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Efficacy and economics of leafy spurge (*Euphorbia esula*) control in pasture[1]

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Abstract:

Herbicide treatments containing the butoxyethanol ester of 2,4-D [(2,4-dichlorophenoxy)acetic acid], the dimethylamine salt of dicamba (3,6-dichloro-*o*-anisic acid), the potassium salt of picloram (4-amino-3,5,6-trichloropicolinic acid), and the isopropylamine salt of glyphosate [*N*-(phosphonomethyl)glycine] were applied for 6 years to a pasture in east-central South Dakota containing leafy spurge (*Euphorbia esula* L. #[2] EPHES). Several treatments resulted in leafy spurge control exceeding 90%. Mean herbage dry-weight yield in treated plots was 2340 kg/ha, a 67% increase over untreated plots. Forage yields did not significantly differ among treatments controlling 90% or more leafy spurge. Marginal net return over marginal cost from herbicide treatments ranged from $35 to -$63/ha. Treatments providing satisfactory leafy spurge control with minimum economic risk were annual spring applications of 2,4-D at 1.7 kg ae/ha or dicamba + 2,4-D at 0.6 + 1.1 kg ae/ha and the biannual application of 2,4-D at 0.8 kg ae/ha.

Additional index words:

Sensitivity analysis, dicamba, 2,4-D, picloram, glyphosate, and EPHES.

[1] Received for publication June 18, 1984, and in revised form October 29, 1984. Contribution from the South Dakota State Agric. Exp. Stn., South Dakota State Univ., J. Art. No. 1997.

[2] Letters following this symbol are a WSSA-approved computer code from Important Weeds of the World, 3rd ed., 1983. Available from WSSA, 309 West Clark St., Champaign, IL 61820.

Introduction

Leafy spurge is a pernicious perennial that is competitive in both cropland and pastures due to rapid spread by seeds and rhizomes. Leafy spurge was first noted in the U.S. in 1827 and is present in 26 states (3). Seed is borne in capsules that dehisce when mature and can be displaced up to 5 m from the parent plant (1). Leafy spurge seed can remain dormant in the soil for up to 5 years, and under adequate moisture will germinate throughout the growing season (10). Growth can also occur from adventitious buds present on roots. Shoots from root buds grew through 1 m of tamped soil within 12 months (10), which is indicative of the energy reserves stored in root tissue. Root buds germinated 3 m deep in pits dug for root studies (1), and shoots can grow from root segments as short as 1.25 cm (4). Plants achieve an average growth of 0.25 m in height, a root depth of 1.1 m, and a 0.6m-diameter root spread at 3 months age (4). Leafy spurge can live 10 years and develop roots 4.75 m deep (1).

Leafy spurge was first noted in South Dakota in 1902 (1) and has spread to occupy approximately 20,000 ha in the state (2). Several herbicides can be used to control leafy spurge, but treatment costs vary considerably. While weed control in cropland is generally economically beneficial, many producers question whether perennial weeds such as leafy spurge can be controlled economically in pastures. One difficulty with an economic analysis of weed control is assigning representative costs for herbicides used and production received. Prices vary considerably throughout a long-term study and can greatly influence profitability of treatments. Use of a sensitivity analysis in which returns are calculated for a range of herbicide or product prices can better determine herbicide treatments economically beneficial over a wide range of prices (5).

Several studies have demonstrated that perennial weed control in pastures can increase forage production. Control of mixed stands of Canada thistle (*Cirsium arvense* (L.) Scop. # CIRAR) and musk thistle (*Carduus nutans* L. # CRUNU) in pasture resulted in 100 to 314% additional forage production during a 3-year period of treatment (9). Perennial warm-season grass production increased 428 to 1440 kg/ha 7 months after herbicide applications in another study (8).

The objectives of this research were a) to determine efficacy of herbicide treatments on leafy spurge, and b) to evaluate the economics of leafy spurge control in pasture for several herbicide treatments.

