of the magnitudes of various economic and physical variables on returns from treatment. Potential gross revenues from leafy spurge control were estimated. The long-term feasibility of treating the entire infestation or treating only the perimeter of an infestation was evaluated.

Potential Returns to Control

Potential returns from leafy spurge control (costs of no treatment) include lost grazing outputs from the initial infestation and lost outputs from subsequent expansion. The present value (PV) of potential returns from control was estimated for various livestock carrying capacities, AUM values, and expansion rates (table 2).

As expected, the value of lost grazing outputs from leafy spurge infestations increases with increases in land productivity, AUM values, and rates of spread. The PV of the grazing losses from a one-acre leafy spurge infestation over 20 years can vary from less than $50 to over $400 in the Upper Great Plains (table 2). Changes in carrying capacities and AUM values resulted in direct, proportional changes in losses. However, doubling the rate of leafy spurge spread from 2 to 4 radial feet per year increased losses only 28% over 20 years (table 2).

Economics of Long-Term Control

Evaluations included cost/return analysis (revenues compared to expenses) and least-loss analysis (treatments result in less loss than no treatment). Least-loss occurs when even the best control measure results in negative net returns, but those negative returns are minimized. Each evaluation used a baseline scenario to analyze the various treatment programs. Values for physical and economic inputs were changed to evaluate a variety of treatment situations and assess the influence those variables have on long-term economic feasibility of herbicide treatments.

Controlling an Entire Infestation. Treating an entire infestation usually reduces stand density and inhibits seed development, simultaneously recovering grazing capacity, and stopping spread. Under the base scenario, break-even carrying capacities (i.e., the level of land productivity where net returns from treatments first become positive) ranged from 0.50 AUMs per acre (Glph1) to well over 1.0 AUMs per acre (Dic2) (table 3). Least-loss carrying capacities (i.e., the level of land productivity needed for treatments to result in less loss than no control) were as low as 0.25 AUMs per acre.

Under conditions of fast spread (3.0 to 4.0 radial feet per year), break-even carrying capacities decreased by 0.10 to 0.15 AUMs per acre and net returns increased at each carrying capacity when compared with normal spread rates. Two treatments (Glph1 and Glph3), under scenarios of rapid spread, provided positive net returns down to carrying capacities of 0.35 AUMs per acre and had least-loss carrying capacities of 0.20 AUMs per acre. Lower initial plant 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 plant density.

The effect of restarting treatments in years when control dropped to 20% or less was evaluated. Returns from four programs decreased while returns for five programs improved slightly. The effect of reducing control by 10% in treatment years, reducing control 20% in years following applications, and reducing grazing recovery 8% decreased net returns but did not affect break-even carrying capacities.

Returns from treating infestations of less than one acre in size were greater (in $/acre treated) than results from treating patches larger than one acre in size. Returns diminished quickly when infestation area was increased beyond one acre; however, as infestation area increased beyond 5 acres, returns diminished only slightly in relation to area. Returns across all treatments decreased $30 to $55 per acre when infestation area was increased from 0.25 to 50 acres, while break-even and least-loss carrying capacities changed substantially. For example, the Pic5 treatment with a 0.25-acre infestation broke even at 0.50 AUMs per acre; whereas, using the same treatment on a 50-acre infestation resulted in a 0.95 AUMs per acre break-even carrying capacity. Least-loss carrying capacities also increased substantially.

Small infestations generated the most attractive net returns of any treatment situation examined, due primarily to preventing the potential for large infestations in the future. Least-loss carrying capacities for six treatments dropped to 0.20 AUMs per acre with infestation sizes below 0.10 acre. Seven treatments generated positive returns at 0.20

Table 3. Long-Term Net Returns from Control of Leafy Spurge in Rangeland Using Herbicides

Carrying Capacity (AUMs/ acre)	Herbicide Treatments														
	Pic1	Pic2	Pic3	Pic4	Pic5	Pic6	Pic7	Dic1	Dic2	Dic3	TFD1	TFD2	Glph1	Glph2	Glph3
	(dollars/acre)[a]														
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[b]														
	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

Note: Initial conditions: $15.5 per AUM, patch spread at 2.0 radial feet per year, 1-acre infestation, maximum leafy spurge density, herbicide costs based on 1995 North Dakota retail prices, and application costs of $2.25 per acre.