Materials and methods

General

A field experiment was established on a Clarno (Typic Haplustoll; fine-loamy, mixed, mesic) Bonilla (Pachic Haplustoll; fine-loamy, mixed, mesic) loam in a pasture near Woonsocket, SD, in 1978. Leafy spurge occurred uniformly throughout the pasture with a density of approximately 100 plants/m^2 at study initiation. Kentucky bluegrass (*Poa pratensis* L. # POAPR) was the primary forage component of the pasture. Smooth bromegrass (*Bromus inermis* Leyss. # BROIN), switchgrass (*Panicum virgatum* L. #

PANVI), slender wheatgrass (*Agropyron trachycaulum* L. # AGRTR), big bluestem (*Andropogon gerardi* Vitman # ANOGE), and little bluestem (*Andropogon scoparius* Michx. # ANOSC) were also present. The study area was fenced to prevent grazing.

The experiment was designed as a randomized complete block consisting of four replications of 18 treatments in plots 6.1- by 12.2-m. Treatments consisted of spring, or spring and fall, applications of the butoxyethanol ester of 2,4-D alone or in combination with the dimethylamine salt of dicamba, the potassium salt of picloram, or the sodium salt of glyphosate. All herbicide rates are expressed as kg ae/ha. Treatments were applied to the study on May 31, 1978, September 23, 1978, June 12, 1979, October 2, 1979, June 28, 1980, September 12, 1980, June 23, 1981, September 17, 1981, June 3, 1982, September 21, 1982, and June 9, 1983. Leafy spurge was blooming when treatments were applied in the spring and post-blooming when treatments were applied in the fall. Herbicides were applied in 187 L/ha water at 276-pa pressure with flat-fan spray nozzles using a tractor-mounted sprayer. Analysis of variance was performed on all data, and means were separated using the Waller-Duncan K-ratio t-test (11) at K=100 (P=0.05).

Leafy spurge control

Leafy spurge control was visually evaluated (1979 through 1983, at spring treatments) using a 0 to 100% scale in which 0 represented no control and 100 represented complete control of topgrowth. Orthogonal contrasts were made for each year comparing spring applications of 2,4-D at 1.7 and 3.4 kg/ha vs. spring and fall applications of 2,4-D at 0.8 and 1.7 kg/ha.

Forage and leafy spurge production

The area was mowed in late fall in 1981 and 1982 to remove existing topgrowth prior to yield measurements the following year. Total dry-matter production was determined by harvesting and weighing a fresh sample from a 0.6- by 12.2-m area in each plot on August 10, 1982, and August 17, 1983. A 150-g subsample was removed, oven dried, and re-weighed to measure moisture content. An area 1 m^2 was also harvested from each plot at the same time for later drying and separation into forage and leafy spurge fractions. Dry-forage and leafy spurge yields were calculated for all plots based on total production and relative forage and leafy spurge content in each sample.

Economics of leafy spurge control

Economic comparisons between treatments are presented as net marginal returns. Forage value of untreated plots is the baseline from which all marginal returns are calculated. Therefore, the marginal return is the value of additional forage obtained due to treatment. Marginal costs are the additional costs incurred due to treatment. Thus, net marginal return was calculated for each plot for 1982 and 1983 using the formula: net marginal return = marginal return - marginal cost[3]. Forage value was calculated using the

[3] Watson, D.S., 1968. Price Theory and Its Uses. 2nd ed. Houghton-Mifflin Co., Boston, 443 pp.

1982 and 1983 average monthly price of $45.00 per 1000 kg. Herbicide costs represent an average of 1979 and 1982 retail prices, and were: 2,4-D $5.70/kg ae, dicamba $22.55/kg ae, picloram $93.17/kg ae, and glyphosate $49.93/kg ae. Cost of one application was $6.00/ha. Marginal cost for the 1982 and 1983 harvests were calculated by dividing total treatment cost by the number of years since study initiation. For example, 2,4-D applied at 0.84 kg/ha spring and fall had a marginal cost of $21.58 at the 1982 harvest. This was calculated by dividing the cost of herbicide and application for nine applications (spring 1978 to spring 1982) of $97.07 by 4.5 years. Thus, marginal costs were assigned on the assumption that forage yields each year were influenced by the cumulative result of treatments since the beginning of the study. This method overestimates average annual marginal returns, since any temporary decreases in forage yields earlier than 1982 are not reflected in net returns, and no adjustments were made for interest on initial herbicide applications. Sensitivity analysis was performed at 50, 100, and 150% of the herbicide cost and forage price.

Results and discussion

Leafy spurge control

Dicamba or 2,4-D treatments applied only in 1978 did not satisfactorily control leafy spurge (Table 1). Glyphosate applied in the fall of 1978 controlled leafy spurge only in 1979. Re-growth resulted in heavy reinfestation of leafy spurge after 1979.

Annual applications of 2,4-D provided 75% or more, leafy spurge control by 1983. Applying 2,4-D at 0.8 kg/ha spring and fall increased control over a single spring application of 1.7 kg/ha in 1979, 1981, and 1982, although the same total amount of herbicide was applied during the year. Maximum leafy spurge control in 1983 was from 2,4-D applied spring and fall at 3.4 kg/ha. However, control was not significantly different from spring and fall applications of 2,4-D at 1.7 kg/ha.

A significant treatment-by-year interaction was measured when analyzing leafy spurge control ratings across all years of the study. Since the interaction was not significant from 1981 to 1983, ratings were averaged for these years for orthogonal comparisons. No benefit was measured for split 2,4-D applications over single annual applications in 1979 or 1980. For 1981 to 1983, the 83% control rating for split applications was significantly greater than 65% from annual 2,4-D applications. This indicates a long-term benefit from biannual 2,4-D treatments over single annual applications, but the benefit was not measurable during the first 2 years of the study.

Dicamba at 0.6 kg/ha applied biannually did not satisfactorily control leafy spurge (Table 1). When dicamba was applied with 1.1 kg/ha of 2,4-D in the spring, control was equivalent to that from any biannual 2,4-D treatment. However, with a dicamba spring application of 0.6 kg/ha followed with 1.7 kg/ha of 2,4-D in the fall, control after 1980 was significantly less than all biannual 2,4-D treatments and dicamba + 2,4-D applied in the spring. Control was comparable to that of the biannual application of dicamba alone, indicating no benefit from the fall 2,4-D application.

Table 1. Leafy spurge control and mean dry-herbage yield of leafy spurge and forage.