[a] Present value of net returns from herbicide treatments, 20-year period, 4% discount rate.

[b] Minimum carrying capacity needed for the treatment to result in less loss than no control.

AUMs per acre with the smallest infestation size (0.022 acres in size, or about 35 feet in diameter).

Increasing AUM values to $19 resulted in greater returns at all carrying capacities (about $10 per acre at low carrying capacities to nearly $50 per acre at high carrying capacities, depending upon treatment and infestation size), thereby lowering break-even and least-loss carrying capacities. Returns decreased proportionately and break-even and least-loss carrying capacities increased when grazing was reduced to $12 per AUM.

When herbicide prices were assumed to be 20% lower than actual, increases in per acre returns typically ranged from $10 to $25 per acre. The largest decreases in break-even carrying capacities came from treatments with higher herbicide costs and higher break-even carrying capacities. Some treatments reached least-loss carrying capacities down to 0.25 AUMs per acre with lower herbicide costs and base scenario conditions.

Perimeter Control. An alternative to controlling an entire infestation is to treat just the perimeter of an infestation to prevent expansion. Treating 15 feet of periphery under baseline conditions resulted in break-even carrying capacities ranging from 0.35 AUMs per acre (TFD1-pc and Glph2-pc) to 0.65 AUMs per acre (Pic2-pc) (table 4). This means that the present value of net returns to control was zero at these AUMs, positive at higher AUM levels, and negative at lower levels. Least-loss carrying capacities were generally 0.35 AUMs per acre or less. In other words, at lower AUM levels the least-loss alternative would be to do nothing.

Under fast spread conditions (3.0 and 4.0 radial feet per year), break-even carrying capacities decreased by 0.10 to 0.25 AUMs per acre and net returns increased at each carrying capacity when compared with baseline spread rates. Three treatments under scenarios of rapid spread (4.0 radial feet per year) provided positive net returns down to carrying capacities of 0.20 AUMs per acre. Spread rates of 1.0 radial foot per year generally decreased net returns by $45 across all treatments when compared with break-even carrying capacities under baseline spread rates. Reduced spread rates increased break-even carrying capacities by 0.45 AUMs per acre and increased least-loss carrying capacities by 0.20 AUMs per acre.

Size of the infestation did not materially affect returns from long-term perimeter control. For each 2.5 radial feet reduction in periphery treated, break-even carrying capacities decreased 0.05 AUMs per acre. Break-even carrying capacities decreased only 0.05 AUMs per acre with $19 AUMs. Reduced grazing values ($12 per AUM) increased break-even carrying capacities about 0.10 AUMs per acre and increased least-loss carrying capacities about 0.05 AUMs per acre. Reducing herbicide prices by 20% resulted in similar changes in returns and break-even carrying capacities as observed with higher grazing values. Thus, as with controlling an entire infestation, the economics of perimeter control is a function of several parameters. Perimeter control is viable when controlling the entire infestation is not feasible but conditions have not reached the point where doing nothing is the best alternative.

Findings

In addition to generating numeric estimates of discounted returns and economic break-even and least-loss thresholds, observations and interpretations of model outputs provide insights into leafy spurge control strategies. Probably the most pronounced result is the

Table 4. Long-Term Returns of Perimeter Control Strategies for Leafy Spurge

Carrying Capacity (AUMs/acre)	Herbicide Treatments					
	Pic1-pc	Pic2-pc	Pic5-pc	TFD1-pc	Glph1-pc	Glph2-pc
	(total dollars)[a]					
0.20	(91)	(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[b]					
	0.25	0.35	0.25	0.20	0.20	0.20

Note: Initial situation: $15.5 per AUM, patch spread at 2.0 radial feet per year, 1-acre infestation, maximum leafy spurge density, 15 feet of periphery treated, herbicide costs based on 1995 North Dakota retail prices, and application costs of $2.25 per acre.

[a] Present value of net returns from herbicide treatments, 20-year period, 4% discount rate.