Treatment			Treatment application[a]			Leafy spurge control[b]					Mean dry-herbage yield[c]	
No.	Herbicide	Rate	1978	1979	1980-1983	1979	1980	1981	1982	1983	Leafy spurge	Forage
		(kg/ha)				(%)					(kg/ha)	
1	2,4-D	1.7	S	…	…	36 fgh	26 def	1 f	17 ef	11 fg	860 bcd	1600 ghi
2	2,4-D	0.8	S&F	S&F	S&F	60 c-g	50 cd	74 abc	87 ab	83 bc	66 g	2620 bcd
3	2,4-D	1.7	S	S	S	39 fgh	60 bc	42 de	51 d	75 cd	160 fg	2550 bcd
4	2,4-D	1.7	S&F	S&F	S&F	62 b-f	67 bc	75 abc	88 ab	93 ab	28g	2630 bcd
5	2,4-D	3.4	S	S	S	50 d-g	74 abc	67 bc	75 bc	82 bc	24 g	2400 cde
6	2,4-D	3.4	S&F	S&F	S&F	67 b-e	81 ab	90 ab	97 a	982	13 g	2900 ab
7	Dicamba	0.6	S	…	…	14 hi	18 ef	4 f	20 e	23 f	1300 b	1260 ij
8	Dicamba	0.6	S&F	S&F	S&F	37 fgh	31 de	30e	46 d	59 e	770 cde	1930 efg
9	Dicamba +2,4-D	0.6+ 1.1	S	S	S	64 b-f	67 bc	71 abc	86 ab	87 abc	1 g	2720 a-d
10	Dicamba	0.6	S	S	S	33 gh	49 cd	35 e	61 cd	63 de	560 def	1820 fgh
	+2,4-D	1.7	F	F	F							
11	Picloram	0.3	S	S	S	49 d-g	87 ab	62 cd	79 b	83 bc	69g	2310 def
12	Piclorarn	2.2	S	S	…	86 abc	98 a	94 a	92 ab	88 abc	360 efg	2520 bcd
13	Picloram +2,4-D	0.3 +1.1	S	S	S	55 d-g	66 bc	78 abc	86 ab	94 ab	12g	2880 abc
14	Picloram	0.3	S	S	S	62 b-f	83 ab	84 abc	91 ab	95 ab	73 fg	2630 bcd
	+2,4-D	1.7	F	F	F							
15	Glyphosate	3.4	F	…	…	98 a	15 ef	0 f	2 fg	0 g	2350 a	790 j
16	Glyphosate	1.1	S	…	…	89 ab	66 bc	68 bc	91 ab	91 ab	32g	2990ab
	+ 2,4-D	1.7	F	S&F	S&F							
17	Glyphosate	3.4	S	…	…	76 a-d	86 ab	79 abc	87 ab	88 abc	45g	3150 a
	+ 2,4-D	1.7	…	S	S							
	Untreated	…	…	…	…	0 i	0 f	0 f	0 g	0 g	1140 bc	1400 hi

[a] S is spring and F is fall herbicide application.
[b] Means within a column followed by the same letter are not significantly different at the 5% level using aller-Duncan test.
[c] Leafy spurge yield and forage yield are the averages of 1982 and 1983 harvests.

Picloram applied at 2.2 kg/ha in 1978 and 1979 controlled leafy spurge throughout the term of this study (Table 1). The standard treatment for patch control of leafy spurge is 2.2 kg/ha, since a single application can provide leafy spurge control for several years. However, control appeared to diminish with time, indicating a need for follow-up applications to maintain high levels of control. By 1983, picloram at 0.3 kg/ha applied annually controlled leafy spurge as effectively as 2.2 kg/ha of picloram applied in 1978 and

1979. Picloram at 0.3 kg/ha applied with either spring or fall 2,4-D provided control after 1980, which was equivalent to the best treatment.

Glyphosate applied in the spring of 1978 at either 1.1 or 3.4 kg/ha followed annually by 2,4-D at 1.7 kg/ha provided leafy spurge control equivalent to that from the best treatment in 1979, 1982, and 1983. Control from 1.1 kg/ha glyphosate followed with biannual 2,4-D applications of 1.7 kg/ha was significantly higher than from the biannual 2,4-D applications of 1.7 kg/ha in 1979. Control from the two treatments was similar each succeeding year. Benefit from the 1.1 kg/ha glyphosate was realized for only 1 year after treatment.

Forage and leafy spurge production

Forage and leafy spurge weights presented in Table 1 are means of 1982 and 1983 harvests. Leafy spurge production indicated a strong inverse relationship to leafy spurge control (r = -0.75). Thus, visual control ratings were effective predictors of the dry weight of leafy spurge present. There was no difference between forage and leafy spurge dry weights from plots with 2,4-D or dicamba applied only in 1978 and plots that were not treated. Maximum leafy spurge was present in plots treated with glyphosate at 3.4 kg/ha the fall of 1978, with significantly less forage than the untreated plots. Forage was severely damaged by the glyphosate treatment, allowing leafy spurge to grow with little forage competition. Morrow (7) reported that competition by a perennial grass sod inhibited growth and reproduction of leafy spurge. Mean weight of leafy spurge did not differ between any repeated 2,4-D treatments, dicamba + 2,4-D spring applications, picloram treatments, and spring glyphosate treatments. Significantly less leafy spurge was present in each of these than in untreated plots. All repeated herbicide treatments significantly decreased the dry weight of leafy spurge compared to untreated plots.

Forage dry weight was highest when glyphosate was applied at 3.4 kg/ha in 1978 followed with annual 2,4-D treatments. However, considerable grass injury was observed from the glyphosate + 2,4-D treatments for 2 years following application (data not shown). No difference in forage production was found among treatments of dicamba + 2,4-D applied in the spring, 2,4-D applied spring and fall at 3.4 kg/ha, picloram + 2,4-D spring applications, or glyphosate + 2,4-D. A strong positive correlation occurred between leafy spurge control and forage yield, and a strong negative correlation between leafy spurge yield and forage yield (r = 0.69 and -0.79, respectively). It is thus apparent that leafy spurge is a strong competitor with pasture forages, and leafy spurge control will increase forage yields.

Economics of leafy spurge control

Annual spring treatments that increased net marginal return over untreated plots at initial (100%) herbicide costs and forage values (Table 2) were: 2,4-D at 1.7 kg/ha, dicamba + 2,4-D, and picloram + 2,4-D (treatments 3, 9, and 13, respectively). Biannual applications of 0.8 or 1.7 kg/ha of 2,4-D (treatments 2 and 4) and all spring glyphosate treatments (treatments 16 and 17) also provided significantly higher returns than untreated plots. Treated plots yielding significantly lower net marginal returns than untreated plots received two applications of picloram at 2.2 kg/ha (treatment 12) and the fall glyphosate application (treatment 15). Marginal cost for picloram at 2.2 kg/ha was $87/ha, the highest cost of any treatment in the study. Although forage yield was considerably greater than from untreated plots, the additional forage yield was insufficient to pay for the treatment. An application of 2.2 kg/ha is a recommended spot treatment for leafy spurge but is not economical for broadcast applications based on these results. Use of picloram may cause yield reductions in some circumstances, since smooth brome can be severely injured by picloram (6). Severe forage damage from the fall glyphosate treatment (treatment 15) significantly decreased forage yield relative to untreated plots. Even if there were no cost for the fall glyphosate treatment, it would still yield a net loss.

The influence of forage yield differences on net marginal return under alternative combinations of forage value and herbicide price is shown in Table 2. At the most favorable situation of 50% herbicide cost and 150% forage value, 11 of the 17 herbicide-treated plots provided significantly higher net marginal returns than the untreated plots. Only the fall glyphosate-treated plots gave less return than the untreated plots. Alternatively, at the most stringent pricing situation of 150% herbicide cost and 50% forage value, no treatments gave a net economic benefit. Furthermore, twelve treatments significantly decreased net marginal returns. Annual application of 1.7 kg/ha of 2,4-D (treatment 3) was economically beneficial in seven of the nine alternative pricing situations, and in no instance caused an economic loss. Both the biannual application of 2,4-D at 0.8 kg/ha (treatment 2) and the dicamba + 2,4-D spring application (treatment 9) yielded a profit under six of the pricing alternatives, and never a loss. In contrast, the biannual dicamba treatment, spring dicamba + fall 2,4-D (treatments 8 and 9, respectively), 2.2 kg/ha of picloram, and fall glyphosate provided an economic loss with four or more of the alternatives, and never a positive net return.