[b] Minimum carrying capacity needed for the treatment to result in less loss than no treatment.

inverse relationship between infestation size and treatment payoff (fig. 2). Much of the economic relationship between infestation size and treatment returns can be attributed to patch expansion dynamics. Small (less than an acre in size) patches spread much faster, as a percentage of original area, than do large infestations. A patch of leafy spurge 75 feet in diameter spreading at 2.0 radial feet per year will increase in size 330% over 20 years; whereas, a 10-acre infestation will increase only 23% in size. Also, small patches of leafy spurge (75 feet in diameter) generate proportionally more grazing loss from expansion than losses from the original infestation. While large infestations consume more area as they expand than small patches, 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 from small to large infestations, returns become more dependent upon grazing recovery and less sensitive to grazing retention.

Other findings include (*a*) the relationship between treatment frequency, rates applied, and control received; and (*b*) influences of patch expansion rates. More frequent treatments at lower application rates (e.g., Pic1, Pic5) are more efficient than less frequent treatments using higher application rates (e.g., Pic3, Pic4, Dic2). Typically, in order to achieve control for two or more years following a single treatment, relatively high doses

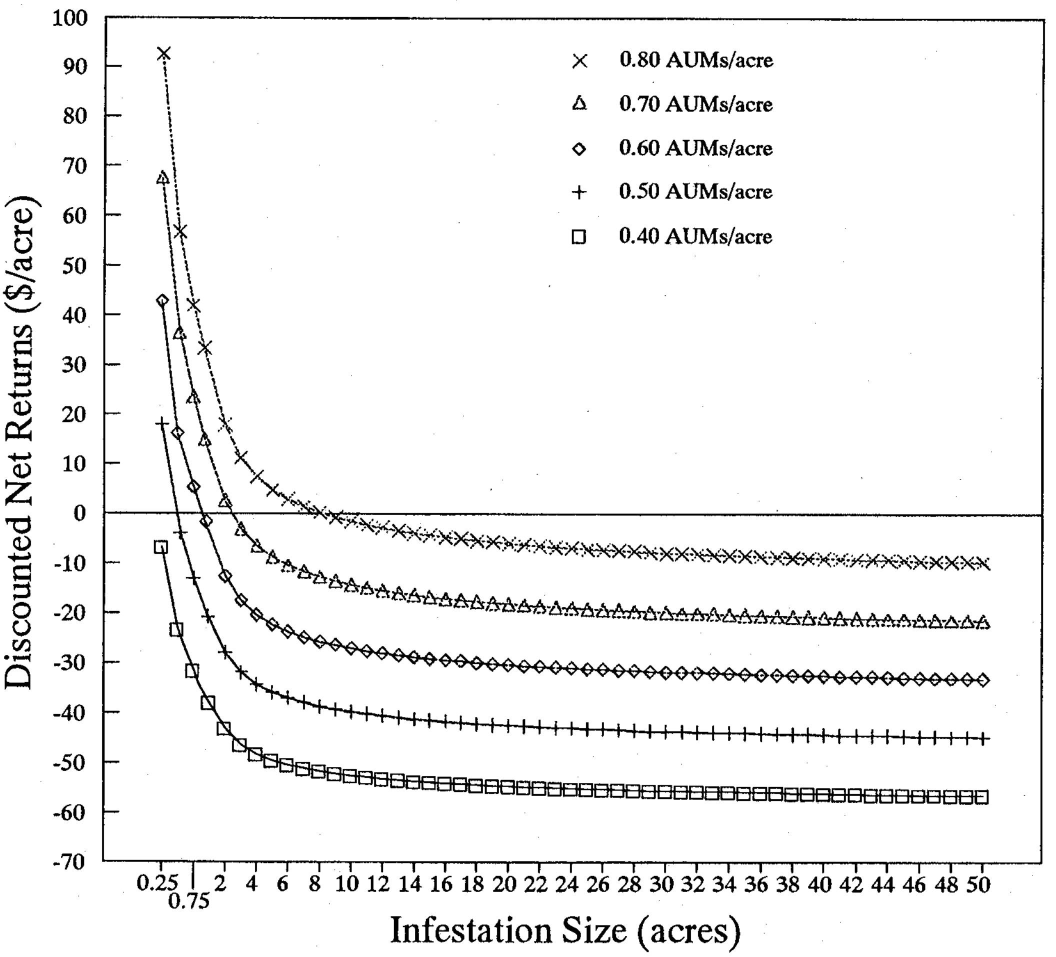

Figure 2. Relationship between discounted net returns ($/acre) and leafy spurge infestation size (acres) at various AUM levels

of herbicide are required; however, the long-term returns of this type of control do not offset the costs. Treatments applied at low rates over 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 appear less risky than high-rate single-year treatments since stand reduction and control are less responsive to a single application. Also, multiple-year treatments are generally less expensive in terms of cumulative treatment costs.

When treating small infestations, faster spread rates enhance an already economically advantageous situation; whereas, with acre-sized infestations, faster spread rates produce break-even thresholds close to grazing land productivity levels in the Upper Great Plains (0.40 to 0.60 AUMs/acre). Faster than baseline spread rates in large infestations (five acres and larger) do little to improve the long-term returns from broadcast treatments; however, those rates decisively influence returns from perimeter-only approaches. Likewise, slower than baseline spread rates (less than 2.0 radial feet per year) have negative effects on treatment returns.

Treatment involving large infestations, particularly in less productive land (lower

AUMs per acre), will likely be more risky than those for small patches. A less risky approach to treating the entire infestation (large) is perimeter control. These strategies should result in preventing further patch expansion with lower cash outlays than other treatment approaches.

A critical aspect of the economic feasibility of long-term herbicide treatments for leafy spurge is grazing recovery (getting cattle to graze within or near treated infestations). Treating large infestations is more risky than treating small patches since (*a*) a relatively large amount of resources are committed in an attempt to recover grazing outputs from the infestation, and (*b*) the economic feasibility of treating large infestations is heavily dependent upon grazing recovery. This point is accentuated because (*a*) most treatment programs will not eliminate all plants and, thus, will not totally remove the aversion cattle have for grazing in the patch; and (*b*) small reductions in anticipated control could be enough for cattle to avoid the infestations altogether.

The economic impacts of leafy spurge extend beyond the financial impacts to commercial grazing to some of the other multiple uses of grazing land. Leafy spurge reduces the capacity of the range to support wildlife, it limits the marketability of native hay, and it affects the soil and water conservation properties of a heterogenous vegetative cover. Those that affect landowners directly would also affect our conclusions about the economics of control.

Conclusions

Leafy spurge is like a rangeland cancer with almost no effective or efficient cure unless detected early. Diagnoses fall into three categories. First, if detected early before infestations have spread, herbicide control can be effective and efficient in many situations. Second, if the infestation is widespread it may be feasible, in some situations, to use herbicides to prevent further spread by controlling the perimeter. However, in less productive rangeland, where an infestation has spread beyond a small area, treating with herbicides will slow the rate of rangeland productivity loss, but the present value of the net benefits of treating may not be sufficient to offset treatment costs. In these instances (e.g., severe infestation on marginal rangeland) the best (although not attractive) alternative, from an individual landowner's perspective, is to not use chemicals to control leafy spurge and bear the ongoing losses in productivity.

The economic feasibility of chemical control of leafy spurge is sensitive to site-specific conditions. For example, returns from control are higher (*a*) in locations with higher carrying capacities, (*b*) in situations where control is more effective or less expensive, and (*c*) for smaller infestations (small patch size), other things being equal. Recommendations for investments in control can only be made with location-specific information.

Since society also has an interest in leafy spurge control, due to the economy-wide impacts the weed causes, the public sector often shares part of the costs of control. Landowners and regional economies both benefit from research to improve the efficiencies of leafy spurge control, whether through technological advances in chemical control or through development of other controls. As practical alternatives to controlling leafy spurge with herbicides become available (e.g., biocontrol), long-term economic viability of those methods, and combinations of treatment methods, also needs to be assessed.

Certainly the confidence in the results of this study could be improved with better information for key relationships and assumptions, particularly grazing recovery and spread characteristics. Additionally, modeling the variables as stochastic, rather than using their expected mean values, would help to identify the frequencies of control outcomes. Finally, in some situations whole farm analyses may be more appropriate than assessing only the costs and returns of weed control. These are offered as suggestions for further research.

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