These results indicate that profitability of a herbicide treatment varies considerably based on relative herbicide and forage prices. However, a treatment that is profitable under a wide range of pricing alternatives and seldom results in a net loss can be applied with minimal economic risk. This research identified three treatments, annual spring application of 2,4-D at 1.7 kg/ha or dicamba + 2,4-D at 0.6 + 1.1 kg/ha, and biannual application of 2,4-D at 0.8 kg/ha, which controlled leafy spurge in pasture with little economic risk. One factor not considered by these economic calculations is the intrinsic value of reducing the population and spread of a noxious weed. Minimizing further spread and reducing the chance of reinfestation can produce long-term economic and cultural benefits that are not measured by immediate net returns. Thus, selecting a treatment that effectively controls the spread of leafy spurge from spot infestations, while yielding less than maximum net profit, may be the most economical treatment from a "total farm" point of view. Generally, herbicidal control of leafy spurge was profitable in the pasture tested. Treatments that were not applied more than one year did not provide long-term control.

Table 2. Added return over treatment costs under various herbicide costs and forage values.

Treatment no.	Mean[a] treatment cost	Mean[a] net value of forage increase over untreated	50% Herbicide cost[b]			100% Herbicide cost[b]			150% Herbicide cost[b]			Total number of cases	
			50% Grass value	100% Grass value	150% Grass value	50% Grass value	100% Grass value	150% Grass value	50% Grass value	100% Grass value	150% Grass value	Exceeding untreated	Less than untreated
	($/ha)												
1	3	9	2 b-e	7 def	12 efg	1 a-d	6 bcd	11 d-g	0 ab	5 cde	10 cde	0	0
2	22	55	11 abc	38 abc	65 abc	6 ab	33 a	61 ab	1 ab	28 ab	56 a	6	0
3	17	52	14 a	40 abc	66 abc	9 a	35 a	60 ab	3 a	29 a	55 a	7	0
4	31	55	6 a-d	34 abc	62 a-d	-3 b-e	24 ab	52 abc	-13 c	15 a-d	42 abc	5	1
5	28	45	5 a-e	28 bcd	51 bcd	- 5 b-f	17 abc	40 a-d	-16 c	7 b-c	30a-d	4	1
6	50	68	3 a-e	37 abc	71 abc	-16 gh	18 abc	51 abc	-36 efg	-2 de	32 a-d	3	2
7	4	-6	-6 ef	-9 f	-12 g	-7 c-g	-10d	-13 g	-8 bc	-11 ef	-14 e	0	0
8	37	24	-13 fg	-1 ef	11 efg	-25 h	-13 d	-1 fg	-38 fg	-26 f	-14 e	0	4
9	28	59	13 ab	42 abc	72 abc	2 abc	32a	61 ab	-8 bc	21 abc	51 a	6	0
10	35	19	-14 fg	-4 f	5 fg	-25 h	-16 de	-6 fg	-36 efg	-27 f	-17 e	0	4
11	35	41	-1 cde	20 cde	40 cde	-15 fgh	6 bcd	26 c-f	-29 def	-9 ef	12 cde	1	2
12	87	50	-19 g	6 def	31 def	-62 j	-36 e	-11 g	-104 i	-78 g	-53 f	0	6
13	42	67	9 abc	42 abc	75 ab	-9 d-g	24 ab	57 abc	-27 de	6 b-e	40 abc	4	1
14	49	55	-3 def	25 bcd	52 bcd	-22 h	6 bcd	34 b-c	-40 g	-13 ef	15 b-e	2	2
15	35	-27	-32 h	-46 g	-59 h	-49 i	-63 f	-76 h	-66 h	-80 g	-93 g	0	9
16	41	72	10 abc	45 ab	81 ab	-5 b-f	31 a	67 ab	-19 cd	17 a-d	53 a	5	1
17	49	79	12 ab	51 a	90 a	-10 efg	30a	69 a	-31 efg	9 a-c	48 ab	6	1
Untreated	0	0	0 cde	0 ef	0 fg	0 a-e	0 cd	0 efg	0 ab	0 cde	0 de	0	0

[a] Means of 1982 and 1983 assigned prices. Negative means indicate net loss in forage value due to decreased forage production relative to untreated.
[b] Means within a column followed by the same letter are not significantly different at the 5% level using Waller-Duncan test. Negative returns denote an economic loss from herbicide treatment relative to untreated.

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